premiam

POLLUTION RESPONSE IN EMERGENCIES
MARINE IMPACT ASSESSMENT AND MONITORING

POST-INCIDENT MONITORING GUIDELINES




SCIENCE SERIES
TECHNICAL REPORT NO.146

premiam

POLLUTION RESPONSE IN EMERGENCIES
MARINE IMPACT ASSESSMENT AND MONITORING

POST-INCIDENT MONITORING GUIDELINES

Robin J. Law[1], Mark F. Kirby[1], Jon Moore[2], Jon Barry[1],
Melanie Sapp[1] and Jan Balaam[1]

[1] The Centre for Environment, Fisheries and Aquaculture Science, Cefas Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT.

[2] Coastal Assessment, Liaison & Monitoring (CALM), Ti Cara, Point Lane, Cosheston, Pembroke Dock, Pembrokeshire SA72 4UN.

premiam

POST-INCIDENT
MONITORING
GUIDELINES

These guidelines are produced as part of the Premiam project. This project represents an initiative fully supported by all major government stakeholders across the United Kingdom.

The Premiam partners are:

Cefas

defra

afbi Agri-Food and Biosciences Institute

Cyngor Cefn Gwlad Cymru
Countryside Council for Wales

Department of Agriculture and Rural Development
www.dardni.gov.uk

DEPARTMENT OF ENERGY & CLIMATE CHANGE

Environment Agency

FOOD STANDARDS AGENCY

Health Protection Agency

JNCC
Joint Nature Conservation Committee

Local Government Association

marinescotland

mca

MMO marine management organisation

NATURAL ENGLAND

NIEA Northern Ireland Environment Agency
www.ni-environment.gov.uk

SEPA
SCOTTISH ENVIRONMENT PROTECTION AGENCY

Scottish Natural Heritage
All of nature for all of Scotland

Llywodraeth Cymru
Welsh Government

Origin

These guidelines were produced for Defra, as a deliverable within project ME5407: "PREMIAM: Pollution Response in Emergencies Marine Impact Assessment and Monitoring" as the officially supported UK national approach to post-incident monitoring and as a complementary document to the Maritime and Coastguard Agency's UK National Contingency Plan for Marine Pollution from Shipping and Offshore Installations.

Citation

The report should be cited as:

Law, R.J., Kirby, M.F., Moore, J., Barry, J., Sapp, M. and Balaam, J., 2011. PREMIAM – Pollution Response in Emergencies Marine Impact Assessment and Monitoring: Post-incident monitoring guidelines. Science Series Technical Report, Cefas, Lowestoft,146: 164pp.

A copy can be obtained by downloading from the Premiam website at
www.cefas.defra.gov.uk/premiam

ISSN 0308-5589

CONTENTS

ACRONYMS AND ABBREVIATIONS

AChE	Acetylcholinesterase
AFBI	The Agri-Food and Biosciences Institute in Northern Ireland
ALA-D	δ-amino levulinic acid dehydratase
AR CALUX	Androgen-responsive chemically activated luciferase gene expression
AURIS	Aberdeen University Research & Industrial Services
BEQUALM	Biological Effects Quality Assurance in Monitoring Programmes
BTEX	Benzene, toluene, ethylbenzene and xylenes
BTO	British Trust for Ornithology
CCW	Countryside Council for Wales
CEDRE	Centre of Documentation, Research and Experimentation on Accidental Water Pollution in France
CHEMET	Chemical meteorology
COWRIE	Collaborative Offshore Wind Research Into the Environment
CPR	Continuous Plankton Recorder
CSEMP	UK Clean Seas Environment Monitoring Programme
CSIP	Cetacean Strandings Investigation programme
CYP1A	Cytochrome P450 1A
DARD	Department of Agriculture and Rural Development in Northern Ireland
DR CALUX	Dioxin-responsive chemically activated luciferase gene expression
DTAPS	Disposable Toxicological Agent Protective System
EA	Environment Agency in England and Wales
EG	Environment Group
ER-CALUX	Estrogen-responsive chemically activated luciferase gene expression
EROCIPS	Emergency Response to Coastal Oil, Chemical and Inert Pollution from Shipping
EROD	Ethoxyresorufin-O-deethylase
ESGOSS	Ecological Steering Group on the Oil Spill in Shetland
GCxGC	Comprehensive two-dimensional gas chromatography
GC-MS	Gas chromatography – mass spectrometry
GLP	Good Laboratory Practice
GPS	Global positioning system
HBDSEG	Healthy and Biologically Diverse Seas Evidence Group
HNS	Hazardous and Noxious Substances
HPA	Health Protection Agency
HPLC	High-performance liquid chromatography
ICES	International Council for the Exploration of the Sea
ICP-MS	Inductively-coupled plasma-mass spectrometry
ICP-OES	Inductively-coupled plasma-optical emission spectrometry
IMO	International Maritime Organization
IOPC	The International Oil Pollution Compensation Funds
IPIECA	International Petroleum Industry Environmental Conservation Association
IQI	Infaunal Quality Index
ISO	International Organization for Standardization
ITOPF	International Tanker Owners Pollution Federation
JAMP	OSPAR Joint Assessment and Monitoring Programme
JNCC	UK Joint Nature Conservation Committee

LC-MS	Liquid chromatography – mass spectrometry
MARPOL	International Convention for the Prevention of Pollution from Ships
MCA	Maritime and Coastguard Agency
MEDIN	Marine Environmental Data and Information Network
MMO	UK Marine Management Organisation
MMSI	Maritime Mobile Service Identity
MNR	Marine Nature Reserve
MSFD	EU Marine Strategy Framework Directive
NCP	UK National Contingency Plan for Marine Pollution from Shipping and Offshore Installations
NEBA	Net environmental benefit analysis
NIEA	Northern Ireland Environment Agency
NIOZ	Royal Netherlands Institute for Sea Research
NMBAQC	UK National Marine Biological Association Quality Control scheme
NNR	National Nature Reserve
NOAA	US National Oceanic and Atmospheric Administration
NVC	National Vegetation Classification
OSPAR	Oslo and Paris Commissions
PACs	Polycyclic aromatic compounds
PAH	Polycyclic aromatic hydrocarbons
PCA	Principal Component Analysis
PCBs	Polychlorinated biphenyls
PDA	Portable digital assistant
QUASIMEME	Quality Assurance of Information for Marine Environmental Monitoring in Europe
RIB	Rigid inflatable boat
RPI	Research Planning, Incorporated
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SAC	Special Area of Conservation
SCAT	Shoreline Cleanup Assessment Team
SEEEC	Sea Empress Environmental Evaluation Committee
SEG	Standing Environment Group
SEPA	Scottish Environment Protection Agency
SSPCA	Scottish Society for the Prevention of Cruelty to Animals
SSSI	Site of Special Scientific Interest
STAC	Science and Technical Advice Cell
STOp	Scientific, technical and operational
TIMES	ICES Techniques in Marine Environmental Sciences series
ToFMS	Time of Flight Mass Specrometry
UKAS	United Kingdom Accreditation Service
UKTAG	UK Technical Advisory Group on the Water Framework Directive
US EPA	US Environmental Protection Agency
USPCA	Ulster Society for the Prevention of Cruelty to Animals
WeBS	Wetland Bird Survey
WFD	EU Water Framework Directive
YAS	Yeast androgen screen
YES	Yeast estrogen screen

Executive summary

Spillages of oil and chemicals at sea can be high-profile events which give rise to significant environmental impacts. Under the UK National Contingency Plan for Marine Pollution from Shipping and Offshore Installations, if a marine pollution incident is expected to have a significant environmental impact, arrangements should be made to begin to monitor and assess the long-term, as well as the short- and medium-term, environmental impacts. In addition to providing environmental and public health advice to the response centres, the Environment Group (EG) established during the incident should initiate and encourage the collection and evaluation of data for the assessment of the environmental impact of the incident (these are sometimes described as operational and non-operational monitoring, respectively). An EG is usually established quite quickly for maritime emergencies by activating the local Standing Environment Group (SEG) whose core membership has already been established. Where a maritime incident poses a significant threat to public health (e.g. chemical fumes from a stricken vessel blowing across a coastal town) the Strategic Coordinating Group (SCG) may also feel the need to establish a Science and Technical Advice Cell (STAC) under Civil Contingencies arrangements. To avoid duplication or the provision of conflicting advice, close liaison should be established between the EG and the STAC.

One of the roles of the SEGs, between incidents, is to gather and record data concerning the pre-existing baseline conditions within their area, for use as reference points during an incident. In major incidents, impact assessment projects or monitoring or survey studies may need to be commissioned. The appropriate government department or devolved administration responsible for environmental issues for the waters in which the incident occurs takes the lead in co-ordinating the commissioning of such work, which should be linked with the monitoring and assessment activities. The NCP suggests establishing an Environmental Impact Assessment Group at an early stage, transferring responsibilities from the EG so as to allow them to focus on providing advice to the response cells. This group would also be charged with obtaining funding for the impact assessment (including any impacts on public health) and long-term monitoring programmes. The UK National Contingency Plan for Marine Pollution from Shipping and Offshore Installations (NCP) does not, however, go into further detail regarding post-incident monitoring activities, and that is the role of the present document. This provides guidelines on initiating, designing and determining the scope of a post-incident monitoring programme designed (amongst other aims) to facilitate environmental impact assessment. This includes aspects of survey design, sampling, chemical analysis and ecotoxicological testing, ecological monitoring, taint-testing and the collection and rehabilitation of affected wildlife. Where guidance has been developed during or following oil or chemical spill incidents, whether within the UK or elsewhere, this has been extensively referenced.

This document gives guidance and sets standards for post-incident monitoring and is intended to act as a resource for those of the monitoring agencies advising incident EGs and the wider UK monitoring community. Although intended primarily for the use of the UK monitoring community, the principles and approach will be broadly applicable elsewhere. Through their participation in the Steering Group directing the PREMIAM project, this approach is endorsed by the Countryside Council for Wales, Department of Energy and Climate Change, Department of Environment, Food and Rural Affairs, the Department of the Environment Northern Ireland, the Environment Agency, the Food Standards Agency, the Health Protection Agency, the Joint Nature Conservation Council, the Marine Management Organisation, Marine Scotland Science, the Maritime and Coastguard Agency, Natural England, the Northern Ireland Environment Agency, the Scottish Environment Protection Agency, Scottish Natural Heritage and the Welsh Government. It is anticipated that the post-incident monitoring guidelines will, in time, be integrated with response plans, including the National Contingency Plan.

Introduction

Spillages of oil and chemicals into the marine environment can be high-profile events which can also give rise to significant environmental impacts. Although there is evidence that the number of oil spills has decreased in recent decades (Huijer, 2005; Burgherr, 2007; Schmidt-Etkin, 2011; ITOPF tanker spill statistics 2010 at: www.itopf.com/information-services/data-and-statistics/statistics/documents/StatsPack2010.pdf accessed 28 July 2011) as a result of improved practices and prevention, there are still occasional large, high-profile incidents (*Deepwater Horizon*, *Hebei Spirit* and *Tasman Spirit*, for example). Also, small spills, which can nevertheless have significant local impacts, and "near-miss" potential spills occur on an almost daily basis. It is against this background that the UK authorities (and those of other countries) require the development and maintenance of an effective spill response and clean-up capability, including the ability to initiate and conduct scientifically robust post-incident environmental monitoring and impact assessment. An effective post-incident monitoring programme, facilitated by clear guidance as presented here, will ensure that:

- Key stakeholders, including government and the general public, are provided with early and accurate evidence of the potential hazards and risks posed by the incident
- There is an appropriate and effective means of investigating both short-term and longer-term impacts
- Better co-ordination will result in a more effective use of resources and the ability to conduct integrated assessments
- Information is gathered relating to the effectiveness of spill response and clean-up activities (including the use of dispersants) and that this provides a direct input into evolving response strategies

Under the UK National Contingency Plan (NCP) (Maritime and Coastguard Agency, 2006), if a marine pollution incident is expected to have a significant environmental impact, arrangements should be made to begin to monitor and assess the long-term, as well as the short- and medium-term, environmental impacts. In addition to providing operational advice to the response centres, the Environment Group (EG) established during the incident should initiate and encourage the collection and evaluation of data for the assessment of the environmental impact of the incident (these are sometimes described as operational and non-operational monitoring, respectively). IPIECA (1996, 2000) have outlined the processes of pre-incident sensitivity mapping of resources and the selection of response options in order to minimise harm to the environment (NEBA: net environmental benefit analysis) – see also publications from the US National Research Council (1999, 2005). One of the roles of the Standing Environment Groups (SEGs), between incidents, is to record data concerning the pre-existing baseline conditions within their area, for use as reference points during an incident. In major incidents, impact assessment projects and monitoring or survey studies may need to be commissioned.

The appropriate government department or devolved administration responsible for environmental issues for the waters in which the incident occurs (Defra Marine Strategy and Evidence Division for England, for example) takes the lead in co-ordinating the commissioning of such work, which should be linked with any existing monitoring and assessment activities. The NCP suggests establishing an Environmental Impact Assessment Group at an early stage, transferring responsibilities from the EG so as to allow them to focus on providing advice to the response cells. This group would also be charged with obtaining funding for the impact assessment (including any impacts on public health) and long-term monitoring programmes. The NCP does not, however, go into further detail regarding the co-ordination of such a group or its specific monitoring activities, and that is the role of the present document.

There are, therefore, some important preparedness and capability gaps with respect to establishing and conducting an effective post-incident monitoring programme. In particular, there are no established expert guidelines in the UK for post-incident monitoring and impact assessment, nor is there a fully co-ordinated mechanism for overseeing the practical aspects of any programme (e.g. survey design, sampling, analysis and interpretation). The PREMIAM project, of which these guidelines are an important deliverable, was established to help address these issues.

Although other, more locally based, documents exist (e.g. Moore et al., 2005, which was developed for Wales), this is the first to be nationally focussed. If adopted and implemented effectively it aims to strengthen monitoring and impact assessment activities in terms of:

- Speed – providing a faster response in order to gain early impact information and baseline data for areas under threat
- Cost effectiveness
- Identification and availability of the expertise needed for an effective monitoring programme
- Use of best practice and the ability to learn from studies of earlier incidents
- Improved co-ordination and integration

This guidance is divided into two parts. Part 1 poses points to be considered, which are intended to aid the design and targeting of the monitoring programme, bearing in mind that there will be a large degree of incident and location specificity depending on the substance(s) involved in the incident and the habitats and resources at risk. Part 2 describes the tools that are available to realise the aims of the programme.

Much of this document highlights the difficulty of obtaining absolute statistical proof that an impact has occurred, because the natural environment is so variable (both spatially and temporally), because the accidental nature of an oil or chemical spill does not allow for much experimental control and because suitable historical/baseline data are rarely available. The most useful and informative damage assessment studies have usually resulted from opportunistic situations, where very recent and good-quality baseline data happen to be available for an impacted resource; or where someone with appropriate expertise and technique is available and immediately begins studies on a sensitive resource. These situations are rare and most assessments have to work with inadequate baseline data. The literature also suggests that useful insights on impacts have come more from good natural-history observation than detailed survey/monitoring analysis – recognising and correctly interpreting the signs and symptoms of unnatural effects and of the recovery process – even if proof was not achievable. The objectives of most damage assessments should aim to accumulate a weight of evidence using a range of methodologies, each of which will need to be tailored to the particular circumstances.

Following two major oil spill incidents that took place before the Environment Groups were established – the *Braer* spill in Shetland in 1993 and the *Sea Empress* spill in Wales in 1996 – the government set up incident-specific steering groups which oversaw the assessment of environmental impacts. These were known as ESGOSS (Ecological Steering Group on the Oil Spill in Shetland) and SEEEC (Sea Empress Environmental Evaluation Committee). In order to give some idea of the scale of these assessments, Appendix 1 lists the projects commissioned by the SEEEC within its three topic task groups, tailored to the characteristics (species and habitats at risk) of the impacted areas in South and West Wales. These ran alongside a fish and shellfish monitoring programme operated by Cefas which was undertaken in order to underpin the fishery closures established after the oil spill and to further feed into environmental impact assessment.

Finally, it should be recognised that designing a monitoring programme is not a one-off event. Circumstances will change as an incident proceeds, particularly if it is protracted (as in the *Deepwater Horizon* subsea blow-out, for example) and the monitoring programme should evolve to meet changing aims. Logistics are also an important consideration.

- Expertise, equipment and capacity – many of the more technical studies will require specialist expertise and equipment and laboratory analysis of samples; large studies may stretch the availability of those resources.
- Tides and weather – survey timing will need to take account of tide times and weather.
- Access to sites – survey and sampling sites may be located in areas that are difficult to access or where access requires permission.
- Licences – some species are protected by law, and studies may require a licence from the relevant agency for any handling or collection.

To facilitate ease of finding works that are cited in the text, references are provided at the end of each section. In addition, a full bibliography is provided at the end of the document.

REFERENCES

Burgherr, P. 2007. In-depth analysis of accidental oil spills from tankers in the context of global oil spill trends from all sources. *Journal of Hazardous Materials*, **140**: 245–256.

Huijer, K. 2005. *Trends in oil spills from tanker ships 1995–2004*. Paper presented at the 28th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 7–9 June 2005, Calgary, Canada. www.itopf.com/_assets/documents/amop05.pdf [accessed 14 June 2011].

IPIECA. 1996. *Sensitivity mapping for oil spill response*. IPIECA Report Series, Volume 1. International Petroleum Industry Environmental Conservation Association, London, UK. 24pp. http://www.ipieca.org/system/files/publications/IMO_Vol1.pdf [accessed 4 November 2011].

IPIECA. 2000. *Choosing spill response options to minimize damage: net environmental benefit analysis*. IPIECA Report Series, Volume 10. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol10_NEBA_1.pdf [accessed 2 July 2010].

Maritime and Coastguard Agency. 2006. National Contingency Plan for Marine Pollution from Shipping and Offshore Installations. www.mcga.gov.uk/c4mca/mcga07-home/emergencyresponse/mcga-pollutionresponse/mcga2007-ncp.htm [accessed 23 September 2010].

Moore, J.J., Hill, A.S., and Sanderson, W.G. 2005. Development of CCW impact assessment framework for a marine pollution oil spill incident. CCW Marine Monitoring Report No: 20, Countryside Council for Wales, Bangor, UK.

National Research Council. 1999. *Spills of nonfloating oils: risk and response*. Committee on Marine Transportation of Heavy Oils. National Academies Press, Washington, DC, USA. 88pp. www.nap.edu/catalog.php?record_id=9640 [accessed 2 July 2010].

National Research Council. 2005. *Oil spill dispersants: efficacy and effects*. Committee on Understanding Oil Spill Dispersants. National Academy Press, Washington, DC, USA. 378pp. www.nap.edu/catalog.php?record_id=11283 [accessed 2 July 2010].

Schmidt-Etkin, D. 2011. Spill occurrences: a world overview. In: *Oil spill science and technology* Chapter 2, pp. 7–48 (Fingas, M., ed.). Gulf Professional Publishing. ISBN 978-1-85617-943-0.

1

DEFINING A MONITORING PROGRAMME

When do we need to monitor?

"When an incident is expected to have a significant environmental impact."
This is related to the oil and/or chemical spilled, or that may be spilled, the quantity, the location and the resources at risk locally.

It is a question that can be fairly readily assessed using inputs from modellers, chemists and ecotoxicologists from Cefas for England and Wales (or agencies such as the Agri-Food and Biosciences Institute or Marine Scotland Science in the devolved administrations of Northern Ireland and Scotland), backed up by natural resource information from the statutory nature conservation agencies (Natural England, Countryside Council for Wales, Scottish Natural Heritage and the Joint Nature Conservation Committee) and fisheries resource and activity information from the Marine Management Organisation or devolved administrations. It should consider physico-chemical properties (density, solubility, volatility, ability to bind to particles, persistence and reactivity), inherent toxicity to both wildlife (including aspects such as smothering and bioaccumulative capacity) and humans, and the likely movement of the material, whether as a coherent slick or not, in relation to the resources threatened. Initially, information on the actual severity of the incident may not be available. While worst-case scenarios rarely see a total loss of cargo and bunker fuel, this may be a good starting point for early modelling until more accurate information is available. This process will also clarify the answers to the additional questions listed below, which will begin to focus the aims and extent of the monitoring programme.

- When species/habitats of nature conservation importance are likely to be impacted
- When commercial fish and shellfish stocks are likely to be impacted
- When contamination of the human foodchain is likely
- When an incident may have other human health implications

Why do we monitor?

Possible aims might be:

- To assess the impact on species/habitats of nature conservation importance – for instance, in relation to the EU Birds and Habitats Directives
- To assess the impact on commercial stocks of fish and shellfish
- To assess the impact on the human food chain
- To inform fishery closure/re-opening
- To assess the efficacy of chosen response options
- To assess any impact on the local human population
- To provide public reassurance

However clear the direction of the monitoring programme is, there will also be a number of overlapping aspects to consider. Clouds of volatile chemicals close to centres of population with an onshore wind point towards impacts on the local human population, but may also impact species of nature conservation importance – fisheries and birds, for example. In major incidents, there will be considerable interest from the media and the public, who also need information to be provided in an appropriate manner. “Can I still eat fish?” is a perfectly legitimate question and should be answerable in a straightforward manner. Finally, we have a statutory duty to do so. In transitional and coastal waters as defined by the Water Framework Directive (WFD) we have a statutory duty to ascertain the magnitude and impacts of accidental pollution to inform the establishment of a programme of measures for the achievement of the environmental objectives of WFD, and to identify specific measures necessary to remedy the effects. Also, under the Marine Strategy Framework Directive (MSFD), for waters at a greater distance from shore, we have an obligation to investigate the occurrence, origin and extent of significant acute pollution events and their impact on biota physically affected by this pollution, in order to assess the impact of the pollution events on Good Environmental Status within the affected region or sub-region.

What do we monitor?

- Important commercial species of fish and shellfish
- Oiled and rescued birds, or birds likely to be impacted by a spillage
- Species/habitats of nature conservation importance
- Seawater and sediments
- Air
- Public health impacts
- The general state of the marine ecosystem

This is dependent on the concerns identified above.

Where do we monitor?

- Impacted areas
- Unimpacted areas nearby, which may be impacted later
- Unimpacted areas nearby, likely to remain so, as reference sites

Use of fate and transport modelling to predict oil/chemical behaviour helps to identify sites likely and unlikely to be impacted later.

During an oil incident response (and possibly also during a chemical incident response, depending on the nature of the chemical), Shoreline Cleanup Assessment Teams (SCATs) are often deployed to systematically survey and document affected areas to provide a rapid and accurate geographic picture of shoreline oiling conditions. This information is used to develop real-time decisions regarding shoreline treatment and clean up operations. Initially developed 20 years ago following the *Nestucca* and *Exxon Valdez* oil spills, the SCAT approach has been used on many occasions worldwide. A SCAT manual is available from the Maritime and Coastguard Agency (2007).

Overall this information will also be of use in identifying impacted and unimpacted areas and the degree of contamination at specific locations, which will be of use when defining and interpreting the results of a monitoring programme. See also NOAA (2000, 2003).

All impacted areas should be considered for monitoring. Hence the scale of the impact will drive the scale of the monitoring programme, as was the case, for example, for the *Braer* and *Sea Empress* oil spills. Also, the outcome of modelling studies will help to define areas outside the currently impacted area which may be affected later. These should also be incorporated into the monitoring plan. The limits to which oil or chemicals might be transported will define the maximum size of the impacted area for the incident – areas outside the impacted area that are similar to those inside (in relation to sediment characteristics, species of fish and shellfish present, etc.) can be utilised as reference areas if there is no or little background information available from the area before the incident. Comparisons between impacted sites and reference sites or background information allow the impacts of an incident to be inferred. Habitat-sensitivity mapping, conducted prior to an incident primarily to help guide a pollution response, can also provide information useful in the selection of sites to be monitored.

How frequently do we monitor?

- Frequently enough to follow changes in status
- Infrequently enough to keep within the funding constraints
- Time-series measurements at multiple sites are very valuable in following the development of impacts resulting from an incident, and recovery

Contamination and degree of impact can increase rapidly during the initial stages of an incident, as the oil or chemical spilled will be present in the environment at the highest concentrations. These will be reduced over time by dilution, evaporation, dissolution, beaching and a range of other processes. Typically, levels of contamination by, for example, polycyclic aromatic hydrocarbons (PAH) from oils, rise rapidly, peak, and decline over a longer period – see Appendix 2 for more detail. Bioaccumulated chemicals can be expected to follow a similar profile. This means that the frequency of monitoring is likely to be more intensive initially and scaled back over time to allow monitoring to be cost-effective. In all post-incident monitoring, there is a balance to be struck between the frequency of monitoring and the level of funding available with which to undertake it.

REFERENCES

Maritime and Coastguard Agency. 2007. The UK SCAT manual: a field guide to the documentation of oiled shorelines in the UK. Maritime & Coastguard Agency, Southampton, UK, 47pp+ vi. www.dft.gov.uk/mca/corp_118.pdf [accessed 5 October 2011].

NOAA. 2000. *Shoreline assessment manual*. HAZMAT Report No. 2000–1. National Oceanic and Atmospheric Administration. 58pp + appendices. http://response.restoration.noaa.gov [accessed 2 July 2010].

NOAA. 2003. *The coastal resource coordinator's bioassessment manual.* Office of Response and Restoration, National Oceanic and Atmospheric Administration. 260pp + appendices. http://response.restoration.noaa.gov [accessed 2 July 2010].

2

PREMIAM
POST-INCIDENT
MONITORING
GUIDELINES

IMPLEMENTING A MONITORING PROGRAMME: HOW DO WE MONITOR?

2.1 IMMEDIATELY, IDENTIFY AND ACCESS ANY PRE-EXISTING BASELINE DATA

Information on pre-existing baseline data is gathered by SEGs as part of their role between incidents, and so the local SEG(s) should be the first port of call. Monitoring programmes undertaken by the relevant environmental regulator (e.g. the Environment Agency in England and Wales, EA, the Scottish Environment Protection Agency, SEPA, in Scotland; see Section 2.15) may also yield useful information, as may the UK's national marine monitoring programme (the Clean Seas Environment Monitoring Programme, CSEMP). Relevant surveys and studies may also have been undertaken by local Wildlife Trusts and other nature conservation agencies, the Royal Society for the Protection of Birds and the British Trust for Ornithology, universities and research institutes. These will most probably not be well catalogued and may require some effort to unearth.

2.2 IMMEDIATELY, COLLECT SAMPLES AND STORE TO PROVIDE A BASELINE

The availability of pre-incident monitoring data is one of the topics that the SEGs in each area should have addressed. They should be contacted very rapidly in order to establish what data are available and where they can be obtained from. In the absence of pre-existing baseline information, samples (sediments and biota, preferably) can be collected from selected locations and stored in a suitable way (frozen in the case of sediments and biota for chemical analysis) against future need. This will be particularly useful in the case of chemicals (Hazardous and Noxious Substances: HNS compounds) where, for the majority of chemicals transported by sea, there is very little likelihood of data having been collected before. Ideally, sampling locations should be chosen so as to represent both reference sites (those that are unlikely to be impacted during the incident) and sites that are likely to be impacted. In some cases, useful physical evidence of baseline conditions may also be gathered from recently impacted areas (e.g. stem density in marshes). In order to help define sites that may be impacted in the future, computer modelling of the likely movement of slicks or floating or dissolved chemicals should be used, as was done successfully following the *MSC Napoli* container-ship grounding incident in 2007 (Law, 2008). Also, the characteristics of the samples taken from the two sets of locations should be similar wherever possible – for example, muddy sediment; mussels or fish/ invertebrates of the same species. When selecting species as monitoring organisms, consideration should also be given to the commercial fishery activities in the local area so that those contributing significantly to the local landings in terms of quantity or value are included. Similarly, species of significant nature conservation importance should be considered for inclusion.

Within the boundaries of WFD water bodies, WFD tools should be used as there will be a need to assess and report on the ecological and chemical status of the water body post-incident.

REFERENCE

Law, R. 2008. Environmental monitoring conducted in Lyme Bay following the grounding of *MSC Napoli* in January 2007, with an assessment of impact. Science Series, Aquatic Environment Monitoring Report No. 61, Cefas, Lowestoft, UK. 36pp. www.Cefas.co.uk/publications/aquatic/aemr61.pdf [accessed 26 May 2010].

2.3 SURVEY DESIGN

Designing an impact assessment study for a particular ecological resource must be undertaken with considerable attention to detail. A large number of decisions need to be taken that will affect the value of the study and its ability to provide useful conclusions. The following sections aim to provide guidance on how to design appropriate studies, but more technical guidance on specific methods requires reference to other literature. Various methodological manuals are available providing standard methods and procedures that have been used in previous oil spill studies (e.g. Australian Maritime Safety Authority, 2003a, 2003b; IMO/UNEP, 2009; Moreira et al., 2007; Robertson, 2001).

After careful prioritization, each impact assessment study would typically be based on:

- Selected biological features or key indicators, chosen according to their ecological significance and their sensitivity
- Essential environmental parameters (chemical/physical characteristics of the habitat that help identify changes from previous environmental conditions)
- Chemical analysis of the pollutant (to confirm its identity and to allow monitoring of the decline of the pollutant towards baseline level)

It is not usually necessary to investigate all the ecosystem's components in order to build up a picture of the harm caused by the accident. Sometimes indicator species can be selected that will give a general indication of the scale and extent of the impact. In general, amphipods (a diverse group of small shrimp-like crustacea widespread in the marine environment) are sensitive to hydrocarbons in water and are often used as indicators in biological effects studies or sediment bioassays. On rocky shores, limpets are another indicator species that may act as a surrogate for the whole rocky shore community. Bivalve molluscs, such as cockles, oysters and mussels, are often of commercial importance and also are effective bioaccumulators of many contaminants. Where appropriate, the biological element most sensitive to the particular pressure caused by the incident should be monitored. Within WFD water bodies, WFD assessment methods should be used where possible.

Studies should also aim to establish a link of causation ("Pathway" in US damage assessment parlance) between the impacts and the incident, and this will be a strict requirement if compensation is to be sought under the international oil pollution compensation conventions, such as those administered by the International Oil Pollution Compensation Funds (IOPC). It should also be noted that survey design is an iterative process, particularly in long-running incidents (such as may result from a subsea blow-out on an oil platform), as concerns will change as the incident evolves.

REFERENCES

Australian Maritime Safety Authority. 2003a. *Oil spill monitoring handbook*. AMSA, Canberra. www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/Oil_Spill_Monitoring_Handbook.pdf [accessed 24 May 2010].

Australian Maritime Safety Authority. 2003b. *Oil spill monitoring background paper*. AMSA, Canberra. www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/oil_spill_monitoring_background_paper.pdf [accessed 24 May 2010].

IMO/UNEP. 2009. *IMO/UNEP guidance manual on the assessment and restoration of environmental damage following marine oil spills*. London, UK. 104pp.

Moreira, S., Santos, M., Cunha, I., Sousa, A., Lima, D., Coimbra, J., Reis-Henriques, M.A., Guilhermino, L. 2007. *EROCIPS Report for Task 7.3.5: environmental monitoring report*. www.erocips.org/reports_press_releases.htm [accessed 24 May 2010]. http://www.erocips.org/7.3_environmental_monitoring_report_erocips-2.pdf [accessed 14 January 2011].

Robertson, S.B. 2001. Guidelines and methods for determining oil spill effects. *Proceedings of the 2001 International Oil Spill Conference*, pp. 1545–1548. American Petroleum Institute, Washington, DC, USA.

2.3.1 Design process

The following points describe a logical process for designing a survey of a natural resource:

1. Identify the natural resources for which there is concern (see Section 2.9.2) and carry out reconnaissance surveys to assess the spatial extent and level of exposure to oil or chemicals (see Sections 2.9.1 and 2.9.3).

2. Define the aims and objectives of the study – first understand clearly what question(s) are to be answered. Examples of typical questions and their consequences are given in Appendix 3. Bear in mind that many objectives will not require detailed studies, particularly if there are severe visible impacts. For many objectives, the results of the reconnaissance survey may be adequate and more detailed study is likely to be expensive. Conversely, for the more subtle effects, consider the realistic possibility that detailed studies may still not yield statistical proof that an impact has occurred.

3. Define the geographic scope, time limits and the scale of the study. A balance is needed here between the desire to understand the full extent of the effects in space and time and the imperatives of budgets and deadlines. A focus on the worst affected areas and typical timescales of effects, with an associated but less intensive strategy for the wider area, may be appropriate.

4. Examine information from past studies of the resource in the affected area (see Section 2.1) or elsewhere to evaluate whether the methodologies used are appropriate for application to oil spill impact assessment, whether a modified methodology would work or whether a new methodology needs to be devised. Evaluation of the pre-spill data from the affected area should also be made to assess its usefulness as a baseline.

5. With the above in mind, select suitable parameters/attributes for measurement (see Sections 2.9.3 and 2.9.4) – ensuring that they are suitable for detecting relevant change, that they are technically and logistically feasible within the timescale of the study, and that they will produce reliable and reproducible results.

6. Select or design an appropriate method to obtain the necessary data, including preparation of detailed protocols to ensure quality and consistency, to agreed standards (see Section 2.13).

7. Analyse existing pre-incident data from the site or from similar resources to understand the potential levels of natural variability (temporal fluctuations and spatial patchiness).

8. Decide on the level of accuracy that is appropriate. A specialist in the resource, possibly with the aid of a statistician, will be able to interpret the available information on natural variability and advise on the consequences of under- or over-sampling. This will be particularly important if it is expected that the results of the study could be challenged in a legal or scientific forum.

9. Decide on a basic impact assessment strategy – i.e. whether to compare post-incident and pre-incident data, impacted and reference sites, follow recovery at sites impacted during the incident, or a combination of two or more strategies. See Section 2.3.2.

10. Consider the likely data analytical requirements – it is often advisable to get guidance on appropriate statistical methods and computer software packages before collecting data.

11. Decide how many impacted sites and reference sites to survey and/or sample, how many replicate samples/records to take at each site and how frequently to carry out survey/sampling; taking into account financial constraints and the need for statistical rigour (see Point 8 above).

12. Decide or estimate the duration of the study – you may wish to monitor until levels return to a pre-defined baseline, but this may take a much longer or shorter time than you predict. Periodic interim evaluations of the data will help to refine the monitoring programme so as to keep its focus.

13. Define procedures for tracking samples/data and other chain-of-custody (see Sections 2.5 and 2.13.1) requirements. Confirm availability of sufficient specialist expertise and laboratory analysis capacity (particularly for large studies) (e.g. via the PREMIAM network, www.cefas.defra.gov.uk/premiam.aspx).

14. Prepare relevant health and safety risk assessments, organise logistics and plan work schedule – generic assessments and procedures may already be in place in the relevant agencies. The SEG should be aware of these ahead of time, and the EG should be prepared to adapt them to meet the specific circumstances of the incident.

15. Prepare recording forms and database.

16. Select sites to represent the different levels of impact, taking account of confounding factors and logistical issues. See Section 2.3.3.

17. Test and thoroughly review the methodology.

18. Initiate survey.

It must be recognised that survey design is, to a large degree, an iterative process, as the monitoring programme must continue to meet current needs. Biological and chemical sampling and surveys are typically carried out by different personnel, to different protocols, and often by different organisations (due to their very different academic disciplines). Unfortunately, this may result in a lack of co-ordination between the collection of biological and chemical data, with consequent difficulties for comparison and correlation. Coordination is important to ensure that the data can be integrated and assessed together at a later date.

2.3.2 Survey strategy

Reconnaissance surveys are a prerequisite before any detailed studies are carried out, particularly for biological studies. Section 2.9.1 describes the conspicuous impacts that may be observed and should be recorded, and Section 2.9.3 describes the types of information that can be collected during reconnaissance surveys. As noted above, it is possible that results from the reconnaissance surveys may be adequate to meet the defined objectives. However, if more detailed studies are required, then there are three main strategies to impact assessment studies following oil or chemical incidents:

a. Comparison of post-incident data with pre-incident data
b. Comparison of data from impacted sites with data from reference sites
c. Analysis of post-incident data monitored over a period of time to describe the recovery process

Each strategy has different advantages and disadvantages, but while the most reliable option would be to use a combination of all three strategies, this is not always possible. It is difficult to prove beyond all doubt that damage (more than the obvious short-term impacts) has occurred, but with carefully designed studies it is often possible to describe the level of change and prove beyond reasonable doubt whether it was caused by the oil/chemicals or not.

Comparison of post-incident data with pre-incident data

Pre-incident data are very valuable to impact assessment studies, so this is the best comparison if appropriate data are available. However, even if pre-incident data exist, the quality of those data will greatly affect the conclusions that can be derived from them. The best pre-incident datasets will include a series of data collected over time, so as to show the levels of natural fluctuations. A single snapshot of data will be much less valuable, particularly if it is old. There will also be a level of uncertainty if the pre-incident data are from a site that was not badly impacted, do not include some important parameters (such as PAH, background hydrocarbon levels, etc.) or from a location that cannot be found precisely enough for reliable direct comparison with the impacted area. It is often advisable to carry out additional studies using the other strategies to provide further evidence. For many habitats and species, it will be important to carry out the post-incident survey at the same time of year as the pre-incident survey, to avoid seasonal changes.

Comparison of data from impacted sites with data from reference sites

Comparison with reference sites is the most common strategy for assessing post-incident impacts and has many advantages for practical planning purposes (e.g. in the event of an oil or chemical spill, sites can be carefully chosen to be representative of the various levels of impact and you are free to select the most appropriate parameters to record). However, it is important to note that reference sites are not control sites in a scientific sense, and it will never be possible to select reference sites that have exactly the same environmental conditions as the impacted sites prior to the incident. It is, therefore, rarely possible to demonstrate with certainty that differences in the parameters you record between the reference sites and the impacted sites are due to primary or secondary effects of the incident, and the oil or chemical(s) involved. While proof is not possible, by very careful selection of the reference sites and by collecting good-quality data from as many sites as reasonably feasible, it is possible to provide a weight of evidence that goes beyond reasonable doubt. For surveys of biological communities and populations, which are typically very patchy, in order to allow statistical inference it is recommended that samples are collected from numerous stations properly allocated. Researchers typically select at least 10 impacted sites and at least 5 reference sites, though the appropriate level of sampling differs based on the circumstances of each incident. Impacted and reference sites will vary between habitats and species. After statistical analysis, even this number of samples may be found to be inadequate to detect any impact (if there was one), but that level of sampling effort typically provides a practical compromise that takes account of available time, financial budgets and statistical rigour. Furthermore, while an impact may still be suspected, the inability of a study to detect it provides valuable evidence that the impact is, at most, relatively small. Surveys of chemical contaminants may require fewer samples, due to their more consistent distribution and the relatively low concentrations that are naturally present in the environment. The fact that an incident has had no measurable impact on the environment may be just as important as being able to report the scale of a large impact.

Analysing post-incident data monitored over a period of time to describe a recovery process

If pre-incident data are not available and the impacted resource is fairly discrete (not possible to collect data from many sites and there are no suitable reference sites), it may still be possible to prepare a weight of evidence from monitoring at just a few sites within and around the affected area. The aim of this post-incident monitoring is to identify and describe any recovery process that occurs. If this recovery process is clearly identified, and distinguished from natural trends, it shows that the impacts must have occurred as a result of the incident. Distinguishing impact recovery from natural trends (including seasonal changes) will only be possible if unimpacted sites nearby are also monitored (which may not be directly comparable as reference sites, but which can provide information on natural trends).

If possible, an improvement on this strategy is to start collecting data from affected resources in the immediate post-incident period and to monitor the early stages of the impacts. In some situations it may even be possible to collect data before the impacts have had time to manifest themselves or when evidence provided using collected samples is still available to provide a reasonable description of the pre-incident conditions. For example, in some intertidal and shallow subtidal habitats it may be possible to establish sites and record densities of sessile organisms before they die or get washed away. This strategy may also be applied to some commercial and recreational resources – for example, aquaculture, where you may be able to assess condition of the farm stock and interview staff before animals start to die. Logistical and practical concerns (i.e. oil or chemicals obscuring the features, safety issues in impacted areas and closure of areas for spill response activities) may make this strategy impossible; but it is worthy of some consideration.

2.3.3 Selection and establishment of sites for survey and sampling

Selecting sites and stations for environmental surveys and monitoring programmes will depend on the occurrence of the resource chosen to sample/record, but it should also take account of the following:

Level of oiling or chemical impact – sites and stations should preferably represent a range of impact conditions. Remember that shoreline oiling or chemical contamination can be very patchy, so good evidence will be necessary for the degree to which each site and station was exposed (i.e. at the whole-shore scale and at the smaller scale of the individual stations). [Note: realistically it is unlikely that ecological impacts will be detected in cases of very light oiling (sheens or small patches of oil) or low-level chemical contamination, unless the resource is extremely sensitive and the pre-incident data are very good.]

Influences from other environmental factors – the quality of the habitat/population will be influenced by a variety of other factors, including wave exposure, height on shore, substratum type, rock features etc. As far as possible, stations with very similar environmental conditions should be selected.

Influences from other human activities or pollution from other sources – avoid locations within recreational areas, close to discharges, affected by heavy fishing activity etc., unless the other sites (particularly the reference sites) are similarly affected by these factors and their influence can be distinguished from the effects of the oil or chemical(s).

Accessibility – preferably allow easy and frequent access without it being too easy for other people to disturb the site. Monitoring sites at extreme low-water level, which can only be visited on extreme low tides, should be avoided.

Ease of relocation – it is not advisable to mark monitoring sites with paint, poles or other conspicuous signs, which can attract unwanted interest (resulting in vandalism or other damage to the resource). It is therefore preferable to select locations that can be easily identified in digital photographs and with simple descriptions. Fixing of the location using GPS is also desirable.

Once selected, establishing the sites should also be done with some attention to detail. The following actions can greatly improve the quality of the data:

Coordinate biological and hydrocarbon sampling – it will be much easier to interpret the results if biological impacts and chemical concentration data are recorded from the same locations.

Record the patchiness of the oil or chemicals – pollution from accidents is normally very patchy, so a good record of the oiling history on the particular area of study will also aid interpretation. If the nature of a spilled chemical makes similar recording possible, then do this for chemical spills also.

Record clean-up activity – clean-up activity is also patchy, so a good record of the clean-up applied to the particular area of study will also aid later interpretation.

Reference sites – these should be established in locations and habitats that are as similar as possible to the impacted sites, especially in relation to substratum, tidal height and water movement. It is worth taking considerable time and effort over their selection.

Accurate recording – accurately recording the positions of sampling stations is a critical component of sampling and data collection, both to verify that they have been taken from predetermined locations and to allow repeat samples to be undertaken from the same locations over time for trend analysis purposes. Fix station locations as accurately as possible – the use of GPS units and digital cameras makes it relatively easy to fix sites for relocation, but it is necessary to develop a systematic methodology for this, so that new surveyors can be confident that they are sampling/surveying the same locations. When photographs of prominent features are taken, it may also be useful to record the position of the camera using the GPS unit for future reference. For greatest reliability it is advisable to prepare site location sheets including: location map showing access route; latitude/longitude position (including chart datum); annotated photographs, hand-drawn diagrams to illustrate sampling positions/transects etc.; and brief notes on access, safety issues, habitat features etc.

2.4 SAMPLING STRATEGIES AND METHODS

Sampling should include both impacted and reference (unimpacted) sites, ideally with similar characteristics as outlined in Section 2.3.3 above. Sites that are not impacted at the time of sampling but are thought likely to be impacted later on during the incident (e.g. as indicated by predictive modelling of the trajectory of the spilled material) can provide excellent reference (pre-incident) information.

The range of samples to be collected can be very wide, including water, subtidal and intertidal sediments, subtidal and intertidal biota, coastal (supratidal) biota and sediments, commercial fish and shellfish, and samples of the spilled oil or chemical(s) from the sea surface or from beaches. Dissolved concentrations of determinands are usually very low even during marine incidents, and great care must be taken in selection of sampling devices, their cleaning prior to use and the avoidance of cross-contamination. Plastics are generally not suitable materials as they are not resistant to solvents commonly used to clean sampling devices, and phthalate esters added as plasticizers (substances added to plastics to increase their flexibility, transparency, durability and longevity) can leach into water samples. For oils and chemicals generally, glass is the preferred material. (Further information on sampling methods for water, sediments and biota is given in Appendix 4.)

2.4.1 Statistical considerations

The monitoring study needs to be designed so that it is able to answer the main questions required of it. Generally, the main choices to be made will be in terms of the number of locations to monitor and the frequency of monitoring at each location. Two typical aims are to determine:

1. Whether mean levels of pollutants at the contaminated site are "similar" to those at a reference site (we could define "similar" to be "within *X* units");

2. Whether levels of pollutants are reducing/increasing at the contaminated site. That is, is there a downward or upward trend of magnitude at least *Y* at the contaminated site? Such a trend at the contaminated site might well be examined relative to any trend at the reference site. Note that, in practice, trends may not always be straightforward linear trends. For example, the trends may go up for a period and then down for the next. For linear trends, simple techniques such as linear regression may well be adequate. However, for more complicated trends, use of statistical smoothing techniques will usually be required.

For both the detection of mean differences and the detection of trends, the concept of statistical power is important. There is a need to make sure that there are sufficient stations and sufficient frequencies of temporal measurements to be able to demonstrate effects with a fairly high degree of certainty.

For determining mean differences (Aim 1), there will need to be a compromise between the sample size and the choice of X such that the probability of being able to determine X statistically is sufficiently high (say 80%) but that X is not so large that safety is at risk. If X is very low, then there will be a need for a lot of observations; if X is high, then fewer observations will be needed. Clearly, there are resource implications here too – but remember that if the monitoring programme is not adequate to answer the questions posed initially, undertaking the monitoring may be a waste of time and money. Similarly, for detecting a trend (Aim 2), the design of the monitoring programme should ensure the ability to detect scientifically important trends with high probability.

The statistical power of the programme design will be governed by the sample size, but also by the magnitude of the variation in the data. The design becomes more powerful (and hence fewer measurements are needed) as the variability becomes lower. The use of good techniques to collect and analyse contaminated data that reduces the variation in the results will also increase the statistical power of the monitoring design.

The above explanation is in terms of statistical power, which is useful for statistical significance tests. However, it is often more appropriate to estimate levels of pollutants at the contaminated site (or the difference between a test and a contaminated site) with a certain degree of precision. The sample size and variation of results have a similar effect on precision as they do on power. The higher the sample size and the lower the variation, the higher the precision. The sampling design should be selected in order to achieve some agreed precision in the results.

Another concept that will be useful when comparing levels of pollutants at a contaminated site with some reference level is the use of, so called Green tests. These follow the precautionary principle – that is, they need to demonstrate that the levels of pollutants in the contaminated area are below some threshold. This means that, for Green tests, the null hypothesis is that the mean pollution level in the contaminated site is greater than or equal to the threshold level. The alternative hypothesis would be that the mean pollution levels are less than the threshold. The contaminated site is determined to be "healthy" only if the null hypothesis is rejected. In other words, the assumption is that the threshold has been breached, unless the data can demonstrate otherwise.

One difficulty with Green tests is the choice of the threshold. Ideally, we might want the threshold to be the background level of the pollutant from some uncontaminated site. However, even if the test site is at background levels, some part of a confidence limit for the mean level of the pollutant, calculated from sample data from the site, will inevitably be higher than the background level. Thus, in reality, the threshold needs to be set at a level higher than background level. There are many ways to do this. However, one pragmatic approach is to set the threshold such that mean level of data from a site at background level would pass the Green test on, say, 95% of occasions.

2.5 CHAIN OF CUSTODY

Chain of custody is a legal term that refers to the ability to guarantee the identity and integrity of the specimen from collection through to reporting of the test results, and it should be applied in post-spill monitoring studies. It is a process used to maintain and document the chronological history of the specimen. Documents should include a unique identifier (specimen number) by which the sample can be identified, the name of the individual collecting the specimen, each person or entity subsequently having custody of it and its location, the date the specimen was collected or transferred, and a brief description of the specimen. Containers in which samples are transported and stored should be sealed with custody seals so that they cannot be opened without breaking the seal. A secure chain of custody, together with the use of robust, validated and quality-controlled analytical techniques to confirm the identity and establish the concentrations of contaminants present in a specimen, leads to the production of valid and legally defensible data. Examples of chain-of-custody forms for registering changes of stewardship of samples are given as appendices in IMO (1998) and Yender *et al.* (2002).

REFERENCES

IMO. 1998. IMO guidelines for sampling and identification of oil spills. *Manual on oil pollution, Section VI*. 44pp. London, UK. ISBN 978-92-801-1451-5.

Yender, R., Michel, J. and Lord, C. 2002. *Managing seafood safety after an oil spill*. Hazardous Materials Response Division, Office of Response and Restoration. National Oceanic and Atmospheric Administration, Seattle, WA, USA. 72pp.
http://response.restoration.noaa.gov/book_shelf/963_seafood2.pdf [accessed 27 May 2010].

2.6 TRANSPORT AND STORAGE

All samples should be transferred to the analytical laboratory for storage prior to processing and analysis as soon as possible after collection. If the sampling personnel are not returning to the laboratory (e.g. partway through an extended sampling programme) then overnight couriers can be used to transport the samples. In a major and protracted incident, it is unlikely that the laboratory will have sufficient spare freezer capacity to hold all the samples, but additional units that will sit in the car park can be rented from a number of suppliers. This system was used during the *Sea Empress* incident. Priority was then given to the analysis of samples directly relevant to the management of fishery closures, and samples related to the overall impact assessment were banked in the freezer until the pressure on the analytical facility eased as segments of the fisheries were re-opened.

2.7 SAMPLE PREPARATION CONSIDERATIONS

It is also important to prevent both contamination of samples during preparation and analysis and loss of analytes. The detailed procedures by which this can be done will be very dependent on the analytical requirements of the compounds to be determined and their properties. Potential sources of contamination and loss should be identified and controlled. For example, some compounds may be sensitive to degradation by UV light, and UV filters will then need to be fitted to laboratory lights so that analytes are not broken down. Also, amber glassware should be used. If this is not possible, then transparent glassware can be wrapped in aluminium foil to exclude light. Biota tissue samples are particularly at risk because of the time taken to remove tissues by dissection, so this should be conducted in a dust-free atmosphere, which can be achieved by having an input of filtered air and maintaining a positive pressure in the laboratory.

2.8 CHEMICAL ANALYTICAL METHODS

2.8.1 Analytical techniques

In the case of oil spills, the choice of determinands is simple. Oil is composed of a complex mixture of hydrocarbons, including aliphatic hydrocarbons, one-ring aromatic hydrocarbons, usually known as BTEX (benzene, toluene, ethylbenzene and xylenes), and the polycyclic aromatic hydrocarbons (PAH: those with two to six fused aromatic rings). PAH formed by combustion processes comprise predominantly parent (non-alkylated) PAH, while in oils, alkylated PAH predominate and the mixture is much more complex. This means that, while analytical methods based upon HPLC methodologies can be used satisfactorily to determine the smaller number of combustion PAH, the available resolution using this technique is inadequate for the analysis of oil-derived PAH and gas chromatography–mass spectrometry (GC-MS) with either a quadrupole or ion-trap mass spectrometer is the preferred technique. This technique is now widely available and relatively inexpensive. Electron impact ionisation yields PAH parent ions with high abundance, and ion-trap MS detection is preferred as it can be operated in full scan mode (collecting signals for all ions formed) without loss of sensitivity, making the use of single/multiple ion monitoring unnecessary. Recent work has also demonstrated that the use of tandem mass spectrometry using a triple quadrupole instrument can yield lower detection limits by reducing noise. The use of full-scan GC-MS also yields the possibility for the investigation of aliphatic hydrocarbons and biomarker compounds (e.g. *n*-alkanes, pristane and phytane; steranes and triterpanes – see 2.8.2 below) in the same samples used for PAH determination. The development of a methodology for the determination of PAH has been outlined (de Boer and Law, 2003) and the current status summarised (Law et al., 2011) elsewhere. Many methods have been developed utilising different extraction and clean-up techniques, but one that has been used in oil spill studies and other monitoring programmes for 30 years, and so is well tried and tested, is described in Kelly *et al.* (2000).

Spills of HNS compounds are more problematic, as a very wide range of chemicals are transported in either bulk or packaged form and so may be lost from vessels. Metals (other than mercury) can be readily determined using either inductively coupled plasma-mass spectrometry (ICP-MS) or inductively coupled plasma-optical emission spectrometry

(ICP-OES). Mercury can also be determined using these techniques, but more appropriately using cold-vapour atomic absorption spectrophotometry or atomic fluorescence spectrometry.

All of the techniques mentioned above may be useful for the determination of specific chemicals, depending upon their physico-chemical properties, but the combination of liquid chromatography–mass spectrometry (LC-MS) and GC-MS has the capability to be used for the analysis of an extremely wide range of compounds. It is unlikely that fully validated, targeted analytical methods will be available for all of the wide range of possible spilled chemicals, as most are not included in routine monitoring programmes. In some programmes (e.g. those operated in coastal waters by the EA in England and Wales or SEPA in Scotland), screening techniques are deployed in order to detect and semi-quantify non-target compounds, with the aim of identifying those that may merit future inclusion in the full programme as a result of environmental concerns and so for which fully quantitative methods with appropriate quality control will need to be developed. These typically use spot sampling combined with GC-MS and/or LC-MS techniques, utilising samples collected alongside routine surveys. In some cases, passive sampling devices are used for sample collection purposes, with the advantage that time-weighted average concentrations can then be derived. Passive samplers are less useful in an emergency context, due to the relatively long equilibration and deployment times (on the order of months) required.

REFERENCES

de Boer, J. and Law, R.J. 2003. Developments in the use of chromatographic techniques in marine laboratories for the determination of halogenated contaminants and polycyclic aromatic hydrocarbons. *Journal of Chromatography A*, **1000**: 223–251.

Kelly, C.A., Law, R.J. and Emerson, H.S. 2000. Methods of analysis for hydrocarbons and polycyclic aromatic hydrocarbons (PAH) in marine samples. Aquatic environment protection: analytical methods, 12. Cefas, Lowestoft, UK.
www.Cefas.co.uk/publications/aquatic/aepam12.pdf [accessed 24 May 2010].

Law, R.J., Webster, L., Theobald, N., Rumney, H.S. and de Boer, J. 2011. Organic micropollutants. In: *Chemical marine monitoring: policy framework and analytical trends*, 1st edition, Chapter 6, pp. 161–196 (Roose, P., Verreet, G. and Quevauviller, P., eds.). Wiley-Blackwell, Chichester, UK. 376pp. ISBN 978-0-470-74765-0.

2.8.2 Chemical fingerprinting

Environmental forensics has been defined as the systematic and scientific evaluation of physical, chemical and historical information for the purpose of developing defensible scientific conclusions relevant to the liability for environmental contamination. Under this heading, chemical fingerprinting using a variety of methods and target biomarker compounds has been widely applied to oil spills of both known and unknown origin (e.g. in the case of the *Prestige* oil spill and of two mystery oil spills in Brazil and Canada). Wang and Stout (2007) have gathered these approaches together in an authoritative book, and a summary of the approaches is provided in Appendix 5.

REFERENCE

Wang, Z. and Stout, S.A. 2007. *Oil spill environmental forensics: fingerprinting and source identification*. Elsevier, Inc., Amsterdam, The Netherlands. 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

2.9 ECOLOGICAL IMPACT ASSESSMENT

2.9.1 General recording of conspicuous impacts

Reliable records of conspicuous impacts to wildlife, particularly corpses, provide the most persuasive evidence of ecological impacts. Some caution is necessary to ensure that the impacts are caused by the oil or chemicals and are not just coincidental, but it is obviously important to initiate recording schemes as early as possible, before the evidence disappears.

Although corpses of dead wildlife may not come ashore for a few days, it is important to prepare procedures for recording and collating data as quickly as possible. Beached bird surveys can require considerable manpower (possibly by volunteers) to thoroughly survey the coastline (initially on a daily basis and then less frequently).

Collection of dead wildlife for possible necropsies, morphometric studies and hydrocarbon analysis can provide valuable information. However, establishing an effective system for collecting dead wildlife, maintaining the necessary records (numbers, species, locations, dates, etc.) and producing relevant statistics is a specialist task that should not be underestimated (IPIECA, 2004) (see also Section 2.12 below).

It will never be possible to record all wildlife deaths, and multiplication factors are typically applied to the statistics to give estimated totals. Credibility will be greater if a range of scientifically validated factors are applied and presented, rather than a single factor that may be seen as an under- or over-estimate (Camphuysen and Heubeck, 2001). Oil or chemical spills that coincide with severe storms may lead to mortalities that cannot be attributed to one effect or the other.

Marine fish and invertebrates (including bivalves, crabs, sea urchins and starfish) that live in shallow coastal waters have also sometimes been washed up dead or moribund on the shore after an oil spill (e.g. following the *Sea Empress* oil spill in Wales in 1996; see Law and Kelly, 2004). Records (*ad hoc* or from systematic surveys) of the numbers and species present should be collated, with photographs and at least some specimens taken for later analysis. Some specimens should be frozen for potential chemical analysis – this may be required if there is any doubt as to whether the animals were impacted by the spill or by a natural event.

Other conspicuous signs of impact of the spill may also appear as time goes by, including the development of green algal “flushes” (resulting from the reduced feeding of grazing animals) and bleaching of algae. Records of such changes should also be made and collated. The degree of natural variability in algal cover can be seen in the NOAA Mearns Rock time series (currently 15 years in length, available at: http://oceanservice.noaa.gov/education/stories/oilymess/downloads/photo_series.pdf accessed 14 January 2011) initiated following the *Exxon Valdez* oil spill in Alaska in 1989.

REFERENCES

Camphuysen, K. and Heubeck, M. 2001. *Marine oil pollution and beached bird surveys: the development of a sensitive monitoring instrument. Environmental Pollution*, **112**: 443–461. www.sciencedirect.com/science/journal/02697491 [accessed 2 July 2010].

IPIECA. 2004. *A guide to oiled wildlife response planning*. IPIECA Report Series, Volume 13. International Petroleum Industry Environmental Conservation Association, London, UK. 52pp. http://www.ipieca.org/publication/guide-oiled-wildlife-response-planning [accessed 4 November 2011].

Law, R.J. and Kelly, C. 2004. The impact of the "*Sea Empress*" oil spill. *Aquatic Living Resources*, **17**: 389–394.

2.9.2 Selecting/prioritizing subjects for surveys and monitoring

Before selecting a particular species or biological community to study, it is worth having an understanding of its expected sensitivity and vulnerability to the possible impacts of the incident – for example specific oils or chemical(s) – and its expected potential for natural recovery. Experience from previous spills provides considerable information on the sensitivity and vulnerability of different resources. The following generalisations may help to decide which resources deserve a higher priority; but it is important to appreciate that they are only generalisations and may not always be appropriate. Furthermore, it may also be appropriate to focus at least some attention on resources that are not known to be sensitive, to demonstrate that many may be relatively unaffected and to provide a balanced description of the overall impact of the incident.

More information on the sensitivity and vulnerability of the various biological resources is given in Section 2.9.4.

- The majority of serious long-term impacts occur from oil on the surface of the water and on shorelines – i.e. subtidal impacts are much less common and are generally shorter in duration. Even when high concentrations of hydrocarbons are dispersed into the water column (either naturally or by the application of chemical dispersants), the resulting impact reduces rapidly as depth increases. It is therefore normally appropriate to put less emphasis on studies of subtidal resources, particularly in deep water, unless there is evidence that oil or chemicals have been carried into deeper waters and there is particular concern for a very important population or community
- Oil reaching the marine environment in high amounts as a result of oil spills constitutes an important pollution source directly affecting microbial populations. A summary of the current state of knowledge in this area is given in Appendix 6, although they have not to date been considered a high priority for study for most incidents
- Planktonic communities have generally been found to show no more than transient impacts from oil spills and are not normally studied for impact assessments
- Adult fish of most species will move away from contaminated waters if they can, so fish kills are unlikely in open coast spill situations and have not been reported in offshore spill situations. Fish eggs, larvae and juveniles are more sensitive and vulnerable, particularly those that are concentrated in shallow coastal habitats

- In shallow water or in the case of sunken oil/chemical(s), mobile marine species (nekton) are less at risk of contamination than are sessile species or slow-moving species that spend all or part of their life cycle in proximity of the sea floor (benthos/benthic organisms)
- Wave-sheltered habitats are usually much more sensitive to oil spills than are wave-exposed habitats, due to the persistence of the oil. Similarly, habitats that are not well flushed by tidal movements will also tend to retain oil and have longer lasting impacts
- Some intertidal habitats where oil/chemical(s) may become trapped are more vulnerable to effects and may suffer longer term impacts. Many of these habitats are also important for their species richness. These include rockpools, under boulders, and in fissures and crevices
- Bulk oil tends not to remain lying on wet lower shore habitats, but concentrates along upper shore strandlines. If the oil is very weathered before it arrives at the shore, it is then unlikely to have a measurable toxic effect on the lower and middle shore habitats. Behaviour of spilled chemicals will be very dependent on their physico-chemical properties
- Oil tends not to penetrate into muddy sediments unless there are large crab burrows or the spill occurs during severe weather. However, muddy sediments tend to be anaerobic, and therefore oil trapped in such sediments will be very persistent. Behaviour of spilled chemicals will be very dependent on their physico-chemical properties
- Birds that spend time on the surface of the water are most at risk from spills of oil or floating chemicals. Seabirds that spend most of their lives in the air or on their roosting/nesting sites and relatively little time in contact with the water are much less vulnerable
- Wading birds are not often badly oiled. They could be affected by reduced access to feeding grounds or reduced food supply, but there is little empirical evidence of such effects. Effects may be more likely if food resources are already limiting
- Most marine algae, including intertidal species, can survive considerable oiling, probably due (in part) to their mucous coating
- Some groups of invertebrate animals are known to be particularly sensitive to oil. These are primarily the mobile forms, particularly small crustaceans (amphipods, isopods and shrimps), some types of intertidal snails (limpets and some other gastropods), burrowing clams in lower shore and very shallow subtidal (< 5m) sediments, starfish and sea urchins on the lower shore and very shallow subtidal (< 5m). Sensitivity to spilled chemicals is likely to be very variable, and probably largely unknown

The likelihood of adverse effects is an important consideration when selecting species or biological communities to study, but there are others. We should also appreciate the often high natural variability (both spatial and temporal) of many of the species or biological communities we may wish to study. In addition to the spill itself, it is likely that other human activities or pollutants may also affect the resource (confounding factors), and it may therefore be difficult to distinguish the impact of the spill.

Reviews of historical oil spill impact assessment programmes have highlighted that many studies detected no impacts and provided little value to the spill assessment except to prove that a resource was still present and apparently functioning – *and that this result was predictable before the study was initiated*. While it may be politically useful to show to the public that a natural resource was not impacted, this can deplete limited budgets. Some prioritisation of assessment studies is therefore appropriate. The considerable knowledge and experience available from previous spills can be used to assess the value of proposed studies. The main factors to consider when assessing the value of post-spill studies are:

Contamination – degree or likelihood of oil/chemical(s) reaching the resource:
Observed degree of oiling or chemical contamination
Vulnerability to oil/chemical(s)
Likelihood of a transport pathway for oil/chemical(s)

Importance of resource:
Nature conservation importance
Rarity and distribution
Ecological/functional importance
Profile of resource – public/scientific expectations
Commercial value
Human health concerns

Impact detection – likelihood that you will be able to detect (and prove) an impact:
Known or likely sensitivity to an oil or chemical spill (including recovery potential)
Quality of existing baseline information
Confounding factors (i.e. resource is influenced by other pollutants or human impacts)
Scale of natural fluctuations (temporal and spatial)
Existing methodological protocols/known indicators that can give meaningful results

Feasibility:
Logistical factors – access, expertise, laboratory capacity, licensing, etc.
Available budget and cost-effectiveness

2.9.3 Survey planning

Reconnaissance

Early reconnaissance is appropriate for many intertidal habitats (e.g. saltmarsh, seagrass beds and other features and sites of particular interest) that have received significant oiling (more than sheens or a few small patches) or chemical contamination. The reconnaissance should be carried out by an ecologist with relevant expertise as soon as possible after free oil or chemical(s) have stopped moving around. The reconnaissance may be carried out during detailed SCAT-style surveys, but in addition to oil/chemical distribution mapping (preferably using the standard SCAT oiling descriptors) the survey should include:

- Basic biotope/NVC[1] mapping of contaminated areas (this is a primary purpose of the reconnaissance, but the level of detail only needs to be adequate for the purpose of identifying potential study areas)
- Numerous photographs [view shots (endeavour to include features that will aid relocation), habitat shots (include quadrat, ruler or familiar object – e.g. pencil – to give scale) and close-ups] (mark location on map or geo-reference with hand-held GPS)
- Ecological observations of condition of impacted plants and animals (any signs of decay or stress, growth status and evidence of new growth, reproductive status, which parts of the plants are oiled or show signs of chemical contamination)

1 National Vegetation Classification

- Brief assessment of the condition of any known populations of protected species (typically only the conspicuous species, unless a key species needs to be sampled)
- Collection of a representative sample of impacted vegetation (stored as pressed specimens)
- Other relevant observations (e.g. dead animals, green algal cover, evidence of any clean-up etc.)
- Brief assessment of potential for follow-up surveys (including practical and logistical constraints)
- Geo-references of all information collected

For some studies, it will be appropriate to standardise the methodology used for these observations. Reconnaissance of small areas of selected shallow subtidal priority habitats (e.g. maerl beds, *Zostera marina* beds, lagoons) may also be appropriate if particularly high concentrations of hydrocarbons in water have been recorded in the vicinity. The primary aim here is to make ecological observations of the condition of plants and animals and assess potential for follow-up surveys, though photography would also be useful. [Note: as with any survey work, the health and safety of survey personnel is paramount, so a risk assessment must be conducted and appropriate procedures set up to ensure that surveyors are not exposed to levels of hydrocarbons that may be unsafe.]

Biological features and parameters

The range of biological features that could be considered for post-spill impact assessment studies is very large, even if it is decided to concentrate solely on those resources that are considered of high priority. For each biological feature there are also many possible attributes to choose from, and for each attribute there will also be a variety of optional study techniques and detailed protocols. These biological features, and the effects that oil spills can have upon them, can be broadly grouped as follows:

Community effects – studies that describe changes in whole communities or assemblages of different plants and animals, including distribution and spatial extent (regionally or locally), species richness/species diversity, or species composition of the community. Community composition and species diversity studies can require considerable time and effort, but may be appropriate if there are no obvious indicator species (see below) or if it is considered necessary to assess effects on the whole community. Changes in species diversity can be particularly useful and relevant to community health, but many factors can affect diversity and interpretation of the results may not be straightforward.

Population effects – studies that describe changes in populations of particular species or species groups, including size or spatial extent of population, local, regional or national distribution of the species, age or size structure of the population. Other studies that are very useful for our understanding of spill impacts on wildlife describe the temporal pattern of mortality, extent/distribution of mortality, and causes/mechanisms of mortality. Previous oil spill studies have identified a few species and species groups that may act as bioindicators of oil pollution effects. It may be appropriate to concentrate studies on these particular bioindicator species. Some species are bioindicators because they are particularly sensitive to the toxicity of the oil or spilled chemicals, while others may be relatively tolerant and their populations may opportunistically increase following a spill.

Individual (sublethal) effects – studies that describe changes in individuals of particular species or species groups, including physical (external pathology), internal (histopathology), reproductive, biochemical and genetic condition, and animal behaviour. Conspicuous effects that can be studied in the field or on whole organisms (e.g. growth rates of plants and sessile invertebrates, poor egg laying by birds and abnormal growths on fish) are useful for some species, but in recent years there have been developments in various techniques to identify sublethal effects of pollutants in the tissues of individual animals, sometimes referred to as biomarkers[2]. See Section 2.10 for information on biomarker methodologies. However, even if sublethal effects are found and are linked to the spilled oil or chemicals, their relevance and importance to the condition of animal populations and the ecosystems they live in may not be apparent.

One would not be surprised to see effects at an individual level following a spill of oil or chemicals and perhaps even community effects in large incidents, but it would be exceptionally rare to ever see true population effects.

Toxicity and bioassay tests – see Section 2.10.

Note: all biological features are influenced by a range of environmental factors, many of which can confound the effects of the oil or chemical spill and complicate the interpretation of study results. When collecting samples and biological data for communities, populations and species, it is important that samples and measurements are also taken of those factors that characterise their habitat.

Biological sampling, survey and laboratory methods

While standard methodological protocols are available for some habitats and species, most will require at least some modification to make them appropriate to the particular characteristics of the resource affected and the spill conditions. Section 2.9.4 includes references to standard methodological texts for surveying and monitoring biological resources and to other guidance documents that specifically relate to oil spills (e.g. the Oil Spill Monitoring Handbook; Australian Maritime Safety Agency, 2003a, 2003b). Assessment of the effects of the *Deepwater Horizon* spill is also generating a large number of detailed methodologies and protocols. The methodology should include choice of suitable sampling/survey/laboratory equipment and definition of precise procedures and protocols for recording field data, taking the samples, preservation and storage of samples, processing the samples in the laboratory, and analysing and interpreting the data. The method should also minimise sampling error, ensure that there will be no cross-contamination between samples and include strict quality-control measures. The choice of survey and laboratory personnel will also require certain minimum levels of qualifications and experience.

---

2 Biomarkers – this term is used in two ways, both of which are relevant in this document: (1) a specific sublethal biochemical or physiological measurement that is used to predict a toxic event in an animal; (2) a hydrocarbon compound found in oil that was originally produced by living organisms and is mostly unchanged (sometimes called a "molecular fossil") and is used in hydrocarbon analysis to uniquely characterise ("fingerprint") the particular oil.

The amount of data you will need to collect will depend on the natural variability of the resource and other statistical requirements. This will be the basis for how many impacted sites and reference sites to survey/sample, how many replicate samples/records to take at each site and how frequently to carry out survey/sampling. Sampling stations can be positioned selectively (selective sampling), randomly (random sampling) or at regular intervals (systematic sampling). Site selection criteria are given in Section 2.3.3.

Analyse and compare data

Ideally the methods of data analysis will already have been considered during the survey design (Section 2.3.1) and will be structured as appropriate to the overall strategy (Section 2.3.2). Very little generic guidance can be given here because there are so many different techniques, but typical objectives of the analysis may include:

- Identifying and describing any impacts caused by the oil or chemical spill or the subsequent clean-up activity on natural resources
- Describing the status and speed of the ongoing recovery processes
- Informing about measures needed to remediate the impact of the incident

It is emphasised that obtaining absolute statistical proof that an impact has occurred may not be achievable because of the inherent variability of the natural environment and the excessive monitoring time and costs that may be required to do so. A crucial task at this stage is to ensure that all data, including raw field survey data and summary data, are collated, catalogued and securely stored in such a way that they can be extracted, decoded and re-analysed at some time in the future. Data standards developed by the Marine Environmental Data and Information Network (MEDIN) should be followed (see Section 2.12.1 below).

REFERENCES

Australian Maritime Safety Authority. 2003a. *Oil spill monitoring handbook*. AMSA, Canberra. www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/Oil_Spill_Monitoring_Handbook.pdf [accessed 24 May 2010].

Australian Maritime Safety Authority. 2003b. *Oil spill monitoring background paper*. AMSA, Canberra. www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/oil_spill_monitoring_background_paper.pdf [accessed 24 May 2010].

2.9.4 Biological resources – specific guidance

The guidance given in this section is primarily derived from experience gained from studies mounted during oil spills. Similar studies have not generally been undertaken following chemical spills in the marine environment. Similar considerations will generally apply, although the broader range of physico-chemical properties and behaviours of chemicals will affect the applicability of the guidance depending on the chemical(s) spilled.

The following sections provide guidance for eight broad habitats and eight broad groups of mobile species. Plants and invertebrates are considered within the relevant habitat sections, as impacts to their populations are generally closely linked with the sensitivities and vulnerabilities of the habitats. Much of the guidance is still generic, as the variety of habitats, species and their associated sensitivities is far too great for detailed specific guidance. It is also inevitable that habitats and species that may be important in some regions of the UK are not adequately covered, so the reader will need to adapt the approaches and methods given in the most relevant sections.

One notable group, the marine reptiles, have not been included below. This is because the leatherback turtle, which is the only marine reptile of any significant ecological interest in UK waters, is still uncommon and non-breeding here. Recent information from the *Deepwater Horizon* oil spill in the Gulf of Mexico suggests that marine turtles can be vulnerable to floating oil and tar balls, and survey and monitoring methodologies are being developed. Future editions of the PREMIAM guidelines may include turtles; meanwhile, the methods and strategies described in Section 2.9.4.16 (cetaceans) may be useful, and further information is given in NOAA (2003) and the IMO/UNEP (2009) guidelines.

The guidance given in each section highlights the methods and strategies that have been effective in previous studies, typically including reconnaissance methods and a variety of biological survey attributes and, in some cases, suggesting sublethal effects measures. It is likely that a more joined-up approach, linking effects at different biological levels during impact and recovery, would help to strengthen the potential of sublethal biomarker methods as useful screening/early warning tools.

REFERENCES

IMO/UNEP. 2009. *IMO/UNEP guidance manual on the assessment and restoration of environmental damage following marine oil spills*. London, UK. 104pp.

NOAA. 2003b. *Oil and sea turtles: biology, planning and response* (G. Shigenaka (tech. ed.). US National Oceanic and Atmospheric Administration. 116pp.
http://response.restoration.noaa.gov/book_shelf/35_turtle_complete.pdf [accessed 19 September 2011].

BIOLOGICAL RESOURCES: CONTENTS

2.9.4.1 TERRESTRIAL MARITIME HABITATS

Terrestrial maritime habitats

Known vulnerability and sensitivity

Habitats above the level of spring high tides are not normally vulnerable to marine oil or chemical spills. Few studies have therefore been carried out on oil spill impacts to terrestrial maritime habitats, and fewer have detected any notable impacts. The *Braer* oil spill was one of the few to result in significant terrestrial contamination, due to incredibly strong winds and the large volumes of light oil that were released next to the coast. Studies at other marine oil spills, including the *Sea Empress*, have shown no discernible effects on vegetation that was not heavily oiled. It is concluded that terrestrial vegetation is not normally vulnerable to marine oil spills and, in any case, impacts are unlikely to be detected unless visibly coated with oil. No such studies have to date been undertaken following chemical spills in the marine environment.

Coastal habitats above the level of spring high tides may be physically impacted by intensive clean-up activity if they are used as an access route to the shore or as a laydown area for equipment. Those that will be particularly vulnerable include foredune communities of sand dunes, vegetated shingle ridge communities and machair. Sand dunes and other vegetated marine habitats also provide important erosion protection to some coastlines, and it is possible that physical damage due to clean-up activities could initiate more serious erosion.

Terrestrial maritime habitats are also important to a large variety of animals, including insects and other invertebrates, amphibians (e.g. natterjack toad), reptiles (e.g. sand lizard) and small mammals. These species may also be vulnerable to clean-up activity, including disturbance. No specific guidance is provided for these animals, but approaches and methods can be adapted from other sections.

Impact assessment methods

In some regards, post-spill impact assessment is easier for terrestrial marine vegetation than for intertidal areas. The work is not hindered by sea/tides and the natural removal of surface contamination and impacted vegetation, although the initial scorching and dieback effects may disappear when new growth begins (i.e. in the following spring/summer).

Reconnaissance – taking particular note of scorching and dieback effects.

Biological survey attributes – some of the more likely potential indicators are: vegetation condition (signs of scorching and dieback). Recovery will be indicated by new growth from spill-damaged perennials.

Strategy

If good-quality pre-incident data exists from the impacted area – re-establish previous survey sites and use the same methodology to survey impacted vegetation.

If no (or inadequate) pre-incident data are available from the impacted area, but oiling or chemical contamination is very severe and significant impacts are expected – establish discontinuous belt transects or random quadrats across selected impacted communities (preferably stratified by level of oiling or contamination) and in reference areas outside; use standard botanical survey methods to survey plant communities; monitor changes at seasonal intervals. Comparisons between impacted and reference sites will be strongly influenced by other environmental factors.

Potential bioassay studies on soil from the contaminated areas and reference sites should include counts of germinating seeds of local grasses.

Effects of clean-up

Methods to study effects of physical damage from access and clean-up would depend on the affected habitat, but measurements and monitoring of percentage cover are likely to be appropriate. (Further useful information can be found in Bayfield and Frankiss, 1997; Evans, 1998; Little et al., 2001; Wolseley and James, 1997.)

REFERENCES

Bayfield, N.G. and Frankiss, J.R. 1997. Impacts of oil pollution from the Braer on semi-natural vegetation. In: *The Impact of an Oil Spill in Turbulent Waters: The Braer*, pp. 52–62 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Evans, S. 1998. *Effects of oil and clean-up of oil from the Sea Empress on the nationally rare and scarce vascular plants of Pembrokeshire*. CCW, Pembrokeshire, UK. 20pp + appendices.

Little, A.E., Moore, J.J. and Dyrynda, P.J. 2001. *Ecological impacts of shoreline clean-up during the Sea Empress oil spill*. A report to the Countryside Council for Wales. 124pp + plates.

Wolseley, P. and James, P. 1997. *Report of resurvey of lichen quadrats on Skomer Island NNR*. Report to CCW from The Natural History Museum. 79pp.

2.9.4.2 SALTMARSHES

Saltmarshes

Known vulnerability and sensitivity

Saltmarshes are generally considered to be very vulnerable to oil spills, because they form in the upper part of sheltered muddy shores where oil becomes concentrated, and once oil gets into a marsh it is trapped by the vegetation where it is difficult to remove and causes long-term contamination. Damage to the saltmarsh vegetation affects the whole marsh ecosystem and is also likely to affect neighbouring ecosystems that rely on services from the marsh. Saltmarshes are also a difficult habitat to clean, due to the soft muddy substratum. Attempts to clean up these areas are not generally recommended without specialist advice, and it may be concluded that clean-up activities in certain areas may do more environmental damage than the spill itself. Effects can also be expected due to spilled chemicals entering saltmarsh areas. There is a considerable body of literature on impacts of oil spills and on spill clean-up on saltmarsh. IPIECA (1994) summarised information on their sensitivity and recovery potential. Aberdeen University Research & Industrial Services (AURIS, 1994), Baker *et al.* (1996) and Sell *et al.* (1995) reviewed the literature on impacts and recovery of saltmarshes following a number of oil spills and experimental studies. A summary of likely effects is given in Baker *et al.* (1996):

Light to moderate oiling, oil mainly on perennial vegetation with little penetration of sediment – some plant shoots may be killed, but recovery can usually take place from the underground systems. Good recovery commonly occurs within one to two years.

Light to moderate oiling, oil mainly on annual vegetation with little penetration of sediment – it is possible that areas of vegetation may die completely. If large areas are affected, recovery may be delayed because seed has not been produced or cannot germinate because it has been oiled.

Oiling of perennial vegetation such that species composition is altered – following oiling, it is sometimes found that species composition is altered for some time because relatively resistant species take over from more susceptible species. Provided that a good vegetative cover (of whatever species composition) is established quickly, there will be minimal risk of soil erosion.

Oiling of shoots combined with substantial penetration of oil into sediments – this is more likely to happen with relatively fresh light crude oils or light products such as No. 2 fuel oil [diesel], because these are less viscous. Damage to the underground systems results from the subsurface oil, and recovery is delayed. Areas of vegetation may die completely. Sediment erosion may occur if recolonisation does not start within a year.

Thick deposits of viscous oil or mousse on the marsh surface – vegetation may killed by smothering, and recovery delayed because persistent deposits inhibit recolonisation.

A classification of different saltmarsh plants according to their recovery potential after oil spills, based on field experiments in British marshes, is also given in Baker *et al.* (1996). This classification may be useful when prioritising and planning impact assessment studies:

Group 1 Filamentous algae (e.g. *Ulothrix*, *Enteromorpha*, *Vaucheria*). Filaments may be quickly killed by some oils, but populations can recover rapidly by growth and vegetative reproduction of any unharmed fragments, or by spores.

Group 2 Shallow rooting, usually annual plants with no underground storage organs (e.g. some species of *Suaeda* (seablite) and *Salicornia* (glasswort)). The plants can be quickly killed by a single oil spillage, and recovery depends upon the successful germination of seeds. Seedlings of perennial plants are also easily killed.

Group 3 Shrubby perennials with exposed branch ends (e.g. *Halimione* (sea purslane), *Iva* (marsh-elder), *Baccharis* (tree groundsel)) which may be badly damaged by oil. If some parts of the plant remain undamaged, recovery can take place through new shoot formation.

Group 4 Perennial grasses and some other grass-like plants which usually recover well from light or moderate oiling (e.g. *Festuca* (fescue grass), *Puccinellia* (common saltmarsh-grass)). New growth can take place from the basal areas, which are typically protected from oil by overlying vegetation or old leaf sheaths. Some grasses, notably *Spartina* (cord-grass), have extensive underground systems with food reserves; these are an advantage when new shoots are produced after a spill. Other grasses (e.g. *Agrostis stolonifera* (bent grass)) may have competitive advantage in vegetation recovering from oil, because of their fast rate of growth and mat-forming habitat.

Group 5 Perennials, usually of rosette habit, with robust underground storage organs (e.g. tap roots) (e.g. *Armeria* (thrift), *Limonium* (sea-lavender) and *Plantago* (plantain)). Such plants tend to be the most resistant to oiling, with new growth occurring from the rosette centres.

Baker *et al.* (1996) also describe the importance of seasonal timing of an oil spill on recovery processes in saltmarshes, with differences related to the natural periods of dormancy of saltmarsh plants, timing of seed setting and the storage of energy in underground tubers. Physical or chemical clean-up of oiled saltmarsh areas has been shown on a number of occasions to cause considerable long-term damage, and it is now well recognised amongst professional oil spill responders that the best option is "leave-alone" (cf. IPIECA, 1994). However, mistakes still occur and impacts can include damage to root systems, large semi-permanent ruts, oil pressed deep into muddy sediments and sometimes significant erosion of marsh edges.

Impact assessment methods

Spatial patchiness and temporal variability are not as high in salt marshes as they are in many other habitats, but seasonal and inter-annual changes can still be very marked. This means that, while baseline data will be very valuable, impacts on salt marsh communities may be best assessed by methodically monitoring their condition over the following weeks, months and possibly years, and by using the same methods in unoiled reference sites. It is recommended that aerial photographs (or multispectral scans) are taken, as soon as possible, of the oiled marsh and surrounding area. If the oil causes plants to die or lose their leaves, the aerial photographs/images will provide a baseline for assessing and monitoring the extent of impacts, although this will need to take account of natural seasonal die-back.

Recording dead wildlife – counts of *recently* dead crabs and snails will provide useful evidence of impact.

Reconnaissance – taking particular note of the condition of oiled plants (signs of decay in leaves, shoots and roots; evidence of new growth; reproductive status); which parts of the plants are oiled; any evidence of long-term natural trends (signs of natural die-back; is marsh young and spreading or old and degenerating?). Aerial photographs (preferably vertical views and geo-referenced) will help to define the area of impact and may be useful for site selection.

Biological survey attributes – some of the more likely potential indicators are: vegetation condition (decay and death of leaves, stems and roots), opportunistic algal cover, and sediment/epifloral macro-fauna abundance (particularly snails and opportunistic polychaetes). Recovery will be indicated by new growth from oil-damaged perennials, the lodging and rooting of vegetative fragments on mud surfaces, invasion of damaged areas by vegetative runners from undamaged areas, germination of seeds and seedling growth. Aerial photo-monitoring of vegetation cover may show extent and recovery from severe impacts.

Strategy

Some assessment should be carried out in all marsh zones that were significantly coated with oil (i.e. more than sheens or a few small patches).

Re-survey and compare with pre-incident data if available, bearing in mind that natural fluctuations will be high for annual plant species and mobile invertebrates.

Comparison between stations with different degrees of oiling, including unoiled areas, may be possible within extensive marshes.

Different marshes may be possible but will be strongly influenced by other environmental factors.

Another option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least 1 year at selected sites.

Effects of clean-up

Methods to study effects of physical damage will depend on the affected features and extent of damage, but are likely to include basic ecological observation, vegetation mapping and, in worst cases, measures of the rate of erosion at marsh edges.

Key methodological references

Dalby (1987), JNCC (2004). (Further useful information can be found in Bell et al., 1999; Getter et al., 1984; RPI, 2002.)

REFERENCES

AURIS. 1994. *Scientific criteria to optimise oil spill clean-up operations and effort*. A report by AURIS Environmental, Aberdeen, UK. 56pp + appendices, figures and tables.

Baker, J., Little, A. and Heaps, L. 1996. *Guidelines for assessing the ecological condition and recovery of oiled shores*. A report by AURIS Environmental, Aberdeen, UK. 89pp.

Bell, S.A., Stevens, P.A., Norris, D.A., Radford, G.L., Gray, A.J., Rossall, M.J. and Wilson, D. 1999. *Damage assessment survey of saltmarsh affected by the Sea Empress oil spillage*. Report by Institute of Terrestrial Ecology to CCW. 45pp + appendices and figs.

Dalby, D.H. 1987. Salt marshes. In: *Biological surveys of estuaries and coasts*, Chapter 3, pp. 38–80 (Baker, J.M. and Wolff, W.J., eds.). Estuarine and Brackish Water Sciences Association handbook. University of Cambridge Press, Cambridge, UK.

Getter, C.D., Cintron, G., Dicks, B., Lewis, R.R. and Seneca, E.D. 1984. The recovery and restoration of salt marshes and mangroves following an oil spill. In: *Restoration of habitats impacted by oil spills*, Chapter 3, pp. 65–113 (Cairns, J.J. and Buikemea, J., eds.). Butterworth Publishing Co., Boston, MA, USA.

IPIECA. 1994. *Biological impacts of oil pollution: saltmarshes*. IPIECA Report Series, Volume 6. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol6_Saltmarshes_0.pdf [accessed 2 July 2010].

JNCC. 2004a. Common standards monitoring guidance for saltmarsh habitats. Version August 2004. 23pp. *www.jncc.gov.uk/page-2204* [accessed 2 July 2010].

RPI. 2002. *Salt marsh reconnaissance*. www.researchplanning.com/services/nrda/saltmarsh.recon.pdf [accessed 2 July 2010].

Sell, D., Conway, L., Clark, T., Picken, G.B., Baker, J.M., Dunnet, G.M., McIntyre, A.D. and Clark, R.B. 1995. *Scientific criteria to optimize oil spill clean-up, pp. 595–610. Proceedings of the 1995 International Oil Spill Conference*. American Petroleum Institute, Washington, DC, USA.

2.9.4.3 SEAGRASS BEDS

Seagrass beds

Known vulnerability and sensitivity

Two distinctly different forms of seagrass bed are found around UK coasts – intertidal beds (comprising either *Zostera noltii* (dwarf eelgrass) or *Z. angustifolia* (narrow-leaved eelgrass)) and shallow subtidal beds (comprising *Zostera marina* (eelgrass)). The intertidal beds form a short and often sparse turf of narrow-leaved plants, while the subtidal beds form tall and often dense beds of broader-leaved plants. There have been few studies of oil spill impacts on temperate *Zostera* beds (AURIS, 1995), but those that have been done have highlighted the potential sensitivity of intertidal and shallow subtidal beds (Zieman *et al.,* 1984). While most of these studies have found that oil tends to have minimal observable impact on the *Zostera* plants themselves (except for some blackening of the leaves and temporarily reduced growth rates; e.g. Howard *et al.,* 1989, Jacobs, 1980 and Dean *et al.*, 1998), the oil and dispersed oil can have significant effects on fauna living in and on the sediments and on the leaves (e.g. Jewett *et al.,* 1999). Subtidal seagrass beds are often important fish nursery areas, and juvenile fish will be sensitive to high concentrations of dispersed oil. The vulnerability of subtidal seagrass communities to dispersed oil will depend greatly on the flushing rate of seawater through the bed and the depth of water and on the way in which oil is distributed. Any damage to the plants affects the whole seagrass ecosystem and is also likely to affect neighbouring ecosystems that rely on services from the seagrass. Some seagrass species go through seasonal patterns of growth and die-back.

Clean-up activity can have impacts on seagrass beds, particularly physical damage from trampling and vehicles and boat activity in shallow water. Experiments on impacts of dispersants have shown that worst effects occurred from pre-mixed oil and dispersant, which promotes the penetration of oil into the sediment. Information on dispersants and their use is available (Fiocco and Lewis, 1999).

Impact assessment methods

Although seagrass can go through periods of natural regression, spatial patchiness and temporal variability are not as high in seagrass beds as they are in many other habitats. Detection of conspicuous impacts on the condition of the seagrass plants may therefore be possible if monitoring begins early enough and includes some unoiled reference sites. As described above, however, there are typically greater effects on populations of animals living in the seagrass bed, although these are subject to higher levels of spatial patchiness and temporal variability. Detecting impacts in populations of these sensitive species (e.g. snails and small crustacea) is likely to require considerable efforts to collect data from numerous oiled sites and numerous comparable reference sites.

Intertidal seagrass beds

Recording dead wildlife – counts of dead bivalves etc. will provide useful evidence of impact.

Reconnaissance – taking particular note of condition of *Zostera*, presence of *Hydrobia* (mud snail), *Littorina* (winkle) and *Cerastoderma* (cockle). Aerial photographs (preferably vertical views and geo-referenced), where possible, will help to define the area of impact and may be useful for site selection.

Biological survey attributes – some of the more likely potential indicators are: blade condition (signs of blackening and defoliation), opportunistic algal cover, epifauna abundance (particularly snails) and infauna abundance (particularly cockles and opportunistic polychaetes).

Strategy

Re-survey and compare with pre-incident data if available. Note, however, that it will be difficult to detect any changes beyond the natural variation unless pre-incident data on any of the above attributes are very good (and recent) and oiling by fresh toxic oil or chemical contamination was/is severe.

Comparison between stations with different degrees of oiling may be possible on very extensive beds.

Another option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least 1 year at selected sites.

Effects of clean-up

The most likely impacts are from physical damage (trampling, vehicle traffic), so damage assessment should be based on basic mapping of damage features, ecological observation and seagrass coverage in relation to damage features.

Subtidal seagrass beds (and extreme lower intertidal)

Recording dead wildlife – counts of washed-up bivalves, urchins etc. will provide useful evidence of impact.

Reconnaissance – by snorkelling (at low water), taking particular note on the condition of *Zostera* plants, epifauna on blades (including amphipods in tubes and snails) and speed of retraction of bivalve siphons in sediment.

Biological survey attributes – some of the more likely potential indicators are: epifauna on blades of seagrass, blade condition (signs of blackening and defoliation), opportunistic algal cover, sediment mega-fauna abundance (particularly bivalves), sediment macro-fauna diversity and abundance (particularly tube-dwelling amphipods and opportunistic polychaetes) and juvenile fish abundance.

Strategy

Re-survey and compare with pre-incident data if available. Note, however, that it will be difficult to detect any changes beyond the natural variation unless pre-incident data on any of the above attributes are very good and oiling by toxic concentrations of oil or chemical contamination were/are severe.

Comparison with reference sites will be greatly hampered by influence of other environmental factors (*Z. marina* beds are often relatively small and well separated with distinct site specific characteristics).

The best option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least 1 year at selected sites.

Effects of clean-up

Potential impacts are from physical damage (trampling of beds at extreme low water), oily water run-off (from intertidal flushing operations) and chemically dispersed oil. Impact assessment of the former should be based on basic mapping of damage features, ecological observation and seagrass coverage in relation to damage features. Impact assessment of oily water run-off and chemically dispersed oil could be similar to the oil effects methods above, but it will be difficult to separate clean-up effects from other oil spill effects unless an experimental approach (including pre-clean-up recording) is applied. (Further useful information can be found in Davison and Hughes, 1998; den Hartog and Jacobs, 1980; Hodges and Howe, 1997.)

REFERENCES

AURIS. 1995. *Scoping evaluation of the biological recovery of oiled mangroves, coral reefs, seagrasses and sedimentary shores*. A report by AURIS Environmental, Aberdeen, UK. 148pp.

Davison, D.M. and Hughes, D.J. 1998. *Zostera Biotopes. Volume I: An overview of dynamics and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science (UK Marine SACs Project). 95pp. www.ukmarinesac.org.uk/publications.htm [accessed 2 July 2010].

Dean, T.A., Stekoll, M.S., Jewett, S.C., Smitha, R.O. and Hose, J.E. 1998. Eelgrass (*Zostera marina* L) in Prince William Sound, Alaska: effects of the *Exxon Valdez* oil spill. *Marine Pollution Bulletin*, **36**: 201–210.

den Hartog, C. and Jacobs, R.P.W.M. 1980. Effects of the *Amoco Cadiz* oil spill on an seagrass community at Roscoff (France), with special reference to the mobile benthic infauna. *Helgolander Meersunters*, **33**: 182–191.

Fiocco, R.J. and Lewis, A. 1999. Oil spill dispersants. *Pure and Applied Chemistry*, 71: 27–42.

Hodges, J. and Howe, M. 1997. *Milford Haven waterway. Monitoring of eelgrass Zostera angustifolia following the Sea Empress Oil Spill*. Unpublished report to the Shoreline and Terrestrial Task Group of SEEEC from the Pembrokeshire Coast National Park Authority. 13pp + tables and maps.

Howard, S., Baker, J.M. and Hiscock, K. 1989. The effects of oil dispersants on seagrasses in Milford Haven. In: *Ecological impacts of the oil industry* (Dicks, B., ed.). John Wiley & Sons, Chichester, UK.

Jacobs, R.P.W.M. 1980. Effects of the *Amoco Cadiz* oil spill on the seagrass community at Roscoff, with special reference to the benthic infauna. *Marine Ecology Progress Series*, **2**: 207–212.

Jewett, S.C., Dean, T.A., Smith, R.O. and Blanchard, A. 1999. *Exxon Valdez* oil spill: impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds. *Marine Ecology Progress Series*, **185**: 59–83.

Zieman, J.C., Orth, R., Phillips, R.C., Thayer, G. and Thorhaug, A. 1984. The effects of oil on seagrass ecosystems. In: *Restoration and management of marine ecosystems impacted by oil*, pp. 108–126 (Cairns, J and Buikema, A.L., eds.). Butterworth Publishing Co., Boston, MA, USA.

2.9.4.4 INTERTIDAL SEDIMENTS

Intertidal sediments

Known vulnerability and sensitivity

Sedimentary shores range from coarse shingle/pebble shores exposed to wave action to soft mud flats in sheltered bays. There are a number of physical and biological characteristics of sediment shores that can influence their vulnerability and sensitivity to oil spills, including wave exposure, shore topography, sediment composition, height of water table, presence of large burrows, abundance and diversity of infauna, and use of the shore by birds for feeding and roosting. Wave-exposed clean sandy shores are often considered to have a low vulnerability and sensitivity due to the natural cleaning of the waves and the relatively poor fauna in the sediment. However, a sheltered muddy gravel shore with a high biodiversity, including numerous long-lived bivalves, would have a high vulnerability and sensitivity. If not cleaned up, oil can persist and remain toxic in sheltered muddy sediments for many years (decades), particularly in unoxygenated sediments. AURIS (1995) reviews effects in intertidal sediments from a large number of spills and experimental studies. IPIECA (1999) summarises information on their sensitivity and recovery potential.

As on all shores, bulk oil tends to concentrate along the strandline, so hydrocarbon contamination in lower and middle shore sediments is usually less conspicuous and less persistent. However, if the oil is very fresh and toxic and/or water column concentrations are high, any sensitive fauna may be severely impacted by the acute exposure. Muddy sediments may also become contaminated by incorporation of persistent stranded oil or by dispersed oil adsorbing onto the fine particles, causing longer term impacts and slower recovery. In worst-case situations, long-term chronic seepage of toxic oil trapped in upper shore sediments can have a long-term impact on the middle and lower shore.

Some groups of sediment fauna are more sensitive to oil, than are others. Small crustacea (particularly amphipods and small crabs), some bivalves (e.g. cockles) and surface grazing snails (e.g. winkles) have been identified as the main casualties at a number of oil spills. Some other species of sediment fauna may opportunistically increase following oil spill impacts – particularly various small polychaetes (e.g. *Capitella* spp.).

Sediment meiofauna are also likely to be sensitive to oil and various authors have highlighted the advantages of using them as indicators of anthropogenic effects (e.g. abundance and diversity of nematodes and copepods). However, no reliable indicator of the effects of oil spills or hydrocarbons has yet been developed.

Clean-up activity can have impacts on infaunal communities, particularly physical disturbance of otherwise stable sediments on sheltered beaches. Severe impacts to infaunal communities of intensive and extensive flushing operations (often using hot water) were found on beaches oiled by the 1989 *Exxon Valdez* spill, and effects were still evident more than 2 years later.

Strandline (or drift line) material, particularly decaying seaweed, provides an important habitat for specialised strandline animals, including various amphipods (sand hoppers), insects and beetles. Shackley and Llewellyn (1997) describe the impacts of the *Sea Empress* oil spill and clean-up on strandline communities.

Impact assessment methods

The assessment of potential impacts on communities of sedimentary shores can be difficult, even with good pre-incident information. This is due to some spatial patchiness and high temporal variability and to the fact that impacts are hidden so that laborious sampling and laboratory analysis is usually required. However, some conspicuous impacts may be evident in the first weeks of the incident (e.g. stranded bivalves), so early reconnaissance is recommended. Subsequent assessment of population effects is likely to require sampling from numerous oiled sites and numerous comparable reference sites. Availability of pre-incident baseline data will be very useful.

Note: Surveys and monitoring of sediment communities have two important advantages over rocky shore communities – much reduced small-scale variability (patchiness) of confounding environmental factors and relatively well defined sample units (specified sampling devices, mesh sizes, etc.). However, impacts are generally less conspicuous and temporal fluctuations are just as high as on rocky shores. Bioassay tests – whole-sediment bioassays (e.g. survival of laboratory-reared amphipods in sampled sediment) could provide very useful tests of toxicity, particularly when natural variability of infaunal communities is very high and it is uncertain whether amphipods would naturally be present.

Recording dead wildlife – counts of dead cockles etc. will provide useful evidence of impact.

Reconnaissance – taking particular note of drainage features; the presence of seagrass, surface-grazing snails, cockles and other large bivalves (particularly on the lower shore), lug worm casts, large burrows; areas that would be very difficult to core into (due to subsurface coarse material); presence and character of strandline debris.

Biological survey attributes – some of the more likely potential indicators are: mega-fauna abundance (particularly bivalves); macro-fauna diversity and abundance (particularly amphipods and opportunistic polychaetes); growth rates of long-lived bivalves. The polychaete/ amphipod ratio has been suggested as an oil spill “bioindicator” by Gesteira and Dauvin (2000). Meiofauna abundance and diversity may be useful for following short- to medium-term effects, but natural variability will quickly confuse effects beyond a few months. The development of a method to assess sediment toxicity from natural copepod egg viability may become useful.

Strategy

Re-survey and compare with pre-incident data if available, but consider initially analysing only a selected few of the total samples to assess scale of impact before full re- analysis.

Comparison between stations with different degrees of oiling may be possible on very extensive beaches/shores. Comparison between sites on different shores will be complicated by confounding environmental factors.

Monitoring changes in some of the above attributes at intervals (bimonthly or seasonal) from the early stages of a spill and for at least 1 year at selected sites may show stages in impacts and recovery.

Effects of clean-up

Potential impacts are from physical disturbance and burial of oil (particularly from trenching), removal of strandline debris, and oily water run-off (from intertidal flushing operations). Such operations are most likely on firm sand beaches. Impact assessment could be similar to the oil effects methods described above, but it will be difficult to separate clean-up effects from other oil spill effects unless an experimental approach (including pre-clean-up sampling) is applied. Physical disturbance effects are more likely if these operations are allowed to occur on sheltered muddy sediments; monitoring of the infaunal communities should be able to detect impacts and follow recovery.

Key methodological references

Baker & Wolff (1987), Dalkin and Barnett (2002), JNCC (2004). (Further useful information can be found in Elliott et al., 1998; Holme and McIntyre, 1984; Kingston et al., 1997; Lee et al., 1999; Lindley et al., 1998; Moore et al., 1997; Rostron, 1998; Shackley and Llewelyn, 1997; Thomas, 1978; US EPA, 1994.)

REFERENCES

AURIS. 1995. *Scoping evaluation of the biological recovery of oiled mangroves, coral reefs, seagrasses and sedimentary shores*. A report by AURIS Environmental, Aberdeen, UK. 148pp.

Baker, J.M. and Wolff, W.J. (eds.). 1987. *Biological surveys of estuaries and coasts*. Estuarine and Brackish Water Sciences Association handbook. University of Cambridge Press, Cambridge, UK. 472pp. ISBN10: 0-52-131191-8. ISBN13: 978-0-52-131191-5.

Dalkin, M. and Barnett, B. 2002. Procedural Guideline No. 3–6 Quantitative sampling of intertidal sediment species using cores. In: *JNCC Marine Monitoring handbook*. Joint Nature Conservation Committee, Peterborough, UK.

Elliott, M., Nedwell, S., Jones, N.V., Read, S.J., Cutts, N.D. and Hemingway, K.L. 1998. Intertidal sand and mudflats and subtidal mobile sandbanks. An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project). 151pp. www.ukmarinesac.org.uk/publications.htm [accessed 2 July 2010].

Gesteira, J.L.G. and Dauvin, J.C. 2000. Amphipods are good bioindicators of the impact of oil spills on soft-bottom macrobenthic communities. *Marine Pollution Bulletin*, 40: 1017–1027.

Holme, N.A. and McIntyre, A.D. (eds.). 1984. *Methods for the study of marine benthos*, 2nd edition. IBP handbook, No.16. Blackwell Scientific Publications for International Biological Programme, Oxford, UK.

IPIECA. 1999. *Biological impacts of oil pollution: sedimentary shores*. IPIECA Report Series, Volume 9. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol9_SedimentaryShores.pdf [accessed 2 July 2010].

JNCC. 2004c. Common standards monitoring guidance for littoral sediment habitats. Version August 2004. 33pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

Kingston, P.F., Dixon, I.M.T., Hamilton, S., Moore, C.G. and Moore, D.C. 1997. Studies on the response of intertidal and subtidal marine benthic communities to the Braer oil spill. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 209–233 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Lee, K., Wohlgeschaffen, G.D., Tremblay, G.H., Vandermeulen, J.H., Mossman, D.C., Doe, K.G., Jackman, P.M., Wilson, J.E.H., Prince, R.C., Garrett, R.M. and Haith, C.E. 1999. Natural recovery reduces impact of the 1970 Arrow oil spill. In: *Proceedings of the 1999 International Oil Spill Conference*. American Petroleum Institute, Washington, DC, USA. #432, 5pp.

Lindley, J.A., George, C.L., Evans, S.V. and Donkin, P. 1998. Viability of calanoid copepod eggs from intertidal sediments: a comparison of three estuaries. *Marine Ecology Progress Series*, **162**: 183–190.

Moore, C.G., Harries, D.B. and Ware, F.J. 1997. *The impact of the Sea Empress oil spill on the sandy shore meiofauna of south west Wales*. A report to the Countryside Council for Wales from Heriot-Watt University, Edinburgh, UK. 79pp.

Rostron, D. 1998. *Sea Empress sediment shore impact assessment monitoring: Infauna of heavily oiled shores in Milford Haven and Carmarthen Bay*. A report to the Countryside Council for Wales from SubSea Survey, Pembroke, UK. 51pp + appendices.

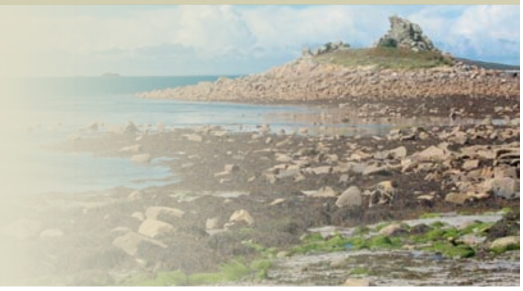
Shackley, S.E. and Llewellyn, P.J. 1997. *Sediment shore impact assessment/monitoring: strandline fauna*. A report to the Countryside Council for Wales from University of Wales, Swansea. 29pp + appendices.

Thomas, M.L.H. 1978. Comparison of oiled and unoiled intertidal communities in Chedabucto Bay, Nova Scotia. J*ournal of the Fisheries Research Board of Canada*, **35**: 707–716.

US EPA. 1994. *Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods*. Office of Research and Development, U.S. Environmental Protection Agency. www.epa.gov/waterscience/library/sediment/marinemethod.pdf [accessed 2 July 2010].

2.9.4.5 ROCKY SHORES (INCL. SPLASH ZONE LICHENS)

Rocky shores (incl. splash zone lichens)



Known vulnerability and sensitivity

The vulnerability of rocky shores to oil spills is mainly dependent on the wave exposure. Exposed rocky shores are normally considered to be one of the least vulnerable habitats to oil spills, because the oil is quickly removed by wave action. Sheltered rocky shores are often more vulnerable and sensitive, particularly if they include lots of rockpools and crevices (Baker *et al.*, 1996)

There is a considerable body of literature on impacts of oil spills and on spill clean-up on rocky shores. IPIECA (1995) summarises information on their sensitivity and recovery potential. AURIS (1994) and Baker *et al.* (1996) review the literature on impacts and recovery of rocky shores following a large number of oil spills and experimental studies. Studies by Southward and Southward (1978) on the effects of the 1967 *Torrey Canyon* oil spill defined the classic impacts and long-term recovery processes that oil and detergents (not “dispersants” as they are now defined) could have on limpet-dominated communities. However, the longevity of the effects they described (in excess of 10 years) have not been described from any spill since, presumably because the chemical agents used on the oil had a much more devastating effect than the oil by itself. More recent studies on various oil spills have found that recovery is normally much quicker (less than 3 years), although chronic persistent oil (particularly residues of viscous black oils in sheltered locations) can have long-term localised impacts.

Splash zone lichens, above the level of most spring tides, are included in this section because they are much more vulnerable to oil than is other terrestrial maritime vegetation. Impacts on these communities were observed during the *Sea Empress* spill in a few relatively sheltered locations where oil came ashore during a period of high spring tides and strong NW winds and coated areas of these communities (SEEEC, 1998). Recovery of these slow-growing lichen species has been slow (pers. obs.). Observations of damage to splash zone lichens following the *Betelgeuse* oil spill in Bantry Bay (Cullinane *et al.,* 1975) also showed similar effects. Splash zone lichens have also on occasion been impacted by clean-up activity. For example, following the *Sea Empress* spill, Little *et al.* (2001) described the damage to lichen colonies caused by high-pressure washing and wiping with sorbent pads.

Conclusions

A number of conclusions on sensitivity and appropriate survey methodologies can be drawn from the various studies of oil spill impacts on rocky shores:

- Acute mortality of intertidal limpets is a good indicator of fresh oil contamination (by liquid oil or very high concentrations in water), but mortality is much reduced if the oil is weathered. Adult limpet abundances are relatively easily recorded and monitored by a variety of quantitative and semi-quantitative techniques. Juvenile limpets (<10 mm in length) may be more sensitive than adults, but abundances are less easily recorded and the most recent recruits are certainly too well hidden to record between November and April. Size frequency monitoring can also provide useful information on impacts and recovery of the limpet populations
- Acute mortality of other gastropods (e.g. winkles and topshells) is also likely if large amounts of fresh oil or high concentrations of oil in water are present, but their cryptic behaviour can limit recordability in some habitats
- Diversity and abundance of small crustacea (e.g. in kelp holdfasts and algal turf habitats) are greatly affected by hydrocarbon concentrations in water (and presumably by liquid oil) and seem to have potential as indicators of oil contamination. More research is required on their sensitivity to different hydrocarbon concentrations and weathered oil, on recovery processes after impact, and on development of appropriate survey/sampling/analysis techniques
- Mortality of barnacles, primarily by smothering rather than chemical toxic effect, is likely where oil covers rocks; however, full recovery is likely to occur by new recruitment in the following year, unless residues of oil are persistent (e.g. from viscous oils in sheltered locations)
- Bleaching of coralline algae (crustose spp. and *Corallina* spp.), and in very worst cases of other red algae, is likely to occur from toxic oil concentrations, but not from weathered oil. However, death of the plants is not inevitable unless oiling and toxicity is very severe, and surviving plants are likely to regain colour quickly
- Other algae appear to be much less sensitive. Sublethal effects on fucoid algal growth have been suggested, but there is limited information on its sensitivity and detection of impacts may be unreliable
- Studies on rockpool communities have suggested that acute and chronic oiling can have effects on diversity and abundance of species, but methodological difficulties so far limit the reliability of monitoring. Further research and development of the techniques are suggested
- Splash zone lichens are vulnerable to oiling on very high tides, and some of these long-lived slow-growing species are sensitive to oil coating their thalli (particularly *Xanthoria parietina*)
- No other reliable indicators of oil spill impacts have been found. It is likely that various other rocky shore species and communities may be sensitive to oil spills (particularly small mobile species in other cryptic sub-habitats, e.g. crevices and under-boulder habitats), but reliable survey and monitoring techniques have not been developed

Impact assessment methods

Detecting impacts on rocky shore communities, beyond the characteristic temporary "green flush", can be very difficult, even with good pre-incident data. This is due to their typically very high spatial patchiness and temporal variability. Early reconnaissance of oiled rocky shores is recommended so that signs of initial impacts can be recorded. Subsequent assessment of population effects is likely to require considerable efforts to collect data from numerous oiled sites and numerous comparable reference sites. A method for macroalgae assessment on rocky shores has been developed for use in WFD monitoring (UKTAG, 2009; see also Wells et al., 2007).

Recording dead wildlife – counts of dead/moribund limpets and other gastropods will provide useful evidence of damage.

Reconnaissance – taking particular note of fresh limpet scars on rock (estimate proportion of scars to live limpets); bleached coralline algae and other red algae; cover of ephemeral green algae; distribution and typical plant sizes of fucoid algae; presence of rock pools with algal turf; presence of mature kelp in sublittoral fringe.

Biological survey attributes – some of the more likely potential indicators are: limpet density and size/age structure of populations; amphipod diversity and abundance in kelp holdfasts (and maybe in algal turfs); proportional cover of bleached coralline algae crusts; abundance of ephemeral algae and percentage cover of the lichens *Xanthoria parietina* and *Ramalina siliquosa*. Reduced grazing pressure over a period of months may result in increased abundance of fucoids and other brown/red algae. Potential indices for measuring sublethal stress in some rocky shore species (e.g. mussels and limpets) have been developed in recent years, but it may be difficult to translate results from these tests into evidence of impact.

Strategy

Re-survey and compare with pre-incident data if available, bearing in mind that age and quality of pre-incident data will greatly affect impact detection.

Comparisons of *conspicuous* species/community data from oiled and unoiled sites, or trends along a gradient of increasing distance from source, are unlikely to detect more than the very gross effects that are obvious anyway, even if moderately large numbers of sites are established. This is due to the influence of many confounding factors that are almost impossible to effectively reduce.

Comparisons of small crustacea (particularly amphipod) diversity and abundance in kelp holdfasts and other cryptic sub-habitats (e.g. algal turfs) from oiled and unoiled sites, or along a gradient of increasing distance from source, may be very useful. Such studies should preferably start fairly soon (within a few weeks) after the spill and be repeated at intervals to show recovery processes.

Monitoring changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least 1 year (more for longer lived species), at selected sites, may show development of effects and then the recovery process.

Combination of re-survey of pre-incident data and continued monitoring of changes, at badly affected sites, will provide best description of effects and recovery process

Effects of clean-up

Methods to study effects of damage from clean-up would depend on the affected habitat, but photographic monitoring and basic ecological observations are likely to be appropriate.

Key methodological references

Baker and Crothers (1987), JNCC (2004), Murray *et al.* (2006). (Further useful information can be found in Barillé-Boyer et al., 2004; Chamberlain, 1997; Crump and Emson, 1998; Crump et al., 1998; Emson and Crump, 1997; Hill et al., 1998; Kingston et al., 1997; Ryland and de Putron, 1998; Somefield and Warwick, 1999.)

REFERENCES

AURIS. 1994. *Scientific criteria to optimise oil spill clean-up operations and effort*. A report by AURIS Environmental, Aberdeen, UK. 56pp + appendices, figures and tables.

Baker, J., Little, A. and Heaps, L. 1996. *Guidelines for assessing the ecological condition and recovery of oiled shores*. A report by AURIS Environmental, Aberdeen, UK. 89pp.

Baker, J.M. and Crothers, J.H. 1987. Intertidal rock. In: *Biological surveys of estuaries and coasts*, pp. 157–197 (Baker, J.M. and Wolff, W.J., eds.). Estuarine and Brackish Water Sciences Association handbook. Cambridge University Press, Cambridge, UK.

Barillé-Boyer, A., Gruet, Y., Barillé, L. and Harin, N. 2004. Temporal changes in community structure of tide pools following the *Erika* oil spill. *Aquatic Living Resources*, **17**: 323–328.

Chamberlain, Y.M. 1997. *Investigation of the condition of crustose coralline red algae in Pembrokeshire after the Sea Empress disaster*, 15–21 February 1996. A report to the Countryside Council for Wales. 30pp + appendices.

Crump, R.G. and Emson, R.H. 1998. Observations of the effects of oil pollution on two species of Asterinid cushion star in rockpools at West Angle Bay, Milford Haven. In: *The Sea Empress Oil Spill*, pp. 423–435 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for the SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Crump, R.G., Morley, H. and Williams, A. 1998. West Angle Bay, a case study: littoral monitoring of permanent quadrats before and after the *Sea Empress* oil spill. In: *The Sea Empress Oil Spill*, pp. 207–222 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for the SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Cullinane, J.P., McCarthy, P. and Fletcher, A. 1975. The effect of oil pollution in Bantry Bay. *Marine Pollution Bulletin*, **6**: 173–176.

Emson, R.H. and Crump, R.G. 1997. *Effects of the Sea Empress oil spill on seaweed animals of the West Angle Bay tide pools*. A report to the Countryside Council for Wales from Kings College, London, UK, and Orielton Field Centre, Pembroke, UK.

Hill, S., Burrows, M.T. and Hawkins, S.J. 1998. *Intertidal reef biotopes. Volume VI: An overview of dynamics and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science (UK Marine SACs Project). 84pp. www.ukmarinesac.org.uk/publications.htm [accessed 2 July 2010].

IPIECA. 1995. *Biological impacts of oil pollution: rocky shores*. IPIECA Report Series, Volume 7. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol7_RockyShores_1.pdf [accessed 2 July 2010].

JNCC. 2004d. Common standards monitoring guidance for littoral rock and inshore sublittoral rock habitats. Version August 2004. 27pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

Kingston, P.F., Dixon, I.M.T., Hamilton, S., Moore, C.G. and Moore, D.C. 1997. Studies on the response of intertidal and subtidal marine benthic communities to the *Braer* oil spill. In: T*he impact of an oil spill in turbulent waters: the Braer*, pp. 209–233 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Little, A.E., Moore, J.J. and Dyrynda, P.J. 2001. *Ecological impacts of shoreline clean-up during the Sea Empress oil spill*. A report to the Countryside Council for Wales. 124pp + plates.

Murray, S.N., Ambrose, R.F. and Dethier, M.N. 2006. *Monitoring Rocky Shores*. University of California Press, Berkeley, CA, USA. 240pp.

Ryland, J. and de Putron, S. 1998. *An appraisal of the effects of the Sea Empress oil spillage on sensitive sessile marine invertebrate communities*. A report to the Countryside Council for Wales from the University of Swansea. 86pp.

SEEEC. 1998. *The environmental impact of the Sea Empress oil spill*. Final report of the Sea Empress Environmental Evaluation Committee. February 1998. The Stationery Office, London, UK. ISBN 0-11-702156-3.

Somerfield, P.J. and Warwick, R.M. 1999. *Appraisal of environmental impact and recovery using Laminaria holdfast faunas*. A report to the Countryside Council for Wales from Plymouth Marine Laboratory. 19pp + appendices.

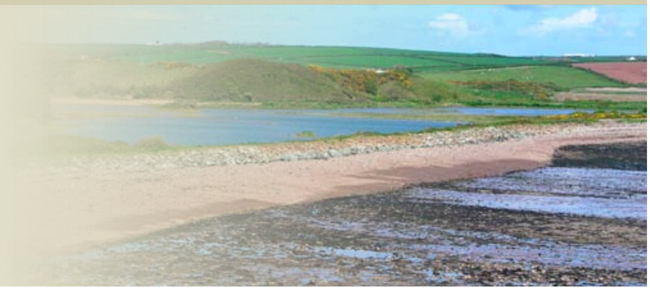
Southward, A.J. and Southward, E.C. 1978. Recolonisation of rocky shores in Cornwall after the use of toxic dispersants to clean up the Torrey Canyon spill. *Journal of the Fisheries Research Board of Canada*, **35**: 682–706.

UKTAG. 2009. *UKTAG coastal water assessment methods macroalgae: rocky shore reduced species list*. Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG). 16pp. ISBN 978-1-906934-17-0

Wells, E., Wilkinson, M., Wood, P. and Scanlan, C. 2007. The use of macroalgal species richness and composition on intertidal rocky shores in the assessment of ecological quality under the European Water Framework Directive. *Marine Pollution Bulletin*, **55**: 151–161.

2.9.4.6 LAGOONS

Lagoons



Known vulnerability and sensitivity

No cases of oil or chemical spills contaminating lagoons in UK or north-west Atlantic coasts have been found. This is not too surprising as most UK lagoons are not very vulnerable to marine spills. Their vulnerability will be dependent on the frequency and route by which seawater enters the lagoon. For those with narrow entrances, it will also be relatively simple to protect them by damming or booming.

The extremely sensitive nature of lagoon habitats if they were to become contaminated is very clear. Evidence from oil spill impacts in North America and various tropical locations shows that oil residues are very persistent and can have long-term impacts on benthic communities, vegetation and wildlife.

Impact assessment methods

Reconnaissance – along shore and by snorkelling, taking particular note of the condition of lagoon vegetation and conspicuous presence of species for which the lagoon is known to be important.

Biological survey attributes – some of the more likely potential indicators are: abundance and diversity of gastropods on emergent vegetation, plant condition (signs of blackening and defoliation), opportunistic algal cover, and sediment macro-fauna diversity (particularly tube-dwelling amphipods and opportunistic polychaetes).

Strategy

If pre-incident data are available – re-survey and comparison of new data with pre-incident data. It will be difficult to detect any changes beyond the natural variation unless toxic concentrations of oil or chemicals are very high.

Comparison with reference sites will be greatly hampered by the influence of other environmental factors (lagoons are relatively small and well separated, with distinct site specific characteristics).

Best option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of incident for at least 1 year at selected sites.

Effects of clean-up

Methods to study effects from access and clean-up will depend on the affected features and extent of impact but are likely to include basic ecological observation and vegetation mapping. If a lagoon is protected from oil ingress by use of a dam (e.g. Pickleridge lagoon during the *Sea Empress* spill) or other prolonged blockage of normal water flow, then monitoring of water quality (e.g. bottom water oxygen concentration) and a related biological attribute may be appropriate. (Further useful information can be found in Bamber, 2004; Bamber et al., 2001; JNCC, 2004.)

REFERENCES

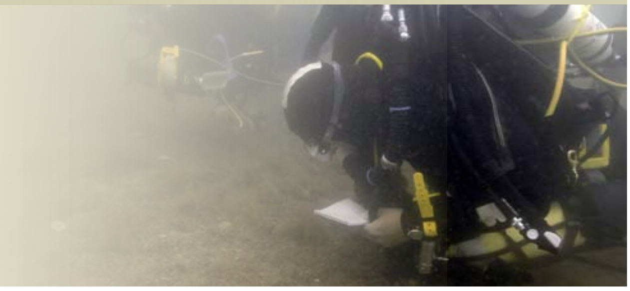
Bamber, R.N. 2004. *Temporal variation and monitoring of important lagoonal communities and species in Wales*. A report to CCW by The Natural History Museum, London, UK. CCW Marine Monitoring Report No. 12. 41pp.

Bamber, R.N., Gilliland, P.M. and Shardlow, M.E.A. 2001. Saline lagoons: A guide to their management and creation (interim version). Peterborough, UK, English Nature.

JNCC. 2004b. Common standards monitoring guidance for lagoons. Version August 2004. 38pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

2.9.4.7 SUBTIDAL SEDIMENTS

Subtidal sediments



Known vulnerability and sensitivity

Dispersed oil in water (in water-soluble form, as fine droplets, or adsorbed to water particulates) and oil bound to shoreline sediments can make its way down to the seabed and contaminate subtidal sediments. It is also likely that high concentrations of dispersed oil can affect sediment epifauna and filter feeders without necessarily becoming bound into the sediment. Impacts to seabed sediment fauna have been described after a number of oil spills, but normally only in shallow depths where oil in water concentrations were particularly high or close to sandy beaches. The extent to which sediment contamination occurs is also a function of the sediment character – oil particles preferentially adsorb onto fine particles of silt and clay, so higher concentrations are normally found in muddy sediments. For this reason such sediments can also contain residues from other historical sources of oil or chemicals, emphasising the value of baseline data and accurate fingerprinting of any hydrocarbons detected.

While it is generally considered unusual for notable quantities of oil from oil spills to reach depths greater than 10 m, there are known cases where this has happened. For example, dispersed oil from the *Braer* spill was apparently carried from the spill site by strong downward currents and was found to have contaminated seabed sediments (concentrations reaching 2,500 mg/kg) a considerable distance to the west and south of Shetland in depths of at least 100 m (Davies et al., 1997).

Some groups of sediment fauna are more sensitive to oil than others. Amphipods (particularly the filter-feeding tube-dwelling species, e.g. *Ampelisca* spp.), filter feeding bivalves (e.g. *Ensis* spp. (razorshells)) and burrowing urchins (e.g. *Echinocardium cordatum* (heart urchin)) have been identified as the main casualties at a number of oil spills. Densities of *Ampelisca* spp. were dramatically reduced over large areas of seabed following the *Amoco Cadiz* spill, and populations took 15 years to return to pre-incident levels (Dauvin, 1998). A similarly widespread impact was shown after the *Sea Empress* spills (see below). [Note: The now well-known sensitivity of amphipods to oil (and other) pollution has resulted in their frequent use in toxicity tests.] Large numbers of filter-feeding bivalves and burrowing urchins are often washed up on beaches after spills.

Note: it has been theorized that sediment contamination is not a requirement for, or indeed the main cause of, the effects described above. Transitory high concentrations of dispersed oil in water could result in these species ejecting themselves from the sediment and then, in a torpid state, becoming washed away and unable to re-establish themselves in the sediment. If the sediment is contaminated, it may have an effect on recovery of those populations.

Some other species of sediment fauna may opportunistically increase following oil spill impacts – particularly various small polychaetes.

While macrofaunal communities of shallow subtidal sediments are likely to be very sensitive to oil spills, there have been relatively few post-spill studies on them, due to the difficulties of sampling. The work by Jewett *et al.* (1999) in shallow subtidal *Zostera marina* (eelgrass) beds following the *Exxon Valdez* spill is one of the few such studies.

Studies on impacts of oil spills on subtidal sediment meiofauna have not shown a consistent response (cf. Moore *et al.,* 1997), although reductions in abundance or diversity are likely.

Impact assessment methods

Note: Surveys and monitoring of sediment communities have two important advantages over epibenthic rock communities – much-reduced small-scale variability (patchiness) of confounding environmental factors and relatively well defined sample units (specified sampling devices, mesh sizes, etc.)

Recording dead wildlife – counts of washed-up bivalves, urchins etc. will provide useful evidence of impact.

Reconnaissance – *in situ* reconnaissance of subtidal sediments is not normally appropriate, but survey sites should not be established without reference to available data on distribution of seabed sediment characteristics. If these data are not available, it would be beneficial to undertake some form of sediment mapping before biological survey sites are established. If biological samples are collected at the same time as the sediment characterisation, it is recommended that the biological samples are not analysed until the sediment data are available. This can greatly reduce unnecessary effort and cost.

Biological survey attributes – some of the more likely potential indicators are: sediment mega-fauna abundance (particularly bivalves), sediment macro-fauna diversity and abundance (particularly amphipods and opportunistic polychaetes). The polychaete/amphipod ratio has been suggested as an oil spill "bioindicator" by Gesteira and Dauvin (2000). Various authors have highlighted the advantages of sediment meiofauna as useful indicators of anthropogenic effects (e.g. abundance and diversity of nematodes and copepods); while reliable techniques for oil spill impact assessment have not yet been developed, they may be useful for following short- to medium-term effects.

Strategy

Initial emphasis should be placed on areas where near-seabed oil-in-water concentrations were likely (from empirical or modelling evidence) to be high.

Re-survey and compare with pre-incident data if available, but consider carrying out a pilot survey at most vulnerable sites (or initially analysing only a selected few of the total samples) to assess scale of impact before full re-survey and analysis.

Establishing comparative reference sites in unaffected areas, or analysing trends with distance from spill site, will be difficult if oil-in-water concentrations are widely distributed (the normal situation), because other confounding environmental factors (e.g. sediment character) are likely to reduce comparability.

If sediments contaminated by oil from the spill are identified, it may be easier to establish viable reference sites or a series of sites along transects, but it is also likely that contaminated sediments will have a different character to the surrounding uncontaminated sediments (e.g. mud content).

Monitoring changes in some of the above attributes at intervals may show recovery processes.

If pre-incident data are unavailable, use evidence of stranded fauna to identify sites and consider a small-scale macrofauna or meiofauna sampling programme with increasing distance from source, re-surveyed at seasonal intervals for 1 or 2 years.

Effects of clean-up

Methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil-in-water concentrations), with some additional considerations for site selection. Methods to study physical damage from anchors (deployed during clean-up) would depend on the affected habitat, but thee would only be appropriate in very unusual circumstances.

Key methodological references

Holme and McIntyre (1984), JNCC (2004). (Further useful information can be found in Kingston et al., 1997; Nikitik and Robinson, 2003; Rostron, 1997; Rutt et al., 1998; US EPA, 1994.)

REFERENCES

Dauvin, J.-C. 1998. The fine sand *Abra alba* community of the Bay of Morlaix twenty years after the *Amoco Cadiz* oil spill. *Marine Pollution Bulletin*, **36**: 669–676.

Davies, J.M., McIntosh, A.D., Stagg, R., Topping, G. and Rees, J. 1997. The fate of the Braer oil in the marine and terrestrial environments. In: *The Impact of an Oil Spill in Turbulent Waters: The Braer*, pp. 26–41 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Gesteira, J.L.G. and Dauvin, J.C. 2000. Amphipods are good bioindicators of the impact of oil spills in soft-bottom macrobenthic communities. *Marine Pollution Bulletin*, **40**: 1017–1027.

Holme, N.A. and McIntyre, A.D. (eds.). 1984. *Methods for the study of marine benthos*, 2nd edition. IBP handbook, No.16. Blackwell Scientific Publications for International Biological Programme, Oxford, UK.

Jewett, S.C., Dean, T.A., Smith, R.O. and Blanchard, A. 1999. *Exxon Valdez* oil spill: impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds. *Marine Ecology Progress Series*, **185**: 59–83.

JNCC. 2004e. Common standards monitoring guidance for inshore sublittoral sediment habitats. Version August 2004. 27 pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

Kingston, P.F., Dixon, I.M.T., Hamilton, S., Moore, C.G. and Moore, D.C. 1997. Studies on the response of intertidal and subtidal marine benthic communities to the *Braer* oil spill. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 209–233 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Moore, C.G., Harries, D.B. and Ware, F.J. 1997. *The impact of the Sea Empress oil spill on the sandy shore meiofauna of south west Wales*. A report to the Countryside Council for Wales from Heriot-Watt University, Edinburgh, UK. 79pp.

Nikitik, C.C.S. and Robinson, A.W. 2003. Patterns in benthic populations in the Milford Haven waterway following the *Sea Empress* oil spill with special reference to amphipods. *Marine Pollution Bulletin*, **46**: 1125–1141.

Rostron, D. 1997. *Sea Empress subtidal impact assessment: Skomer Marine Nature Reserve sediment infauna*. A report to the Countryside Council for Wales from SubSea Survey, Pembroke, UK. 27pp + appendices.

Rutt, G.P., Levell, D., Hobbs, G., Rostron, D.M., Bullimore, B., Law, R.J. and Robinson, A.W. 1998. The effect on the marine benthos. In: *The Sea Empress oil spill*, pp. 189–206 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

US EPA. 1994. *Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods*. Office of Research and Development, U.S. Environmental Protection Agency. www.epa.gov/waterscience/library/sediment/marinemethod.pdf [accessed 2 July 2010].

2.9.4.8 SUBTIDAL ROCK

Subtidal rock

Known vulnerability and sensitivity

Very few studies have been made on oil spill impacts on the epibenthic communities of rocky subtidal habitats [Note: effects of spills on the epibenthic communities of tropical coral reefs are obviously not directly relevant, but the known sensitivity of some groups of animals found on coral reefs have been considered (e.g. NOAA, 2001)]. The lack of a substrata that could retain a persistent oil contamination (apart from some organisms) means that any impacts are only likely to be due to the acute effects of the dispersed oil, unless chronic oiling seeps down from an intertidal oil source.

As described in Section 2.9.4.7 (above), it is generally considered unusual for notable quantities of dispersed oil from oil spills to reach depths greater than 10 m, but there are known cases where this has happened. Various species of sediment-living amphipods are known to be highly sensitive to dispersed oil, and it is expected that epibenthic amphipod species on subtidal rock will also be sensitive. The literature suggests that many other crustacean species may also be sensitive to a lesser extent. There is very little evidence that other epibenthic groups present in European waters are acutely sensitive; however, this may be partly due to a lack of studies in very shallow water.

Studies of sublethal effects on shallow subtidal rock species are extremely limited. It may be assumed that effects that have been described for intertidal mussels (which bio-accumulate hydrocarbons from the water column) may also be relevant to shallow subtidal mussels (cf. references cited in Environment Agency, 2004).

There have also been very few studies of the effects of clean-up activities on subtidal rock habitats. Potential effects could come from increased concentrations of dispersed oil in water following dispersant-spraying or intertidal-flushing operations. Physical damage caused by boat anchors (and spur boom anchors) is also possible and is thought to have occurred following intensive clean-up of some shores after the *Exxon Valdez* spill.

Impact assessment methods

Reconnaissance – may be useful in very shallow areas, possibly by snorkelling (after surface oil has gone), taking particular note of presence of amphipods and snails and any unusual behaviour (suggesting narcotisation) of any mobile fauna.

Biological survey attributes – some of the more likely potential indicators are: amphipod presence (in a range of typical sub-habitats) and abundance (no *in situ* recording method is likely to provide an accurate measure, but it is suggested that a standardised technique for sampling algal turf could be developed); mobile epibenthic invertebrates presence and abundance; inshore fish (e.g. scorpion fish, wrasse, gobies) presence and abundance.

Strategy

Re-survey and compare with pre-incident data if available. Note, however, that it will be difficult to detect any changes beyond the natural variation unless pre-incident data on any of the above attributes is very good and oiling by toxic concentrations of oil were/are high.

Comparison with reference sites will be greatly hampered by influence of other environmental factors, but the characteristics of some sub-habitats (e.g. algal turfs – for amphipod sampling) may be less variable.

Best option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least 1 year at selected sites.

Effects of clean-up

Methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil-in-water concentrations), with some additional considerations for site selection. Methods to study physical damage from anchors (deployed during clean-up) would depend on the affected habitat, but they would only be appropriate in very unusual circumstances. (Further useful information can be found in Dean et al., 1996a, 1996b; JNCC, 2004; Kingston et al., 1997; Rostron and Bunker, 1997.)

REFERENCES

Dean, T.A., Jewett, S.C., Laur, D.R. and Smith, R.O. 1996b Injury to epibenthic invertebrates resulting from the *Exxon Valdez* oil spill. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 424–439.

Dean, T.A., Stekoll, M.S. and Smith, R.O. 1996a. Kelps and oil: the effects of the *Exxon Valdez* oil spill on subtidal algae. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 412–423.

Environment Agency. 2004. A guide to practices, procedures and methodologies following oil spill contamination incidents: Methods for the Examination of Waters and Associated Materials. Standing Committee of Analysts Blue Book No. 193. 105pp.
www.environment-agency.gov.uk/static/documents/Research/Oils_Guide_2004.pdf [accessed 9 May 2011].

JNCC. 2004d. Common standards monitoring guidance for littoral rock and inshore sublittoral rock habitats. Version August 2004. pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

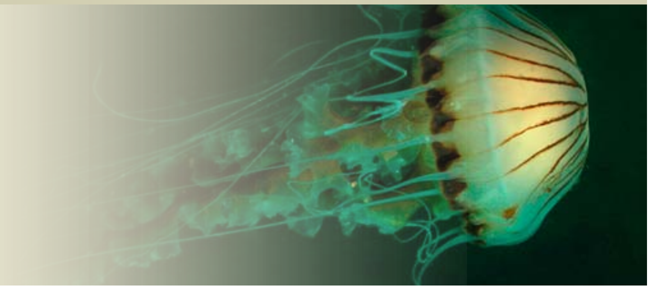
Kingston, P.F., Dixon, I.M.T., Hamilton, S., Moore, C.G. and Moore, D.C. 1997. Studies on the response of intertidal and subtidal marine benthic communities to the *Braer* oil spill. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 209–233 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

NOAA. 2001. *Toxicity of oil to reef-building corals: a spill response perspective*. Technical memorandum NOS OR&R 8. National Oceanic and Atmospheric Administration. 87pp.
http://response.restoration.noaa.gov/book_shelf/1_coral_tox.pdf [accessed 9 May 2011].

Rostron, D. and Bunker, F. 1997. *An assessment of sublittoral epibenthic rock communities and species following the Sea Empress oil spill*. A report to the Countryside Council for Wales from Marine Seen and SubSea Survey, Pembroke, UK. 35pp.

2.9.4.9 PLANKTON

Plankton



Known vulnerability and sensitivity

Planktonic organisms include marine algae and animals (including adults and larvae of invertebrates and larval stage of vertebrates) that have limited powers of locomotion and spend their life cycle or part of it in the water column. Impacts of oil spills on plankton are usually short term and very difficult to measure. Laboratory and field experiments have shown that many species of phytoplankton and zooplankton are very sensitive to toxic components of oil (particularly the water soluble fraction), but that recovery by recruitment from other areas is rapid (National Academy of Sciences, 1985). Most species have short generation times, high fecundity and high abundance over a large area, so recovery potential is high. However, in unusual circumstances and for certain localised populations (e.g. planktonic eggs and larvae of an uncommon species), it is possible that a spill could have a notable impact; however, proving such an impact would be very difficult, and no documented examples have been found. Natural plankton populations are intrinsically extremely patchy and variable over time.

Impact assessment methods

Biological survey attributes – there are no particular attributes of plankton that are considered worthy of special attention. Sublethal effects measures, including growth, may be useful for describing short-term effects.

Strategy

In the unusual circumstances of an oil spill (or release of a chemical with the potential for toxicity or growth stimulation) affecting an area where on-going or recent plankton studies have provided pre-incident data, then re-survey and comparison with that data is appropriate.

No other strategies are currently considered worthwhile. (Further useful information can be found in Batten et al., 1998; Kelly-Gerreyn et al., 2007.)

Following the *Sea Empress* oil spill in Wales in 1996, no impacts on plankton abundance or species composition were observed in Continuous Plankton Recorder (CPR) records from the area (Batten et al., 1998; Law and Kelly, 2004). This method has advantages over discrete plankton sampling and assessment methods, which can be very difficult to interpret due to the large variability observed both spatially and temporally, while the use of CPR records allows both time-trends and spatial variations to be studied. Further information on the CPR can be found at www.sahfos.ac.uk/ (accessed 9 August 2010). Taş *et al.* (2011) studied phytoplankton following the oil spill from the *Volgoneft-248* in Turkey in 1999, and they saw changes in the species composition, abundance and diversity. In the case of the chemical tanker *Ece*, which sank in the English Channel in 2006 with a cargo of phosphoric acid, yielding phosphate in the surrounding waters as a nutrient, Kelly-Gerreyn *et al.* (2007) studied enhancement of phytoplankton communities rather than impairment. Ferrybox data were also used in order to assess elevations of the phosphate concentrations in the vicinity. In the Ferrybox system, ferries and other vessels are instrumented with a "box" of autonomous sensors that can provide data that are logged continuously whilst the vessel is on passage. For further information see www.ferrybox.org or www.noc.soton.ac.uk/ops/ferrybox_index.php (accessed 9 August 2010). Further information on the methodology for nutrient analysis can be found in Kirkwood (1996) and Grasshoff *et al.* (1999), and the marine nitrogen cycle is explained in Capone *et al.* (2008).

REFERENCES

Batten, S.D., Allen, R.J.S. and Wotton, C.O.M. 1998. The effects of the *Sea Empress* oil spill on the plankton of the southern Irish Sea. *Marine Pollution Bulletin*, **36**: 764–774.

Capone, D.G., Bronk, D.A., Mulholland, M.R. and Carpenter, E.J. (eds.). 2008. *Nitrogen in the marine environment*. 2nd edition. Academic Press, Burlington, MA, USA. 1757pp. ISBN10: 0-123-72522-4. ISBN13: 978-0123-72522-4.

Grasshoff, K., Kremling, K. and Ehrhardt, M. 1999. *Methods of seawater analysis*, 3rd edition. Wiley VCH, Weinheim, Germany. 632pp. ISBN10: 352-729589-5. ISBN13: 978-352-729589-5.

Kelly-Gerreyn, B.A., Hydes, D.J., Hartman, M.C., Siddorn, J., Hyder, P. and Holt, M.W. 2007. The phosphoric acid leak from the wreck of MV Ece in the English Channel in 2006: assessment with a ship of opportunity, an operational ecosystem model and historical data. *Marine Pollution Bulletin*, **54**: 850–862.

Kirkwood, D. 1996. Nutrients: practical notes on their determination in sea water. *ICES Techniques in Marine Environmental Sciences*, No.17. 25pp. www.ices.dk/pubs/times/times17/TIMES17.pdf [accessed 3 May 2011].

Law, R.J. and Kelly, C. 2004. The impact of the "*Sea Empress*" oil spill. Aquatic Living Resources, **17**: 389–394.

National Academy of Sciences. 1985. *Oil in the sea: inputs, fates and effects*. National Academy Press, Washington, DC, USA. 601pp. ISBN 0-309-03479-5.

Taş, S., Okuş, E., Ünlü, S. and Atiok, H. 2011. A study on phytoplankton following "Volgoneft-248" oil spill on the north-eastern coast of the Sea of Marmara. *Journal of the Marine Biological Association of the UK*, **91**: 715–725. doi:10.1017/S0025315410000330.

2.9.4.10 FISH

Fish

Known vulnerability and sensitivity

Fish populations are at greatest risk from contamination by oil or chemical spills when the water depth is very shallow. Below 10 m, in open waters, the likelihood that contaminant concentrations will be high enough to affect fish populations is very small, even if chemical dispersants are used to disperse oil. In shallow or enclosed waters or in stationary fish farms, however, high concentrations of freshly dispersed oil may kill some fish and have sublethal effects on others. Within the UK, all application of dispersants in waters <20m depth (or within 1 nautical mile of such shallow waters) is subject to advance approval by the UK regulator. Juvenile fish, larvae and eggs are most sensitive to the oil toxicity, so fish nursery areas are particularly vulnerable. Even if the elevated concentrations of oil do not kill the fish, they may taint the flesh with an oily taste and thereby make it unpalatable. Similar effects may occur with some chemicals, depending on their properties and behaviour. Finfish will usually move away from oil-contaminated water; however, even if their tissues do become contaminated, through the gills or from contaminated food, detoxification enzyme systems are able to metabolise oil, so they do not retain contamination for long. Most fish species can produce high numbers of eggs, and this counteracts high levels of natural as well as oil-induced mortality. Even when many larvae or juveniles have been killed, this has not been subsequently observed to result in fluctuations of the adult populations. Fish in fish farms will not be able to avoid contaminated water and so will be more vulnerable. IPIECA (1997) summarises information on the sensitivity and recovery potential of fish and fisheries.

Impact assessment methods

Fish populations are characterised by considerable natural fluctuations and some species also experience population pressures due to commercial fishing, making it difficult to distinguish pollution effects even if baseline data is available for comparison. Post-incident surveys of fish stock sizes/densities are extremely unlikely to provide any information suitable for an impact assessment. The only exception would be where detailed recent pre-incident population data exist for a particular species.

Reconnaissance – collect samples of selected fish species of nature conservation importance for analysis (including PAH analysis in the case of oil spills, so as to facilitate assessment of risks to human consumers of commercial species).

Biological survey attributes – hepatic EROD (ethoxyresorufin-O-deethylase) activity (and possibly some other biomarkers) in sampled fish is likely to be the best measure of oil exposure (Kirby et al., 2000). Other biological effects techniques may be useful for specific chemicals. Abundance measures of intertidal (e.g. in rockpools) or nearshore shallow-water fish (caught using standardised sampling techniques – traps or nets) may detect severe reductions from high concentrations of dispersed oil or chemicals, but will normally require some pre-incident data. Recently developed techniques can be used to detect sublethal stress in fish tissues and may be useful for monitoring their recovery, but they may not provide a reliable measure of the health of the affected population.

Strategy

Comparison between pre- and post-incident data on EROD activity, followed by monitoring to show recovery, will provide the best evidence of sublethal effects on fish populations from spilled oil.

Comparison between pre- and post-incident data on nearshore shallow-water fish populations will provide the best evidence of impacts on fish populations from spilled oil or chemicals.

Comparison of data between impacted and unimpacted reference areas is unlikely to detect impacts, unless they are substantial and sufficient reference sites are studied to determine levels of natural variability.

Effects of clean-up

Methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil-in-water concentrations), with some additional considerations for site selection. For chemicals, very little is known currently of the effects of different clean-up methodologies.

Key methodological references

Davies *et al.* (2001). (Further useful information can be found in Law et al., 1998; Lyons et al., 1997; Wright et al., 1997.)

REFERENCES

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. and Vincent, M. (eds.). 2001. *Marine Monitoring handbook*. JNCC Procedural Guideline Nos. 4.1, 4.2, 4.3 & 4.4. Joint Nature Conservation Committee, Peterborough, UK, 405pp. www.jncc.gov.uk/page-2430 [accessed 2 July 2010].

IPIECA. 1997. *Biological impacts of oil pollution: fisheries*. IPIECA Report Series, Volume 8. International Petroleum Industry Environmental Conservation Association, London, UK. 28pp. http://www.ipieca.org/sites/default/files/publications/Vol8_Fisheries.pdf [accessed 4 November 2011].

Kirby, M.F., Lyons, B.P., Waldock, M.J., Woodhead, R.J., Goodsir, F., Law, R.J., Matthiessen, P., Neall, P., Stewart, C., Thain, J.E., Tylor, T. and Feist, S.W. 2000. Bio-markers of polycyclic aromatic hydrocarbon (PAH) exposure in fish and their application in marine monitoring. CEFAS Science Series Technical Report No. 110, 30pp.

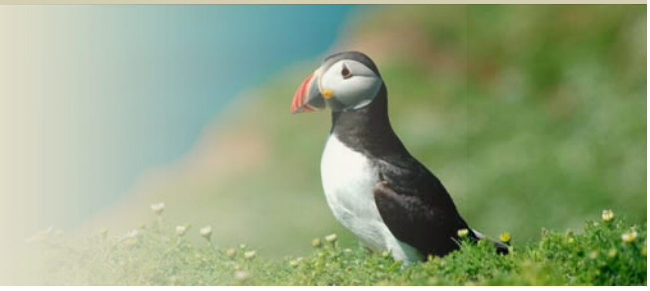
Law, R.J., Thain, J.E., Kirby, M.F., Allen, Y.T., Lyons, B.P., Kelly, C.A., Haworth, S., Dyrynda, E.A., Dyrynda, P.E.J., Harvey, J.S., Page, S., Nicholson, M.D. and Leonard, D.R.P. 1998. The impact of the *Sea Empress* oil spill on fish and shellfish. In: *The Sea Empress oil spill*, pp. 109–136 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Lyons, B.P., Harvey, J.S. and Parry, J.M. 1997. An initial assessment of the genotoxic impact of the *Sea Empress* oil spill by the measurement of DNA adduct levels in the intertidal teleost *Lipophrys pholis*. Mutation Research, **390**: 263–268.

Wright, P.J., Stagg, R.M. and McIntosh, A.D. 1997. The impact of the *Braer* oil spill on sandeels around Shetland. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 161–181 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

2.9.4.11 SEABIRDS

Seabirds



Known vulnerability and sensitivity

There is a considerable literature on the effects of oil spills on seabirds, which are taken here to include auks, terns, gulls, gannets, fulmars, petrels, kittiwakes, skua, cormorants and shag. Seaduck and divers are covered in the next section. Summaries of the effects of oil spills on seabirds are given in NOAA (1992) and Clark (1984).

Seabirds feeding or resting on the sea surface are vulnerable to water-borne pollution, and the period when they will be most vulnerable is when large numbers of birds are aggregated on the water – including during the breeding season, when they are aggregated inshore, and, for species of auk, during the autumnal moult, when gatherings of flightless birds form rafts on the water. However, large numbers of birds have been killed by offshore oil spills that have affected very large areas of the sea (e.g. those from the *Erika* and *Prestige* oil tankers). Vulnerability to pollutants will also be affected by the condition of the birds, so winter food shortages could increase the vulnerability of many birds. By developing techniques for estimating numbers of birds per unit area at sea, the JNCC Seabirds at Sea Team have been able to provide information on the distribution and timing of vulnerable concentrations of seabirds (Webb et al., 1995). The most vulnerable species are those that spend a substantial period of their lives on the water surface, particularly divers, Manx shearwaters, guillemots, puffins and razorbills (see Table 1). Other factors, including the importance of the area to the world population of the species, the species, reliance on the marine environment and the potential rate of recovery of a species are all considered when assessing vulnerability.

Recent oil spills in the northwest Atlantic (*Braer, Sea Empress, Erika, Prestige, Tricolor*) killed large numbers of seabirds, particularly guillemots and razorbills, along with moderate but important numbers of other species including shag and kittiwakes. Descriptions of these impacts are given in Heubeck (1997), SEEEC (1998), Castège *et al.* (2004) and Camphuysen and Leopold (2004). It should be noted that impact is not simply a function of the numbers of birds killed and the species affected, but also the age of the birds killed. Most seabird species are long-lived and annual adult survival is relatively high, so that only low rates of recruitment of immature birds are required each year to sustain the breeding population. So, if the majority of birds killed are immature, the impact on the population is likely to be less than if large numbers of adults are killed (Mitchell and Parsons, 2007). Recovery of affected populations then depends either on the existence of a reservoir of young non-breeding adults, from which breeding colonies can be replenished, or on a high reproductive rate. Assessing the sex ratio of mortality is also important because of the differences in male and female wintering distributions.

Table 1

Vulnerability to surface pollutants of seabirds around the British Isles.

Red-throated diver	29	Scaup	20	Herring gull	15
Black-throated diver	29	Common eider	16	Glaucous gull	17
Great northern diver	29	Long-tailed duck	17	Great black-backed gull	21
Great crested grebe	23	Common scoter	19	Kittiwake	17
Fulmar	18	Velvet scoter	21	Sandwich tern	20
Cory's shearwater	15	Goldeneye	16	Common tern	20
Great shearwater	12	Red-breasted merganser	21	Arctic tern	16
Sooty shearwater	19	Pomarine skua	19	Little tern	19
Manx shearwater	23	Arctic skua	24	Guillemot	22
Storm petrel	18	Great skua	25	Razorbill	24
Leach's petrel	18	Little gull	24	Black guillemot	29
Gannet	22	Black-headed gull	11	Little auk	22
Cormorant	20	Common gull	13	Puffin	21
Shag	24	Lesser black-backed gull	20		

Note: Offshore vulnerability index scores, a higher score indicating greater vulnerability. From JNCC (1995).

Although the apparent impact of oil spills on seabirds is very obvious from the numbers of oiled birds that are collected, the resulting impact on their populations, and the time it takes for those populations to recover, is not always so apparent. Seabird colonies are monitored regularly in many locations around the British Isles within the Seabird Monitoring programme (http://jncc.defra.gov.uk/page-1550 accessed 14 June 2011), and there are more and better monitoring data for these species than for any other vulnerable (to oil and chemical spills) species of mammal, invertebrate or plant. There are also considerable data on densities/distribution of seabirds at sea, but annual variation can be considerable and data for some areas of sea are relatively sparse and dated. Comparisons of good colony count data from pre- and post-incident surveys (e.g. Heubeck, 1997; Haycock *et al.*, 1998) have identified significant (though not necessarily large) reductions in some seabird species, which have correlated well with the dead-bird data. Evidence from recent UK spills suggests that increases in colony counts to pre-incident levels occur within two or three years, as long as other factors (e.g. food) are not limiting. The recovery rate will depend largely on the scale of mortality and the age of the birds affected.

Monitoring seabird populations at their breeding colonies is likely to be the primary method of detecting the effects of accidental spills for most populations, but the method has limitations (Mitchell and Parsons, 2007). The long life spans of most seabird species and the complexities of their behaviours make it very difficult to detect impacts from simple comparison of pre-incident and post-incident counts. Trends in population size over a number of years may provide a better indication, but it is now recognised that that still does not provide a full picture of the impact. Trends in annual survival rates have shown that populations can suffer longer term impacts on their demographics, as described after the *Erika* oil spill (Birkhead, 2001; Votier *et al.,* 2005). Mitchell and Parsons (2007) recommend both methods, but they recognise that annual survival rates are currently measured at very few colonies. Studies on seabird species/colonies for which there is much less pre-incident data will have difficulty assessing impacts on the populations and will rely on counts of corpses. The greatest concerns will always be for species that are both vulnerable and uncommon.

Oil spill response activities can also affect seabirds, particularly through disturbance of nesting grounds when eggs and chicks are present. Terns and some gulls, which nest on sand/shingle beaches and small islands, are particularly vulnerable.

Experimental studies of sublethal and indirect effects on seabirds have shown that oil can reduce reproductive capacity (e.g. decreased fertility, low egg production and reduced survival of hatchlings) and cause haemolytic anaemia (National Research Council, 2003). However, few field-based studies from real oil spills have been carried out, and fewer have detected an impact, at least partly due to a lack of pre-incident data from the affected populations (e.g. Shore and Wright, 1997; Piatt and Anderson, 1996). The main UK exception is following the *Braer* spill in Shetland (see Monaghan *et al.*, 1997). Studies on seabird breeding success after the *Exxon Valdez* spill also showed apparent reductions in some species (e.g. Irons, 1996), but similar studies on several species after the *Sea Empress* spill showed no evidence of such impacts (Monaghan and Turner, 1997).

Impact assessment methods

Recording dead and live casualties – Camphuysen et al. (2007) provide detailed methodologies for post-incident surveys. Counts of dead and oiled or chemically impacted birds will provide the best evidence of actual impact; this requires the urgent mobilisation of beach patrols to collect contaminated birds. Reasonable steps/analysis should be taken to check that death/oiling was caused by the oil or chemical spill. Beached carcass modelling and carcass recovery experiments (preferably using dummy birds) may help to provide better estimates of the proportion of dead birds that were not collected and so of the likely total number impacted. It is essential that surveyors inspect all birds for rings and report details to the British Trust for Ornithology (BTO). Other data to collect from corpses and live oiled birds include a range of biometrics (see Camphuysen et al., 2007) and other details that will help to determine the origin of the birds. Recording of clinical symptoms from sick birds taken to rehabilitation centres, and post-mortem analysis of dead birds, will need to be organised. This may provide useful data to support assessments, including indicating which colonies are likely to be affected.

Biological survey attributes – The first priority should be to mobilise seabird at sea surveys to assess the locations of seabird concentrations liable to be impacted by drifting oil. Surveys will depend on suitable weather conditions and are usually carried out most efficiently from the air. The existing Seabird Monitoring Programme (www.jncc.gov.uk) may provide adequate data from seabird colonies, but studies at colonies likely to be affected should be boosted to ensure good information on changes in numbers and in breeding success. Counts of each species are the primary attributes, and the standardised survey methods and protocols are well developed for each seabird species, both at their breeding sites (Walsh *et al.,* 1995; Gilbert *et al.,* 1998) and at sea (see Seabirds at Sea survey methods on www.jncc.gov.uk and review by Camphuysen *et* *al.,* 2004). Annual survival rates and measurements of breeding success (e.g. numbers of eggs/hatchlings/fledglings) will also be very useful where adequate pre-incident data exist. Other sublethal effects indices may also be useful if good pre-incident data are available [Note: catching and taking samples from birds will require an official licence.]

Strategy

Comparison between pre- and post-incident trends in annual survival rates at seabird colonies will provide the best evidence of impacts to seabird populations, where adequate pre-incident data are available.

Comparison between pre- and post-spill trends in counts from seabird colony counts and seabirds at sea surveys will be available for more species and sites and will provide next-best evidence. If the quality of the pre-incident data is poor, the assessment will rely primarily on the data from corpses, including age structure and ring recoveries.

Comparison of data on sublethal effects indices (e.g. breeding success and other indices of reproductive capacity) between different colonies may provide some evidence of impacts in severe cases, but it is unlikely to provide proof without pre-incident data and will be a low priority for study.

Key methodological references

Gilbert *et al.* (1998), Walsh *et al.* (1995), Seabirds at Sea methods on www.jncc.gov.uk, Camphuysen *et al.* (2004) and Camphuysen *et al.* (2007). (Further useful information can be found in Baines and Earl, 1998; Birkhead, 2001; Bretagnolle et al., 2004; Camphuysen and Heubeck, 2001; Camphuysen et al., 2002; Grantham, 2004; Haycock et al., 1998; Heubeck, 2000; Irons, 1996; JNCC, 2004; Mavor et al., 2004; 2006; Monaghan and Turner, 1997; Monaghan et al., 1997; National Research Council, 2003; Piatt and Anderson, 1996; RPI, 2001; Shore and Wright, 1997; Votier et al., 2005.)

REFERENCES

Baines, M.E. and Earl, S.J. 1998. *Breeding seabird surveys of south-west Wales colonies 1996–98*. Report to CCW from The Wildlife Trust West Wales. 77pp.

Birkhead, T.R. 2001. *Skomer Guillemot Studies 1999–2001. Three-year report*. Unpublished report. University of Sheffield, Sheffield, UK.

Bretagnolle, V., Certain, G., Houte, S. and Métais, M. 2004. Distribution maps and minimum abundance estimates for wintering auks in the Bay of Biscay, based on aerial surveys. *Aquatic Living Resources*, **17**: 353–360.

Camphuysen, C.J, Bao, R., Nijkamp, H. and Heubeck, M. (eds.). 2007, *Handbook on oil impact assessment*. Royal Netherlands Institute for Sea Research, Texel, The Netherlands. http://www.oiledwildlife.eu/capacity-building/eu-sponsored-projects/impact-assessment [accessed 4 November 2010].

Camphuysen, C.J. and Leopold, M.F. 2004. The Tricolor spill: characteristics of seabirds found oiled in The Netherlands. *Atlantic Seabirds*, **6**: 109–128.

Camphuysen, C.J., Heubeck, M., Cox, S.L., Bao, R., Humple, D., Abraham, C. et al. 2002. The Prestige oil spill in Spain. *Atlantic Seabirds*, **4**: 131–140.

Camphuysen, K. and Heubeck, M. 2001. *Marine oil pollution and beached bird surveys: the development of a sensitive monitoring instrument. Environmental Pollution*, **112**: 443–461. www.sciencedirect.com/science/journal/02697491 [accessed 2 July 2010].

Camphuysen, K.J., Fox, A.D., Leopold, M.F. and Petersen, I.K. 2004. *Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K.: a comparison of ship and aerial sampling methods for marine birds, and their applicability to offshore wind farm assessments*. NIOZ report to COWRIE (BAM – 02–2002), Texel, 37pp.

Castège, I, Hémery, G., Roux, N., d'Elbée, J., Lalanne, Y., D'Amico, F. and Mouchès, C. 2004. Changes in abundance and at-sea distribution of seabirds in the Bay of Biscay prior to, and following the "*Erika*" oil spill. *Aquatic Living Resources*, **17**: 361–367.

Clark, R.B. 1984. Impact of oil pollution on seabirds. *Environmental Pollution* (Series A), **33**: 1–22.

Gilbert, G., Gibbons, D.W. and Evans, J. 1998. *Bird monitoring methods: a manual of techniques for key UK species*. Royal Society for the Protection of Birds, Sandy. 464pp. ISBN 1-901-93003-3.

Grantham, M.J. 2004. Age structure and origins of British & Irish Guillemots *Uria aalge* recovered in recent European oil spills. *Atlantic Seabirds*, **6**: 95–108.

Haycock, R.J., Baines, M.E. and Earl, S.J. 1998. Effects of the *Sea Empress* oil spill on breeding seabirds in South West Wales. In: *The Sea Empress oil spill*, pp. 227–246 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Heubeck, M. 1997. The direct effect of the *Braer* oil spill on seabird populations, and an assessment of the role of the Wildlife Response Centre. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 73–90 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Heubeck, M. 2000. Population trends of Kittiwake *Rissa tridactyla*, Black Guillemot *Cepphus grylle* and Common Guillemot *Uria aalge* in Shetland. 1978–98. *Atlantic Seabirds*, 2: 227–244.

Irons, D.B. 1996. Size and productivity of black-legged kittiwake colonies in Prince William Sound before and after the *Exxon Valdez* oil spill. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, 18: 738–747.

JNCC. 1995. Vulnerable concentrations of seabirds to oil spills. Interactive maps and datasets available on Magic website: http://magic.defra.gov.uk

JNCC. 2004f. Common standards monitoring guidance for birds. Version August 2004, Online only. 50pp. www.jncc.gov.uk/page-2224 [accessed 2 July 2010].

Mavor, R.A., Parsons, M., Heubeck, M. And Schmitt, S. 2004. *Seabird numbers and breeding success in Britain and Ireland*. 2003 (UK Nature Conservation, No. 28). Joint Nature Conservation Committee, Peterborough, UK.

Mavor, R.A., Parsons, M., Heubeck, M. and Schmitt, S. 2006. *Seabird numbers and breeding success in Britain and Ireland*. 2005 (UK Nature Conservation, No. 30). Joint Nature Conservation Committee, Peterborough, UK.

Mitchell, P.I. and Parsons, M. 2007. *Strategic review of the UK seabird monitoring programme*. Joint Nature Conservation Committee, Peterborough, UK.

Monaghan, P. and Turner, C.M.R. 1997. Analysis of seabird blood samples following the *Sea Empress* oil spill. Report to the Countryside Council for Wales from the University of Glasgow. 12pp. + figures.

Monaghan, P., Walton, P., Austin, G., Burns, M.D., Turner, C.M. and Wright, P.J. 1997. Sub-lethal effects of the *Braer* oil spill on seabirds. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 91–105 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.
National Research Council. 2003. *Oil in the sea III: inputs, fates and effects*. Committee on Oil in the Sea. National Academies Press, Washington, DC, USA. 601pp. www.nap.edu/catalog/10388.html – includes online reading/search facility [accessed 2 July 2010].

NOAA. 1992. *An introduction to coastal habitats and biological resources*. Chapter 4, Biological Resources. Report No. HMRAD 92–4. National Oceanic and Atmospheric Administration. http://response.restoration.noaa.gov/oilaids/monterey/monterey.html [accessed 2 July 2010].

Piatt, J.F. and Anderson, P. 1996. Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 720–737.

RPI. 2001. *Bird injury quantification*. www.researchplanning.com/services/nrda/Bird.Injury.pdf [accessed 2 July 2010].

SEEEC. 1998. *The environmental impact of the Sea Empress oil spill*. Final report of the Sea Empress Environmental Evaluation Committee. February 1998. The Stationery Office, London, UK. ISBN 0-11-702156-3.

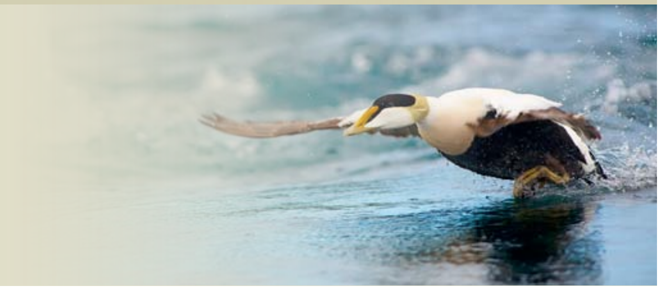
Shore, R.F. and Wright, J. 1997. *Polycyclic aromatic hydrocarbon and n-alkane residues in seabird eggs after the grounding of the Sea Empress*. Report to the Countryside Council for Wales from the Institute of Terrestrial Ecology, Monks Wood, UK. 40pp.

Votier, S.C., Hatchwell, B.J., Beckerman, A., McCleery, R.H., Hunter, F.M., Pellatt, J., Trinder, M. and Birkhead, T.R. 2005. Oil pollution and climate have wide-scale impacts on seabird demographies. *Ecology Letters*, **8**: 1157–1164.

Walsh, P.M., Halley, D.J., Harris, M.P., del Nevo, A., Sim, I.M.W. and Tasker, M.L. 1995. *Seabird monitoring handbook for Britain and Ireland. A compilation of methods for survey and monitoring of breeding seabirds*. Published by JNCC, RSPB, ITE and the Seabird Group. Joint Nature Conservation Committee, Peterborough, UK.
.

2.9.4.12 INSHORE WATERBIRDS

Inshore waterbirds



Known vulnerability and sensitivity

Inshore waterbirds are taken here to include eider, scaup, long-tailed duck, scoter, goldeneye, divers, grebes and mergansers. They are considered separately here from seabirds or wildfowl because of their mainly inshore distribution, very few breed in UK (most wintering seaduck breed in arctic or elsewhere in Europe) and where they do breed their nests are not aggregated in colonies. However, they all form non-breeding concentrations in certain shallow coastal areas. They spend most of the time on the water, diving in shallow areas for bivalve shellfish, and are therefore very vulnerable to oil spills. Summaries of the effects of oil spills on birds are given in NOAA (1992) and Clark (1984). The impacts of oil spills on seaduck and divers have been less apparent compared to seabirds like the auks, which are more abundant and therefore more often affected in large numbers. However, sea ducks and divers are extremely vulnerable to water-borne pollution, and the three species of divers are given the highest vulnerability index value of any “seabird” species (cf. see Table 1 in Section 2.9.4.11, above). Ecologically highly significant numbers of seaduck and divers have been killed by oil spills in the UK, including the *Braer* (Heubeck, 1997) and the *Sea Empress* (SEEEC, 1998; Banks *et al.,* 2008).

Although the apparent impacts on these birds may be very obvious when oiled corpses are collected, the resulting impact on their populations, and the time it takes for those populations to recover, is not always so apparent. It has been suggested (National Academy of Sciences, 1985) that the high reproductive potential of many sea duck may allow more rapid recovery of their populations compared to many seabirds. Scoter and diver concentrations at sea have been surveyed, and to a certain extent monitored, in some locations around UK, but accurate counts are difficult and costly to acquire. Standardised techniques have been developed (and are continuing to be developed) (see Seabirds at Sea methods on www.jncc.gov.uk and Camphuysen *et al.,* 2004). Studies of sublethal and indirect effects of pollutants on seaduck and divers are not known from the UK, but studies following the *Exxon Valdez* oil spill in Alaska did suggest effects on body mass (Esler *et al.,* 2002).

Impact assessment methods

Recording dead wildlife – Camphuysen *et al.* (2007) provide detailed methodologies for post-spill surveys. Counts of dead oiled birds will provide the best evidence of actual impact, therefore requiring urgent mobilisation of beach patrols to collect contaminated birds. Reasonable steps/analysis should be taken to check that contamination was caused by the oil spill. Counts of birds that are cleaned and released should also be recorded as most are unlikely to survive for very long after release. Carcass recovery experiments (preferably using dummy birds) may help to provide better estimates of the proportion of dead birds that were not collected. It is essential that surveyors inspect all birds for rings and report them to the BTO. Other data to collect from corpses and live oiled birds include a range of biometrics (see Camphuysen *et al.,* 2007) and other details that will help to determine the origin of the birds. Recording of clinical symptoms from sick birds taken to rehabilitation centres, and *post-mortem* analysis of dead birds, will therefore need to be organised. It may provide useful data to support assessments, including which colonies are liable to be affected

Biological survey attributes – First priority should be to mobilise seabird at sea surveys to assess location of concentrations of seaduck and divers liable to be impacted by drifting oil. Surveys will depend on suitable weather conditions and are usually carried out most efficiently from the air. Counts of each species are the primary attributes and the standardised survey methods and protocols are well developed (see Seabirds at Sea survey methods on http://www.jncc.gov.uk and review by Camphuysen *et al.,* 2004). Annual survival rates and measurements of breeding success (e.g. numbers of eggs/hatchlings/fledglings) will also be very useful where adequate pre-incident data exist. Other sublethal effects indices might also be useful if good pre-incident data happen to be available [Note: catching and taking samples from birds will require an official licence.]

Strategy

Comparison between pre- and post-spill trends in counts from at sea surveys will provide best evidence. If the quality of the pre-incident data is poor, the assessment will rely primarily on the data from corpses, including age structure and ring recoveries.

Key methodological references

Seabirds at Sea methods on www.jncc.gov.uk Camphuysen *et al.* (2004), Camphuysen *et al.* (2007). (Further useful information can be found in Banks et al., 2004.)

REFERENCES

Banks, A., Bolt, D., Bullock, I., Haycock, B., Musgrove, A., Newson, S., Fairney, N., Sanderson, B., Schofield, R., Taylor, R. and Whitehead, S. 2004. *Marine Monitoring Project: Ground and aerial monitoring protocols for in-shore SPAs. Common Scoter surveys in Carmarthen Bay during the winters of 2002–03 and 2003–04*. Draft report from the British Trust for Ornithology to the Countryside Council for Wales. BTO Research Report No. 366. 160pp + figures and tables.

Banks, A.N., Sanderson, W.G., Hughes, B., Cranswick, P.A., Smith, L.E., Whitehead, S., Musgrove, A.J., Haycock, B. and Fairney, N.P. 2008. The *Sea Empress* oil spill (Wales, UK): effects on common scoter *Melanitta nigra* in Carmarthen Bay and status ten years later. *Marine Pollution Bulletin*, **56**: 895–902.

Camphuysen, C.J, Bao, R., Nijkamp, H. and Heubeck, M. (eds.). 2007, *Handbook on oil impact assessment*. Royal Netherlands Institute for Sea Research, Texel, The Netherlands. http://www.oiledwildlife.eu/publications/handbook-oil-impact-assessment-seabirds [accessed 4 November 2010].

Camphuysen, K.J., Fox, A.D., Leopold, M.F. and Petersen, I.K. 2004. *Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K.: a comparison of ship and aerial sampling methods for marine birds, and their applicability to offshore wind farm assessments*. NIOZ report to COWRIE (BAM – 02–2002), Texel, 37pp.

Clark, R.B. 1984. Impact of oil pollution on seabirds. *Environmental Pollution* (Series A), **33**: 1–22.

Esler, D., Bowman, T.D., Trust, K., Ballachey, B.E., Dean, T.A., Jewett, S.C. and O'Clair, C.E. 2002. Harlequin duck population recovery following the *Exxon Valdez* oil spill: progress, process and constraints. *Marine Ecology Progress Series*, **241**: 271–286.

Heubeck, M. 1997. The direct effect of the *Braer* oil spill on seabird populations, and an assessment of the role of the Wildlife Response Centre. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 73–90 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

National Academy of Sciences. 1985. *Oil in the sea: inputs, fates and effects.* National Academy Press, Washington, DC, USA. 601pp. ISBN 0-309-03479-5.

NOAA. 1992. *An introduction to coastal habitats and biological resources.* Chapter 4, Biological Resources. Report No. HMRAD 92–4. National Oceanic and Atmospheric Administration. http://response.restoration.noaa.gov/oilaids/monterey/monterey.html [accessed 2 July 2010].

SEEEC. 1998. *The environmental impact of the Sea Empress oil spill.* Final report of the Sea Empress Environmental Evaluation Committee. February 1998. The Stationery Office, London, UK. ISBN 0-11-702156-3.

2.9.4.13 WETLAND BIRDS

Wetland birds

Known vulnerability and sensitivity

Wetland birds, including waders, duck, geese and swans, appear to have a relatively low vulnerability to the direct effects of oil spills. It is very unusual for them to become oiled whilst on the shore (this is an unexplained characteristic, but seems to be an avoidance reaction), and relatively few spend time on the water in vulnerable areas. The main exceptions to this trend are the gulls, which are considered above in Section 2.9.4.11. The primary concern for wetland birds during oil spills is the effects of the oil and the clean-up on their feeding and roosting resources. Avoidance of oiled sediment flats, which can be exacerbated by disturbance from clean-up activity, drives the birds away to find feeding and roosting areas elsewhere. If a spill affects a large proportion of the locally available feeding and roosting area, the birds may struggle to find alternative resources. In a worst-case situation, where birds are already stressed by other factors, the effects could result in starvation or other significant sublethal impacts.

Impacts on the food resource – that is reduced densities of prey species killed by the oil – are theoretically possible but have not been proven. This is probably because much of the intertidal fauna is not particularly sensitive to oil, and even a fairly large spill is unlikely to greatly reduce the total infaunal biomass over a large area for more than a few weeks. More subtle effects, particularly on sediment fauna species that are key prey for some birds, are very possible, but the inherent natural variability makes it very difficult to detect an impact on those populations.

A variety of sublethal physiological effects from birds feeding on contaminated prey, and building up a body burden of toxic hydrocarbons, have been shown from experimental studies (National Research Council, 2003), but few field-based studies have shown evidence of population effects (cf. black oystercatcher case studies below).

Impact assessment methods

Recording dead wildlife – Camphuysen *et al.,* 2007 provide detailed methodologies for post-spill surveys. Counts of dead, contaminated birds will provide the best evidence of actual impact, therefore requiring urgent mobilisation of beach patrols to collect contaminated birds. Reasonable steps/analysis should be taken to check that death/oiling was caused by the oil or chemical spill. Counts of birds that are cleaned and released should also be recorded as most are unlikely to survive for very long after release. It is essential that surveyors inspect all birds for rings and report them to the BTO. Other data to collect from corpses and live oiled birds include a range of biometrics (see Camphuysen *et al.,* 2007) and other details that will help to determine the origin of the birds. Recording of clinical symptoms from sick birds taken to rehabilitation centres, and *post-mortem* analysis of dead birds, will therefore need to be organised. It may provide useful data to support assessments, including which colonies are liable to be affected.

Biological survey attributes

Counts of each species in feeding and roosting areas are the primary attributes and standardised survey methods, and protocols are well developed (cf. Pollitt *et al.,* 2003, for Wetland Bird Survey (WeBS) core count survey methods). These can show changes in numbers of birds visiting affected feeding areas, but they are unlikely to detect changes in populations, due to natural fluctuations and survey limitations, unless there is other evidence that a species has been affected (e.g. large numbers of corpses).

Low tide counts (cf. Musgrove *et al.*, 2004), if sufficiently detailed, may provide better information on changes in bird distributions due to oil or chemical spills.

If the breeding sites of a notably affected species are well known and closely correlated, counts of breeding adults and measurements of breeding success (e.g. numbers of eggs/hatchlings/fledglings) may also be useful, but this is unlikely for most species and most situations.

Indirect effects from reduced prey (i.e. intertidal fauna killed by oil or chemicals) could theoretically affect bird condition (body weight etc.), but it is very unlikely that sufficient data could be acquired to show an impact, unless a particular prey population that was shown to be badly affected by the incident was the primary food source of a particular bird population.

Sublethal effects from ingestion of contaminated prey could theoretically affect bird condition (blood anaemia etc.) and breeding success, but detection of a significant impact would be very difficult and such studies would have a low priority. [Note: catching and taking samples from birds would require an official license.]

Strategy

Comparison between pre- and post-incident data (particularly count data) will provide the best evidence of impacts to wetland bird distributions and populations. If the quality of the pre-incident data is poor, the impact assessment will rely primarily on dead bird data.

Comparison of data between different breeding sites (occupancy or breeding success) will only be useful if there is a strong correlation between feeding areas and breeding sites, and even then it is unlikely to provide proof without pre-incident data.

Monitoring changes in any of the above attributes at intervals following the incident is unlikely to provide proof without pre-incident data.

Effects of clean-up

The most likely impacts are from disturbance during feeding and roosting, so impact assessment should be based on standard survey methods described above and basic ecological observation.

Key methodological references

JNCC (2004), Gilbert *et al.* (1998), BTO Wetland Bird Survey website, www.bto.org/webs (accessed 2 July 2010). (Further useful information can be found in Andre, 1999; Armitage et al., 1997, 2000; Burton et al., 2004; Sharp et al., 1996; US EPA, 2002.)

REFERENCES

Andre, B.A. 1999. Black Oystercatcher *Haematopus bachmani*. *Restoration Notebook. Exxon Valdez* Oil Spill Trustee Council. 8pp.

Armitage, M., Burton, N. and Rehfisch, M. 1997. *The abundance and distribution of waterfowl within Milford Haven after the Sea Empress oil spill. One-year report*. Report to CCW from the British Trust for Ornithology, Thetford, UK. 124pp.

Armitage, M., Rehfisch, M. and Burton, N. 2000. *The impact of the Sea Empress oil spill on the abundance and distribution of waterbirds within Milford Haven. Year 3 Final Report*. Report to the Countryside Council for Wales from the British Trust for Ornithology, Thetford, UK. 85pp. + figures.

Burton, N.H.K., Musgrove, A.J. and Rehfisch, M.M. 2004. Tidal variation in numbers of waterbirds: how frequently should birds be counted to detect change and do low tide counts provide a realistic average?: Capsule Variation in numbers needs to be assessed at both site- and species-specific levels, but low tide counts are representative of average usage in most cases. *Bird Study*, **51**: 48–57.

Camphuysen, C.J, Bao, R., Nijkamp, H. and Heubeck, M. (eds.). 2007, *Handbook on oil impact assessment*. Royal Netherlands Institute for Sea Research, Texel, The Netherlands. http://www.oiledwildlife.eu/publications/handbook-oil-impact-assessment-seabirds [accessed 4 November 2010].

Gilbert, G., Gibbons, D.W. and Evans, J. 1998. *Bird monitoring methods: a manual of techniques for key UK species*. Royal Society for the Protection of Birds, Sandy. 464pp. ISBN 1-901-93003-3.

JNCC. 2004f. Common standards monitoring guidance for birds. Version August 2004, Online only. 50pp. www.jncc.gov.uk/page-2224 [accessed 2 July 2010].

Musgrove, A.J., Langston, R.H.W., Baker, H. and Ward, R.M. (eds.). 2004. *Estuarine waterbirds at low tide, the WeBS low tide counts 1992–93 to 1998–99*. 316pp.

National Research Council. 2003. *Oil in the sea III: inputs, fates and effects*. Committee on Oil in the Sea. National Academy Press, Washington, DC, USA. 601pp. www.nap.edu/catalog/10388.html– includes online reading/search facility [accessed 2 July 2010].

Pollitt, M., Hall, C., Holloway, S., Hearn, R., Marshall, P., Musgrove, A., Robinson, J. and Cranswick, P. 2003. *The Wetland Bird Survey 2000–01. Wildfowl and Wader Counts*. BTO/WWT/RSPB/JNCC, Slimbridge.

Sharp, B.E., Cody, M. and Turner, R. 1996. Effects of the *Exxon Valdez* oil spill on the black oystercatcher. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 748–758.

US EPA. 2002. *Methods for evaluating wetland condition: biological assessment methods for birds*. Office of Water, U.S. Environmental Protection Agency, Washington, DC, USA, USA. EPA-822-R-02–023. www.epa.gov/waterscience/criteria/wetlands/13Birds.pdf [accessed 2 July 2010].

2.9.4.14 SEALS

Seals

Known vulnerability and sensitivity

Geraci and St. Aubin (1990) summarise evidence on the impacts of oil on seals. Adult seals appear not to be particularly sensitive to fouling by oil, and evidence of mortalities is mostly circumstantial. Toxic effects from oil vapours and aerosols, however, can have severe effects on respiration and the nervous system and can result in death. If seals are trapped near the source of a spill, they may be seriously affected; particularly if the oil is light with a large proportion of aromatic hydrocarbons. Seal pups are likely to be more sensitive than the adults, and grey seal pups trapped on beaches when oil comes ashore will be more vulnerable. There is, therefore, a seasonal aspect to their vulnerability, related to pupping activity.

Respiratory disorders (indicated by nasal mucus etc. in field surveys and various clinical symptoms in captured animals) have been observed at previous spills. However, natural incidence of respiratory diseases can complicate studies.

Impact assessment methods

Recording dead/oiled wildlife – counts of dead or oiled or sick seals will provide the best evidence of actual impact, although reasonable steps/analysis should be taken to check that death/oiling/sickness was caused by the oil spill. Recording of clinical symptoms from sick animals taken to animal rehabilitation centres, and autopsy descriptions from dead seals, can provide useful data to support assessments. Information on causes of death may arise from veterinary investigations. In some cases, an estimate of the length of time an animal has been dead can be useful in establishing whether the pollution incident is a credible cause or not. Other information may also be available from the Sea Mammal Research Unit based at the University of St Andrews.

Biological survey attributes – some of the more likely potential indicators are *in situ* recording of respiratory symptoms (and other signs possibly related to oil injury) of seals at haul-out sites (likely to be the best short-term indicator of stress); counts of adult seals and pups at haul-out sites and pupping sites, which are the primary measure for population effects and for which standardised census methods are well developed, although annual fluctuations will greatly limit the detection of any impacts. [Note: aerial surveys are widely used for seal counts (adults and pups), but ground-based surveys are generally considered more reliable in some cliffed coastlines where the pups are often hidden in small coves and caves.]

Strategy

Comparison between pre- and post-spill count data for adults and pup production will provide the best evidence of impacts to seal populations.

Comparison between pre- and post-spill respiratory symptom data will be greatly affected by natural seasonal and annual fluctuations, requiring large amounts of pre- and post-spill data to separate natural effects from oil spill effects.

Comparison of data on respiratory symptoms between different haul-outs (oiled and unoiled, or along a gradient of oiling conditions) is likely to provide the best evidence of short-term impacts, as long as surveys are carried out at the same time of year (to allow for seasonal effects).

Comparison of data on post-spill pup productivity between different haul-outs (oiled and unoiled) may be useful in severe cases (and when oiling of the area where the seals are present occurs within a few weeks of the breeding season), but is unlikely to provide proof without pre-incident data.

Effects of clean-up

Methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with areas where dispersants were sprayed), with some additional considerations for site selection. Methods to study effects of the clean-up response on behaviour of seals are currently limited to basic observations.

Key methodological references

Duck (2003), JNCC (2005). (Further useful information can be found in Countryside Council for Wales, 1998; Conroy et al., 1997; Duck et al., 1993.)

REFERENCES

Conroy, J.W.H., Kruuk, H. and Hall, A.J. 1997. The effects of the *Braer* oil spill on otters and seals on Shetland. In: T*he impact of an oil spill in turbulent waters: the Braer*, pp. 106–120 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Countryside Council for Wales. 1998. *Grey seal pup production and monitoring studies following the Sea Empress oil spill*. Summary report prepared for the SEEEC. Countryside Council for Wales, Bangor, UK.

Duck, C. 2003. Monitoring harbour seals in Special Areas of Conservation in Scotland. Scottish Natural Heritage Commission Report F01AA403. 28pp.

Duck, C.D., Hall, A.J. and Ingram, S. 1993. *Monitoring the impact of the MV Braer oil spill in Shetland: Common Seal aerial survey*, August 1993. Sea Mammal Research Unit, Cambridge, UK.

Geraci, J.R. and St. Aubin, D.J. 1990. *Sea mammals and oil: confronting the risks*, Chapters 5 and 6, pp.129–197. Academic Press, New York. 282pp.

JNCC. 2005. Common standards monitoring guidance for marine mammals. Version May 2005, Online only. 36pp. www.jncc.gov.uk/page-2228 [accessed 2 July 2010].

2.9.4.15 OTTERS

Otters

Known vulnerability and sensitivity

Otters are undoubtedly sensitive to oil (Geraci and St. Aubin, 1990), but the vulnerability of otter populations to marine oil or chemical spills is not well understood. Some coastal otters feed in nearshore and intertidal areas, but their reliance on these habitats and associated food resources is not well established as they are also likely to feed in freshwater habitats nearby. While there was some evidence of impacts to otter populations following the 1993 *Braer* oil spill in south Shetland (Conroy et al., 1997) there was no recorded evidence of impacts from the 1996 *Sea Empress* spill to otters in Pembrokeshire (SEEEC, 1998). However, the difficulty of making good estimates of population size and measuring impacts makes assessment of vulnerability unreliable.

Impact assessment methods

Detecting and monitoring of any impacts to otters from oil spills will be extremely difficult. Even if there is considerable oiling of coastal habitats adjacent to areas with a known otter population, visual evidence of otter oiling or clear evidence that they have been directly affected is unlikely. This is compounded by their shy behaviour, complex feeding patterns, a variety of unrelated environmental factors that affect them and a lack of data on the populations in most areas

Recording dead otters – counts of dead or oiled or sick otters will provide the best evidence of actual impact, although reasonable steps/analysis should be taken to check that death/oiling/sickness was caused by the oil or chemical spill.

Biological survey attributes – some of the more likely potential indicators are: signs of otter presence/activity (spraints etc.) (these are the primary attributes and standardised survey methods, and protocols have been developed; cf. Jones and Jones, 2004); records of otter sightings at known sites close to the oil spill area.

Strategy

Comparison between pre- and post-incident data will provide the best evidence of impacts to otter populations, preferably with some monitoring of activity over a few months.

Comparison of otter activity/records between oiled and unoiled areas is very unlikely to be of any value, due to natural variation. (Further useful information can be found in JNCC, 2004.)

REFERENCES

Conroy, J.W.H., Kruuk, H. and Hall, A.J. 1997. The effects of the *Braer* oil spill on otters and seals on Shetland. In: *The impact of an oil spill in turbulent waters: the Braer*, pp. 106–120 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Geraci, J.R. and St. Aubin, D.J. 1990. *Sea mammals and oil: confronting the risks*, Chapters 5 and 6, pp.129–197. Academic Press, New York. 282pp.

JNCC. 2004g. Common standards monitoring guidance for terrestrial mammals. Version August 2004, Online only. 51pp. www.jncc.gov.uk/page-2229 [accessed 2 July 2010].

Jones, T. and Jones, D. 2004. *Otter survey of Wales 2002*. Environment Agency, Bristol, UK. 59pp.

SEEEC. 1998. *The environmental impact of the Sea Empress oil spill*. Final report of the Sea Empress Environmental Evaluation Committee. February 1998. The Stationery Office, London, UK. ISBN 0-11-702156-3.

2.9.4.16 CETACEANS (WHALES, DOLPHINS AND PORPOISES)

Cetaceans

Known vulnerability and sensitivity

Geraci and St Aubin (1990) and Gubbay and Earll (2000) have summarised the evidence of the impacts of oil on cetaceans. This includes information gathered following the most intensely studied incident to date, the *Exxon Valdez* spill in Alaska in 1989. No studies of the effects of spilled chemicals on cetaceans have been conducted to our knowledge. Individuals and small groups of cetaceans have occasionally been seen at the surface in the vicinity of oil spills, and may therefore have come into contact with oil, but very few examples of actual injury to cetaceans have been reported. Much of the evidence of injuries is circumstantial, but it seems likely that individuals are occasionally exposed to oil from large spills, sometimes being attracted to the spill area by the response activity. While their skin is not thought to be particularly sensitive to oil, any accidental ingestion or breathing of oily fumes could cause physiological stress. It will be very difficult to prove an impact on cetacean populations, but current evidence does not suggest more than a low vulnerability. The only notable empirical evidence of a direct effect comes from the monitoring of killer whale (*Orcinus orca*) populations following the *Exxon Valdez* oil spill. Matkin *et al.* (2008) reported evidence of a long-term impact from the spill on one particular pod of these whales, although the larger population within Prince William Sound appeared to be unaffected in both the short and long term.

Impact assessment methods

It is extremely unlikely that post-spill surveys of cetaceans will provide any information suitable for an impact assessment, even if pre-incident data exist. The only exception would be if a well-studied and very stable population of a particular species is normally present in the spill area. Detailed impact assessment studies are therefore not normally recommended unless such exceptional circumstances suggest a higher priority.

Strategy

Record and collate any observations of cetaceans in the spill area, during and in the weeks after the spill, particularly any observations of cetaceans close to slicks and any signs of ill health or unusual behaviour. An aerial survey may be appropriate if ill animals are reported by members of the public.

Any dead, moribund or stranded cetaceans should be studied (species, sex, dimensions etc.) and photographed. Tissue samples and an autopsy may be appropriate to determine cause of death – this will require a cetacean/veterinary specialist. Information on causes of death may arise from the Cetacean Strandings Investigation Programme (CSIP) operated by the Institute of Zoology on behalf of Defra or from other veterinary investigations. In some cases, an estimate of the length of time an animal has been dead can be useful in establishing whether the pollution incident is a credible cause or not.

More information on the reporting of strandings to the CSIP is given at http://ukstrandings.org/how-to-report-a-stranding accessed 14 June 2011.

Acoustic survey methods that are currently being developed may be available in the future for estimating abundances of cetaceans in oil spill affected areas and possibly for studying cetacean behaviour in relation to the spill and the response activity.

Gubbay and Earll (1999) developed proposed guidelines for dealing with cetaceans in the event of an oil spill in the Moray Firth, Scotland. These are currently being reviewed and updated, but they provide useful background material.

Effects of clean-up

Methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil-in-water concentrations). Methods to study effects of the response (e.g. boat activity) on behaviour of cetaceans are currently limited to basic observations.

Key methodological references

JNCC (2005), Evans and Hammond (2004). (Further useful information can be found in Aguilar de Soto et al., 2004; Baines et al., 1997; Ridoux et al., 2004; Scholz et al., 1992.)

REFERENCES

Aguilar de Soto, N., Rogan, E., Ó Cadhla, O., Gordon, J.C.D., Mackey, M. and Connolly, N. 2004. *Cetaceans and seabirds of Ireland's Atlantic Margin. Volume III: Acoustic surveys for cetaceans*. Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porcupine Studies Group project P00/15, and Offshore Support Group (OSG) Project 99/38.

Baines, M., Pierpoint, C. and Earl, S. 1997. *A cetacean sightings database for Wales and an evaluation of impacts on cetaceans from the Sea Empress oil spill*. Report to the Countryside Council for Wales from The Wildlife Trust West Wales. 67pp.

Evans, P.G.H. and Hammond, P.S. 2004. Monitoring cetaceans in European waters. *Mammal Review*, **34**: 131–156.

Geraci, J.R. and St. Aubin, D.J. 1990. *Sea mammals and oil: confronting the risks*, Chapters 5 and 6, pp.129–197. Academic Press, New York. 282pp.

Gubbay, S. and Earll, R. 1999. Proposed guidelines for dealing with cetaceans in the event of an oil spill in the Moray Firth, Scotland. Report to Talisman Energy (UK) Limited and Scottish Natural Heritage.

Gubbay, S. and Earll, R. 2000. Review of literature on the effects of oil spills on cetaceans. *Scottish Natural Heritage Review*, No. 3. 34pp. www.snh.org.uk/pdfs/publications/review/003.pdf [accessed 11 March 2011].

JNCC. 2005. Common standards monitoring guidance for marine mammals. Version May 2005, Online only. 36pp. *www.jncc.gov.uk/page-2228* [accessed 2 July 2010].

Matkin, C.O., Saulitis, E.L., Ellis, G.M., Olesiuk, P. and Rice, S.D. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the *Exxon Valdez* oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series*, **356**: 269–281.

Ridoux, V., Lafontaine, L., Bustamante, P., Caurant, F., Dabin, W., Delcroix, C., Hassani, S., Meynier, L., da Silva, V.P., Simonin, S., Robert, M., Spitz, J. and Van Canneyt, O. 2004. The impact of the *Erika* oil spill on pelagic and coastal marine mammals: combining demographic, ecological, trace metals and biomarker evidences. *Aquatic Living Resources*, **17**: 379–387.

Scholz, D., Michel, J., Shigenaka, G. and Hoff, R. 1992. Biological resources. In: *NOAA report: introduction to coastal habitats and biological resources for spill response*, Chapter 4.

2.10 ECOTOXICOLOGY IN POST INCIDENT MONITORING

2.10.1 General Introduction

One of the most important potential impacts of accidental spills of oil and chemicals into the marine environment is the ability of those spilled substances to elicit a toxic effect within the receiving ecosystem. The effects can either be predicted/anticipated by investigating the toxic hazards associated with specific oils/chemicals or, where release has already caused contamination, the in situ toxicity of the incident can be assessed by conducting ecotoxicological assessments of the affected water, sediment and biota.

The use of ecotoxicological techniques to measure potential and actual biological effects during an incident spill and the post-incident recovery phase are key to the ultimate assessment of impact and can be used as part of a planned monitoring strategy (Kirby and Law, 2010; Martínez-Gómez et al, 2010). Here we provide some general guidelines and recommendations on the approaches that should be employed. However, although certain core approaches are recommended, it is also accepted that a broad range of 'non-standard' techniques may be of relevance for specific incidents, for example, where chemicals with specific modes of action are involved or where specific, ecologically important, species represent the impacted area.

2.10.1.1 Pertinent Questions

When deciding whether it is appropriate to deploy ecotoxicological techniques in post-incident monitoring, there are a number of general questions that need to be addressed. Each incident scenario will be different, but consideration of the questions below will help to determine the type of ecotoxicological approach that is appropriate.

- What has been spilled? Is the substance regarded as potentially toxic or is there significant uncertainty regarding its toxicity?
- Where is the spill and where is it heading?
- What are the key ecological and/or commercially important species in the vicinity of the incident?
- Does the timing of the spill/contamination coincide with any important seasonal biological processes (e.g. spawning, key developmental/growth periods or migration)?
- What is the likely physical behaviour of the substance in seawater (e.g. will it evaporate, float, sink or dissolve)?
- Is this substance known to be persistent or likely to bioaccumulate?
- What are we concerned with? The likely short-term acute impacts or the potential for longer-term chronic impacts?
- Has there been an impact already and is there a need to monitor recovery potential?

2.10.2 Recommended scenarios for ecotoxicological monitoring

Ecotoxicological methods can be used as powerful tools in post-incident monitoring and the assessment of actual or potential impact. Fundamentally, the decisions about the need for and type of ecotoxicological monitoring and the appropriate methods to deploy will depend on the matrix selected for investigation. They will broadly fall into four categories:

1. Water
2. Sediment
3. Biota
4. Chemicals

2.10.2.1 Water

Assessment of the biological effects associated with water exposure might be appropriate for a number of scenario types:

- Where the amounts spilled are sufficiently large and modelling suggests that reasonably high water-borne concentrations of chemical could be present.
- Where the spill occurs in a reasonably sheltered area in which flushing and dilution could be limited.
- Where the spill is of a substance that is highly soluble in seawater and/or of potential high acute toxicity.
- Where a spill involves a complex mixture of chemicals whose toxicity is unknown.
- Where a water body adjacent to an ongoing spill or an ongoing source of contamination (e.g. leachate from contaminated sediment) is being continuously contaminated.
- Where the assessment of the toxicity of “contained” contaminated water (e.g. held within the hull of a flooded ship) can help in the overall risk assessment.

Water samples to be used in ecotoxicological studies should be taken with reference to Section 2.4.

2.10.2.2 Sediment

Assessment of the biological effects associated with sediment exposure might be appropriate for a number of scenario types:

- Where the spill has occurred in the coastal zone or shallow water and the spilled substance will have come into contact with sediments.
- Where the spill occurs in conditions of stormy or turbulent waters such that the spilled substance may have been incorporated into sediments.
- Where the substance in question is a sinker.
- Where the substance in question is hydrophobic and is therefore more likely to become associated with sediments.

Sediment samples to be used in ecotoxicological studies should be taken with reference to Section 2.4.

2.10.2.3 Biota

There are a number of situations in which wild biota can be obtained and assessed for biological impacts as part of an incident impact investigation:

- Where there is a concern that *in situ* biota could have been affected by the contamination (the water/sediment may still be contaminated or the biota could have been exposed to a transient concentration)
- Where the impacted area contains dominant biota types that can act as good sentinel indicators for the area (e.g. molluscs in shellfish beds, macrophytes in seagrass beds)
- Where there are commercially exploitable biota (e.g. fish or shellfish) in or near the impacted area that rely on healthy populations for sustainable harvesting
- Where there are concerns for long-term contamination and biological impacts.
- The use of transplanted or caged biota (such as mussels) may be considered where any of the above concerns exist but naturally occurring specimens are difficult to obtain

2.10.2.4 Chemicals

On occasion there will be the need to conduct direct ecotoxicological testing of a specific chemical. These would more often be when a vessel has foundered or is in danger of breaking up and the cargo is still wholly or partially in place:

- When there is little ecotoxicological information available for the substance in question
- When samples of the chemical cargo are readily available
- When there are significant concerns about mixture or long-term impacts that are best investigated via laboratory-based exposures

2.10.3 Recommended baseline approach

The defined use of specific ecotoxicological methods within an integrated post-incident monitoring programme can be problematic. There are some fundamental differences between monitoring programmes designed to assess long-term temporal trends, such as national marine monitoring programmes, and those required to assess post-incident impacts and recovery (Kirby and Law, 2010). However, it is highly recommended that a baseline standard approach is available, including standardised techniques, to facilitate the prompt deployment of testing following a spill incident. Furthermore, where possible, the design and technical content of the baseline programme should follow internationally accepted protocols such as those set out in the OSPAR JAMP (Joint Assessment Monitoring Programme) guidelines (OSPAR, 1997, 2003). Tables 2 and 3 outline a recommended baseline approach.

2.10.3.1 Bioassays

Table 2

Recommended baseline battery of bioassays for use in post-incident monitoring

TEST MATRIX	RECOMMENDED METHOD	REFERENCE
Water (also relevant for sediment pore waters and elutriates)	Copepod acute toxicity (*Tisbe battagliai* 48-hr LC50)	ISO, 1999. ISO 14669:1999(E) Water quality – Determination of acute lethal toxicity to marine copepods (Copepoda, Crustacea)
	Oyster embryo development (*Crassostrea gigas* 24-hr EC50)	Thain, J.E., 1991. Biological effects of contaminants: oyster (*Crassostrea gigas*) embryo bioassay. ICES Techniques in Marine Environmental Sciences no. 11. 12 pp. http://www.ices.dk/pubs/times/times11/TIMES11.pdf accessed 31 December 2010
	Algal growth inhibition test (*Skeletonema costatum* 72-hr EC50)	ISO, 2006. ISO 14442:2006(E) Water quality – Guidelines for algal growth inhibition tests with poorly soluble materials, volatile compounds, metals and waste water
Sediment	Amphipod whole sediment bioassay (*Corophium volutator* 10-d LC50) and/or	Thain, J. and Roddie, B., 2001. Biological effects of contaminants: *Corophium* sp. sediment bioassay and toxicity test. *ICES Techniques in Marine Environmental Sciences* no. **28**. 21 pp. http://www.ices.dk/products/techniques.asp accessed 24 September 2010
	Polychaete whole sediment bioassay (*Arenicola marina* 10-d LC/EC50)	Thain, J. and Bifield, S., 2001. Biological effects of contaminants: Sediment bioassay using the polychaete *Arenicola marina*. *ICES Techniques in Marine Environmental Sciences* no. **29**. 16 pp. http://www.ices.dk/pubs/times/times29/TIMES29.pdf accessed 31 December 2010
Chemical	Where direct chemical toxicity is required, any of the above recommended tests can be deployed using serial dilution or sediment spiking methods.	As above

2.10.3.2 Biomarkers (short-term)

Table 3

Recommended baseline battery of biomarkers for use in post-incident monitoring

TAXONOMIC GROUP	RECOMMENDED METHODS	REFERENCE
Vertebrates: Fish Dab (*Limanda limanda*) Flounder (*Platichthys flesus*) Plaice (*Pleuronectes platessa*) Cod (*Gadus morhua*)	EROD (Ethoxyresorufin O-deethylase) activity	Stagg, R. and McIntosh, A., 1998. Biological effects of contaminants: Determination of CYP1A-dependent mono-oxygenase activity in dab by fluorimetric measurement of EROD activity. *ICES Techniques in Marine Environmental Sciences* no. **23**. 16 pp. http://www.ices.dk/pubs/times/times23/TIMES23.pdf accessed 31 December 2010
	PAH metabolites in bile	Ariese, F., Beyer, J., Jonsson, G., Visa, C.P. and Krahn, M.M., 2005. Review of analytical methods for determining metabolites of polycyclic aromatic compounds (PACs) in fish bile. *ICES Techniques in Marine Environmental Sciences* no. **39**. 41 pp. http://www.ices.dk/pubs/times/times39/TIMES39.pdf accessed 31 December 2010
	AChE (Acetylcholinesterase) activity	Bocquené, G. and Galgani, F., 1998. Biological effects of contaminants: Cholinesterase inhibition by organophosphate and carbamate compounds. *ICES Techniques in Marine Environmental Sciences* no. **22**. 12 pp. http://www.ices.dk/pubs/times/times22/TIMES22.pdf accessed 31 December 2010
Invertebrates: Molluscs Mussel (*Mytilus edulis*)	Lysosomal stability	Moore, M.N. and Lowe, D., 2004. Biological effects of contaminants: Measurement of Lysosomal membrane stability. *ICES Techniques in Marine Environmental Sciences* no. **36**. 31 pp. http://www.ices.dk/pubs/times/times36/TIMES36.pdf accessed 31 December 2010
	Scope for growth	Widdows, J. and Staff, F., 2006. Biological effects of contaminants: Measurement of scope for growth in mussels. *ICES Techniques in Marine Environmental Sciences* no **40**. 30 pp. http://www.ices.dk/pubs/times/times40/TIMES40.pdf accessed 31 December 2010

2.10.4 Other assays/approaches

While a recommended base set of bioassays and biomarkers offers an important standardised initial approach, it is fully recognised that a plethora of other ecotoxicological techniques could be deployed to meet specific needs. In fact, because marine incidents can involve a wide range of habitats or involve an extensive list of oils or chemicals, it is recommended that other methods are promptly considered and deployed if they offer value in monitoring and impact assessment for a specific incident. Some examples where other techniques should be considered are outlined below.

2.10.4.1 Chemical-specific

Where there is good information about the exact nature of the spilled material, one should consider whether there are any biomarkers available that have a targeted response to a particular chemical. Examples of this are EROD activity (Stagg and McIntosh, 1998) and bile metabolites (Ariese et al., 2005) which become elevated as a result of exposure to certain PAHs, an important component of many oils and, for EROD, certain planar polychlorinated biphenyls (PCBs). Other examples of chemical specific biomarkers include metallothionein (for Cu, Zn, Cd and inorganic Hg) (Viarengo et al., 1997), δ-amino levulinic acid dehydratase (ALA-D) (for Pb) (Johansson-Sjobeck and Larsson, 1978) and AchE inhibition (Bocquené and Galgani, 1998) for a range of neurotoxic chemicals (e.g. organophosphate and carbamate pesticides).

So for incidents in which chemicals are spilled, consideration should be given to the deployment or extended use (either spatially or in other species) of biomarkers that are known to respond specifically to that chemical, if they exist.

2.10.4.2 Mixtures

A particular strength in the use of biological systems and/or whole organisms in the assessment of exposure and effects is their ability to integrate the effects of all the contaminants present, including whether their combined effects might be antagonistic or synergistic. Marine spill events can involve the simultaneous release of a range of chemicals into the environment (e.g. events involving multi-cargo vessels such as chemical tankers or container ships) and biological effects techniques may offer a powerful way to assess potential deleterious impacts quickly in contrast to chemical analysis, which may be too targeted to pick up all potential contaminants. It is therefore recommended that, where substantial mixtures of chemicals are released, ecotoxicological assessment is a core part of any monitoring programme. Furthermore, where a potential mix of contaminants are semi-contained, perhaps in the hull of a flooded vessel, bioassay assessment of the “hull water” has been deployed successfully to ascertain the potential hazard if the contents were to be released to the wider environment (Kirby et al., 2008).

2.10.4.3 Habitat-specific

Specific ecotoxicological techniques can also be extremely valuable in assessing the impact, or potential impact, of spills in particular receiving habitats. Where a particular habitat is at threat or is already impacted, it would be beneficial in the assessment of impact and recovery to be able to use sentinel species that are representative of that particular environment. Published ecotoxicological methodologies using representative species of particular habitats are manifold, and examples might include the use of periwinkles (*Littorina littorea*) (Kirby et al., in prep) or limpets (*Patella vulgata*) (Dicks, 1970) for rocky shore environments, or various macrophytes (e.g. *Zostera, Fucus* or *Ceramium* species) (Chesworth et al., 2004; Brooks et al., 2008; ISO, 2010) for a range of intertidal and coastal environments. Following a pilot study on the coast of Portugal within the EU-funded EROCIPS project, Moreira *et al.* (2007), Lima *et al.* (2008) and Santos *et al.* (2010) have also recommended the use of the shanny (*Lipophrys pholis*) in oil spill monitoring studies. Common on all shores and abundant on rocky shores, it can be found in rock pools and under stones on all UK coasts (Wheeler, 1969). It is not sessile, but has a restricted home range, and so is representative of its immediate environment. Adults feed mainly on barnacles and mussels, which bioaccumulate a wide range of contaminants, so the shanny may also be of use in chemical spill monitoring programmes. The same study also identified the common goby (*Pomatoschistus microps*) as a suitable sentinel organism. The goby is widely distributed around the UK and is abundant in intertidal pools, estuaries and saltings pools on sandy or muddy shores. Its food consists mainly of small crustaceans (Wheeler, 1969).

It is also worth noting that many of the recommended baseline biomarkers can be modified or are equally relevant for a wide range of other fish and invertebrates, so the choice of species may need to be amended to what is readily available and may be different for a range of habitats.

2.10.4.4 Activity screening

A range of biologically based assays are also available to measure specific types of activity or modes of action that can be attributed to released contaminants. Again, this can be useful when dealing with mixtures, unknown quantities, or as a simple biological screen of potential short- or long-term effects. Screening methods available include those for genotoxic or mutatoxic compounds (e.g. the Umu or Ames tests) (Oda et al., 1985; Maron and Ames, 1983) or those with general antimicrobial activity (e.g. ABC assay) (Smith et al., 2007). Others include *in vitro* screens for the assessment of binding to aryl hydrocarbon (e.g. DR CALUX) (Murk et al., 1996), oestrogen (e.g. ER-CALUX, YES assays) (Legler et al., 1999; Routledge and Sumpter, 1996) and androgen (e.g. YAS assay) (Sohoni and Sumpter, 1998) receptors, which can provide important indicators as to the mode of action of the primary contaminants and the type of biological effects that might be manifest in exposed animals.

2.10.4.5 Longer-term effects

It is understandable that the initial focus of any post-incident monitoring programme will be to quickly understand the potential for and/or breadth of short-term acute impacts.

Therefore, the recommended baseline battery of bioassays and biomarkers (Tables 2 and 3) have been selected in order to enable that short-term assessment to be made. However, spills in the marine environment also have the potential to elicit their detrimental effects over longer time periods (Kingston, 2002) and, for example, oil residues have been shown to persist in sediments for several decades under certain conditions (Kirby and Law, 2010; Venosa et al., 2010).

Ecotoxicological methods also offer a wide range of options and specific endpoints that are appropriate to be used to monitor long-term impacts. In particular, these approaches are likely to include assessments of reproductive competence, methods of which exist for many species and can range from measures of reproductive performance, fecundity and inter-generational offspring viability to measures of sperm motility and fertilisation success. Longer term effects might also result from cellular damage and assays of DNA damage (e.g. DNA adducts, micronucleii and comet assay) can act as indicators for the potential for ongoing damage. Ultimately, long-term effects might be evident in the prevalence of tissue damage and neoplastic disease, which can be assessed in a range of species through histopathological techniques (Martínez-Gómez et al., 2010).

2.10.5 Ecotoxicology in post-spill monitoring – other issues

2.10.5.1 An integrated approach

The use of ecotoxicological methods can provide an exceptionally strong input to post-incident monitoring and the assessment of impact. The breadth of methods and species that can be considered is wide and gives a level of flexibility within the programme. However, it is important that the choice of assays and approaches are relevant and that they contribute towards a fully integrated post-incident assessment (ICES, 2009). Results gained using biological methods are of much greater value if they can be interpreted in conjunction with chemical analyses taken at the same time and in the same site/specimen. Furthermore, the selection of methods will benefit from careful consideration of the ecology of the impacted region so that the results can be more usefully interpreted with reference to the particular ecosystem in question.

The choice of method and/or target species should also take account of socio-economic drivers. For example, consideration should be given to using sentinel species that represent important vectors in local fisheries or leisure activities so that the results can be used to provide information on the potential impact to these sectors also.

2.10.5.2 Temporal/spatial considerations

Any ecotoxicological assessments not only need to fit within an integrated assessment programme but also need to incorporate appropriate spatial and temporal coverage in their deployment. The fact that one cannot effectively predict exactly when and where a spill might occur means that good pre-incident data for the area are often not available. Good communications, predictive modelling and pre-planning for the deployment of the recommended baseline battery of methods may mean that samples can be promptly taken in an area before it is impacted, and any spatial sampling plans should take account of predictive modelling. However, it will often be the case that pre-incident data will not be available, and any assessment of impact will be reliant on sufficient spatial coverage and replication, with particular consideration given to representative control sites. The temporal aspect of the monitoring/sampling programme will vary depending on the extent of any impact and the potential for persistence and mobilisation of contaminants in the receiving environment. However, the importance of good sampling in the first days/weeks of any programme is paramount, and one of the primary aims of the PREMIAM project was to facilitate the prompt commencement of sampling activities. Ultimately, the spatial and temporal aspects of any sampling programme will depend on the incident in question; however, it is recommended that, wherever possible, the principles of sampling for biological effects monitoring as set out in the OSPAR JAMP (OSPAR, 2003) should be adhered to.

2.10.5.3 Confounding factors

Of particular importance in the use of biological effects biomarkers and assays is to have an appreciation of a range of confounding factors that can influence the data and their interpretation (Martínez-Gómez et al., 2010). For example, certain biomarkers (e.g. EROD) can be affected by the temperature that the species has been acclimated to, and this and other physical parameters can affect sentinel organism sensitivity and contaminant availability (Kirby et al., 1999). Therefore, in parallel with any water/sediment sampling or the collection of field biota samples, a record of physical parameters (e.g. temperature, salinity, pH etc.) must be taken to aid later interpretation of results.

Other factors such as size, gender and reproductive status can also have a substantial impact on biomarker response, so parameters such as length, weight, sex and gonad weight need to be recorded for all specimens of biota. Wherever possible, standardised sex and size classes should be sampled at all sites and sampling occasions to minimise the effect of variability on the results. For certain biomarkers (e.g. EROD) the status of sexual maturation can have a particularly large effect on biomarker levels (Kirby et al., 1999) and certain times of the year are not recommended for annual monitoring. However, for post-incident monitoring, one cannot choose the time of year and so the collection of these data is even more important. Again, wherever possible, the principles of sampling as set out in the OSPAR JAMP (OSPAR 1997, 2003) should be followed.

REFERENCES

Ariese, F., Beyer, J., Jonsson, G., Visa, C.P. and Krahn, M.M. 2005. Review of analytical methods for determining metabolites of polycyclic aromatic compounds (PACs) in fish bile. *ICES Techniques in Marine Environmental Sciences*, No. 39. 41pp. www.ices.dk/pubs/times/times39/TIMES39.pdf [accessed 31 December 2010].

Bocquené, G. and Galgani, F. 1998. Biological effects of contaminants: cholinesterase inhibition by organophosphate and carbamate compounds. *ICES Techniques in Marine Environmental Sciences*, No. 23. 12pp. www.ices.dk/pubs/times/times22/TIMES22.pdf [accessed 31 December 2010].

Brooks, S.J, Bolam, T., Tolhurst, L., Bassett, J., Roche, J.L., Waldock, M., Barry, J. and Thomas, K.V. 2008. Dissolved organic carbon reduces the toxicity of copper to germlings of the macroalgae, *Fucus vesiculosus. Ecotoxicology and Environmental Safety*, **70**: 88–98.

Chesworth, J.C., Donkin, M.E. and Brown, M.T. 2004. The interactive effects of the antifouling herbicides Irgarol 1051 and Diuron on the seagrass *Zostera marina* (L.). *Aquatic Toxicology*, **66**: 293–305.

Dicks, B. 1970. Some effects of Kuwait crude oil on the limpet, *Patella vulgata*. *Environmental Pollution*, **5**: 219–229.

ICES. 2009. *Report of the Joint ICES/OSPAR Study Group on Integrated Monitoring of Contaminants and Biological Effects (SGIMC).* ICES Document CM 2009/ACOM:30 Ref. OSPAR. www.ices.dk/reports/ACOM/2009/SGIMC/sgimc_2009.pdf [accessed 8 June 2011].

ISO. 1999. *ISO 14669:1999(E) Water quality: determination of acute lethal toxicity to marine copepods (Copepoda, Crustacea).* International Organization for Standardization, Geneva, Switzerland.

ISO. 2006. *ISO 14442:2006(E) Water quality: guidelines for algal growth inhibition tests with poorly soluble materials, volatile compounds, metals and waste water.* International Organization for Standardization, Geneva, Switzerland.

ISO. 2010. *ISO 10710:2010(E) Water quality: growth inhibition test with the marine and brackish water macroalga* Ceramium tenuicorne. International Organization for Standardization, Geneva, Switzerland.

Johansson-Sjobeck, M.-L. and Larsson, A. 1978. The effect of cadmium on the haematology and on the activity of δ-amino levulinic acid dehydratase (ALA-D) in blood and haemopoetic tissues of the flounder *Pleuronectes platessa* L. *Environmental Research*, **17**: 191–294.

Kingston, P.F. 2002. Long-term environmental impact of oil spills. *Spill Science & Technology Bulletin*, **7**: 53–61.

Kirby, M.F. and Law, R.J. 2010. Accidental spills at sea: risk, impact, mitigation and the need for co-ordinated post-incident monitoring. *Marine Pollution Bulletin*, **60**: 797–803.

Kirby, M.F., Devoy, B., Law, R.J., Ward, A. and Aldridge, J. 2008. The use of a bioassay based approach to the hazard/risk assessment of cargo derived toxicity during shipping accidents: a case study – The MSC Napoli. Marine Pollution Bulletin, 56: 781–786.

Kirby, M.F., Neall, P. and Tylor, T. 1999. EROD activity in flatfish from the area of the *Sea Empress* oil spill. *Chemosphere*, **38**: 2929–2949.

Kirby, M.F., Sheahan, D.A., Smith, A.J., Fisher, T. In preparation. Chemical spills at sea and the toxicity of high priority chemicals to keystone species: an approach for risk and impact assessment.

Legler, J., van den Brink, C.E., Brouwer, A., Murk, A.J., van der Saag, P.T., Vethaak, A.D. and van der Burg, B. 1999. Development of a stably transfected estrogen receptor-mediated luciferase reporter gene assay in the human T47D breast cancer cell line. *Toxicological Sciences*, **48**: 55–66.

Lima, D., Santos, M.M., Ferreira, A.M., Micaelo, C. and Reis-Henriques, M.A. 2008. The use of the shanny Lipophrys pholis for pollution monitoring: a new sentinel species for the northwestern European marine ecosystems. *Environment International*, **34**: 94–101. doi: 10.1016/j.envint.2007.07.07.

Maron, D. and Ames, B. 1983. Revised methods for the *Salmonella* mutagenicity test. *Mutation Research*, **113**: 173–215.

Martínez-Gómez, C., Vethaak, A.D., Hylland, K., Burgeot, T., Köhler, A., Lyons, B.P., Thain, J., Gubbins, M.J. and Davies, I.M. 2010. A guide to toxicity assessment and monitoring effects at lower levels of biological organization following marine oil spills in European waters. *ICES Journal of Marine Science*, **67**: 1105–1118.

Moore, M.N. and Lowe, D. 2004. Biological effects of contaminants: measurement of Lysosomal membrane stability. *ICES Techniques in Marine Environmental Sciences*, No. 36. 31pp. www.ices.dk/pubs/times/times36/TIMES36.pdf [accessed 31 December 2010].

Moreira, S., Santos, M., Cunha, I., Sousa, A., Lima, D., Coimbra, J., Reis-Henriques, M.A., Guilhermino, L. 2007. *EROCIPS Report for Task 7.3.5: environmental monitoring report*. www.erocips.org/reports_press_releases.htm [accessed 24 May 2010]. http://www.erocips.org/7.3_environmental_monitoring_report_erocips-2.pdf [accessed 14 January 2011].

Murk, A.J., Legler, J., Denison, M.S., Giesy, J.P., van de Guchte, C. and Brouwer, A. 1996. Chemical-activated luciferase gene expression (CALUX): a novel in vitro bioassay for Ah receptor active compounds in sediments and pore water. *Fundamental and Applied Toxicology*, **33**: 149–160.

Oda, Y., Nakamura, S., Oki, I., Kato, T. and Shinagawa, H. 1985. Evaluation of the new system (umu-test) for the detection of environmental mutagens and carcinogens. *Mutation Research*, **147**: 219–229.

OSPAR. 1997. Guidelines for general biological effects monitoring. Oslo and Paris Commissions, London, UK. Ref. 1997–7.

OSPAR. 2003. Guidelines for contaminant specific biological effects monitoring. Oslo and Paris Commissions, London, UK. Ref. 2003–10.

Routledge, E.J. and Sumpter, J.P. 1996. Estrogenic activity of surfactants and some of their degradation products assessed using a recombinant yeast screen. *Environmental Toxicology and Chemistry*, **15**: 241–248.

Santos, M.M., Solé, M., Lima, D., Hambach, B., Ferreira, A.M. and Reis-Henriques, M.A. 2010. Validating a multi-biomarker approach with the shanny *Lipophrys pholis* to monitor oil spills in European marine ecosystems. *Chemosphere*, **81**: 685–691.

Smith, A.J., Balaam, J.L. and Ward, A. 2007. The development of a rapid screening technique to measure antibiotic activity in effluents and surface water samples. *Marine Pollution Bulletin*, **54**: 1940–1946.

Sohoni, P. and Sumpter, J.P. 1998. Several environmental oestrogens are also anti-androgens. *Journal of Endocrinology*, **158**: 327–339.

Stagg, R. and McIntosh, A. 1998. Biological effects of contaminants: determination of CYP1A-dependent mono-o xygenase activity in dab by fluorimetric measurement of EROD activity. *ICES Techniques in Marine Environmental Sciences*, No. 23. 16pp. www.ices.dk/pubs/times/times23/TIMES23.pdf [accessed 31 December 2010].

Thain, J. 1991. Biological effects of contaminants: oyster (*Crassostrea gigas*) embryo bioassay. *ICES Techniques in Marine Environmental Sciences*, No. 11. 12pp. www.ices.dk/pubs/times/times11/TIMES11.pdf [accessed 31 December 2010].

Thain, J. and Bifield, S. 2001. Biological effects of contaminants: sediment bioassay using the polychaete *Arenicola marina*. *ICES Techniques in Marine Environmental Sciences*, No. 29. 16pp. www.ices.dk/pubs/times/times29/TIMES29.pdf [accessed 31 December 2010].

Thain, J. and Roddie, B. 2001. Biological effects of contaminants: *Corophium* sp. sediment bioassay and toxicity test. *ICES Techniques in Marine Environmental Sciences*, No. 28. 21pp.

Venosa, A.D., Campo, P. and Suidan, M.T. 2010. Biodegradability of lingering crude oil 19 years after the *Exxon Valdez* oil spill. *Environmental Science and Technology*, **44**: 7613–7621.

Viarengo, A., Ponzano, E., Dondero, F. and Fabbri, F. 1997. A simple spectrophotometric method for metallothionein evaluation in marine organisms: an application to Mediterranean and Antarctic molluscs. *Marine Environmental Research*, **44**: 69–84.

Wheeler, A. 1969. *The fishes of the British Isles and North-West Europe*. Macmillan and Co. Ltd., London, UK. 613pp.

Widdows, J. and Staff, F. 2006. Biological effects of contaminants: measurement of scope for growth in mussels. *ICES Techniques in Marine Environmental Sciences*, no 40. 30pp. www.ices.dk/pubs/times/times40/TIMES40.pdf [accessed 31 December 2010].

2.11 TAINT-TESTING

The use of a trained taste panel to assess taints due to oil has often been used after oil spill incidents and may also be applicable for some chemicals. During the *Braer* and *Sea Empress* incidents, for example, taste-testing was used as a component of the management of the fisheries closures. In the former case, taste-testing was used extensively; in the latter case, when PAH concentrations had returned to background, representative samples of fish or shellfish were taste-tested as a final proof that the fishery sector could be reopened. Trained taste panels are expensive and time-consuming to maintain, as the trained status must be maintained over time if the panel is to be effective. Within the UK, there is now only one trained taste panel, at the Marine Scotland Science marine laboratory in Aberdeen, Scotland. More information regarding the use of taste-testing during the *Braer* spill can be found in Whittle *et al.* (1997). A detailed outline of tainting due to chemical contamination and its assessment is given by Howgate (1999) and guidance on sensory testing of seafood following oil spills by Reilly and York (2001).

REFERENCES

Howgate, P. 1999. Tainting of food by chemical contaminants. In: Envir*onmental contaminants in food* (Moffat, Cf. and Whittle, K.J., eds.). Academic Press/CRC Press, Sheffield, UK. ISBN 0-8493-9735-9.

Reilly, T.I. and York, R.K. 2001. Guidance on sensory testing and monitoring of seafood for presence of petroleum taint following an oil spill. NOAA Technical memorandum NOS OR&R 9. NOAA, Seattle, WA, USA. http://response.restoration.noaa.gov/book_shelf/964_seafood.pdf [accessed 27 May 2010].

Whittle, K.J., Anderson, D.A., Mackie, P.R., Moffat, Cf., Shepherd, N.J., McVicar, A.H. 1997. The impact of the *Braer* oil on caged salmon. In: *The impact of an oil spill in turbulent waters: the Braer* (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

2.12 AFFECTED BIRDS

Birds affected by oil or chemicals can be divided into those that are alive and require rehabilitation if thought appropriate, and those that are dead and need to be stored for possible future necropsy and/or other studies. Statistics on oiled birds also feed into any overall impact assessment of an incident, including an assessment of the rate of post-release survival of rehabilitated birds. Such rehabilitation of affected birds has often been conducted following oil spills, but not following HNS spills, although there is no reason to think that this could not happen. In 2006, Nijkamp reviewed the current arrangements in Europe for the Interspill 2006 Conference in London (Nijkamp, 2006), and noted that few response plans include information on dealing with oiled birds, mammals and reptiles. Because of this, the rescue and rehabilitation of such animals is usually left to local wildlife groups that are not integrated into the main response organisation and lack the training and resources to mount a fully effective operation. Nijkamp also recognised that making oiled wildlife response more professional presented an international challenge to key stakeholders, including governments, wildlife responders and the oil, shipping and response industries. Since 2000, the Sea Alarm Foundation has taken a number of initiatives to this end. An increasing number of European governments are starting to develop preparedness for oiled wildlife incidents both at national level and through the European Regional Agreements. An active network of oiled wildlife responders has now been established across Europe, consisting of coastal rehabilitation groups, veterinarians, scientists, universities and national NGOs (formerly known as EMPOWER). At a global level, an international group of oiled wildlife Responders provides a platform for exchange of expertise and experience and the development of practical standards and guidelines. Guidelines for oiled wildlife response planning and good practices in wildlife rehabilitation have also been published (Camphuysen *et al.*, 2007; IPIECA, 2004; Nijkamp, 2007). For further information see www.sea-alarm.org/ and www.oiledwildlife.eu

In the most recent significant UK incident, the grounding of the container ship *MSC Napoli* in Lyme Bay in 2007, analysis of affected seabirds formed part of the environmental impact assessment (Law, 2008). The BTO has provided a list of the key considerations when collecting dead and live birds, and these are given as information in Appendix 7.

The rehabilitation of wildlife is a specialised area and should be undertaken by specialists. The Royal Society for the Prevention of Cruelty to Animals is currently developing guidance to stand alongside the National Contingency Plan. The RSPCA has five regions for England and Wales: East, North, South East, South and South West and Wales and West. In the event of an incident, the RSPCA region in which the incident occurs will assess whether or not they have the capability to manage the incident without help from other regions. If the region identifies the incident as larger than they can cope with then the response will be escalated to a national one. This information will be fed into the SEG network during 2011. The RSPCA wish to be more proactive than in the past and to form more formal relationships with the regional SEGs. The RSPCA can be contacted by e-mail at wildlife@rspca.org.uk.

In Northern Ireland and Scotland, similar issues are addressed by the Ulster Society for the Prevention of Cruelty to Animals and the Scottish Society for the Prevention of Cruelty to Animals, respectively.

REFERENCES

Camphuysen, C.J., Bao, R., Nijkamp, H. and Heubeck, M. (eds.). 2007, *Handbook on oil impact assessment*. Royal Netherlands Institute for Sea Research, Texel, The Netherlands. www.oiledwildlife.eu

IPIECA. 2004. *A guide to oiled wildlife response planning.* IPIECA Report Series, Volume 13. International Petroleum Industry Environmental Conservation Association, London, UK. 52pp. http://www.ipieca.org/publication/guide-oiled-wildlife-response-planning [accessed 24 May 2010].

Law, R. 2008. Environmental monitoring conducted in Lyme Bay following the grounding of *MSC Napoli* in January 2007, with an assessment of impact. Science Series, Aquatic Environment Monitoring Report No. 61, Cefas, Lowestoft, UK. 36pp.
www.Cefas.co.uk/publications/aquatic/aemr61.pdf [accessed 26 May 2010].

Nijkamp, H. (ed.). 2007. *Handbook on good practice for the rehabilitation of oiled birds in the aftermath of an oil spill incident*. Sea Alarm Foundation, Brussels, Belgium. 28pp.
http://www.oiledwildlife.eu/sites/default/files/Rehabilitation%20of%20Oiled%20Birds%20in%20the%20aftermath%20of%20an%20Oil%20Spill%20Incident%20-Handbook-2007_1.pdf [accessed 4 November 2011].

Nijkamp, H. 2006. Preparedness and response to oiled wildlife incidents in Europe.
http://www.interspill.org/previous-events/2006/pdf/wildlife_preparedness_doc.pdf
[accessed 4 November 2011].

2.13 QUALITY CONTROL CONSIDERATIONS

Whether data are derived from chemical analysis, biological effects techniques, ecological surveys or other sources, aspects of quality control need to be incorporated into their collection and processing methodologies. In order for any assessments of environmental impact which are made to be robust, data used must be “fit for purpose”. Accreditation confirms that laboratories have a process in place for assuring the quality of information that they produce, although the methods to be used should still be checked for adequate sensitivity. Routine participation in performance testing schemes intercomparison programmes can usefully supplement the laboratory’s own in-house quality control procedures as a means of ensuring quality.

Data generation as part of a post-spill monitoring programme should be conducted under the auspices of appropriate quality control and accreditation wherever possible. However, it is also recognised that the collection of data during emergency response scenarios is more difficult to control than under routine monitoring programmes. Therefore, all sources of potential data, including opportunistic samples, information from non-standard or unvalidated methods or from studies conducted without accreditation or sufficient QC in place should not be discarded out of hand. They can all be assessed as part of a weight of evidence element to any impact assessment, providing that some reassurance can be given regarding proficiency of staff and validation of the method.

The National Marine Biological Analytical Quality Control group have published an approach to quality assurance in marine biological monitoring (Addison, 2010) which is available at http://www.nmbaqcs.org/media/5358/quality%20assurance%20in%20marine%20biological%20monitoring_jan10.pdf accessed 31 March 2011.

REFERENCE

Addison, P. 2010. *Quality assurance in marine biological monitoring*. A report prepared for the Healthy and Biologically Diverse Seas Evidence Group and the National Marine Biological Analytical Quality Control scheme. Environment Agency/Joint Nature Conservation Committee, January 2010. 8pp.

2.13.1 Quality assurance/quality-control procedures

Personnel experience, qualifications and training – all persons involved in the technical aspects of the assessment work must be sufficiently experienced in the type of work involved (or be sufficiently supervised by someone with the experience) and have received adequate training in the relevant methodology and protocols. Qualifications and accreditations will be appropriate for some roles. Technical aspects for which experience, qualifications and training may be necessary will include (but may not be limited to):

- Designing and planning assessment studies, sampling programmes, survey and monitoring programmes, sample analysis and all associated logistics
- Operation of specialist equipment and vehicles/vessels (including sampling devices, GPS, computer software, surveying and photographic equipment, chemical and sediment analytical equipment, other laboratory equipment)
- Identification of animals and plants to agreed taxonomic standards, *in situ* and/or in laboratory
- Analysis of data using appropriate tests, techniques and software
- Interpretation of results with reference to previous knowledge and literature

Sample collection – detailed written protocols of all aspects of the sample collection should be prepared in advance and used by the sampling staff to ensure accuracy and consistency. Any modifications to the protocols should be documented and dated. Accuracy of position fixing is essential, so quality-control procedures for checking position and reliable recording must be applied. Duplication of samples for analysis by independent laboratories will be appropriate in many situations.

Samples – each type of sample will have its own requirements for handling, preservation and storage. These requirements must be applied rigorously. It is advisable to label samples *in situ*. Relevant information could include sample number, date and time, site name, lat./long. position, location details, habitat details, substratum characteristics, depth below surface, sampled material, species, name(s) of surveyors, visible contamination. Each sample should be assigned a unique code that links it with its metadata.

Chain of custody – If samples will potentially be used in support of legal proceedings, chain-of-custody procedures should also be followed in handling, storing and transferring samples to and from laboratory facilities. Multiple samples – individually sealed, labelled, signed and stored – may be necessary if it is possible that analysis results could be contested.

In situ recording – detailed written protocols should be prepared, and quality-control procedures for position fixing applied (as Sample collection above). Repeat recording and data checks by other surveyors should also be applied to a proportion (e.g. 5%, randomly selected) of records. Field data, photographs and other records must be held safe from loss or damage.

Laboratory analysis of samples – laboratories should be accredited under appropriate schemes. Analyses should be carried out to the relevant standards for the type of samples. A proportion of the samples (e.g. 5%, randomly selected) should be re-analysed to check consistency. For biological community studies, a reference collection of voucher specimens should be prepared and maintained.

Data management – procedures for checking accuracy and completeness of data entry into spreadsheets and databases should be applied. Reliable data backups are essential and should be updated frequently during course of study. Ultimate storage of data must be in file formats that will remain accessible (future-proof), with appropriate metadata. Data standards are prescribed by the Marine Environmental Data and Information Network (MEDIN) and are available at: www.oceannet.org/marine_data_standards/other_marine_data_standards/index.html accessed 11 March 2011.

A summary of WFD data requirements to be used in the assessment of marine invertebrate communities has been produced by the EA, and this is included as appendix 8. In the event of an incident in coastal and transitional waters as defined under WFD, it is likely that WFD-compliant data will need to be collected in order for the impact to be assessed.

2.13.2 Acceptance criteria for PREMIAM database service providers

A large part of the work being carried out under the PREMIAM project is preparedness in the case of an incident. To this end, a database has been compiled that contains details of prospective suppliers of services such as vessels, sampling personnel and analysis. Only suppliers who can demonstrate the quality procedures in place will be accepted onto the database. This may be in the form of accreditation, performance testing or in-house quality and safety systems.

Table 4 shows the minimum requirements expected of service providers held on the PREMIAM database. All laboratories should have a quality manual that is adhered to at all times during sampling, storage and analysis of samples. For some services, further requirements are expected. For example, all boats being used must be registered with the relevant authority relevant to their size and use classification.

Where available, techniques should be conducted to internationally accepted standards and protocols. Preference should be given to suppliers who can demonstrate that they have excellent quality-control and quality assurance procedures in place for specific techniques (e.g. GLP accredited or the use of UKAS accredited techniques). Further evidence of quality control could be provided by participation in and adherence to the principles of quality-control proficiency testing schemes such QUASIMEME (Quality Assurance of Information for Marine Environmental Monitoring in Europe www.quasimeme.org), BEQUALM (Biological Effects Quality Assurance in Monitoring Programmes, www.bequalm.org) and NMBAQC (National Marine Biological Association Quality Control, www.nmbaqcs.org). Individuals may also be accredited – for example, in the case of marine mammals, JNCC offer accreditation as an approved observer. Suppliers will be expected to confirm that they adhere to these standards before being approved suppliers for post-spill monitoring.

Table 4

Minimum requirements expected of service providers held on the PREMIAM database

SERVICE	SUB-SERVICE	QUALITY/SAFETY SYSTEM
Sampling		quality manual, standard protocols
Storage	controlled temperature	loggers
Transport	RIB or small vessel	small commercial vessel certificate
	research/survey vessel	MMSI
	fishing vessel	seafish inspection/MCA safety inspection
Surveys	saltmarsh	quality manual, standard protocols
	intertidal ecol	quality manual, standard protocols
	benthic ecol	NMBAQC proficiency tests/ISO 16665:2005
	plankton survey	UKAS
	fish and shellfish	
	sea birds	JNCC accredited seabird observer
	wetland birds	
	marine mammals	JNCC accredited marine mammal observer
	aerial imagery	quality manual
	Shoreline clean-up (SCAT)	training. UK guidelines
Analytical Chemistry		UKAS/proficiency testing (QUASIMEME)
Ecotox		GLP/DTAPS/BEQUALM
Modelling		quality manual

2.14 IMPACTS ON HUMAN HEALTH

In the MCA STOp notice relating to the establishment and operation of Environment Groups (EGs) during incidents (Maritime and Coastguard Agency, 2009), there is a requirement to provide advice regarding risks to public health as well as to the environment. This is in addition to ensuring full implementation of health and safety measures for personnel working in the field on their behalf, and it addresses potential risks to the wider population. Key tasks for the EG in this regard are to:

- Provide advice on potential and real impacts on public health with respect to oil and chemicals
- Advise on requirements for monitoring of threat to public health.

If required the Environment Group membership can be augmented with those individuals with relevant expertise. Extended membership may include:

- The Centre for Radiation, Chemical and Environmental Hazards within the Health Protection Agency www.hpa.org.uk/AboutTheHPA/WhoWeAre/CentreForRadiationChemicalAndEnvironmentalHazards/

- Local authority Environmental Health departments
- Public Health Services
- Local Health Boards
- Occupational Health advisor
- Food Standards Agency (www.food.gov.uk/)
- Chemical Hazards Advisory Group (convened by the Maritime and Coastguard Agency)
- The National Chemical Emergency Centre (at AEA Technology, http://the-ncec.com/)

In any large marine chemical incident affecting land areas, it is likely that a Strategic Coordinating Group (Gold/Silver Command) would be formed by the police to deal with onshore and inland issues. The Strategic Coordinating Group may also feel it necessary to establish a Science and Technical Advice Cell (STAC) under Civil Contingencies arrangements. To avoid duplication or the provision of conflicting advice, close liaison should be established between the EG and the STAC. The STAC can request the initiation of an air quality cell, which comprises mobile monitoring facilities operated by the EA, to obtain data on airborne pollutants rapidly. STAC can also provide assistance regarding risk assessment for airborne and shoreline contaminants, including exposure standards, personal protective equipment, medical and evacuation advice, decontamination and disposal of waste. In addition to incidents involving volatile chemicals, there will also be a need to carry out monitoring and/or transport and fate modelling for any incidents involving fire, in view of the potential for particulates and combustion products to be formed and to migrate. Basic modelling is usually provided in the form of CHEMETs issued by the Met Office. A CHEMET provides information on plume direction and dispersion in the form of a map image, based upon prevailing atmospheric and meteorological conditions. It does not, however, model pollutant concentrations within the plume. A CHEMET can be used to model plumes from volatile chemicals as well as plumes from combustion events. A CHEMET can be requested by fire and police services or by HPA, EA and other relevant advisors.

In some chemical incidents, in which plumes of volatile chemicals have been atmospherically transported towards populated areas, monitoring and/or modelling of aerial concentrations has been undertaken (for an example in which both were included, see Welch et al., 1999). In the case of the sinking of the chemical tanker *Ievoli Sun* in the English Channel in 2000, monitoring of styrene concentrations in ambient air was undertaken on the Channel Island of Alderney (Law et al., 2003). Depending upon the scale and type of incident, short- or longer term health surveillance (for responders and/or members of the general public) and social impact assessment may also be necessary. Examples of incidents in which these have been undertaken include the *Sea Empress* incident in Wales in 1996 (Lyons et al., 1999), the *Braer* incident in Shetland in 1993 (Campbell et al., 1993, 1994; Cole et al., 1997; Foster et al., 1995; Hall, 1997), the *Prestige* incident in Spain in 2002 (Kostrzewa et al., 2005; Laffon et al., 2006; Pérez-Cadahía et al., 2007, 2008), the *Erika* incident in France in 1999 (Baars, 2002; Dor et al., 2003), the *Exxon Valdez* incident in Alaska in 1989 (Arata et al., 2000; Picou and Gill, 1996, 2000; Picou et al., 2009; Russell et al., 1996), the *Nakhodka* incident in Japan in 1997 (Morita et al., 1999) and the *Hebei Spirit* incident in Korea in 2007 (Lee et al, 2010; Sim et al., 2010). Post-spill monitoring activities undertaken following a number of incidents have been reviewed (Aguilera et al., 2010), and health impacts of the *Deepwater Horizon* oil spill in the Gulf of Mexico have also been considered recently (Solomon and Janssen, 2010). Very recently (in May 2011), the US National Institute of Environmental Health Sciences has launched a major study on the health consequences of the clean-up of the *Deepwater Horizon* spill (Schmidt, 2011). The GuLF STUDY aims to enrol 55,000 subjects, including workers and volunteers involved in the clean-up, and 5,000 control subjects. Funding is currently for five years, but the study design is such that it can be extended to 20 years if further funding is available.

REFERENCES

Aguilera, F., Méndez, J., Pásaro, E. and Laffon, B. 2010. Review on the effects of exposure to spilled oil on human health. *Journal of Applied Toxicology*, **30**: 291–301.

Arata, C.M., Picou, J.S., Johnson, G.D. and McNally, T.S. 2000. Coping with technological disaster: an application of the conservation of resources model to the *Exxon Valdez* oil spill. *Journal of Traumatic Stress*, 13: 23–39. http://stevenpicou.com/pdfs/coping-with-technological-disasters.pdf [accessed 23 September 2010].

Baars, B.-J. 2002. The wreckage of the oil tanker "*Erika*": human health risk assessment of beach cleaning, sunbathing and swimming. *Toxicology Letters*, 128: 55–68.

Campbell, D., Cox, D., Crum, J., Foster, K. and Riley, A. 1994. Later effects of grounding of tanker *Braer* on health in Shetland. *British Medical Journal*, **309**: 773–774.

Campbell, D., Cox, D., Crum, J., Foster, K., Christie, P. and Brewster, D. 1993. Initial effects of the grounding of the tanker *Braer* on health in Shetland. *British Medical Journal*, **307**: 1251–1255.

Cole, J., Beare, D.M., Waugh, A.P.W., Capulas, E., Aldridge, K.E., Arlett, Cf., Green, M.H.L., Crum, J.E., Cox, D., Garner, R.C., Dingley, K.H., Martin, E.A., Podmore, K., Heydon, R. and Farmer, P.B. 1997. Biomonitoring of possible human exposure to environmental genotoxic chemicals: lessons from a study following the wreck of the oil tanker *Braer*. *Environmental and Molecular Mutagenesis*, **30**: 97–111.

Dor, F., Bonnard, R., Gourier-Fréry, C., Cicolella, A., Dujardin, R. and Zmirou, D. 2003. Health risk assessment after decontamination of the beaches polluted by the wrecked *Erika* tanker. *Risk Analysis*, 23: 1199–1208.

Foster, K., Campbell, D., Crum, J. and Stove, M. 1995. Non-response in a population study after an environmental disaster. *Public Health*, **109**: 267–273.

Hall, M. 1997. *The Braer*: environmental health problems associated with the spill. In: *The impact of an oil spill in turbulent waters:* the Braer (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Kostrzewa, A., Moty-Monnereau, C., Ramaroson, H., Harrabi, I., Viance, P., Delarche, C., Bourbigfot, J.F., Dalm, C. and Brochard, P. 2005. Naufrage du *Prestige*: un exemple d'étude épidémiologique impliquant les médecins du travail et de prevention. *Archives des Maladies Professionelles et de l'Environnement*, **66**: 210–218.

Laffon, B., Fraga-Iriso, B., Pérez-Cadahía, B. and Méndez, J. 2006. Genotoxicity associated to exposure to Prestige oil during autopsies and cleaning of oil-contaminated birds. *Food and Chemical Toxicology*, **44**: 1714–1723.

Law, R.J., Kelly, C., Matthiessen, P. and Aldridge, J. 2003. The loss of the chemical tanker *Ievoli Sun* in the English Channel, October 2000. *Marine Pollution Bulletin*, **46**: 254–257.

Lee, C.-H., Kang, Y.-A., Chang, K.-J., Kim, C.-H., Hur, J.-I., Kim, J.-Y. and Lee, J.-K. 2010. Acute health effects of the *Hebei* oil spill on the residents of Taean, Korea. *Journal of Preventive Medicine and Public Health*, **43**: 166–173.

Lyons, R.A., Temple, J.M.F., Evans, D., Fone, D.L. and Palmer, S.R. 1999. *Acute effects of the* Sea Empress *oil spill. Journal of Epidemiology and Community Health*, **53**: 306–310.

Maritime and Coastguard Agency. 2009. Scientific, Technical and Operational Advice Note: STOp 2/2009. Maritime Pollution Response in the UK: The Environment Group. www.mcga.gov.uk/c4mca/stop_2_09_eg_july_2009.pdf [accessed 23 September 2010].

Morita, A., Kusaka, Y., Deguchi, Y., Moriuchi, A., Nakanaga, Y., Iki, M., Miyazaki, S. and Kawahara, K. 1999. Acute health problems among the people engaged in the cleanup of *Nakhodka* oil spill. *Environmental Research*, **81**: 185–194.

Pérez-Cadahía, B., Laffon, B., Valdiglesias, V., Pásaro, E. and Méndez, J. 2008. Cytogenetic effects induced by *Prestige* oil on human populations: the role of polymorphisms in genes involved in metabolism and DNA repair. *Mutation Research*, **653**: 117–123.

Pérez-Cadahía, B., Lafuente, A., Cabaleiro, T., Pásaro, E., Méndez, J. and Laffon, B. 2007. Initial study on the effects of *Prestige* oil on human health. *Environment International*, **33**: 176–185.

Picou, J.S. and Gill, D.A. 1996. The *Exxon Valdez* oil spill and chronic psychological stress. *American Fisheries Society Symposium*, **18**: 879–893. www.jomiller.com/exxonvaldez/articles/picougill2.html [accessed 24 September 2010].

Picou, J.S. and Gill, D.A. 2000. The *Exxon Valdez* disaster as localized environmental catastrophe: dis(similarities) to risk society theory. In: *Risk in the modern age: social theory, science and environmental decision-making*, pp. 143–170 (Cohen, M.J., ed.). Palgrave Macmillan Publishers. ISBN10: 0-312-22216-5. ISBN13: 978-0-312-2216-5. http://stevenpicou.com/pdfs/picou-and-gill%202000_risk-society-theory.pdf [accessed 23 September 2010].

Picou, J.S., Formichella, C., Marshall, B.K. and Arata, C. 2009. Community impacts of the *Exxon Valdez* oil spill: a synthesis and elaboration of social science research. In: *Synthesis: three decades of research on socioeconomic effects related to offshore petroleum development in coastal Alaska* (Braund, S.R. and Kruse, J., eds.) Minerals Management Service report MMS OCS study number 2009–006; Contract number 1435–01–98-CT-30914. http://stevenpicou.com/pdfs/community-impacts-of-the-exxon-valdez-oil-spill.pdf [accessed 23 September 2010].

Russell, J.C., Downs, M.A., Petterson, J.S. and Palinkas, L.A. 1996. Psychological and social impacts of the *Exxon Valdez* oil spill and cleanup. *American Fisheries Society Symposium*, **18**: 867–878.

Schmidt, C.W. 2011. Study to examine health effects in *Deepwater Horizon* oil spill cleanup workers. *Environmental Health Perspectives* **119**, a204-a204. doi: 10.1289/ehp.119-a204.

Sim, M.S., Jo, I.J. and Song, G. 2010. Acute health effects related to the operation mounted to clean the *Hebei Spirit* oil spill in Taean, Korea. *Marine Pollution Bulletin*, **60**: 51–57.

Solomon, G.M. and Janssen, S. 2010. Health effects of the Gulf oil spill. *Journal of the American Medical Association*, **304**: 118–119. doi: 10.1001/jama.2010.1254.

Welch, F., Murray, V.S.G., Robins, A.G., Derwent, R.G., Ryall, D.B., Williams, M.L. and Elliott, A.J. 1999. Analysis of a petrol plume over England: 18–19 January 1997. *Occupational and Environmental Medicine*, **56**: 649–656.

2.15 WHEN TO STOP MONITORING

Unlike many traditional monitoring programmes, such as the UK Clean Seas Environment Monitoring Programme (CSEMP) or the US National Status and Trends Program, post-incident monitoring programmes are not generally open-ended, although in some cases long-term impacts may be studied. Rather, there is an expectation that they will run for a finite time and then cease, at which time an impact assessment can be made. Also, there is no reason why all elements of the programmes should begin and end at the same time, as the speed of environmental recovery will vary across habitats, species, areas with varying degrees of impact, and many other variables. Ideally, the end-point for each programme element should be set at the start of the programme, so that it is clear when that has been reached and monitoring activities can cease. For PAH in commercial shellfish following an oil spill, for example, "return to background concentrations" is a common example. There is often a widespread assumption that spilled oil or chemicals are entering a pristine environment, previously uncontaminated, and that concentrations should return to zero. In the UK this is never the case for PAH and, depending on the location and its degree of remoteness from industry and urban areas, seldom so for some chemicals frequently carried by sea or discharged to estuaries and coastal waters. As noted elsewhere in this document, there are also natural cycles linked to spawning which can influence concentrations of PAH (and other lipophilic contaminants) in shellfish tissues on a seasonal basis. There is, therefore, a need to establish the pre-existing levels of contamination prior to the incident. In an ideal situation, there will be monitoring data available to use as a baseline. If not, then this can be estimated by:

- Collecting and analysing samples taken from impacted areas prior to the arrival of the spilled oil or chemicals
- Collecting and analysing samples taken from outside the impacted areas but in areas thought to have been contaminated to a similar degree before the incident.

The situation is very similar for biological effects techniques that may be relevant for use following oil and/or chemical spills. Background levels of biomarker response may not be zero, either because there is a pre-existing level of exposure to compounds which are detectable by the technique, or because other environmental or physiological processes affect it (Lyons et al., 2010; Martínez-Gómez et al., 2010). For a number of techniques, a study group within the International Council for the Exploration of the Sea (ICES, 2009) has identified a series of response ranges that can be used as assessment criteria. These ranges represent a background response range, an elevated response range, and a range representing a high level of response and so giving cause for concern (Lyons et al., 2010). In this instance, monitoring should be discontinued when values derived from relevant biological effects techniques are either within the background response range, or within an elevated response range typical of the affected area prior to the incident being studied. An example of an integrated chemical and biological effects monitoring study is given by Morales-Caselles *et al.* (2009), undertaken in the wake of the *Prestige* oil spill off Spain in 2002. In addition, ICES has recently completed the provision of advice to OSPAR on integrated chemical and biological effects monitoring, which reflects the current state of the art (available at www.ices.dk/committee/acom/comwork/report/2011/Special%20Requests/OSPAR%20Guidance%20on%20integrated%20monitoring.pdf accessed 8 June 2011.

This advice was based upon the work of the joint ICES/OSPAR Study Group on Integrated Monitoring of Contaminants and Biological Effects (ICES, 2011).

The aim of ecological monitoring is to follow the progress of biological recovery from the effects of the spill, particularly in species of particular sensitivity or of local nature conservation importance. A definition of recovery was given by IPIECA (1991):

"Recovery is marked by the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and are functioning normally"

So, once achieved, this would represent the point at which monitoring should cease.

As noted by IPIECA, there are two important caveats that go along with the definition:

- The re-established healthy community may not have exactly the same composition or age structure as that which was present before the spill.
- It is impossible to say whether an ecosystem that has recovered from a spill is the same as, or different from, that which would have persisted in the absence of the spill.

Both of these points arise from the fact that ecosystems are naturally in a constant state of flux, even in the absence of spilled oil or chemicals.

REFERENCES

ICES. 2009. *Report of the Joint ICES/OSPAR Study Group on Integrated Monitoring of Contaminants and Biological Effects (SGIMC).* ICES Document CM 2009/ACOM:30 Ref. OSPAR. www.ices.dk/reports/ACOM/2009/SGIMC/sgimc_2009.pdf [accessed 8 June 2011].

ICES. 2011. *Report of the Study Group on Integrated Monitoring of Contaminants and Biological Effects (SGIMC).* ICES Document CM 2011/ACOM:30. Ref. ACOM, OSPAR. www.ices.dk/reports/ACOM/2011/SGIMC/sgimc_2011_final.pdf [accessed 8 June 2011].

IPIECA. 1991. *Guidelines on biological impacts of oil pollution*. IPIECA Report Series, Volume 1. International Petroleum Industry Environmental Conservation Association, London, UK. 15pp. www.ipieca.org/system/files/publications/Vol1_BioImpacts.pdf [accessed 2 July 2010].

Lyons, B.P., Thain, J.E., Stentiford, G.D., Hylland, K., Davies, I.M. and Vethaak, A.D. 2010. Using biological effects tools to define Good Environmental Status under the European Union Marine Strategy Framework Directive. *Marine Pollution Bulletin*, **60**: 1647–1651.

Martínez-Gómez, C., Vethaak, A.D., Hylland, K., Burgeot, T., Köhler, A., Lyons, B.P., Thain, J., Gubbins, M.J. and Davies, I.M. 2010. A guide to toxicity assessment and monitoring effects at lower levels of biological organization following marine oil spills in European waters. *ICES Journal of Marine Science*, **67**: 1105–1118.

Morales-Caselles, C., Riba, I. and Ángel DelValls, T. 2009. A weight of evidence approach for quality assessment of sediments impacted by an oil spill: the role of a set of biomarkers as a line of evidence. *Marine Environmental Research*, **67**: 31–37.

2.16 COMPENSATION FOR OIL SPILL DAMAGE

The rules for oil spill compensation under the International Conventions on liability and compensation for oil pollution damage are clearly spelt out in the convention texts and are summarised in two publications available on the web (IOPC, 2008; IPIECA, 2007). In the case of post-spill environmental impact assessment and monitoring studies, it is possible that some of the work undertaken will not be eligible. Monitoring that is undertaken in order to support and manage a fisheries closure would qualify as it is directly linked to incident response. The publications mentioned above give detailed information on the way in which the compensation regime works, and on the submission and assessment of claims received by the IOPC, which is based in London.

REFERENCES

IOPC. 2008. *Claims manual*. IOPC, London. 38 pp. http://www.iopcfund.org/npdf/2008%20claims%20manual_e.pdf [accessed 25 June 2010].

IPIECA. 2007. *Oil spill compensation: a guide to the international conventions on liability and oil pollution damage*. International Petroleum Industry Environmental Conservation Assocation, London. 22 pp. http://www.ipieca.org/system/files/publications/Compensation_1.pdf [accessed 25 June 2010].

2.17 THE ENVIRONMENTAL DAMAGE REGULATIONS

The Environmental Damage (Prevention and Remediation) Regulations 2009 came into force on 1 March 2009 in England, and implemented Directive 2004/35/EC on Environmental Liability with Regard to the Preventing and Remedying of Environmental Damage. Amended Regulations came into force on 12 January 2010. Similar legislation has been enacted in Northern Ireland (into force 24 July 2009), Scotland (into force 24 June 2009) and Wales (into force 6 May 2009). They are based on the "polluter pays" principle, so those responsible prevent and remediate environmental damage rather than the taxpayer paying. "Environmental damage" has a specific meaning in the regulations, covering only the most serious cases. Existing legislation with provisions for environmental liability remains in place.

The regulations require the operator of a public or private economic activity that is causing, or has caused, environmental damage (as defined under the regulations) to prevent further damage occurring and/or to take remediation action in respect of the damage that has occurred. The regulations define environmental damage to biodiversity as damage to the **favourable conservation status** of a **European protected species** or **habitat**, or **damage to the integrity of a Site of Special Scientific Interest (SSSI)**. There are a considerable number of SSSIs in the marine environment – for examples of the largest sites in England (larger than 100 hectares (or 1 km^2), see the list at http://en.wikipedia.org/wiki/List_of_the_largest_Sites_of_Special_Scientific_Interest_in_England [accessed 6 August 2010].

Environmental damage also includes adverse effects on surface water or groundwater consistent with a deterioration in the water's status (i.e. under WFD).

The regulations do not apply in relation to environmental damage caused by an incident in respect of which liability or compensation falls within the scope of (i) the International Convention of 27 November 1992 on Civil Liability for Oil Pollution Damage; (ii) the International Convention of 27 November 1992 on the Establishment of an International Fund for Compensation for Oil Pollution Damage; or (iii) the International Convention on Civil Liability for Bunker Oil Pollution Damage 2001.

The enforcing authorities/competent authorities for this legislation are:

The Environment Agency (EA) (in England and Wales) for:

Damage caused by operations regulated by the EA under the Environmental Permitting Regulations.

Damage to EU species and habitats in the sea caused by operations regulated by the EA.

Damage to water caused by activities regulated by Local Authorities under the Environmental Permitting Regulations (*enforcing remediation requirements in Part 3 of the Regulations only*).

Damage caused by other operations to water, or species and habitats in water but not in the sea.

The Marine Management Organisation (MMO) (in England) and the Welsh Government (in Wales) for:

Damage to EU species and habitats and SSSIs in the sea, other than where the operation is regulated by the EA.

The Countryside Council for Wales (in Wales) and Natural England (in England) for:

Damage to EU species and habitats on land or to an SSSI (except where an operation is regulated under the Environmental permitting Regulations).

Damage to EU species and habitats on land or to an SSSI caused by operations regulated by Local Authorities under the Environmental Permitting Regulations (*enforcing remediation requirements in Part 3 of the Regulations only*).

Local Authorities in England and Wales for:

Damage caused by operations regulated by Local Authorities under the Environmental Permitting Regulations (*enforcing preventive requirements in Part 2 of the Regulations only*).

Damage to land caused by operations regulated by Local Authorities under the Environmental Permitting Regulations (*enforcing remediation requirements in Part 3 of the Regulations only*).

Damage to land other than SSSIs for activities other than those regulated under the Environmental Permitting Regulations.

In Scotland, the competent authorities are:

Scottish Ministers for:

Damage to protected species or natural habitats in the territorial sea or coastal waters.

Scottish Natural Heritage for:

Damage to protected species or natural habitats in any other place.

The Scottish Environment Protection Agency for:

Damage to waters or land.

In Northern Ireland

The competent authority is the Department of the Environment (Northern Ireland).

The Northern Ireland Environment Agency (NIEA) are the lead agency for pollution response in an emergency, however, due to the devolved government arrangements in place, the Department of Agriculture and Rural Development (DARD) have responsibility for fisheries and aquaculture.

The Agri-Food and Biosciences Institute (AFBI) undertake an emergency response function on behalf of DARD, and co-operate with the NIEA on a range of environmental issues. The AFBI also represent DARD on the existing emergency pollution response groups.

The Loughs Agency is a body co-sponsored by DARD and the Irish Republic with authority for the management role in relation to cross-border catchments and coastal waters between Northern Ireland and the Irish Republic (Lough Foyle and Carlingford Lough).

In relation to these monitoring guidelines, the enforcing authority would need monitoring data to establish:

- Whether there is "environmental damage" under the regulations and, if so, is the damage attributable to operator activities?
- What is the extent of the damage?
- Are the operator's remediation proposals suitable? or what remediation measures should be enacted if the enforcing authority has to devise remediation proposals?
- Is the proposed remediation expected to compensate for the environmental damage caused?

Some monitoring is also likely to be needed to establish whether the remediation process is meeting its stated goals.

The guidance given in this document is directly applicable for monitoring undertaken under these regulations. Cost recovery may be possible, so careful documentation of the work undertaken and the reasoning underlying the decisions for inclusion of elements of the monitoring programme is essential. Following the logic outlined in section 1 of these guidelines will aid considerably in this process.

Acknowledgements

Photographs in Section 2.9 are © Jon Moore (except for those in 2.9.4.6, which is © Blaise Bullimore, and 2.9.4.7, which is © Keith Hiscock,) and are used with permission. Cover image: oil spill © Roger Hutchings/In Pictures/Corbis; page 14: oily beach © Ocean/Corbis; page 18: Lizard Point © David Joyner iStockphoto.com; page 77 and back cover: eider duck © alarifoto iStockphoto.com. All remaining photographs are from Cefas or the Environment Agency and are British Crown copyright.

The sections on survey design and ecological methods are adapted from text originally prepared by one of the authors (Jon Moore) for the Countryside Council for Wales (Moore et al., 2005) and UNEP (IMO/UNEP, 2009). Valuable review and comments on these texts have been provided by representatives from a broad range of individuals and organisations, including JNCC, Environment Agency, the National Oceanography Centre and other members of the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG). Particular assistance has been provided by Andy Webb and Ian Mitchell (JNCC).

Bibliography

Addison, P. 2010. *Quality assurance in marine biological monitoring*. A report prepared for the Healthy and Biologically Diverse Seas Evidence Group and the National Marine Biological Analytical Quality Control scheme. Environment Agency/Joint Nature Conservation Committee, January 2010. 8pp.

Aguilar de Soto, N., Rogan, E., Ó Cadhla, O., Gordon, J.C.D., Mackey, M. and Connolly, N. 2004. *Cetaceans and seabirds of Ireland's Atlantic Margin. Volume III: Acoustic surveys for cetaceans.* Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porcupine Studies Group project P00/15, and Offshore Support Group (OSG) Project 99/38.

Aguilera, F., Méndez, J., Pásaro, E. and Laffon, B. 2010. Review on the effects of exposure to spilled oil on human health. *Journal of Applied Toxicology*, **30**: 291–301.

Alonso-Gutiérrez, J., Figueras, A., Albaigés, J., Jiménez, N., Viñas, M., Solanas, A.M., Novoa, B. 2009. Bacterial communities from shoreline environments (Costa da Morte, Northwestern Spain) affected by the *Prestige* oil spill. *Applied Environmental Microbiology*, **75**: 3407–3418.

Andre, B.A. 1999. Black Oystercatcher *Haematopus bachmani. Restoration Notebook. Exxon Valdez* Oil Spill Trustee Council. 8pp.

Arata, C.M., Picou, J.S., Johnson, G.D. and McNally, T.S. 2000. Coping with technological disaster: an application of the conservation of resources model to the *Exxon Valdez* oil spill. *Journal of Traumatic Stress*, **13**: 23–39.
http://stevenpicou.com/pdfs/coping-with-technological-disasters.pdf [accessed 23 September 2010].

Arey, J.S., Nelson, R.K. and Reddy, C.M. 2007a. Disentangling oil weathering using GCxGC: 1. Chromatogram analysis. *Environmental Science and Technology*, **41**: 5738–5746.

Arey, J.S., Nelson, R.K., Plata, D.L. and Reddy, C.M. 2007b. Disentangling oil weathering using GCxGC: 2. Mass transfer calculations. Environmental Science and Technology, 41: 5747–5755.

Ariese, F., Beyer, J., Jonsson, G., Visa, C.P. and Krahn, M.M. 2005. Review of analytical methods for determining metabolites of polycyclic aromatic compounds (PACs) in fish bile. *ICES Techniques in Marine Environmental Sciences,* No. 39. 41pp.
www.ices.dk/pubs/times/times39/TIMES39.pdf [accessed 31 December 2010].

Armitage, M., Burton, N. and Rehfisch, M. 1997. *The abundance and distribution of waterfowl within Milford Haven after the Sea Empress oil spill. One-year report*. Report to CCW from the British Trust for Ornithology, Thetford, UK. 124pp.

Armitage, M., Rehfisch, M. and Burton, N. 2000. *The impact of the* Sea Empress *oil spill on the abundance and distribution of waterbirds within Milford Haven. Year 3 Final Report*. Report to the Countryside Council for Wales from the British Trust for Ornithology, Thetford, UK. 85pp. + figures.

AURIS. 1994. *Scientific criteria to optimise oil spill clean-up operations and effort*. A report by AURIS Environmental, Aberdeen, UK. 56pp + appendices, figures and tables.

AURIS. 1995. *Scoping evaluation of the biological recovery of oiled mangroves, coral reefs, seagrasses and sedimentary shores*. A report by AURIS Environmental, Aberdeen, UK. 148pp.

Australian Maritime Safety Authority. 2003a. *Oil spill monitoring handbook*. AMSA, Canberra. ` www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/Oil_Spill_Monitoring_Handbook.pdf [accessed 24 May 2010].

Australian Maritime Safety Authority. 2003b. *Oil spill monitoring background paper*. AMSA, Canberra. www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/oil_spill_monitoring_background_paper.pdf [accessed 24 May 2010].

Baars, B.-J. 2002. The wreckage of the oil tanker "*Erika*": human health risk assessment of beach cleaning, sunbathing and swimming. *Toxicology Letters*, **128**: 55–68.

Bachoon, D.S., Hodson, R.E. and Araujo, R. 2001. Microbial community assessment in oil-impacted salt marsh sediment microcosms by traditional and nucleic acid-based indices. *Journal of Microbiological Methods*, **46**: 37–49.

Baines, M., Pierpoint, C. and Earl, S. 1997. *A cetacean sightings database for Wales and an evaluation of impacts on cetaceans from the Sea Empress oil spill*. Report to the Countryside Council for Wales from The Wildlife Trust West Wales. 67pp.

Baines, M.E. and Earl, S.J. 1998. *Breeding seabird surveys of south-west Wales colonies 1996–98*. Report to CCW from The Wildlife Trust West Wales. 77pp.

Baker, J., Little, A. and Heaps, L. 1996. *Guidelines for assessing the ecological condition and recovery of oiled shores*. A report by AURIS Environmental, Aberdeen, UK. 89pp.

Baker, J.M. and Crothers, J.H. 1987. Intertidal rock. In: *Biological surveys of estuaries and coasts*, pp. 157–197 (Baker, J.M. and Wolff, W.J., eds.). Estuarine and Brackish Water Sciences Association handbook. Cambridge University Press, Cambridge, UK.

Baker, J.M. and Wolff, W.J. (eds.). 1987. *Biological surveys of estuaries and coasts*. Estuarine and Brackish Water Sciences Association handbook. University of Cambridge Press, Cambridge, UK. 472pp. ISBN10: 0-52-131191-8. ISBN13: 978-0-52-131191-5.

Bamber, R.N. 2004. *Temporal variation and monitoring of important lagoonal communities and species in Wales.* A report to CCW by The Natural History Museum, London, UK. CCW Marine Monitoring Report No. 12. 41pp.

Bamber, R.N., Gilliland, P.M. and Shardlow, M.E.A. 2001. Saline lagoons: A guide to their management and creation (interim version). Peterborough, UK, English Nature.

Banks, A., Bolt, D., Bullock, I., Haycock, B., Musgrove, A., Newson, S., Fairney, N., Sanderson, B., Schofield, R., Taylor, R. and Whitehead, S. 2004. *Marine Monitoring Project: Ground and aerial monitoring protocols for in-shore SPAs. Common Scoter surveys in Carmarthen Bay during the winters of 2002–03 and 2003–04*. Draft report from the British Trust for Ornithology to the Countryside Council for Wales. BTO Research Report No. 366. 160pp + figures and tables.

Banks, A.N., Sanderson, W.G., Hughes, B., Cranswick, P.A., Smith, L.E., Whitehead, S., Musgrove, A.J., Haycock, B. and Fairney, N.P. 2008. The *Sea Empress* oil spill (Wales, UK): effects on common scoter Melanitta nigra in Carmarthen Bay and status ten years later. *Marine Pollution Bulletin*, **56**: 895–902.

Barillé-Boyer, A., Gruet, Y., Barillé, L. and Harin, N. 2004. Temporal changes in community structure of tide pools following the *Erika* oil spill. *Aquatic Living Resources*, **17**: 323–328.

Bartolomé, L., Deusto, M., Etxebarria, N., Navarro, P., Usobiaga, A. and Zuloaga, O. 2007. Chemical fingerprinting of petroleum biomarkers in biota samples using retention-time locking chromatography and multivariate analysis. *Journal of Chromatography A*, **1157**: 369–375.

Batten, S.D., Allen, R.J.S. and Wotton, C.O.M. 1998. The effects of the *Sea Empress* oil spill on the plankton of the Southern Irish Sea. *Marine Pollution Bulletin*, **36**: 764–774.

Bayfield, N.G. and Frankiss, J.R. 1997. Impacts of oil pollution from the *Braer* on semi-natural vegetation. In: *The Impact of an Oil Spill in Turbulent Waters*: The Braer, pp. 52–62 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Bell, S.A., Stevens, P.A., Norris, D.A., Radford, G.L., Gray, A.J., Rossall, M.J. and Wilson, D. 1999. *Damage assessment survey of saltmarsh affected by the* Sea Empress *oil spillage*. Report by Institute of Terrestrial Ecology to CCW. 45pp + appendices and figs.

Bence, A.E., Page, D.S. and Boehm, P.D. 2007. Advances in forensic techniques for petroleum hydrocarbons: the Exxon Valdez experience. In: *Oil Spill Environmental Forensics: Fingerprinting and Source Identification*, Chapter 15, pp. 449–487 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Birkhead, T.R. 2001. *Skomer Guillemot Studies 1999–2001. Three-year report*. Unpublished report. University of Sheffield, Sheffield, UK.

Bocquené, G. and Galgani, F. 1998. Biological effects of contaminants: cholinesterase inhibition by organophosphate and carbamate compounds. *ICES Techniques in Marine Environmental Sciences*, No. 23. 12pp. www.ices.dk/pubs/times/times22/TIMES22.pdf [accessed 31 December 2010].

Boehm, P.D., Barak, J.E., Fiest, D.L. and Elskus, A.A. 1982. A chemical investigation of the transport and fate of petroleum hydrocarbons in littoral and benthic environments: the Tsesis oil spill. *Marine Environmental Research*, **6**: 157–188.

Boehm, P.D., Page, D.S., Burns, W.A., Bence, A.E., Mankiewicz, P.J. and Brown, J.S. 2001. Resolving the origin of the petrogenic hydrocarbon background in Prince William Sound, Alaska. *Environmental Science and Technology*, **35**: 471–479.

Brakstad, O. and Lødeng, A. 2005. Microbial diversity during biodegradation of crude oil in seawater from the North Sea. *Microbial Ecology*, **49**: 94–103.

Bretagnolle, V., Certain, G., Houte, S. and Métais, M. 2004. Distribution maps and minimum abundance estimates for wintering auks in the Bay of Biscay, based on aerial surveys. *Aquatic Living Resources*, **17**: 353–360.

British Trust for Ornithology (BTO) Wetland Bird Survey website: www.bto.org/webs [accessed 2 July 2010].

Brooks, S.J, Bolam, T., Tolhurst, L., Bassett, J., Roche, J.L., Waldock, M., Barry, J. and Thomas, K.V. 2008. Dissolved organic carbon reduces the toxicity of copper to germlings of the macroalgae, *Fucus vesiculosus*. *Ecotoxicology and Environmental Safety*, **70**: 88–98.

Burgherr, P. 2007. In-depth analysis of accidental oil spills from tankers in the context of global oil spill trends from all sources. *Journal of Hazardous Materials*, **140**: 245–256.

Burns, W.A., Mudge, S.M., Bence, A.E., Boehm, P.D., Brown, J.S., Page, D.S. and Parker, K.R. 2006. Source allocation by least-squares hydrocarbon fingerprint matching. *Environmental Science and Technology*, **40**: 6561–6567.

Burton, N.H.K., Musgrove, A.J. and Rehfisch, M.M. 2004. Tidal variation in numbers of waterbirds: how frequently should birds be counted to detect change and do low tide counts provide a realistic average?: Capsule Variation in numbers needs to be assessed at both site- and species-specific levels, but low tide counts are representative of average usage in most cases. *Bird Study*, **51**: 48–57.

Camilli, R., Reddy, C.M., Yoerger, D.R., Van Mooy, B.A.S., Jakuba, M.V., Kinsey, J.C., McIntyre, C.P., Sylva, S.P. and Maloney, J.V. 2010. Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon. *Science*, **330**: 201–204. doi: 10.1126/science.1195223.

Campbell, D., Cox, D., Crum, J., Foster, K. and Riley, A. 1994. Later effects of grounding of tanker *Braer* on health in Shetland. *British Medical Journal*, **309**: 773–774.

Campbell, D., Cox, D., Crum, J., Foster, K., Christie, P. and Brewster, D. 1993. Initial effects of the grounding of the tanker *Braer* on health in Shetland. *British Medical Journal*, **307**: 1251–1255.

Camphuysen, C.J, Bao, R., Nijkamp, H. and Heubeck, M. (eds.). 2007, *Handbook on oil impact assessment*. Royal Netherlands Institute for Sea Research, Texel, The Netherlands. www.oiledwildlife.eu

Camphuysen, C.J. and Leopold, M.F. 2004. The *Tricolor* spill: characteristics of seabirds found oiled in The Netherlands. *Atlantic Seabirds*, **6**: 109–128.

Camphuysen, C.J., Heubeck, M., Cox, S.L., Bao, R., Humple, D., Abraham, C. et al. 2002. The Prestige oil spill in Spain. Atlantic Seabirds, 4: 131–140.

Camphuysen, K. and Heubeck, M. 2001. Marine oil pollution and beached bird surveys: the development of a sensitive monitoring instrument. *Environmental Pollution*, **112**: 443–461. www.sciencedirect.com/science/journal/02697491 [accessed 2 July 2010].

Camphuysen, K.J., Fox, A.D., Leopold, M.F. and Petersen, I.K. 2004. *Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K.: a comparison of ship and aerial sampling methods for marine birds, and their applicability to offshore wind farm assessments*. NIOZ report to COWRIE (BAM – 02–2002), Texel, 37pp.

Capone, D.G., Bronk, D.A., Mulholland, M.R. and Carpenter, E.J. (eds.). 2008. N*itrogen in the marine environment*. 2nd edition. Academic Press, Burlington, MA, USA. 1757pp. ISBN10: 0-123-72522-4. ISBN13: 978-0123-72522-4.

Cappello, S., Caruso, G., Zampino, D., Monticelli, L.S., Maimone, G., Denaro, R., Tripodo, B., Troussellier, M., Yakimov, M. and Giuliano, L. 2007. Microbial community dynamics during assays of harbour oil spill bioremediation: A microscale simulation study. *Journal of Applied Microbiology*, **102**: 184–194.

Castège, I, Hémery, G., Roux, N., d'Elbée, J., Lalanne, Y., D'Amico, F. and Mouchès, C. 2004. Changes in abundance and at-sea distribution of seabirds in the Bay of Biscay prior to, and following the "*Erika*" oil spill. *Aquatic Living Resources*, **17**: 361–367.

Chamberlain, Y.M. 1997. *Investigation of the condition of crustose coralline red algae in Pembrokeshire after the* Sea Empress *disaster, 15–21 February 1996*. A report to the Countryside Council for Wales. 30pp + appendices.

Chesworth, J.C., Donkin, M.E. and Brown, M.T. 2004. The interactive effects of the antifouling herbicides Irgarol 1051 and Diuron on the seagrass *Zostera marina* (L.). *Aquatic Toxicology*, **66**: 293–305.

Christensen, J.H. and Tomasi, G. 2007. Practical aspects of chemometrics for oil spill fingerprinting. *Journal of Chromatography A*, **1169**: 1–22.
Clark, R.B. 1984. *Impact of oil pollution on seabirds. Environmental Pollution (Series A),* **33**: 1–22.

Cole, J., Beare, D.M., Waugh, A.P.W., Capulas, E., Aldridge, K.E., Arlett, Cf., Green, M.H.L., Crum, J.E., Cox, D., Garner, R.C., Dingley, K.H., Martin, E.A., Podmore, K., Heydon, R. and Farmer, P.B. 1997. Biomonitoring of possible human exposure to environmental genotoxic chemicals: lessons from a study following the wreck of the oil tanker *Braer*. *Environmental and Molecular Mutagenesis*, **30**: 97–111.

Conroy, J.W.H., Kruuk, H. and Hall, A.J. 1997. The effects of *the Braer* oil spill on otters and seals on Shetland. In: *The impact of an oil spill in turbulent waters:* the Braer, pp. 106–120 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Countryside Council for Wales. 1998. *Grey seal pup production and monitoring studies following the* Sea Empress *oil spill*. Summary report prepared for the SEEEC. Countryside Council for Wales, Bangor, UK.

Crump, R.G. and Emson, R.H. 1998. Observations of the effects of oil pollution on two species of Asterinid cushion star in rockpools at West Angle Bay, Milford Haven. In: *The* Sea Empress *Oil Spill*, pp. 423–435 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for the SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Crump, R.G., Morley, H. and Williams, A. 1998. West Angle Bay, a case study: littoral monitoring of permanent quadrats before and after the Sea Empress oil spill. In: The Sea Empress Oil Spill, pp. 207–222 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for the SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Cullinane, J.P., McCarthy, P. and Fletcher, A. 1975. The effect of oil pollution in Bantry Bay. *Marine Pollution Bulletin*, **6**: 173–176.

Cuny, P., Miralles, G., Cornet-Barthaux, V., Acquaviva, M., Stora, G., Grossi, V. and Gilbert, F. 2007. Influence of bioturbation by the polychaete *Nereis diversicolor* on the structure of bacterial communities in oil contaminated coastal sediments. *Marine Pollution Bulletin*, **54**: 452–459.

Dalby, D.H. 1987. Salt marshes. In: *Biological surveys of estuaries and coasts*, Chapter 3, pp. 38–80 (Baker, J.M. and Wolff, W.J., eds.). Estuarine and Brackish Water Sciences Association handbook. University of Cambridge Press, Cambridge, UK.

Dalkin, M. and Barnett, B. 2002. Procedural Guideline No. 3–6 Quantitative sampling of intertidal sediment species using cores. In: *JNCC Marine Monitoring handbook*. Joint Nature Conservation Committee, Peterborough, UK.

Dauvin, J.-C. 1998. The fine sand *Abra alba* community of the Bay of Morlaix twenty years after the *Amoco Cadiz* oil spill. *Marine Pollution Bulletin*, **36**: 669–676.

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. and Vincent, M. (eds.). 2001. *Marine Monitoring handbook*. JNCC Procedural Guideline Nos. 4.1, 4.2, 4.3 & 4.4. Joint Nature Conservation Committee, Peterborough, UK, 405pp. www.jncc.gov.uk/page-2430 [accessed 2 July 2010].

Davies, J.M., McIntosh, A.D., Stagg, R., Topping, G. and Rees, J. 1997. The fate of the *Braer* oil in the marine and terrestrial environments. In: *The Impact of an Oil Spill in Turbulent Waters*: The Braer, pp. 26–41 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Davison, D.M. and Hughes, D.J. 1998. Zostera *Biotopes. Volume I: An overview of dynamics and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science (UK Marine SACs Project). 95pp. www.ukmarinesac.org.uk/publications.htm [accessed 2 July 2010].

de Boer, J. and Law, R.J. 2003. Developments in the use of chromatographic techniques in marine laboratories for the determination of halogenated contaminants and polycyclic aromatic hydrocarbons. *Journal of Chromatography A*, **1000**: 223–251.

Dean, T.A., Jewett, S.C., Laur, D.R. and Smith, R.O. 1996b Injury to epibenthic invertebrates resulting from the *Exxon Valdez* oil spill. In: *Proceedings of the* Exxon Valdez *Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 424–439.

Dean, T.A., Stekoll, M.S. and Smith, R.O. 1996a. Kelps and oil: the effects of the *Exxon Valdez* oil spill on subtidal algae. In: *Proceedings of the* Exxon Valdez *Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 412–423.

Dean, T.A., Stekoll, M.S., Jewett, S.C., Smitha, R.O. and Hose, J.E. 1998. Eelgrass (*Zostera marina* L) in Prince William Sound, Alaska: effects of the *Exxon Valdez* oil spill. *Marine Pollution Bulletin*, **36**: 201–210.

den Hartog, C. and Jacobs, R.P.W.M. 1980. Effects of the *Amoco Cadiz* oil spill on an seagrass community at Roscoff (France), with special reference to the mobile benthic infauna. *Helgolander Meersunters*, **33**: 182–191.

Dicks, B. 1970. Some effects of Kuwait crude oil on the limpet, *Patella vulgata*. *Environmental Pollution*, **5**: 219–229.

Diplock, E., Alhadrami, H. and Paton, G. 2010. Application of microbial bioreporters in environmental microbiology and bioremediation. *Advances in Biochemical Engineering/ Biotechnology*, **118**: 189–210.

Dor, F., Bonnard, R., Gourier-Fréry, C., Cicolella, A., Dujardin, R. and Zmirou, D. 2003. Health risk assessment after decontamination of the beaches polluted by the wrecked *ERIKA* tanker. *Risk Analysis*, **23**: 1199–1208.

Duck, C. 2003. *Monitoring harbour seals in Special Areas of Conservation in Scotland*. Scottish Natural Heritage Commission Report F01AA403. 28pp.

Duck, C.D., Hall, A.J. and Ingram, S. 1993. *Monitoring the impact of the* MV Braer *oil spill in Shetland: Common Seal aerial survey, August 1993*. Sea Mammal Research Unit, Cambridge, UK.

Elliott, M., Nedwell, S., Jones, N.V., Read, S.J., Cutts, N.D. and Hemingway, K.L. 1998. Intertidal sand and mudflats and subtidal mobile sandbanks. An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project). 151pp. www.ukmarinesac.org.uk/publications.htm [accessed 2 July 2010].

Emson, R.H. and Crump, R.G. 1997. *Effects of the Sea Empress oil spill on seaweed animals of the West Angle Bay tide pools*. A report to the Countryside Council for Wales from Kings College, London, UK, and Orielton Field Centre, Pembroke, UK.

Environment Agency. 2004. A guide to practices, procedures and methodologies following oil spill contamination incidents: Methods for the Examination of Waters and Associated Materials. Standing Committee of Analysts Blue Book No. 193. 105pp.
www.environment-agency.gov.uk/static/documents/Research/Oils_Guide_2004.pdf [accessed 9 May 2011].

Esler, D., Bowman, T.D., Trust, K., Ballachey, B.E., Dean, T.A., Jewett, S.C. and O'Clair, C.E. 2002. Harlequin duck population recovery following the *Exxon Valdez* oil spill: progress, process and constraints. *Marine Ecology Progress Series*, **241**: 271–286.

Evans, P.G.H. and Hammond, P.S. 2004. Monitoring cetaceans in European waters. *Mammal Review*, **34**: 131–156.

Evans, S. 1998. *Effects of oil and clean-up of oil from the Sea Empress on the nationally rare and scarce vascular plants of Pembrokeshire*. CCW, Pembrokeshire, UK. 20pp + appendices.

Fiocco, R.J. and Lewis, A. 1999. Oil spill dispersants. *Pure and Applied Chemistry*, **71**: 27–42.

Foster, K., Campbell, D., Crum, J. and Stove, M. 1995. Non-response in a population study after an environmental disaster. *Public Health*, **109**: 267–273.

Gaines, R.B., Frysinger, G.S., Reddy, C.M. and Nelson, R.K. 2007. Oil spill source identification by comprehensive two-dimensional gas chromatography (GC x GC). In: *Oil spill environmental forensics: fingerprinting and source identification*, Chapter 5, pp. 169–206 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Geraci, J.R. and St. Aubin, D.J. 1990. *Sea mammals and oil: confronting the risks*, Chapters 5 and 6, pp.129–197. Academic Press, New York. 282pp.

Gertler, C., Gerdts, G., Timmis, K.N. and Golyshin, P.N. 2009. Microbial consortia in mesocosm bioremediation trial using oil sorbents, slow-release fertilizer and bioaugmentation. *FEMS Microbiology Ecology*, **69**: 288–300.

Gesteira, J.L.G. and Dauvin, J.C. 2000. Amphipods are good bioindicators of the impact of oil spills on soft-bottom macrobenthic communities. *Marine Pollution Bulletin*, **40**: 1017–1027.

Getter, C.D., Cintron, G., Dicks, B., Lewis, R.R. and Seneca, E.D. 1984. The recovery and restoration of salt marshes and mangroves following an oil spill. In: *Restoration of habitats impacted by oil spills*, Chapter 3, pp. 65–113 (Cairns, J.J. and Buikemea, J., eds.). Butterworth Publishing Co., Boston, MA, USA.

Gilbert, G., Gibbons, D.W. and Evans, J. 1998. Bird *monitoring methods: a manual of techniques for key UK species*. Royal Society for the Protection of Birds, Sandy. 464pp. ISBN 1-901-93003-3.

Grantham, M.J. 2004. Age structure and origins of British & Irish Guillemots *Uria aalge* recovered in recent European oil spills. *Atlantic Seabirds*, **6**: 95–108.

Grasshoff, K., Kremling, K. and Ehrhardt, M. 1999. *Methods of seawater analysis*, 3rd edition. Wiley VCH, Weinheim, Germany. 632pp. ISBN10: 352-729589-5. ISBN13: 978-352-729589-5.

Gubbay, S. and Earll, R. 1999. Proposed guidelines for dealing with cetaceans in the event of an oil spill in the Moray Firth, Scotland. Report to Talisman Energy (UK) Limited and Scottish Natural Heritage. www.morayfirth-partnership.org/work-2-sac-publications.html [accessed 11 March 2011].

Gubbay, S. and Earll, R. 2000. Review of literature on the effects of oil spills on cetaceans. *Scottish Natural Heritage Review*, No. 3. 34pp.

Hall, M. 1997. *The Braer*: environmental health problems associated with the spill. In: T*he impact of an oil spill in turbulent waters:* the Braer (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Haycock, R.J., Baines, M.E. and Earl, S.J. 1998. Effects of the Sea Empress oil spill on breeding seabirds in South West Wales. In: *The Sea Empress oil spill*, pp. 227–246 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Hazen, T.C., Dubinsky, E.A., DeSantis, T.Z., Andersen, G.L., Piceno, Y.M., Singh, N., Jansson, J.K., Probst, A., Borglin, S.E., Fortney, J.L., Stringfellow, W.T., Bill, M., Conrad, M.E., Tom, L.M., Chavarria, K.LO., Alusi, T.R., Lamendella, R., Joyner, D.C., Spier, C., Baelum, J., Auer, M., Zemla, M.L., Chakraborty, R., Sonnenthal, E.L., D'haeseleer, P., Holman, H.-Y.N., Osman, S., Lu, Z., Van Nostrand, J.D., Deng, Y., Zhou, J. and Mason, O.U. 2010. Deep-sea plume enriches indigenous oil-degrading bacteria. *Science*, **330**: 204–208. doi: 10.1126/science/1195979.

Hegazi, A.H. and Andersson, J.T. 2007. Characterization of polycyclic aromatic sulphur heterocycles for source identification. In: *Oil spill environmental forensics: fingerprinting and source identification*, Chapter 4, pp. 147–168 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Heubeck, M. 1997. The direct effect of the *Braer* oil spill on seabird populations, and an assessment of the role of the Wildlife Response Centre. In: *The impact of an oil spill in turbulent waters*: the Braer, pp. 73–90 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Heubeck, M. 2000. Population trends of Kittiwake *Rissa tridactyla*, Black Guillemot *Cepphus grylle* and Common Guillemot *Uria aalge* in Shetland. 1978–98. *Atlantic Seabirds*, **2**: 227–244.

Hill, S., Burrows, M.T. and Hawkins, S.J. 1998. *Intertidal reef biotopes*. *Volume VI: An overview of dynamics and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science (UK Marine SACs Project). 84pp. *www.ukmarinesac.org.uk/publications.htm* [accessed 2 July 2010].

Hodges, J. and Howe, M. 1997. *Milford Haven waterway*. *Monitoring of eelgrass* Zostera angustifolia *following the* Sea Empress *Oil Spill*. Unpublished report to the Shoreline and Terrestrial Task Group of SEEEC from the Pembrokeshire Coast National Park Authority. 13pp + tables and maps.

Holme, N.A. and McIntyre, A.D. (eds.). 1984. *Methods for the study of marine benthos*, 2nd edition. IBP handbook, No.16. Blackwell Scientific Publications for International Biological Programme, Oxford, UK.

Howard, S., Baker, J.M. and Hiscock, K. 1989. The effects of oil dispersants on seagrasses in Milford Haven. In: *Ecological impacts of the oil industry* (Dicks, B., ed.). John Wiley & Sons, Chichester, UK.

Howgate, P. 1999. Tainting of food by chemical contaminants. In: *Environmental contaminants in food* (Moffat, Cf. and Whittle, K.J., eds.). Academic Press/CRC Press, Sheffield, UK. ISBN 0-8493-9735-9.

Huijer, K. 2005. *Trends in oil spills from tanker ships 1995–2004*. Paper presented at the 28th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 7–9 June 2005, Calgary, Canada. www.itopf.com/_assets/documents/amop05.pdf [accessed 14 June 2011].

ICES. 2009. *Report of the Joint ICES/OSPAR Study Group on Integrated Monitoring of Contaminants and Biological Effects (SGIMC).* ICES Document CM 2009/ACOM:30 Ref. OSPAR. www.ices.dk/reports/ACOM/2009/SGIMC/sgimc_2009.pdf [accessed 8 June 2011].

ICES. 2011. *Report of the Study Group on Integrated Monitoring of Contaminants and Biological Effects (SGIMC).* ICES Document CM 2011/ACOM:30. Ref. ACOM, OSPAR. www.ices.dk/reports/ACOM/2011/SGIMC/sgimc_2011_final.pdf [accessed 8 June 2011].

IMO. 1998. IMO guidelines for sampling and identification of oil spills. Ma*nual on oil pollution, Section VI*. 44pp. London, UK. ISBN 978-92-801-1451-5.

IMO/UNEP. 2009. *IMO/UNEP guidance manual on the assessment and restoration of environmental damage following marine oil spills*. London, UK. 104pp.

IOPC. 2008. *Claims manual*. International Oil Pollution Compensation Fund, London, UK. 38pp. www.iopcfund.org/npdf/2008%20claims%20manual_e.pdf [accessed 25 June 2010].

IPIECA. 1991. *Guidelines on biological impacts of oil pollution*. IPIECA Report Series, Volume 1. International Petroleum Industry Environmental Conservation Association, London, UK. 15pp. www.ipieca.org/system/files/publications/Vol1_BioImpacts.pdf [accessed 2 July 2010].

IPIECA. 1994. *Biological impacts of oil pollution: saltmarshes*. IPIECA Report Series, Volume 6. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol6_Saltmarshes_0.pdf [accessed 2 July 2010].

IPIECA. 1995. *Biological impacts of oil pollution: rocky shores*. IPIECA Report Series, Volume 7. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol7_RockyShores_1.pdf [accessed 2 July 2010].

IPIECA. 1996. *Sensitivity mapping for oil spill response*. IPIECA Report Series, Volume 1. International Petroleum Industry Environmental Conservation Association, London, UK. 24pp. www.ipieca.org/publications/publications_summary.php?id=41 [accessed 2 July 2010].

IPIECA. 1997. *Biological impacts of oil pollution: fisheries*. IPIECA Report Series, Volume 8. International Petroleum Industry Environmental Conservation Association, London, UK. 28pp. http://www.ipieca.org/sites/default/files/publications/Vol8_Fisheries.pdf [accessed 4 November 2010].

IPIECA. 1999. *Biological impacts of oil pollution: sedimentary shores*. IPIECA Report Series, Volume 9. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol9_SedimentaryShores.pdf [accessed 2 July 2010].

IPIECA. 2000. *Choosing spill response options to minimize damage: net environmental benefit analysis*. IPIECA Report Series, Volume 10. International Petroleum Industry Environmental Conservation Association, London, UK. 20pp. www.ipieca.org/system/files/publications/Vol10_NEBA_1.pdf [accessed 2 July 2010].

IPIECA. 2004. *A guide to oiled wildlife response planning*. IPIECA Report Series, Volume 13. International Petroleum Industry Environmental Conservation Association, London, UK. 52pp. http://www.ipieca.org/publication/guide-oiled-wildlife-response-planning [accessed 4 November 2011].

IPIECA. 2007. *Oil spill compensation: a guide to the international conventions on liability and oil pollution damage*. International Petroleum Industry Environmental Conservation Association, London, UK. 22pp. www.ipieca.org/system/files/publications/Compensation_1.pdf [accessed 25 June 2010].

Irons, D.B. 1996. Size and productivity of black-legged kittiwake colonies in Prince William Sound before and after the *Exxon Valdez* oil spill. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. American Fisheries Society Symposium, 18: 738–747.

ISO. 1999. *ISO 14669:1999(E) Water quality: determination of acute lethal toxicity to marine copepods (Copepoda, Crustacea).* International Organization for Standardization, Geneva, Switzerland.

ISO. 2006. *ISO 14442:2006(E) Water quality: guidelines for algal growth inhibition tests with poorly soluble materials, volatile compounds, metals and waste water*. International Organization for Standardization, Geneva, Switzerland.

ISO. 2010. *ISO 10710:2010(E) Water quality: growth inhibition test with the marine and brackish water macroalga* Ceramium tenuicorne. International Organization for Standardization, Geneva, Switzerland.

Jacobs, R.P.W.M. 1980. Effects of the *Amoco Cadiz* oil spill on the seagrass community at Roscoff, with special reference to the benthic infauna. *Marine Ecology Progress Series*, **2**: 207–212.

Jewett, S.C., Dean, T.A., Smith, R.O. and Blanchard, A. 1999. *Exxon Valdez* oil spill: impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds. Marine Ecology Progress Series, **185**: 59–83.

JNCC. 1995. Vulnerable concentrations of seabirds to oil spills. Interactive maps and datasets available on Magic website: http://magic.defra.gov.uk

JNCC. 2004a. Common standards monitoring guidance for saltmarsh habitats. Version August 2004. 23pp. www.jncc.gov.uk/page-2204 [accessed 2 July 2010].

JNCC. 2004b. Common standards monitoring guidance for lagoons. Version August 2004. 38pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

JNCC. 2004c. Common standards monitoring guidance for littoral sediment habitats. Version August 2004. 33pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

JNCC. 2004d. Common standards monitoring guidance for littoral rock and inshore sublittoral rock habitats. Version August 2004. 27 pp. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

JNCC. 2004e. Common standards monitoring guidance for inshore sublittoral sediment habitats. Version August 2004. www.jncc.gov.uk/page-2236 [accessed 2 July 2010].

JNCC. 2004f. Common standards monitoring guidance for birds. Version August 2004, Online only. 50pp. *www.jncc.gov.uk/page-2224* [accessed 2 July 2010].

JNCC. 2004g. Common standards monitoring guidance for terrestrial mammals. Version August 2004, Online only. 51pp. www.jncc.gov.uk/page-2229 [accessed 2 July 2010].

JNCC. 2005. Common standards monitoring guidance for marine mammals. Version May 2005, Online only. 36pp. www.jncc.gov.uk/page-2228 [accessed 2 July 2010].

Johansson, S., Larsson, U. and Boehm, P. 1980. The *Tsesis* oil spill. *Marine Pollution Bulletin*, **11**: 284–293.

Johansson-Sjobeck, M.-L. and Larsson, A. 1978. The effect of cadmium on the haematology and on the activity of δ-amino levulinic acid dehydratase (ALA-D) in blood and haemopoetic tissues of the flounder *Pleuronectes platessa* L. *Environmental Research*, **17**: 191–294.

Jones, T. and Jones, D. 2004. *Otter survey of Wales 2002*. Environment Agency, Bristol, UK. 59pp.

Kelly, C.A., Law, R.J. and Emerson, H.S. 2000. Methods of analysis for hydrocarbons and polycyclic aromatic hydrocarbons (PAH) in marine samples. Aquatic environment protection: analytical methods, 12. Cefas, Lowestoft, UK.
www.Cefas.co.uk/publications/aquatic/aepam12.pdf [accessed 24 May 2010].

Kelly-Gerreyn, B.A., Hydes, D.J., Hartman, M.C., Siddorn, J., Hyder, P. and Holt, M.W. 2007. The phosphoric acid leak from the wreck of MV Ece in the English Channel in 2006: assessment with a ship of opportunity, an operational ecosystem model and historical data. *Marine Pollution Bulletin*, **54**: 850–862.

Kingston, P.F. 2002. Long-term environmental impact of oil spills. *Spill Science & Technology Bulletin*, **7**: 53–61.

Kingston, P.F., Dixon, I.M.T., Hamilton, S., Moore, C.G. and Moore, D.C. 1997. Studies on the response of intertidal and subtidal marine benthic communities to the *Braer* oil spill. In: The impact of an oil spill in turbulent waters: the Braer, pp. 209–233 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Kirby, M.F. and Law, R.J. 2010. Accidental spills at sea: risk, impact, mitigation and the need for co-ordinated post-incident monitoring. *Marine Pollution Bulletin*, **60**: 797–803.

Kirby, M.F., Devoy, B., Law, R.J., Ward, A. and Aldridge, J. 2008. The use of a bioassay based approach to the hazard/risk assessment of cargo derived toxicity during shipping accidents: a case study – The *MSC Napoli*. *Marine Pollution Bulletin*, **56**: 781–786.

Kirby, M.F., Lyons, B.P., Waldock, M.J., Woodhead, R.J., Goodsir, F., Law, R.J., Matthiessen, P., Neall, P., Stewart, C., Thain, J.E., Tylor, T. and Feist, S.W. 2000. Bio-markers of polycyclic aromatic hydrocarbon (PAH) exposure in fish and their application in marine monitoring. CEFAS Science Series Technical Report No. 110, 30pp.

Kirby, M.F., Neall, P. and Tylor, T. 1999. EROD activity in flatfish from the area of the *Sea Empress* oil spill. *Chemosphere*, **38**: 2929–2949.

Kirby, M.F., Sheahan, D.A., Smith, A.J., Fisher, T. In preparation. Chemical spills at sea and the toxicity of high priority chemicals to keystone species: an approach for risk and impact assessment.

Kirkwood, D. 1996. Nutrients: practical notes on their determination in sea water. ICES Techniques in Marine Environmental Sciences, No.17. 25pp.
www.ices.dk/pubs/times/times17/TIMES17.pdf [accessed 3 May 2011].

Kostrzewa, A., Moty-Monnereau, C., Ramaroson, H., Harrabi, I., Viance, P., Delarche, C., Bourbigfot, J.F., Dalm, C. and Brochard, P. 2005. Naufrage du *Prestige*: un exemple d'étude épidémiologique impliquant les médecins du travail et de prevention. *Archives des Maladies Professionelles et de l'Environnement*, **66**: 210–218.

Laffon, B., Fraga-Iriso, B., Pérez-Cadahía, B. and Méndez, J. 2006. Genotoxicity associated to exposure to Prestige oil during autopsies and cleaning of oil-contaminated birds. *Food and Chemical Toxicology*, **44**: 1714–1723.

Lanfranconi, M.P., Bosch, R. and Nogales, B. 2010. Short-term changes in the composition of active marine bacterial assemblages in response to diesel oil pollution. *Microbial Biotechnology*, **3**: 607–621.

Law, R. 2008. Environmental monitoring conducted in Lyme Bay following the grounding of MSC Napoli in January 2007, with an assessment of impact. Science Series, Aquatic Environment Monitoring Report No. 61, Cefas, Lowestoft, UK. 36pp.
www.Cefas.co.uk/publications/aquatic/aemr61.pdf [accessed 26 May 2010].

Law, R.J. 1980. Changes in the composition of oil from the "*Amoco Cadiz*". *Science of the Total Environment*, **15**: 37–49.

Law, R.J. and Kelly, C. 2004. The impact of the "*Sea Empress*" oil spill. *Aquatic Living Resources*, **17**: 389–394.

Law, R.J. and Whinnett, J.A. 1993. The determination of polycyclic aromatic hydrocarbons in seawater from the FLUXMANCHE transect (Dover Strait). *Oceanologica Acta*, **16**: 593–597.

Law, R.J., Kelly, C., Matthiessen, P. and Aldridge, J. 2003. The loss of the chemical tanker *Ievoli Sun* in the English Channel, October 2000. *Marine Pollution Bulletin*, **46**: 254–257.

Law, R.J., Thain, J.E., Kirby, M.F., Allen, Y.T., Lyons, B.P., Kelly, C.A., Haworth, S., Dyrynda, E.A., Dyrynda, P.E.J., Harvey, J.S., Page, S., Nicholson, M.D. and Leonard, D.R.P. 1998. The impact of the *Sea Empress* oil spill on fish and shellfish. In: *The Sea Empress oil spill*, pp. 109–136 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Law, R.J., Webster, L., Theobald, N., Rumney, H.S. and de Boer, J. 2011. Organic micropollutants. In: *Chemical marine monitoring: policy framework and analytical trends*, 1st edition, Chapter 6, pp. 161–196 (Roose, P., Verreet, G. and Quevauviller, P., eds.). Wiley-Blackwell, Chichester, UK. 376pp. ISBN 978-0-470-74765-0.

Lee, C.-H., Kang, Y.-A., Chang, K.-J., Kim, C.-H., Hur, J.-I., Kim, J.-Y. and Lee, J.-K. 2010. Acute health effects of the Hebei oil spill on the residents of Taean, Korea. *Journal of Preventive Medicine and Public Health*, **43**: 166–173.

Lee, K., Wohlgeschaffen, G.D., Tremblay, G.H., Vandermeulen, J.H., Mossman, D.C., Doe, K.G., Jackman, P.M., Wilson, J.E.H., Prince, R.C., Garrett, R.M. and Haith, C.E. 1999. Natural recovery reduces impact of the 1970 Arrow oil spill. In: *Proceedings of the 1999 International Oil Spill Conference*. American Petroleum Institute, Washington, DC, USA. #432, 5pp.

Legler, J., van den Brink, C.E., Brouwer, A., Murk, A.J., van der Saag, P.T., Vethaak, A.D. and van der Burg, B. 1999. Development of a stably transfected estrogen receptor-mediated luciferase reporter gene assay in the human T47D breast cancer cell line. *Toxicological Sciences*, **48**: 55–66.

Lima, D., Santos, M.M., Ferreira, A.M., Micaelo, C. and Reis-Henriques, M.A. 2008. The use of the shanny *Lipophrys pholis* for pollution monitoring: a new sentinel species for the northwestern European marine ecosystems. *Environment International*, **34**: 94–101. doi: 10.1016/j.envint.2007.07.07.

Lindley, J.A., George, C.L., Evans, S.V. and Donkin, P. 1998. Viability of calanoid copepod eggs from intertidal sediments: a comparison of three estuaries. *Marine Ecology Progress Series*, **162**: 183–190.

Little, A.E., Moore, J.J. and Dyrynda, P.J. 2001. *Ecological impacts of shoreline clean-up during the Sea Empress oil spill*. A report to the Countryside Council for Wales. 124pp + plates.

Lobão, M.M., Cardoso, J.N., Mello, M.R., Brooks, P.W., Lopes, C.C. and Lopes, R.S.C. 2010. Identification of source of a marine oil-spill using geochemical and chemometric techniques. *Marine Pollution Bulletin*, **60**: 2263–2274.

Lyons, B.P., Harvey, J.S. and Parry, J.M. 1997. An initial assessment of the genotoxic impact of the Sea Empress oil spill by the measurement of DNA adduct levels in the intertidal teleost *Lipophrys pholis*. *Mutation Research*, **390**: 263–268.

Lyons, B.P., Thain, J.E., Stentiford, G.D., Hylland, K., Davies, I.M. and Vethaak, A.D. 2010. Using biological effects tools to define Good Environmental Status under the European Union Marine Strategy Framework Directive. *Marine Pollution Bulletin*, **60**: 1647–1651.

Lyons, R.A., Temple, J.M.F., Evans, D., Fone, D.L. and Palmer, S.R. 1999. Acute effects of the Sea Empress oil spill. *Journal of Epidemiology and Community Health*, **53**: 306–310.

Maritime and Coastguard Agency. 2006. National Contingency Plan for Marine Pollution from Shipping and Offshore Installations. www.mcga.gov.uk/c4mca/mcga07-home/emergencyresponse/mcga-pollutionresponse/mcga2007-ncp.htm [accessed 23 September 2010].

Maritime and Coastguard Agency. 2007. The UK SCAT manual: a field guide to the documentation of oiled shorelines in the UK. Maritime & Coastguard Agency, Southampton, UK, 47pp+ vi. www.dft.gov.uk/mca/corp_118.pdf [accessed 5 October 2011].

Maritime and Coastguard Agency. 2009. Scientific, Technical and Operational Advice Note: STOp 2/2009. Maritime Pollution Response in the UK: The Environment Group. www.mcga.gov.uk/c4mca/stop_2_09_eg_july_2009.pdf [accessed 23 September 2010].

Maron, D. and Ames, B. 1983. Revised methods for the *Salmonella* mutagenicity test. *Mutation Research*, **113**: 173–215.

Martínez-Gómez, C., Vethaak, A.D., Hylland, K., Burgeot, T., Köhler, A., Lyons, B.P., Thain, J., Gubbins, M.J. and Davies, I.M. 2010. A guide to toxicity assessment and monitoring effects at lower levels of biological organization following marine oil spills in European waters. *ICES Journal of Marine Science*, **67**: 1105–1118.

Matkin, C.O., Saulitis, E.L., Ellis, G.M., Olesiuk, P. and Rice, S.D. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the *Exxon Valdez* oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series*, **356**: 269–281.

Mavor, R.A., Parsons, M., Heubeck, M. And Schmitt, S. 2004. *Seabird numbers and breeding success in Britain and Ireland*. 2003 (UK Nature Conservation, No. 28). Joint Nature Conservation Committee, Peterborough, UK.

Mavor, R.A., Parsons, M., Heubeck, M. and Schmitt, S. 2006. *Seabird numbers and breeding success in Britain and Ireland. 2005* (UK Nature Conservation, No. 30). Joint Nature Conservation Committee, Peterborough, UK.

McKew, B.A., Coulon, F., Osborn, A.M., Timmis, K.N. and McGenity, T.J. 2007. Determining the identity and roles of oil-metabolizing marine bacteria from the Thames estuary, UK. *Environmental Microbiology*, **9**: 165–176.

Miralles, G., Nérini, D., Mante, C., Acquaviva, M., Doumenq, P., Michotey, V., Nazaret, S., Bertrand, J.C. and Cuny, P. 2007. Effects of spilled oil on bacterial communities of Mediterranean coastal anoxic sediments chronically subjected to oil hydrocarbon contamination. *Microbial Ecology*, **54**: 646–661.

Mitchell, P.I. and Parsons, M. 2007. *Strategic review of the UK seabird monitoring programme*. Joint Nature Conservation Committee, Peterborough, UK.

Monaghan, P. and Turner, C.M.R. 1997. Analysis of seabird blood samples following the Sea Empress oil spill. Report to the Countryside Council for Wales from the University of Glasgow. 12pp. + figures.

Monaghan, P., Walton, P., Austin, G., Burns, M.D., Turner, C.M. and Wright, P.J. 1997. Sub-lethal effects of the *Braer* oil spill on seabirds. In: *The impact of an oil spill in turbulent waters:* the Braer, pp. 91–105 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Moore, C.G., Harries, D.B. and Ware, F.J. 1997. *The impact of the* Sea Empress *oil spill on the sandy shore meiofauna of south west Wales*. A report to the Countryside Council for Wales from Heriot-Watt University, Edinburgh, UK. 79pp.

Moore, J.J., Hill, A.S., and Sanderson, W.G. 2005. Development of CCW impact assessment framework for a marine pollution oil spill incident. CCW Marine Monitoring Report No: 20, Countryside Council for Wales, Bangor, UK.

Moore, M.N. and Lowe, D. 2004. Biological effects of contaminants: measurement of Lysosomal membrane stability. *ICES Techniques in Marine Environmental Sciences*, No. 36. 31pp. www.ices.dk/pubs/times/times36/TIMES36.pdf [accessed 31 December 2010].

Morales-Caselles, C., Riba, I. and Ángel DelValls, T. 2009. A weight of evidence approach for quality assessment of sediments impacted by an oil spill: the role of a set of biomarkers as a line of evidence. *Marine Environmental Research*, **67**: 31–37.

Moreira, S., Santos, M., Cunha, I., Sousa, A., Lima, D., Coimbra, J., Reis-Henriques, M.A., Guilhermino, L. 2007. *EROCIPS Report for Task 7.3.5: environmental monitoring report*. www.erocips.org/reports_press_releases.htm [accessed 24 May 2010]. http://www.erocips.org/7.3_environmental_monitoring_report_erocips-2.pdf [accessed 14 January 2011].

Morita, A., Kusaka, Y., Deguchi, Y., Moriuchi, A., Nakanaga, Y., Iki, M., Miyazaki, S. and Kawahara, K. 1999. Acute health problems among the people engaged in the cleanup of *Nakhodka* oil spill. *Environmental Research*, **81**: 185–194.

Mudroch, A. and MacKnight, S.D. 1994. *Handbook of techniques for aquatic sediments sampling*, 2nd edition. CRC Press, Boca Raton, FL, USA. 256pp. ISBN10: 1-56-670027-2. ISBN13: 978-1-56-670027-6.

Murk, A.J., Legler, J., Denison, M.S., Giesy, J.P., van de Guchte, C. and Brouwer, A. 1996. Chemical-activated luciferase gene expression (CALUX): a novel in vitro bioassay for Ah receptor active compounds in sediments and pore water. *Fundamental and Applied Toxicology*, **33**: 149–160.

Murray, S.N., Ambrose, R.F. and Dethier, M.N. 2006. *Monitoring Rocky Shores*. University of California Press, Berkeley, CA, USA. 240pp.

Musgrove, A.J., Langston, R.H.W., Baker, H. and Ward, R.M. (eds.). 2004. *Estuarine waterbirds at low tide, the WeBS low tide counts 1992–93 to 1998–99.* 316pp.

National Academy of Sciences. 1985. *Oil in the sea: inputs, fates and effects*. National Academy Press, Washington, DC, USA. 601pp. ISBN 0-309-03479-5.

National Research Council. 1999. *Spills of nonfloating oils: risk and response*. Committee on Marine Transportation of Heavy Oils. National Academies Press, Washington, DC, USA. 88pp. www.nap.edu/catalog.php?record_id=9640 [accessed 2 July 2010].

National Research Council. 2003. *Oil in the sea III: inputs, fates and effects*. Committee on Oil in the Sea. National Academies Press, Washington, DC, USA. 601pp. www.nap.edu/catalog/10388.html – includes online reading/search facility [accessed 2 July 2010].

National Research Council. 2005. *Oil spill dispersants: efficacy and effects*. Committee on Understanding Oil Spill Dispersants. National Academy Press, Washington, DC, USA. 378pp. www.nap.edu/catalog.php?record_id=11283 [accessed 2 July 2010].

Nijkamp, H. (ed.). 2007. Handbook on good practice for the rehabilitation of oiled birds in the aftermath of an oil spill incident. Sea Alarm Foundation, Brussels, Belgium. 28pp. www.oiledwildlife.eu/files/Rehabilitation%20of%20Oiled%20Birds%20in%20the%20aftermath%20of%20an%20Oil%20Spill%20Incident%20-Handbook-2007.pdf [accessed 24 May 2010].

Nijkamp, H. 2006. Preparedness and response to oiled wildlife incidents in Europe. www.interspill.com/pastevents/cp8.htm [accessed 24 May 2010].

Nikitik, C.C.S. and Robinson, A.W. 2003. Patterns in benthic populations in the Milford Haven waterway following the Sea Empress oil spill with special reference to amphipods. *Marine Pollution Bulletin*, **46**: 1125–1141.

NOAA. 1992. *An introduction to coastal habitats and biological resources*. Chapter 4, Biological Resources. Report No. HMRAD 92–4. National Oceanic and Atmospheric Administration. http://response.restoration.noaa.gov/oilaids/monterey/monterey.html [accessed 2 July 2010].

NOAA. 2000. *Shoreline assessment manual*. HAZMAT Report No. 2000–1. National Oceanic and Atmospheric Administration. 58pp + appendices. http://response.restoration.noaa.gov [accessed 2 July 2010].

NOAA. 2001. *Toxicity of oil to reef-building corals: a spill response perspective*. Technical memorandum NOS OR&R 8. National Oceanic and Atmospheric Administration. 87pp. http://response.restoration.noaa.gov/book_shelf/1_coral_tox.pdf [accessed 9 May 2011].

NOAA. 2003a. *The coastal resource coordinator's bioassessment manual*. Office of Response and Restoration, National Oceanic and Atmospheric Administration. 260pp + appendices. http://response.restoration.noaa.gov [accessed 2 July 2010].

NOAA. 2003b. *Oil and sea turtles: biology, planning and response* (G. Shigenaka (tech. ed.). US National Oceanic and Atmospheric Administration. 116pp. http://response.restoration.noaa.gov/book_shelf/35_turtle_complete.pdf [accessed 19 September 2011].

Nyyssönen, M., Kapanen, A., Piskonen, R., Lukkari, T. and Itävaara, M. 2009. Functional genes reveal the intrinsic PAH biodegradation potential in creosote-contaminated groundwater following in situ biostimulation. *Applied Microbiology and Biotechnology*, **84**: 169–182.

Oda, Y., Nakamura, S., Oki, I., Kato, T. and Shinagawa, H. 1985. Evaluation of the new system (umu-test) for the detection of environmental mutagens and carcinogens. *Mutation Research*, **147**: 219–229.

OSPAR. 1997. Guidelines for general biological effects monitoring. Oslo and Paris Commissions, London, UK. Ref. 1997–7.

OSPAR. 2003. Guidelines for contaminant specific biological effects monitoring. Oslo and Paris Commissions, London, UK. Ref. 2003–10.

Paissé, S., Coulon, F., Goñi-Urriza, M., Peperzak, L., McGenity, T.J. and Duran, R. 2008. Structure of bacterial communities along a hydrocarbon contamination gradient in a coastal sediment. *FEMS Microbiology Ecology*, **66**: 295–305.

Panicker, G., Mojib, N., Aislabie, J. and Bej, A. 2010. Detection, expression and quantitation of the biodegradative genes in Antarctic microorganisms using PCR. Antonie van Leeuwenhoek *Journal of Microbiology*, **97**: 275–287.

Pérez-Cadahía, B., Laffon, B., Valdiglesias, V., Pásaro, E. and Méndez, J. 2008. Cytogenetic effects induced by Prestige oil on human populations: the role of polymorphisms in genes involved in metabolism and DNA repair. *Mutation Research*, **653**: 117–123.

Pérez-Cadahía, B.,Lafuente, A., Cabaleiro, T., Pásaro, E., Méndez, J. and Laffon, B. 2007. Initial study on the effects of Prestige oil on human health. *Environment International*, **33**: 176–185.

Peters, K.E. and Moldowan, J.W. 1993. *The biomarker guide: interpreting molecular fossils in petroleum and ancient sediments*. Prentice Hall, Englewood Cliffs, NJ, USA. ISBN10: 0-13-086752-7. ISBN13: 978-0-13-086752-7.

Peters, K.E., Walters, C.C. and Moldowan, J.W. 2005a. *The biomarker guide. Volume 1: Biomarkers and isotopes in the environment and human history*. Cambridge University Press, Cambridge, UK. 492pp. ISBN10: 0-52-178697-5. ISBN13: 978-0-52-178697-3.

Peters, K.E., Walters, C.C. and Moldowan, J.W. 2005b. *The biomarker guide. Volume 2: Biomarkers and isotopes in petroleum systems and earth history*. Cambridge University Press, Cambridge, UK. 704pp. ISBN10: 0-52-103998-3. ISBN13: 978–052-103998-7.

Piatt, J.F. and Anderson, P. 1996. Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. *American Fisheries Society Symposium*, **18**: 720–737.

Picou, J.S. and Gill, D.A. 1996. The *Exxon Valdez* oil spill and chronic psychological stress. *American Fisheries Society Symposium*, **18**: 879–893. www.jomiller.com/exxonvaldez/articles/picougill2.html [accessed 24 September 2010].

Picou, J.S. and Gill, D.A. 2000. The *Exxon Valdez* disaster as localized environmental catastrophe: dis(similarities) to risk society theory. In: *Risk in the modern age: social theory, science and environmental decision-making*, pp. 143–170 (Cohen, M.J., ed.). Palgrave Macmillan Publishers. ISBN10: 0-312-22216-5. ISBN13: 978-0-312-2216-5. http://stevenpicou.com/pdfs/picou-and-gill%202000_risk-society-theory.pdf [accessed 23 September 2010].

Picou, J.S., Formichella, C., Marshall, B.K. and Arata, C. 2009. Community impacts of the Exxon Valdez oil spill: a synthesis and elaboration of social science research. In: Synthesis: three decades of research on socioeconomic effects related to offshore petroleum development in coastal Alaska (Braund, S.R. and Kruse, J., eds.) Minerals Management Service report MMS OCS study number 2009–006; Contract number 1435–01–98-CT-30914. http://stevenpicou.com/pdfs/community-impacts-of-the-exxon-valdez-oil-spill.pdf [accessed 23 September 2010].

Pollitt, M., Hall, C., Holloway, S., Hearn, R., Marshall, P., Musgrove, A., Robinson, J. and Cranswick, P. 2003. *The Wetland Bird Survey 2000–01. Wildfowl and Wader Counts*. BTO/WWT/RSPB/JNCC, Slimbridge.

Powell, S.M., Riddle, M.J., Snape, I. and Stark, J.S. 2005a. Location and DGGE methodology can influence interpretation of field experimental studies on the response to hydrocarbons by Antarctic benthic microbial community. *Antarctic Science*, **17**: 353–360.

Powell, S.M., Snape, I., Bowman, J.P., Thompson, B.A.W., Stark, J.S., McCammon, S.A. and Riddle, M.J. 2005b. A comparison of the short term effects of diesel fuel and lubricant oils on Antarctic benthic microbial communities. *Journal of Experimental Marine Biology and Ecology*, **322**: 53–65.

Reilly, T.I. and York, R.K. 2001. Guidance on sensory testing and monitoring of seafood for presence of petroleum taint following an oil spill. NOAA Technical memorandum NOS OR&R 9. NOAA, Seattle, WA, USA. *http://response.restoration.noaa.gov/book_shelf/964_seafood.pdf* [accessed 27 May 2010].

Ridoux, V., Lafontaine, L., Bustamante, P., Caurant, F., Dabin, W., Delcroix, C., Hassani, S., Meynier, L., da Silva, V.P., Simonin, S., Robert, M., Spitz, J. and Van Canneyt, O. 2004. The impact of the *Erika* oil spill on pelagic and coastal marine mammals: combining demographic, ecological, trace metals and biomarker evidences. *Aquatic Living Resources*, **17**: 379–387.

Robertson, S.B. 2001. Guidelines and methods for determining oil spill effects. *Proceedings of the 2001 International Oil Spill Conference,* pp. 1545–1548. American Petroleum Institute, Washington, DC, USA.

Roling, W.F.M., Milner, M.G., Jones, D.M., Fratepietro, F., Swannell, R.P.J., Daniel, F. and Head, I.M. 2004. Bacterial community dynamics and hydrocarbon degradation during a field-scale evaluation of bioremediation on a mudflat beach contaminated with buried oil. *Applied Environmental Microbiology*, **70**: 2603–2613.

Rooney-Varga, J.N., Anderson, R.T., Fraga, J.L., Ringelberg, D. and Lovley, D.R. 1999. Microbial communities associated with anaerobic benzene degradation in a petroleum-contaminated aquifer. *Applied Environmental Microbiology*, **65**: 3056–3063.

Rostron, D. 1997. Sea Empress *subtidal impact assessment: Skomer Marine Nature Reserve sediment infauna*. A report to the Countryside Council for Wales from SubSea Survey, Pembroke, UK. 27pp + appendices.

Rostron, D. 1998. Sea Empress *sediment shore impact assessment monitoring: Infauna of heavily oiled shores in Milford Haven and Carmarthen Bay*. A report to the Countryside Council for Wales from SubSea Survey, Pembroke, UK. 51pp + appendices.

Rostron, D. and Bunker, F. 1997. *An assessment of sublittoral epibenthic rock communities and species following the* Sea Empress *oil spill*. A report to the Countryside Council for Wales from Marine Seen and SubSea Survey, Pembroke, UK. 35pp.

Routledge, E.J. and Sumpter, J.P. 1996. Estrogenic activity of surfactants and some of their degradation products assessed using a recombinant yeast screen. *Environmental Toxicology and Chemistry*, **15**: 241–248.

RPI. 2001. *Bird injury quantification*. www.researchplanning.com/services/nrda/Bird.Injury.pdf [accessed 2 July 2010].

RPI. 2002. *Salt marsh reconnaissance*. www.researchplanning.com/services/nrda/saltmarsh.recon.pdf [accessed 2 July 2010].

Russell, J.C., Downs, M.A., Petterson, J.S. and Palinkas, L.A. 1996. Psychological and social impacts of the *Exxon Valdez* oil spill and cleanup. *American Fisheries Society Symposium*, **18**: 867–878.

Rutt, G.P., Levell, D., Hobbs, G., Rostron, D.M., Bullimore, B., Law, R.J. and Robinson, A.W. 1998. The effect on the marine benthos. In: *The Sea Empress oil spill,* pp. 189–206 (Edwards, R. and Sime, H., eds.). Proceedings of a conference held in Cardiff, 11–13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management, London, UK.

Ryland, J. and de Putron, S. 1998. *An appraisal of the effects of the Sea Empress oil spillage on sensitive sessile marine invertebrate communities*. A report to the Countryside Council for Wales from the University of Swansea. 86pp.

Salas, N., Ortiz, L., Gilcoto, M., Varela, M., Bayona, J.M., Groom, S., Álvarez-Salgado, X.A. and Albaigés, J. 2006. Fingerprinting petroleum hydrocarbons in plankton and surface sediments during the spring and early summer blooms in the Galician coast (NW Spain) after the *Prestige* oil spill. *Marine Environmental Research*, **62**: 388–413.

Santos, M.M., Solé, M., Lima, D., Hambach, B., Ferreira, A.M. and Reis-Henriques, M.A. 2010. Validating a multi-biomarker approach with the shanny *Lipophrys pholis* to monitor oil spills in European marine ecosystems. *Chemosphere*, **81**: 685–691.

Schmidt, C.W. 2011. Study to examine health effects in *Deepwater Horizon* oil spill cleanup workers. *Environmental Health Perspectives* 119, a204-a204. doi: 10.1289/ehp.119-a204.

Schmidt-Etkin, D. 2011. Spill occurrences: a world overview. In: *Oil spill science and technology* Chapter 2, pp. 7–48 (Fingas, M., ed.). Gulf Professional Publishing. ISBN 978-1-85617-943-0.

Scholz, D., Michel, J., Shigenaka, G. and Hoff, R. 1992. Biological resources. In: *NOAA report: introduction to coastal habitats and biological resources for spill response*, Chapter 4.

SEEEC. 1998. *The environmental impact of the* Sea Empress *oil spill*. Final report of the Sea Empress Environmental Evaluation Committee. February 1998. The Stationery Office, London, UK. ISBN 0-11-702156-3.

Sell, D., Conway, L., Clark, T., Picken, G.B., Baker, J.M., Dunnet, G.M., McIntyre, A.D. and Clark, R.B. 1995. *Scientific criteria to optimize oil spill clean-up*, pp. 595–610. Proceedings of the 1995 International Oil Spill Conference. American Petroleum Institute, Washington, DC, USA.

Shackley, S.E. and Llewellyn, P.J. 1997. *Sediment shore impact assessment/monitoring: strandline fauna*. A report to the Countryside Council for Wales from University of Wales, Swansea. 29pp + appendices.

Sharp, B.E., Cody, M. and Turner, R. 1996. Effects of the *Exxon Valdez* oil spill on the black oystercatcher. In: *Proceedings of the* Exxon Valdez *Oil Spill Symposium*, Anchorage, Alaska, USA, February 1993. American Fisheries Society Symposium, 18: 748–758.

Shore, R.F. and Wright, J. 1997. *Polycyclic aromatic hydrocarbon and n-alkane residues in seabird eggs after the grounding of the* Sea Empress. Report to the Countryside Council for Wales from the Institute of Terrestrial Ecology, Monks Wood, UK. 40pp.

Short, J.W., Kvenvolden, K.A., Carlson, P.R., Hostettler, F.D., Rosenbauer, R.J. and Wright, B.A. 1999. Natural hydrocarbon background in benthic sediments of Prince William Sound, Alaska – oil vs. coal. *Environmental Science and Technology*, **33**: 34–42.

Sim, M.S., Jo, I.J. and Song, G. 2010. Acute health effects related to the operation mounted to clean the Hebei Spirit oil spill in Taean, Korea. *Marine Pollution Bulletin*, **60**: 51–57.

Smith, A.J., Balaam, J.L. and Ward, A. 2007. The development of a rapid screening technique to measure antibiotic activity in effluents and surface water samples. *Marine Pollution Bulletin*, **54**: 1940–1946.

Sohoni, P. and Sumpter, J.P. 1998. Several environmental oestrogens are also anti-androgens. *Journal of Endocrinology*, **158**: 327–339.

Solomon, G.M. and Janssen, S. 2010. Health effects of the Gulf oil spill. *Journal of the American Medical Association*, **304**: 118–119. doi: 10.1001/jama.2010.1254.

Somerfield, P.J. and Warwick, R.M. 1999. *Appraisal of environmental impact and recovery using* Laminaria *holdfast faunas*. A report to the Countryside Council for Wales from Plymouth Marine Laboratory. 19pp + appendices.

Southward, A.J. and Southward, E.C. 1978. Recolonisation of rocky shores in Cornwall after the use of toxic dispersants to clean up the *Torrey Canyon* spill. *Journal of the Fisheries Research Board of Canada*, **35**: 682–706.

Stagg, R. and McIntosh, A. 1998. Biological effects of contaminants: determination of CYP1A-dependent mono-oxygenase activity in dab by fluorimetric measurement of EROD activity. *ICES Techniques in Marine Environmental Sciences*, No. 23. 16pp. www.ices.dk/pubs/times/times23/TIMES23.pdf [accessed 31 December 2010].

Stout, S.A. and Wang, Z. 2007. Chemical fingerprinting of spilled or discharged petroleum: methods and factors affecting petroleum fingerprints in the environment. In: *Oil spill environmental forensics: fingerprinting and source identification*, Chapter 1, pp. 1–53 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands. 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Taketani, R., Franco, N., Rosado, A. and van Elsas, J. 2010. Microbial community response to a simulated hydrocarbon spill in mangrove sediments. *Journal of Microbiology*, **48**: 7–15.

Taş, S., Okuş, E., Ünlü, S. and Atiok, H. 2011. A study on phytoplankton following "Volgoneft-248" oil spill on the north-eastern coast of the Sea of Marmara. *Journal of the Marine Biological Association of the UK*, 91: 715–725. doi:10.1017/S0025315410000330.

Tecon, R., Beggah, S., Czechowska, K., Sentchilo, V., Chronopoulou, P.-M., McGenity, T.J. and van der Meer, J.R. 2010. Development of a multistrain bacterial bioreporter platform for the monitoring of hydrocarbon contaminants in marine environments. *Environmental Science and Technology*, **44**: 1049–1055.

Thain, J. 1991. Biological effects of contaminants: oyster (*Crassostrea gigas*) embryo bioassay. *ICES Techniques in Marine Environmental Sciences*, No. 11. 12pp. www.ices.dk/pubs/times/times11/TIMES11.pdf [accessed 31 December 2010].

Thain, J. and Bifield, S. 2001. Biological effects of contaminants: sediment bioassay using the polychaete *Arenicola marina*. *ICES Techniques in Marine Environmental Sciences*, No. 29. 16pp. www.ices.dk/pubs/times/times29/TIMES29.pdf [accessed 31 December 2010].

Thain, J. and Roddie, B. 2001. Biological effects of contaminants: *Corophium* sp. sediment bioassay and toxicity test. *ICES Techniques in Marine Environmental Sciences*, No. 28. 21pp.

Thomas, M.L.H. 1978. Comparison of oiled and unoiled intertidal communities in Chedabucto Bay, Nova Scotia. *Journal of the Fisheries Research Board of Canada*, **35**: 707–716.

Uad, I., Silva-Castro, G.A., Pozo, C., González-López, J. and Calvo, C. 2010. Biodegradative potential and characterization of bioemulsifiers of marine bacteria isolated from samples of seawater, sediment and fuel extracted at 4000 m of depth (*Prestige* wreck). *International Biodeterioration and Biodegradation*, **64**: 511–518.

UKTAG. 2009. UKTAG coastal water assessment methods macroalgae: rocky shore reduced species list. Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG). 16pp. ISBN 978-1-906934-17-0

US EPA. 1994. *Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods*. Office of Research and Development, U.S. Environmental Protection Agency.
www.epa.gov/waterscience/library/sediment/marinemethod.pdf [accessed 2 July 2010].

US EPA. 1998. *Method for the determination of semi-volatile organic compounds by gas chromatography/mass spectrometry (GC/MS)*. Method number 8270D.
www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/8270d.pdf [accessed 13 July 2010].

US EPA. 2002. *Methods for evaluating wetland condition: biological assessment methods for birds*. Office of Water, U.S. Environmental Protection Agency, Washington, DC, USA, USA. EPA-822-R-02–023.
www.epa.gov/waterscience/criteria/wetlands/13Birds.pdf [accessed 2 July 2010].

Venosa, A.D., Campo, P. and Suidan, M.T. 2010. Biodegradability of lingering crude oil 19 years after the *Exxon Valdez* oil spill. *Environmental Science and Technology*, 44: 7613–7621.

Viarengo, A., Ponzano, E., Dondero, F. and Fabbri, F. 1997. A simple spectrophotometric method for metallothionein evaluation in marine organisms: an application to Mediterranean and Antarctic molluscs. *Marine Environmental Research*, **44**: 69–84.

Vidal, M., Domínguez, J. and Luís, A. 2011. Spatial and temporal patterns of polycyclic aromatic hydrocarbons (PAHs) in eggs of a coastal bird from northwestern Iberia after a major oil spill. *Science of the Total Environment*, **409**: 2668–2673.

Votier, S.C., Hatchwell, B.J., Beckerman, A., McCleery, R.H., Hunter, F.M., Pellatt, J., Trinder, M. and Birkhead, T.R. 2005. Oil pollution and climate have wide-scale impacts on seabird demographies. *Ecology Letters*, **8**: 1157–1164.

Walsh, P.M., Halley, D.J., Harris, M.P., del Nevo, A., Sim, I.M.W. and Tasker, M.L. 1995. *Seabird monitoring handbook for Britain and Ireland*. A compilation of methods for survey and monitoring of breeding seabirds. Published by JNCC, RSPB, ITE and the Seabird Group. Joint Nature Conservation Committee, Peterborough, UK.

Wang, Z. and Stout, S.A. 2007. *Oil spill environmental forensics: fingerprinting and source identification*. Elsevier, Inc., Amsterdam, The Netherlands. 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Wang, Z., Stout, S.A. and Fingas, M. 2006. Forensic fingerprinting of biomarkers for oil spill characterization and source identification. *Environmental Forensics*, **7**: 105–146.

Wang, Z., Yang, C., Fingas, M., Hollebone, B., Yim, U.H. and Oh, J.R. 2007. Petroleum biomarker fingerprinting for oil spill characterization and source identification. In: *Oil spill environmental forensics: fingerprinting and source identification* Chapter 3, pp. 73–146 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Wang, Z., Yang, C., Hollebone, B., Brown, C.E., Lambert, P., Landriault, M., Sun, J. Yang, Z. and Atkinson, S. 2009. *Forensic fingerprinting and source identification of the 2008 Lake Temiskaming (Quebec) oil spill*, pp. 1–30. Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response 1. Environment Canada, Ottawa, Ontario, Canada.

Wardlaw, G.D., Arey, J.S., Reddy, C.M., Nelson, R.K., Vebtura, G.T. and Valentine, D.L. 2008. Disentangling oil weathering at a marine seep using GCxGC: broad metabolic specificity accompanies subsurface petroleum biodegradation. *Environmental Science and Technology*, **42**: 7166–7173.

Welch, F., Murray, V.S.G., Robins, A.G., Derwent, R.G., Ryall, D.B., Williams, M.L. and Elliott, A.J. 1999. Analysis of a petrol plume over England: 18–19 January 1997. *Occupational and Environmental Medicine*, **56**: 649–656.

Wells, E., Wilkinson, M., Wood, P. and Scanlan, C. 2007. The use of macroalgal species richness and composition on intertidal rocky shores in the assessment of ecological quality under the European Water Framework Directive. *Marine Pollution Bulletin*, **55**: 151–161.

Wheeler, A. 1969. *The fishes of the British Isles and North-West Europe.* Macmillan and Co. Ltd., London, UK. 613pp.

Whittle, K.J., Anderson, D.A., Mackie, P.R., Moffat, Cf., Shepherd, N.J., McVicar, A.H. 1997. The impact of the Braer oil on caged salmon. In: *The impact of an oil spill in turbulent waters: the Braer* (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Widdows, J. and Staff, F. 2006. Biological effects of contaminants: measurement of scope for growth in mussels. *ICES Techniques in Marine Environmental Sciences*, no 40. 30pp. www.ices.dk/pubs/times/times40/TIMES40.pdf [accessed 31 December 2010].

Wolseley, P. and James, P. 1997. *Report of resurvey of lichen quadrats on Skomer Island NNR*. Report to CCW from The Natural History Museum. 79pp.

Wright, P.J., Stagg, R.M. and McIntosh, A.D. 1997. The impact of the *Braer* oil spill on sandeels around Shetland. In: *The impact of an oil spill in turbulent waters:* the Braer, pp. 161–181 (Davies, J.M. and Topping, G., eds.). The Stationery Office Limited, Edinburgh, UK. ISBN 0-11-495798-3.

Yender, R., Michel, J. and Lord, C. 2002. *Managing seafood safety after an oil spill*. Hazardous Materials Response Division, Office of Response and Restoration. National Oceanic and Atmospheric Administration, Seattle, WA, USA. 72pp. http://response.restoration.noaa.gov/book_shelf/963_seafood2.pdf [accessed 27 May 2010].

Young, L.Y. and Phelps, C.D. 2005. Metabolic biomarkers for monitoring *in situ* anaerobic hydrocarbon degradation. *Environmental Health Perspectives*, **113**: 62–67.

Zieman, J.C., Orth, R., Phillips, R.C., Thayer, G. and Thorhaug, A. 1984. The effects of oil on seagrass ecosystems. In: *Restoration and management of marine ecosystems impacted by oil,* pp. 108–126 (Cairns, J and Buikema, A.L., eds.). Butterworth Publishing Co., Boston, MA, USA.

APPENDIX 1

List of projects established under SEEEC to study the impact of the *Sea Empress* oilspill and the recovery of affected areas

Task Group 1: Marine impacts

Impact on local bass stocks.

Impact on herring stocks in Milford Haven.

Effect of oil on sandeel distribution and on bait-fish: the significance for predators.

Hydrocarbon levels in territorial fish species.

Genetic and potentially carcinogenic damage in marine species produced by oil exposure.

Studies of DNA adduct formation.

Impact on the commercial and recreational salmonid fisheries in west Wales.

Impact on the amenity value of the migratory salmonid fishery.

Accumulation by and toxicity of oil to salmonids entering the sea as smolts during the spill aftermath.

Influence of crude oil and dispersants on salmonid migratory behaviour.

Analysis of lobster and crab fisheries and stock biometrics.

Effect of oil on whelk fishery in Carmarthen Bay.

Impact on phytoplankton and zooplankton populations.

Subtidal benthic survey of Milford Haven, Carmarthen Bay and surrounding area.

Subtidal benthic survey of the Celtic Deep.

Laminaria hyperborea holdfast fauna.

Assessment of epibenthic communities and species.

Permanent monitoring site mid-channel rocks.

Skomer marine nature reserve impact assessment/monitoring.

Co-ordination of diver observation reports.

Task Group 2: Shoreline and terrestrial

Pembrokeshire marine species inventory.

Greater Horseshoe bat survey – Castlemartin.

Counts, collection and storage of dead seabirds.

Late winter attendance in seabird colonies.

Coastal/shore bird counts.

Tagged bird release – boat and beached birds.

Ringing rehabilitated birds.

Assessment of affected shores.

Completion of analysis of hydrocarbon levels in dead and moribund biota collected from lower shores and strandlines immediately after the spill.

Summary and interpretation of accessible field data covering the first 6 weeks.

Sensitive sessile communities.

"Before–after control impact paired series" sites for marine and coastal impact measurement around Wales.

Learning from the *Sea Empress* oil spill.

The role of benthic/subaerial algae in coastal ecosystems contaminated with oil.

Skomer, Milford Haven, Dale Fort Field Centre and Orielton Field Centre permanent monitoring transects.

Paludinella littorina monitoring.

Impact and recovery using *Laminaria* communities.

Rock pool communities.

Investigation of the condition of crustose coralline red algae.

Recruitment and reproductive potential of *Asterina* species.

Permanent lichen quadrat monitoring in West Angle Bay.

Permanent lichen quadrat monitoring at Sawdern Point.

Autecological studies of sensitive invertebrate populations in Milford Haven.

Rock pool fauna at West Angle Bay and Manorbier.

Limpet recruitment and age structure.

Infauna of heavily oiled shores in Milford Haven waterway and western Carmarthen Bay.

Infauna in waterfowl feeding/eelgrass areas.

Eelgrass (*Zostera* spp.).

Strandline fauna and flora.

Impacts on meiofauna.

Monitoring of the long-term fate of crude oil in intertidal sediments.

Milford Haven saltmarsh survey.

Terrestrial lichen impact monitoring – re-surveys of existing permanent lichen quadrats at Skomer Island and Stackpole NNRs.

Terrestrial lichen impact monitoring – re-surveys of *Teloschistes flavicans.*

Rare coastal higher plant impact monitoring.

Task Group 2: Shoreline and terrestrial (continued)

Terrestrial sampling programme at key sites – grass, soil, etc.

Razorbill survival, Skomer.

Impacts on the breeding ecology of kittiwakes at Skomer Island.

Survey of breeding seabird colonies in south west Wales.

Impact on breeding cormorant colonies.

Oil contamination of gannets and their nests.

Sampling seabird eggs for sublethal effects.

Sampling seabirds' blood for haemolytic anaemia.

Biometrics and gut contents of dead seabirds.

Land-based counts of common scoter in Carmarthen Bay.

Aerial survey of scoter, Carmarthen Bay.

Biometrics and gut contents of dead scoter from Carmarthen Bay.

Repeat breeding survey of common scoter, Scotland and Ireland.

Survival rates of rehabilitated guillemots.

Review of effectiveness of, and management procedures for, cleaning live oiled birds.

Winter waterfowl counts and bioaccumulation, Milford Haven & Cleddau estuary.

Continue and extend monitoring of grey seal breeding success.

Cetaceans – continue monitoring sightings, and support for the strandings co-ordinator.

Reviewing and refining the assessment of aesthetic impact on the shoreline, and developing criteria.

Amenity and public enjoyment impact assessment.

Re-survey of chronic impact on shoreline aesthetic.

Impact of oil and clean-up on intertidal and shoreline archaeological sites, features and structures.

Assessment of environmental impact of clean-up activities.

Skomer MNR sediment infauna and field data analysis.

Survey of shorelines affected by the spill.

Development of monitoring strategy.

Task Group 3: Pollutant behaviour

Review the effectiveness of the clean-up operation.

The fate of oil on shorelines.

Evaluation of bioremediation techniques.

Benchmarking of existing hydrocarbon data for the area affected by the *Sea Empress*.

Hydrocarbon data review and quality control.

Refinement of the estimated shoreline figure in the oil budget.

Macrobenthic survey of Milford Haven.

Hydrocarbons in the surface microlayer – Milford Haven.

Sediment transport paths outside Milford Haven, in relation to long-term transport of *Sea Empress* oil.

Modelling the vapour cloud.

Review of remote sensing images (aerial/satellite) and their interpretation.

APPENDIX 2

Uptake and loss of PAH in shellfish following the *Sea Empress* oil spill in Wales in 1996

Levels of contamination and the degree of impact can increase rapidly during the initial stages of an incident, as the oil or chemical spilled will be present in the environment at the highest concentrations. These will be reduced over time by dilution, evaporation, dissolution, beaching and a range of other processes. Typically, levels of contamination by, for example, PAH from oils rise rapidly, peak, and then decline over a longer period (see Figure 1).

This suggests that variable timing of sampling events, with shorter time intervals during the initial stages and longer time intervals as the incident progresses, is the most effective means of structuring the programme. In the example given above, which shows PAH in cockles in a closed fishery following the *Sea Empress* incident, all sampling took place at weekly intervals, from 21 February to 26 June. Clearly, with the aim of following the

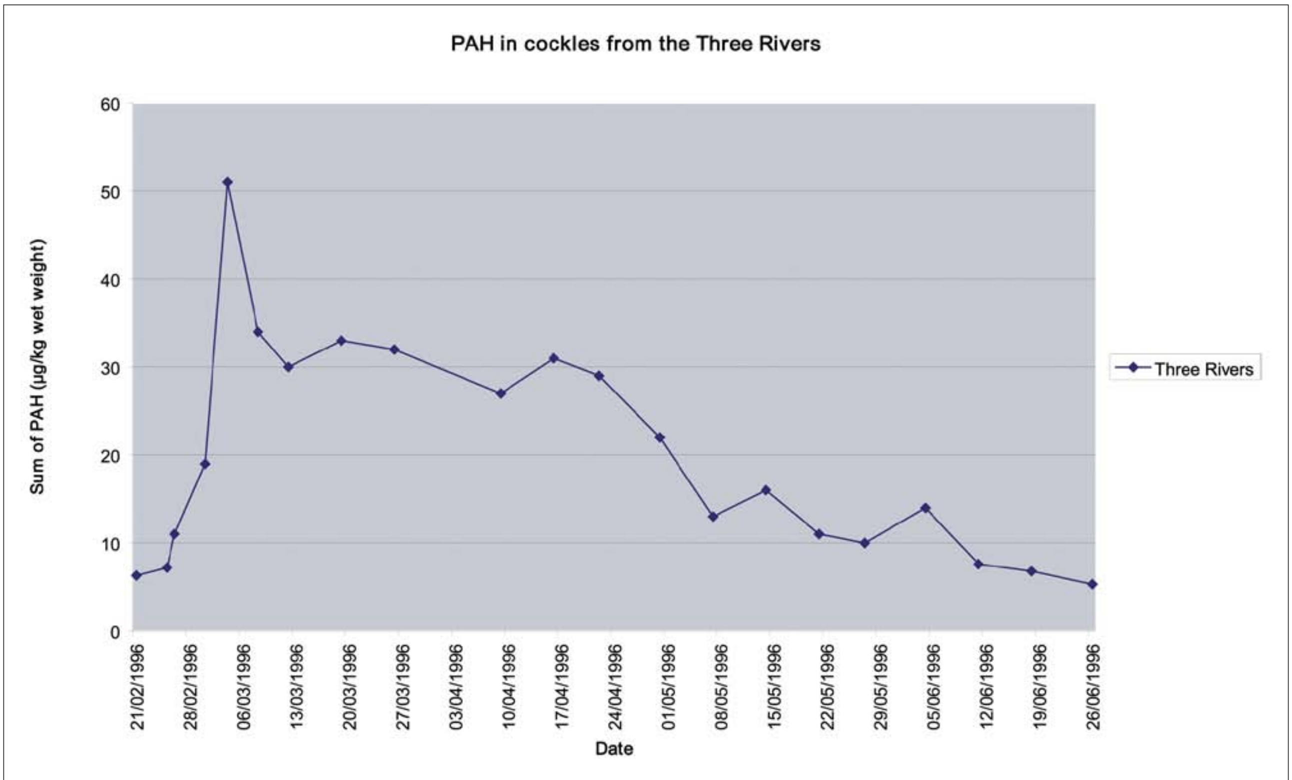


Figure 1

Sum of PAH in cockles from the Three Rivers area, off Carmarthen Bay, following the *Sea Empress* oil spill in 1996.

return to background concentrations at which point the fishery would be reopened, fortnightly or monthly sampling would have sufficed after 13 March. In addition, one should always be aware that no UK locations are entirely uncontaminated. There will be a background level of oil contamination (and of some chemicals, at least close to industrial and urban sites) from multiple sources, and one of the aims of the monitoring programme should be to disentangle these influences so that the true effects of the spill can be assessed. As an example, we can study PAH data for bivalve molluscs collected following the *Sea Empress* spill of 1996.

The principal component analysis (PCA) plot shown in Figure 2 derives from PAH data for bivalve molluscs collected over an almost 18-month period following the spill in February 1996. In simple terms, in PCA plots, vectors that point in similar directions are showing similar behaviour. This plot shows the vectors for the primarily oil-derived PAH (naphthalene, phenanthrene and their alkylated derivatives) clustering away from the combustion-derived PAH, implying that the two groups of compounds are behaving

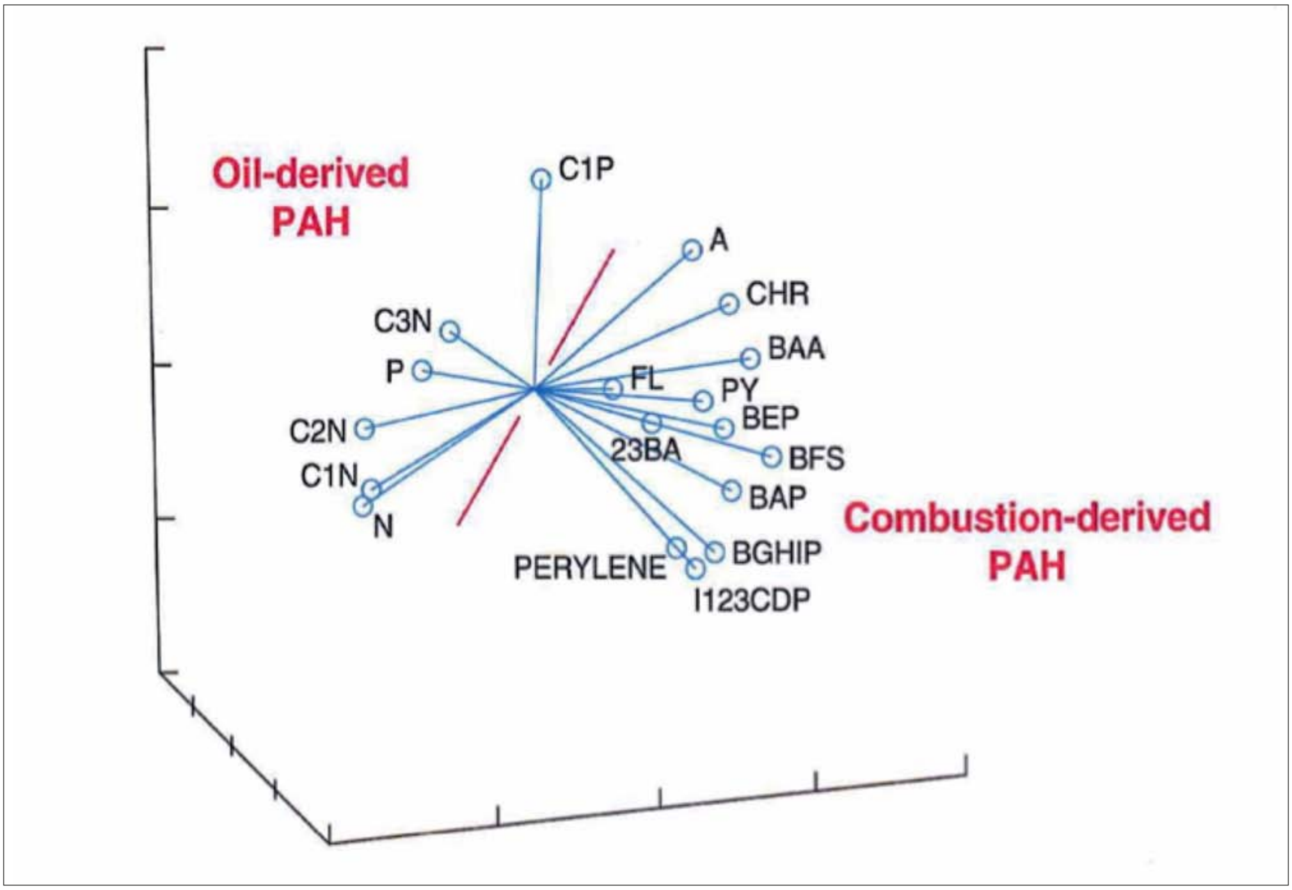


Figure 2

Plot of PAH data for bivalve molluscs (cockles, mussels and oysters) from west Wales derived from principal component analysis.

differently. The first group, the oil-derived PAH, rose to high concentrations immediately after the spill and then declined steadily over the whole period. In contrast, Figure 3 shows the behaviour of one of the combustion PAH (benzo[*a*]pyrene) in mussels from Angle Bay and Dale (both sites within Milford Haven, impacted by bulk oil) over the same period. This shows two peaks of concentration in each case, approximately one year apart and synchronised with each other. This reflects seasonal changes in concentrations of PAH from local combustion sources, unrelated to the spill. Peak concentrations occur just prior to spawning, at which point there is a large release of lipid material and the contaminants (including PAH) sequestered within it. As the animals begin to come back into spawning condition through the autumn, and the lipid content of the animals increases, so concentrations rise once more.

In Figure 4, the same information is presented for three combustion PAH at four locations (see figure caption for details). It is clear from this that the same pattern is observed for PAH and at all sites, including Oxwich Bay in 1997, which was not affected by the oil and

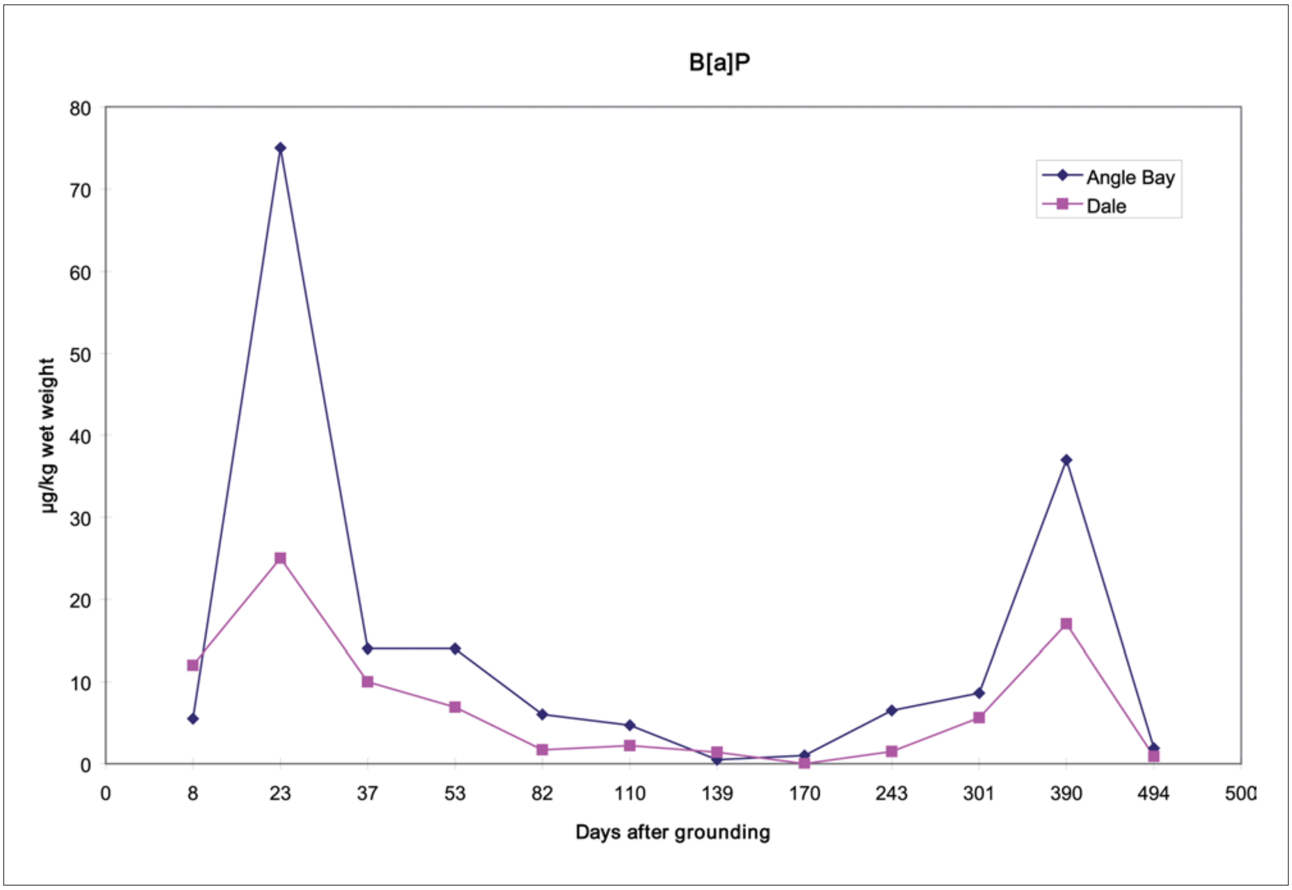


Figure 3

The concentrations of benzo[a]pyrene in mussels from Angle Bay and Dale over the 500-day period following the grounding of the *Sea Empress*.

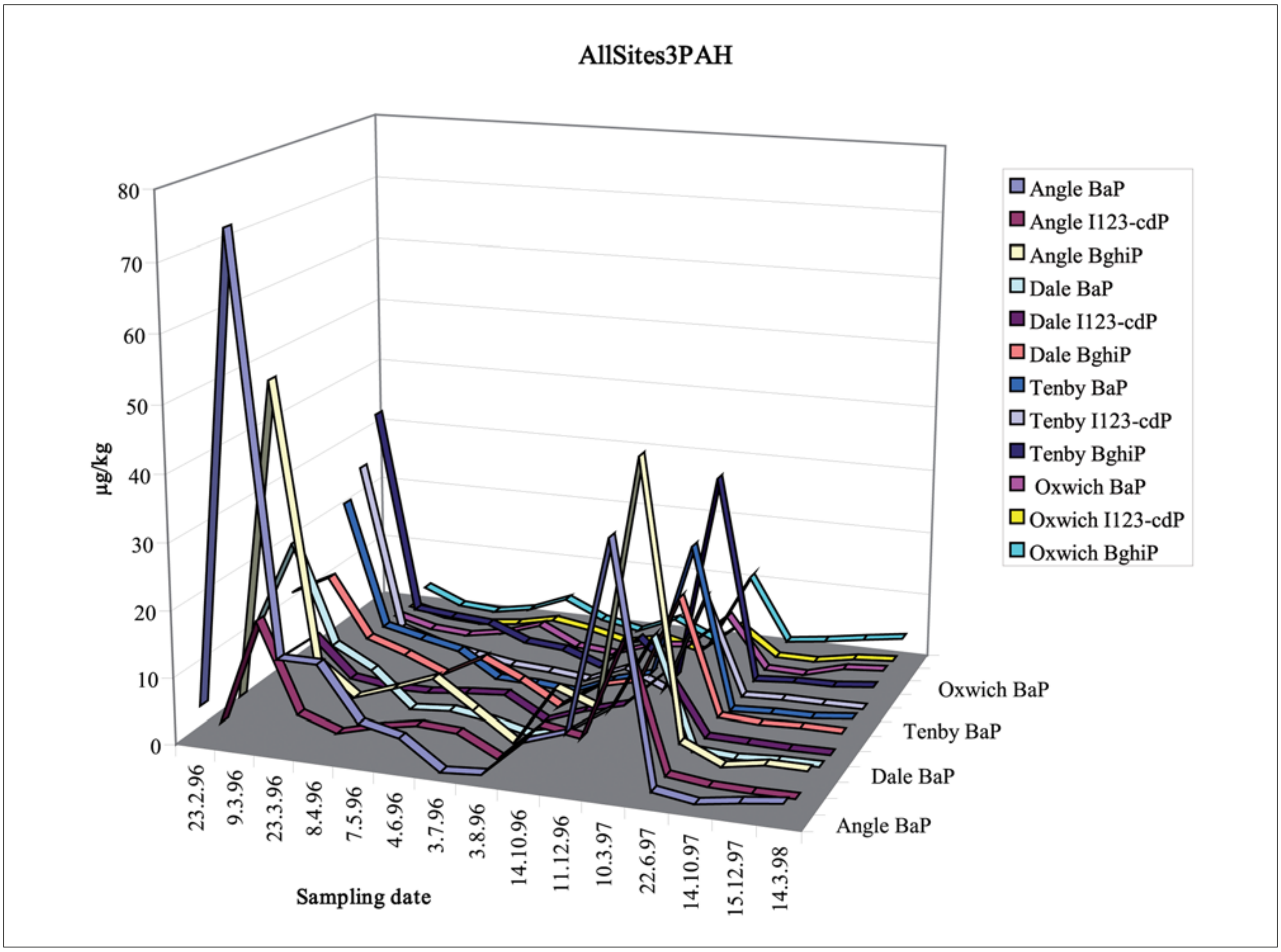


Figure 4

The concentrations of three combustion PAH (benzo[*a*]pyrene, benzo[*ghi*]perylene and indeno[1,2,3-*cd*]pyrene) in mussels from four locations (Angle Bay, Dale, Tenby and Oxwich Bay) over the 500-day period following the grounding of the *Sea Empress*.

was selected as a reference site in late March 1996. What this also demonstrates is that it is essential to monitor for a sufficiently long period to allow such seasonal/annual cycles to operate if comprehensive assessments are going to be possible.

A recent study of spatial and temporal variability of PAH in Kentish plover following the *Prestige* oil spill identified variations in the PAH profiles from year to year, but apparently unrelated to the spilled oil (Vidal et al., 2011). Increases in PAH concentrations and a change in profile towards 4- and 5-ring parent PAH compounds in 2007 was ascribed to forest fires in the area during 2006.

REFERENCE

Vidal, M., Domínguez, J. and Luís, A., 2011. Spatial and temporal patterns of polycyclic aromatic hydrocarbons (PAHs) in eggs of a coastal bird from northwestern Iberia after a major oil spill. *Science of the Total Environment* **409**, 2668-2673.

APPENDIX 3

Typical questions that may be asked at the start of an ecological damage assessment process for an oil or chemical spill

QUESTION	LIMITATIONS AND ISSUES
Describing the acute impact of the oil:	
1. Has oil impacted the ecological resource?	What characteristics of the resource are of interest? – distribution, extent, abundance, productivity, biodiversity, reproductive capacity etc.
2. How many individuals were killed by the oil?	Likely to require extrapolation from available data. Should be put in context with information on regional resource.
3. Has population decreased since the spill?	At what spatial scale?
3a. Has population decreased at selected study sites?	Are selected study sites representative of the region? Could decrease be due to natural decline?
3b. Has regional population decreased since the spill?	Requires thorough census and comparable pre-incident data. Valuable for providing regional context. However, if acute impacts are relatively small or localised, they are likely to be masked by natural variability in total population data
3c. Can pattern of population changes within the region be correlated to oil distribution?	Recognises that there will be natural fluctuations. Requires detailed surveys at numerous oiled and unoiled sites
4. Has extent of habitat decreased?	Similar issues and options as question 3 above
5. Has quality of habitat/community decreased?	Numerous quality attributes to consider
5a. Has productivity/biomass decreased?	Relates well to ecosystem function, but pre-incident data may not be available for many resources
5b. Has abundance of important/ characterising species decreased?	Good chance that pre-incident data and well-developed survey methods are available
5c. Has species richness/diversity decreased?	Relates well to ecosystem function, but results are often strongly influenced by small differences in methodology and associated protocols
5d. Has community composition changed?	Whole-community studies are more likely to identify the more subtle effects, but require more time and effort in sampling and analysis.
5e. Are juveniles more sensitive than adults?	Juvenile stages are often more sensitive to oil, but study methods are often not designed to sample or distinguish them from adults
6. Has oil had sublethal impacts on health of wildlife?	Large range of options for study, including growth rates, reproductive capacity, incidence of disease
Describing processes and causes:	
7. What is relationship between level of oiling and scale of impact?	Different levels of oiling should be built into the impact studies for most resources.
7a. Did fresh oil have more impact than weathered oil?	Toxicity and viscosity of the oil are likely to change dramatically during the course of the spill

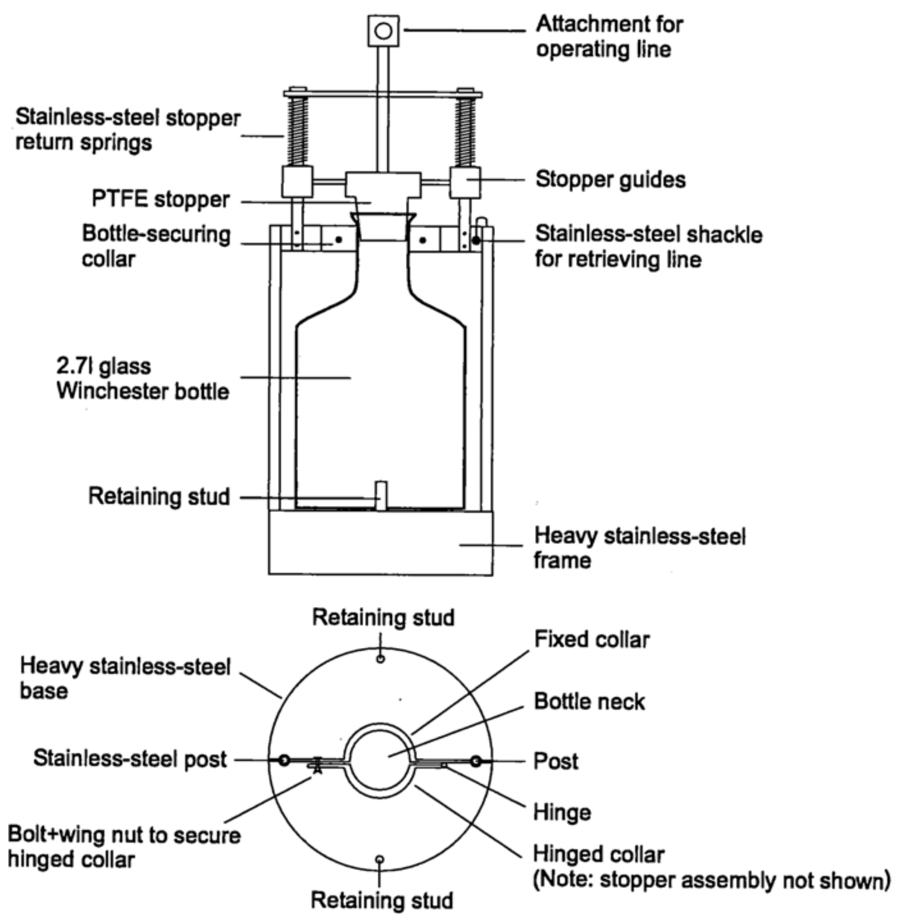
8. What effects did acute impacts have on ecological processes associated with the resource? i.e. what were the knock-on effects.	Requires wide-ranging study of numerous biological and physical components
9. Did other human activities influence the effects of the spill on the resource?	Understanding the influence of confounding factors will be very valuable to the overall assessment of the spill. However, there may be a lot of such factors
10. What physiological/chemical processes caused the impacts?	Likely to be laboratory-based studies. Need to maintain strong link to the reality of natural conditions
Monitoring recovery and other changes:	
11. How long until resource has recovered?	Return to pre-incident conditions or same conditions as unoiled reference areas? For most resources it is likely that logistical and budgetary constraints will limit monitoring to selected sites
11a. How long until resource has returned to pre-incident conditions?	Do you know what it was like before the incident? The natural environment is constantly changing, so resource may never return to pre-incident condition
11b. How long until resource has same conditions as unoiled reference areas?	Are there unoiled reference areas that are directly comparable? Critics will highlight any differences. Need multiple oiled and unoiled sites to provide statistical power
11c. What were natural removal rates of remaining oil?	Natural removal can be surprisingly rapid, but study of its rates will require some sites to remain uncleaned
11d. How does recovery progress between start and end points?	A continuous linear progression in recovery is unlikely.
11e. Do patterns of post-spill changes correlate with level of initial impact?	Understanding thresholds in oiling and recovery rates will be very valuable, but will require a lot of time and effort
Describing the effects of the response:	
12. Did spill response activity have beneficial or detrimental effect on resource?	Often not straightforward. Could involve assessment of short-, medium- and long-term physical damage; toxicity of acute and chronic oiling; knock-on effects to associated wildlife; behavioural (e.g. disturbance) effects; etc.
12a. Did removal of oil speed up recovery of habitat/community?	Could be studied at broad scale, assessing recovery on basis of broad parameters like extent; or at site specific level with more detailed community sampling
12b. What effect did dispersants have on resource?	Will require considerable temporal data on the distribution and concentrations of oil in the water/sediment, and on the ecological resource
12c. What was behavioural response of shore birds to beach clean-up?	Behavioural response is difficult to study, but can provide valuable information to aid our understanding of ecological effects
13. Did habitat restoration measures work?	Assessing the success of restoration activity (e.g. replanting saltmarsh or stabilising damaged dunes) should be related to the initial objectives of the work

APPENDIX 4

Sampling

A simple subsurface water sampler is described in Kelly *et al.* (2000). Glass Winchester solvent bottles (2.7 l volume) are mounted in a weighted stainless-steel frame which is deployed by means of a nylon rope. The bottle is sealed using a PTFE stopper, which may be removed when the sampler is at the required sampling depth by means of a second nylon rope. The stopper is spring-loaded so that the bottle may be resealed when full, being open, therefore, only during sample collection and sealed during deployment and recovery. This prevents contamination by any surface films that may be present on the sea. Sample bottles are rigorously cleaned with pentane (the solvent used for extraction of water samples) before use. The sampler (particularly the stopper) is cleaned with pentane at the start of each day's sampling, periodically during sampling, following a period of inactivity, or after use in areas in which high concentrations of the determinands may have been encountered.

Figure 5
Design of a Cefas shallow-water sampler



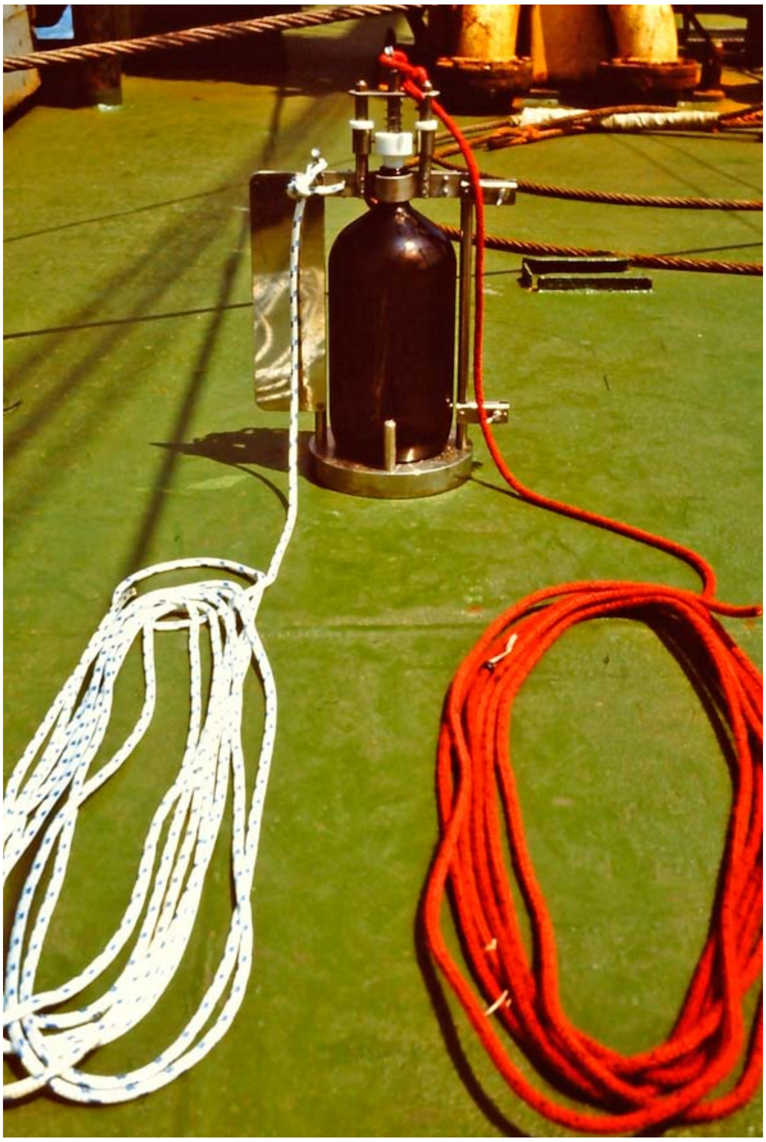


Figure 6

Cefas shallow-water sampler rigged for use. The sampler is lowered using the white rope, and opened and closed using the red rope. Note the clips and stabilising vane for deployment from a hydrowire.

This shallow water sampler has been in use for over 25 years and has proved to be both robust and reliable. It has been shown to be capable of collecting uncontaminated samples for a variety of other trace organic contaminants as well as hydrocarbons, including *iso*-propyl benzene, tetrachloroethene and phthalate esters in the low ng l^{-1} concentration range. When deployed from a hydrowire following the addition of mounting clips and an aluminium vane to prevent spinning (see Figure 6), the bottles can be used to a depth of at least 50 m without imploding (Law and Whinnett, 1993); for sampling at depths of 10 m or less, the sampler can be operated by hand using two lines. When deployed from a hydrowire (Kevlar preferred), only the opening/closing line is used once the sampler is at the required depth.

Recent experience in the Gulf of Mexico following the *Deepwater Horizon* oil spill suggests that sampling may also be needed in deeper waters, such as those to the west of the Shetland Islands. Oil production is already under way in water depths of 140–600 m. Production in the Foinaven, Schiehallion and Clair oilfields began in 1997–2005.

Drilling in the Lagavulin prospect, in a water depth >1500 m, began in 2010. Water sampling for oil and chemicals can be undertaken using hydrographic sampling bottles, preferably with a PTFE internal lining, such as available for the GO-FLO bottle produced by General Oceanics in the USA. These are deployed by hydrowire and the bottles closed at sampling depth using either a messenger or by signal from the deploying vessel via a rosette sampler. Oil concentrations in deeper water can be monitoring semi-continuously using a Chelsea Instruments Ltd (UK-based) UV AQUA^{tracka} fluorimeter, which is towed behind a vessel and can be used to depths of 6,000 m. The sampling rate is approximately 0.5 Hz and the limit of detection is ca. 1 µg/l oil. Sediment samples can be taken using grabs or coring devices, or by means of remotely operated vehicles deployed and controlled from a surface vessel. Initial findings from the monitoring studies undertaken following the *Deepwater Horizon* spill can be found at www.restorethegulf.gov/release/2010/12/16/data-analysis-and-findings . (see also Camilli et al., 2010, and Hazen et al., 2010). Sediment samples can be collected by hand in intertidal areas. The use of stainless-steel spoons for sample collection is recommended, as they can be readily solvent cleaned between samples to prevent cross-contamination. In subtidal areas grabs and corers can be used, although this requires the use of a boat. Corers are generally used to remove a core from the seabed. If samples are taken from stable sediment areas, then increasing depth in the sediment (down the core from the surface) represents an increasing time since the sediment was laid down. Sediment core slices can be dated by determination of the ^{210}Pb content. ^{210}Pb is a radioactive form of lead, which is one of the last elements created by the radioactive decay of uranium 238 (^{238}U). ^{210}Pb forms naturally in the sediments and rocks that contain ^{238}U, as well as in the atmosphere (a by-product of radon gas), from which it falls to the Earth's surface. The ^{210}Pb eventually decays into a non-radioactive form of lead. ^{210}Pb has a half-life of 22.3 years. It takes about 7 half-lives, or 150 years, for the ^{210}Pb in a sample to reach near-zero radioactivity, so that is the maximum time that can be determined. In a post-spill situation, though, it is the recent history that is of interest, so grab samplers that sample the top few centimetres of the sediments are most often used. A van Veen grab is shown in Figure 7. Small versions can

Figure 7

A van Veen grab in the cocked position, ready for sampling.

Figure 8
A hand-held van Veen grab used for sampling in estuaries from wharves, jetties or small boats, showing the sediment collected.

be operated "hand-held" from small boats, jetties, quaysides, etc. (see Figure 8).
Further offshore, a range of grab devices can be deployed from larger vessels. The choice of grab can be influenced by the type of sediment to be sampled. A 0.1 m^2 modified Day grab is a good general-purpose grab, but in sediments that contain stones the bottom-closing jaws of the grab can be held open, causing the sediment to wash out as the grab is recovered after sampling. In this case a Shipek grab, whose single jaw closes at the side of the sampler, is preferred. In full gravels a Hamon grab is generally more effective. Because of their weight, grabs are usually deployed by means of a winch. However, a rope can be used instead, with deployment by free-fall and recovery using a whipping drum. If a wire is used to deploy the grab, a ca. 2 m length of rope should be attached between the eye of the winch wire and the grab to prevent contamination from the greases used on the wire.

Figure 9
A 0.1 m^2 modified Day grab about to be deployed.

Sediment samples should be stored in either glass or aluminium canisters. For the former, pre-cleaned 500 ml wide-mouthed Beatson jars are preferred, although, as these have waxed lid liners, a sheet of cleaned aluminium foil should be placed over the top of the jar before the lid is screwed on to prevent contact between lid liner and sample, so as to avoid possible contamination of the sample. The containers should not be filled to more than 80% of their capacity, to allow for expansion when the sediment samples are stored frozen at –20°C prior to analysis.

Mudroch and MacKnight (1994) provide comprehensive guidance on sampling procedures for collection of bottom sediments, suspended particulate material and sediment pore water. In some instances, it may be desirable to use sediment traps to sample particles falling through the water column in order to estimate the flux of spilled oil or chemicals to the seabed sediments. We have not been able to locate any guidance relating to their use, but references relating to one oil spill study in which these were deployed are given (Boehm et al., 1982; Johansson et al., 1980).

The methods used for sampling biota (primarily fish and shellfish) will vary depending on the species that are of interest and the habitats in which they subsist. Pelagic and demersal fish are best collected using commercial fishing gears at preselected locations, using fishing vessels and utilising the knowledge of the fishermen themselves regarding suitable areas. Shellfish and other intertidal organisms can be hand-collected on a suitable tide, or taken using a variety of nets, dredges, etc., as used by commercial boats. Biota should be whole and should be transported on ice or with cool blocks if the laboratory is sufficiently close to the sampling sites (in both space and time). If this is not feasible then the samples can be frozen prior to transport. Purchasing fish from retail outlets (such as fish markets) is not recommended, as point-of-origin records are notoriously unreliable. All contaminants in biota exhibit significant variability in concentrations between individuals, and a number of fish and shellfish should be taken and analysed (either individually or as pooled samples) in order to reduce the level of variability. The number of each species needed in order to provide a “representative” sample should be established with reference to the level of variability for the determinand(s) of concern, but it is often of the order of 5 individual fish, crabs and lobsters, and 25 individual shellfish in the case of mussels, oysters, clams etc. When sampling for human health risk assessment – for example, in the case of a fishery closure – local consumption should be taken into account. Following the *Sea Empress* oil spill in 1996, three seaweed species were included within the monitoring programme as these are eaten in Wales (Law and Kelly, 2004). This is also the case in Northern Ireland.

Of prime importance is the avoidance of contamination of the biota samples during collection and transport to the analytical laboratory. On board vessels, this could include cross-contamination from sampling gear, shipboard fuels, lubricants and greases, engine exhaust and overboard discharges.

Sample label information

Station number:
Sample number:
Sample type:
Sampling date:

Sampling time:
Destination laboratory:
For attention of:

Logsheet information

Station number:
Sample number:
Sampling date:
Sampling platform (ship) code (if relevant):
Sampling time (GMT/UTC):
Site code:
Location (name, and lat./long. or National Grid Reference):
Position fixing type code:
Sample type:
Sampling method
Destination laboratory:
For attention of:
Storage temperature:
Analysis (or analyses) to be undertaken:
Additional information:

Additional information for biota

Species common name:
Species scientific name:
Benthos sample: Y/N

Additional information for seawater

Sampling bottle code:
Sampling depth (m):
Filtration method (if used):

Additional information for sediments

Sediment type (visual characterisation):

Additional information for birds

Ring attached?: Y/N
Ring description and number:

UK Clean Seas Environment Monitoring Programme.

Notes: positions should fixed using WGS-84 chart datum (see Green Book at www.cefas.defra.gov.uk/publications/scientific-series/green-book.aspx).
Sampling platform codes, position fixing type codes, site codes, method of storage codes, fishing gear codes, seawater sampling equipment codes, and seawater filtration codes can also be found here.

Sample tracking using barcodes and barcode readers

Keeping track of a large number of samples is difficult and requires organisation. One very successful and simple technique involves the addition of a barcode label to a sample at the time of collection, tied to a database holding full information about the sample via a portable digital assistant (PDA, also known as a handheld or palm computer). Such sample tracking is an important aspect of quality assurance, and it ensures that information relating to the sample location, stage in processing and the person with current custody of the sample is immediately available. A clearly defined procedure for storage, analysis, tracking and disposal of samples is also required.

The system works by using a fixed computer that holds the sample database, synchronising with an integrated PDA with a laser barcode reader that can removed from its cradle and then be used as a portable device. The barcode label affixed to each sample does not carry the sample number directly: each time a barcode is generated the barcode value increments by 1. It is the database that ties the barcode, sample number and sample information together. Storage locations (cupboards, freezers, shelves etc.) can also be barcoded and scanned when samples are moved and the new location recorded. User names and passwords are required in order to change the person currently responsible for the sample, therefore providing chain-of-custody information.

REFERENCES

Boehm, P.D., Barak, J.E., Fiest, D.L. and Elskus, A.A. 1982. A chemical investigation of the transport and fate of petroleum hydrocarbons in littoral and benthic environments: the Tsesis oil spill. *Marine Environmental Research*, **6**: 157–188.

Camilli, R., Reddy, C.M., Yoerger, D.R., Van Mooy, B.A.S., Jakuba, M.V., Kinsey, J.C., McIntyre, C.P., Sylva, S.P. and Maloney, J.V. 2010. Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon. *Science*, **330**: 201–204. doi: 10.1126/science.1195223.

Hazen, T.C., Dubinsky, E.A., DeSantis, T.Z., Andersen, G.L., Piceno, Y.M., Singh, N., Jansson, J.K., Probst, A., Borglin, S.E., Fortney, J.L., Stringfellow, W.T., Bill, M., Conrad, M.E., Tom, L.M., Chavarria, K.LO., Alusi, T.R., Lamendella, R., Joyner, D.C., Spier, C., Baelum, J., Auer, M., Zemla, M.L., Chakraborty, R., Sonnenthal, E.L., D'haeseleer, P., Holman, H.-Y.N., Osman, S., Lu, Z., Van Nostrand, J.D., Deng, Y., Zhou, J. and Mason, O.U. 2010. Deep-sea plume enriches indigenous oil-degrading bacteria. *Science*, **330**: 204–208. doi: 10.1126/science/1195979.

Johansson, S., Larsson, U. and Boehm, P. 1980. The Tsesis oil spill. *Marine Pollution Bulletin*, **11**: 284–293.

Kelly, C.A., Law, R.J. and Emerson, H.S. 2000. Methods of analysis for hydrocarbons and polycyclic aromatic hydrocarbons (PAH) in marine samples. Aquatic environment protection: analytical methods, 12. Cefas, Lowestoft, UK. www.Cefas.co.uk/publications/aquatic/aepam12.pdf [accessed 24 May 2010].

Law, R.J. and Kelly, C. 2004. The impact of the "*Sea Empress*" oil spill. Aquatic Living Resources, **17**: 389–394.

Law, R.J. and Whinnett, J.A. 1993. The determination of polycyclic aromatic hydrocarbons in seawater from the FLUXMANCHE transect (Dover Strait). *Oceanologica Acta*, **16**: 593–597.

Mudroch, A. and MacKnight, S.D. 1994. *Handbook of techniques for aquatic sediments sampling*, 2nd edition. CRC Press, Boca Raton, FL, USA. 256pp. ISBN -10-1-56-670027-2. ISBN13: 978-1-56-670027-6.

APPENDIX 5

Chemical fingerprinting

Environmental forensics has been defined as the systematic and scientific evaluation of physical, chemical and historical information for the purpose of developing defensible scientific conclusions relevant to the liability for environmental contamination (Wang and Stout, 2007). Under this heading, chemical fingerprinting using a variety of methods and target biomarker compounds has been widely applied to oil spills of both known and unknown origin (e.g. in the case of the *Prestige* oil spill: Bartolomé et al., 2007; Salas et al., 2006; and two mystery oil spills in Brazil and Canada: Lobão et al., 2010; Wang et al., 2009). Wang and Stout (2007) have gathered these approaches together in an authoritative book, and a summary of the approaches will be provided here.

Oil enters the sea from both anthropogenic and natural sources, such as oil seeps. Operational discharges of oil from ships have been banned in the seas around the UK since 1999, when the NW European seas were declared a special area under annex 1 of MARPOL, but they may still occur occasionally and illegally. The aim of chemical fingerprinting is the generation and comparison of diagnostic chemical features amongst oil samples (those taken from the environment and suspected source oils) (Stout and Wang, 2007). In addition, chemical fingerprinting seeks to distinguish contamination due to specific oils from that due to chronic inputs that form a background contamination pattern. Allocation of the contribution of any pre-existing anthropogenic and/or naturally occurring “background” hydrocarbons from those spilled is also necessary, as is accounting for changes in the spilled oil over time due to weathering processes. The application of these types of source allocation techniques following the *Exxon Valdez* spill in Alaska can be found in, for example, Short *et al.* (1999), Boehm *et al.* (2001) and Burns *et al.* (2006), and an overview is given in Bence *et al.* (2007). The application of chemometrics to oil spill fingerprinting has been reviewed by Christensen and Tomasi (2007).

Coupled high-resolution (capillary) gas chromatography–mass spectrometry (GC-MS) is the method of choice for chemical fingerprinting and is the most commonly used technique (Stout and Wang, 2007). However, developments in the field of comprehensive two-dimensional gas chromatography (GC x GC) make it a technique that has the potential to revolutionise forensic oil spill investigations, as the increased resolving power allows the separation of many more compounds in complex mixtures than can be made with traditional (one-dimensional) gas chromatography (Arey et al., 2007a, 2007b; Gaines *et al*., 2007; Wardlaw et al., 2008). Increased chromatographic resolution is achieved by using two chromatographic columns of different selectivity joined together using a modulator. This periodically traps a portion of the eluent from the first column and injects it into the second column for further separation (Gaines et *al.*, 2007). Because of the speed of response needed to adequately sample the fast eluting peaks, GC x GC is preferably coupled to a time-of-flight mass spectrometer (ToFMS), to form a GC x GC-ToFMS system. In GC-MS, both low-resolution (quadrupole or ion-trap MS) and high-resolution MS instruments can be used satisfactorily. In fact, the preferred instrument in terms of low cost and performance is an ion-trap MS, as it can be operated in full scan mode with no limitation in sensitivity, unlike a quadrupole MS which displays higher sensitivity in single/multiple-ion monitoring mode. This means that stored scans from targeted PAH analyses can also be used for chemical fingerprinting purposes. Suitable instrumental conditions for chemical fingerprinting using GC-MS can be found in US EPA standard method 8270D (US EPA, 1998).

Whereas combustion PAH consist primarily of parent (unalkylated) PAH compounds, oils contain mainly alkylated PAH. Generally, in post-oil spill studies, a range of PAH compounds including C_1- to C_4-substituted PAH are determined (a typical list is given in Stout and Wang, 2007). These can have a large number of isomers, and the distribution of these will vary in different oils, so the PAH isomer profiles can be used for comparative purposes and for matching of spill samples and potential (or known) source oils. Profiles of aromatic sulphur heterocyclic compounds (derivatives of benzothiophene, dibenzothiophene and naphthobenzothiophene) can be used in the same way as those for, for example, fluorene, naphthalene, phenanthrene/anthracene, fluoranthene/pyrene and chrysene/benzanthracene (Hegazi and Andersson, 2007).

Biomarkers (= biological markers) are complex hydrocarbon molecules derived from formerly living organisms, and are present in crude oils at low concentrations (<100 ppm) (Wang *et al.*, 2007). Environmental applications of biomarker fingerprinting have been extensively reviewed elsewhere (Peters *et al.*, 2005a, 2005b; Wang *et al.*, 2006) but will be summarised below.

All oil biomarker compounds are based on isoprene subunits (isoprene is 2-methyl-1, 3-butadiene: $CH_2=C(CH_3)-CH=CH_2$) (Peters and Moldowan, 1993). Compounds composed of isoprene subunits are called terpenoids or isoprenoids.

Acyclic terpenoids or isoprenoids

The most commonly determined of this class of compounds are pristane and phytane (2,6,10,14-tetramethylpentadecane and 2,6,10,14-tetramethylhexadecane). On low-polarity GC columns they elute just after *n*-heptadecane and *n*-octadecane, respectively. Both compounds occur in oils, but pristane is also produced naturally (e.g. by algae) and so also reflects biogenic inputs, so the ratio of pristine to phytane can be used to identify natural inputs. These branched chain hydrocarbons are more resistant to biodegradation than the normal straight chain alkanes, and so tracking reductions in the C_{17}:pristane and C_{18}:phytane rations can be used to reflect the progress of biodegradation of oils in the environment (Law, 1980).

Cyclic terpenoids

The most commonly used of these compounds in forensic oil spill studies are the steranes and terpanes – for a comprehensive list of those compounds, see Table 3-1 in Wang *et al.* (2007). These compounds are visualised by extracting mass chromatograms at m/z values of 191 (terpanes) and 217 (steranes). Wang *et al.* (2007) also provide a comprehensive series of chromatograms in which the peaks due to all commonly used biomarker compounds are identified, and also a wide range of illustrative material indicating oil-to-oil variations and the use of pattern matching to distinguish sources.

REFERENCES

Arey, J.S., Nelson, R.K. and Reddy, C.M. 2007a. Disentangling oil weathering using GCxGC: 1. Chromatogram analysis. *Environmental Science and Technology*, **41**: 5738–5746.

Arey, J.S., Nelson, R.K., Plata, D.L. and Reddy, C.M. 2007b. Disentangling oil weathering using GCxGC: 2. Mass transfer calculations. *Environmental Science and Technology*, **41**: 5747–5755.

Bartolomé, L., Deusto, M., Etxebarria, N., Navarro, P., Usobiaga, A. and Zuloaga, O. 2007. Chemical fingerprinting of petroleum biomarkers in biota samples using retention-time locking chromatography and multivariate analysis. *Journal of Chromatography A*, **1157**: 369–375.

Bence, A.E., Page, D.S. and Boehm, P.D. 2007. Advances in forensic techniques for petroleum hydrocarbons: the *Exxon Valdez* experience. In: *Oil Spill Environmental Forensics: Fingerprinting and Source Identification*, Chapter 15, pp. 449–487 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Boehm, P.D., Page, D.S., Burns, W.A., Bence, A.E., Mankiewicz, P.J. and Brown, J.S. 2001. Resolving the origin of the petrogenic hydrocarbon background in Prince William Sound, Alaska. E*nvironmental Science and Technology*, **35**: 471–479.

Burns, W.A., Mudge, S.M., Bence, A.E., Boehm, P.D., Brown, J.S., Page, D.S. and Parker, K.R. 2006. Source allocation by least-squares hydrocarbon fingerprint matching. *Environmental Science and Technology*, **40**: 6561–6567.

Christensen, J.H. and Tomasi, G. 2007. Practical aspects of chemometrics for oil spill fingerprinting. *Journal of Chromatography A*, **1169**: 1–22.

Gaines, R.B., Frysinger, G.S., Reddy, C.M. and Nelson, R.K. 2007. Oil spill source identification by comprehensive two-dimensional gas chromatography (GC x GC). In: *Oil spill environmental forensics: fingerprinting and source identification*, Chapter 5, pp. 169–206 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Hegazi, A.H. and Andersson, J.T. 2007. Characterization of polycyclic aromatic sulphur heterocycles for source identification. In: *Oil spill environmental forensics: fingerprinting and source identification*, Chapter 4, pp. 147–168 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Law, R.J. 1980. Changes in the composition of oil from the "*Amoco Cadiz*". Science of the Total Environment, **15**: 37–49.

Lobão, M.M., Cardoso, J.N., Mello, M.R., Brooks, P.W., Lopes, C.C. and Lopes, R.S.C. 2010. Identification of source of a marine oil-spill using geochemical and chemometric techniques. *Marine Pollution Bulletin*, **60**: 2263–2274.

Peters, K.E. and Moldowan, J.W. 1993. *The biomarker guide: interpreting molecular fossils in petroleum and ancient sediments*. Prentice Hall, Englewood Cliffs, NJ, USA. ISBN10: 0-13-086752-7. ISBN13: 978-0-13-086752-7.

Peters, K.E., Walters, C.C. and Moldowan, J.W. 2005a. *The biomarker guide. Volume 1: Biomarkers and isotopes in the environment and human history*. Cambridge University Press, Cambridge, UK. 492pp. ISBN10: 0-52-178697-5. ISBN13: 978-0-52-178697-3.

Peters, K.E., Walters, C.C. and Moldowan, J.W. 2005b. *The biomarker guide. Volume 2: Biomarkers and isotopes in petroleum systems and earth history*. Cambridge University Press, Cambridge, UK. 704pp. ISBN10: 0-52-103998-3. ISBN13: 978–052-103998-7.

Salas, N., Ortiz, L., Gilcoto, M., Varela, M., Bayona, J.M., Groom, S., Álvarez-Salgado, X.A. and Albaigés, J. 2006. Fingerprinting petroleum hydrocarbons in plankton and surface sediments during the spring and early summer blooms in the Galician coast (NW Spain) after the Prestige oil spill. *Marine Environmental Research*, **62**: 388–413.

Short, J.W., Kvenvolden, K.A., Carlson, P.R., Hostettler, F.D., Rosenbauer, R.J. and Wright, B.A. 1999. Natural hydrocarbon background in benthic sediments of Prince William Sound, Alaska – oil vs. coal. *Environmental Science and Technology*, **33**: 34–42.

Stout, S.A. and Wang, Z. 2007. Chemical fingerprinting of spilled or discharged petroleum: methods and factors affecting petroleum fingerprints in the environment. In: *Oil spill environmental forensics: fingerprinting and source identification*, Chapter 1, pp. 1–53 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands. 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

US EPA. 1998. *Method for the determination of semi-volatile organic compounds by gas chromatography/mass spectrometry (GC/MS)*. Method number 8270D. www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/8270d.pdf [accessed 13 July 2010].

Wang, Z. and Stout, S.A. 2007. *Oil spill environmental forensics: fingerprinting and source identification*. Elsevier, Inc., Amsterdam, The Netherlands. 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Wang, Z., Stout, S.A. and Fingas, M. 2006. Forensic fingerprinting of biomarkers for oil spill characterization and source identification. *Environmental Forensics*, **7**: 105–146.

Wang, Z., Yang, C., Fingas, M., Hollebone, B., Yim, U.H. and Oh, J.R. 2007. Petroleum biomarker fingerprinting for oil spill characterization and source identification. In: *Oil spill environmental forensics: fingerprinting and source identification* Chapter 3, pp. 73–146 (Wang, Z. and Stout, S.A., eds.). Elsevier, Inc., Amsterdam, The Netherlands 554pp. ISBN10: 0-12-369523-6. ISBN13: 978-0-12-369523-9.

Wang, Z., Yang, C., Hollebone, B., Brown, C.E., Lambert, P., Landriault, M., Sun, J. Yang, Z. and Atkinson, S. 2009. *Forensic fingerprinting and source identification of the 2008 Lake Temiskaming (Quebec) oil spill*, pp. 1–30. *Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response 1*. Environment Canada, Ottawa, Ontario, Canada.

Wardlaw, G.D., Arey, J.S., Reddy, C.M., Nelson, R.K., Vebtura, G.T. and Valentine, D.L. 2008. Disentangling oil weathering at a marine seep using GCxGC: broad metabolic specificity accompanies subsurface petroleum biodegradation. *Environmental Science and Technology*, **42**: 7166–7173.

APPENDIX 6

A review of hydrocarbon-induced impacts on microbial communities

Many studies have investigated in detail hydrocarbon-induced impacts on microbial communities and their potential for recovery. Generally, it is well known that contamination with hydrocarbons causes changes in microbial community structure (Taketani et al., 2010; Rooney-Varga et al., 1999; Bachoon et al., 2001; Powell et al., 2005a, 2005b; Cappello et al., 2007; Cuny et al., 2007; McKew et al., 2007; Miralles et al., 2007; Paissé et al., 2008; Alonso-Gutiérrez et al., 2009; Lanfranconi et al., 2010). In particular, it has been observed that, especially, marine hydrocarbon degraders like *Alcanivorax* sp. or sp. increase as a result of oil contamination. This is accompanied by an increase in overall bacterial abundance and in enzyme activities (Cappello et al., 2007). Based on experimental studies, it can be shown that microbial communities can recover within months following oil contamination (Bachoon et al., 2001); however, recent findings showed a more complex response, especially under field conditions (Taketani et al., 2010; Alonso-Gutierrez et al., 2009). Because of the pivotal role of biodegraders for remediation following oil contamination, biostimulation procedures are currently being developed and tested widely (see, for example, including reference therein, Brakstad and Lødeng, 2005; Gertler et al., 2009; Panicker et al., 2010; Uad et al., 2010). Within the field of emergency response, the possible use of hydrocarbon degraders for remediation is considered by organisations like CEDRE (www.cedre.fr/) and ITOPF (www.itopf.com/) on a case-by-case basis.

Interestingly, monitoring approaches using microorganisms are much less developed, although this group of organisms has been shown to be strongly affected by hydrocarbon contamination, and biological response tests are needed to elucidate bioavailability, toxicity and recovery of oil, impacted systems (Martínez-Gómez et al., 2010). Currently, no commercial monitoring of hydrocarbon degraders takes place. However, small-scale projects (either solely academic or involving industry) have detected changes in microbial community structure, indicating leakage, degradation or recovery of polluted systems (C. Gertler and C. Whitby, pers. comm.). Methods applied in such projects have ranged from molecular detection of specific organisms (Roling et al., 2004) and the use of whole-cell bioreporters (Tecon et al., 2010) to toxicity testing. For the latter, the MARA test system was promoted recently (www.energyinternat.com/pdf/459-pdf/459-citn.pdf). As molecular techniques and toxicity tests can be time consuming and require support by laboratory equipment, biomarkers are considered as a fast and sensitive solution to detect pollution. For this purpose, the development of a bacterium indicating hydrocarbon contamination via a colour response has been announced (by Prof van der Meer, University of Lausanne: http://cleantechnica.com/2008/10/01/scientists-develop-oil-spill-and-pollution-spotting-bacteria/;). It has also been suggested that some methods developed within biodegradation studies could also be used to monitor changes in microbial communities, specifically related to different phases of hydrocarbon degradation, so informing questions concerning recovery (Young and Phelps, 2005; Nyyssönen et al., 2009). These are based on the detection either of specific genes or of chemical molecules released during hydrocarbon breakdown. Overall, it has been suggested that the application of microbial bio-reporters in field situations might be limited by a lack of integration between method developers and end-users (Diplock et al., 2010). However, new technological advances might facilitate the integration of molecular detection methods and end-user friendly, real -time, applications.

A promising development is the Environmental Sample Processor developed at the Monterey Bay Aquarium Research Institute (www.mbari.org/ESP/) which uses automated detection of microorganisms in this manner. The methods implemented will allow flexibility in the choice of targets used for detection, which can range from specific microbial species to genetic characteristics known to be involved either in certain breakdown processes or in microbial stress responses. In the future, such devices could be used deployed from buoys, quays and jetties, or alongside autonomous SmartBuoy monitoring platforms from which other parameters can also be measured, providing a reasonable temporal and spatial coverage to detect chosen microbial indicators in a timely way.

REFERENCES

Alonso-Gutiérrez, J., Figueras, A., Albaigés, J., Jiménez, N., Viñas, M., Solanas, A.M., Novoa, B. 2009. Bacterial communities from shoreline environments (Costa da Morte, Northwestern Spain) affected by the *Prestige* oil spill. *Applied Environmental Microbiology*, **75**: 3407–3418.

Bachoon, D.S., Hodson, R.E. and Araujo, R. 2001. Microbial community assessment in oil-impacted salt marsh sediment microcosms by traditional and nucleic acid-based indices. *Journal of Microbiological Methods*, **46**: 37–49.

Brakstad, O. and Lødeng, A. 2005. Microbial diversity during biodegradation of crude oil in seawater from the North Sea. *Microbial Ecology*, **49**: 94–103.

Cappello, S., Caruso, G., Zampino, D., Monticelli, L.S., Maimone, G., Denaro, R., Tripodo, B., Troussellier, M., Yakimov, M. and Giuliano, L. 2007. Microbial community dynamics during assays of harbour oil spill bioremediation: A microscale simulation study. *Journal of Applied Microbiology*, **102**: 184–194.

Cuny, P., Miralles, G., Cornet-Barthaux, V., Acquaviva, M., Stora, G., Grossi, V. and Gilbert, F. 2007. Influence of bioturbation by the polychaete *Nereis diversicolor* on the structure of bacterial communities in oil contaminated coastal sediments. *Marine Pollution Bulletin*, **54**: 452–459.

Diplock, E., Alhadrami, H. and Paton, G. 2010. Application of microbial bioreporters in environmental microbiology and bioremediation. *Advances in Biochemical Engineering/Biotechnology*, **118**: 189–210.

Gertler, C., Gerdts, G., Timmis, K.N. and Golyshin, P.N. 2009. Microbial consortia in mesocosm bioremediation trial using oil sorbents, slow-release fertilizer and bioaugmentation. *FEMS Microbiology Ecology*, **69**: 288–300.

Lanfranconi, M.P., Bosch, R. and Nogales, B. 2010. Short-term changes in the composition of active marine bacterial assemblages in response to diesel oil pollution. *Microbial Biotechnology*, **3**: 607–621.

Martínez-Gómez, C., Vethaak, A.D., Hylland, K., Burgeot, T., Köhler, A., Lyons, B.P., Thain, J., Gubbins, M.J. and Davies, I.M. 2010. A guide to toxicity assessment and monitoring effects at lower levels of biological organization following marine oil spills in European waters. *ICES Journal of Marine Science*, **67**: 1105–1118.

McKew, B.A., Coulon, F., Osborn, A.M., Timmis, K.N. and McGenity, T.J. 2007. Determining the identity and roles of oil-metabolizing marine bacteria from the Thames estuary, UK. *Environmental Microbiology*, **9**: 165–176.

Miralles, G., Nérini, D., Mante, C., Acquaviva, M., Doumenq, P., Michotey, V., Nazaret, S., Bertrand, J.C. and Cuny, P. 2007. Effects of spilled oil on bacterial communities of Mediterranean coastal anoxic sediments chronically subjected to oil hydrocarbon contamination. *Microbial Ecology*, **54**: 646–661.

Nyyssönen, M., Kapanen, A., Piskonen, R., Lukkari, T. and Itävaara, M. 2009. Functional genes reveal the intrinsic PAH biodegradation potential in creosote-contaminated groundwater following in situ biostimulation. *Applied Microbiology and Biotechnology*, **84**: 169–182.

Paissé, S., Coulon, F., Goñi-Urriza, M., Peperzak, L., McGenity, T.J. and Duran, R. 2008. Structure of bacterial communities along a hydrocarbon contamination gradient in a coastal sediment. *FEMS Microbiology Ecology*, **66**: 295–305.

Panicker, G., Mojib, N., Aislabie, J. and Bej, A. 2010. Detection, expression and quantitation of the biodegradative genes in Antarctic microorganisms using PCR. *Antonie van Leeuwenhoek Journal of Microbiology*, **97**: 275–287.

Powell, S.M., Riddle, M.J., Snape, I. and Stark, J.S. 2005a. Location and DGGE methodology can influence interpretation of field experimental studies on the response to hydrocarbons by Antarctic benthic microbial community. *Antarctic Science*, **17**: 353–360.

Powell, S.M., Snape, I., Bowman, J.P., Thompson, B.A.W., Stark, J.S., McCammon, S.A. and Riddle, M.J. 2005b. A comparison of the short term effects of diesel fuel and lubricant oils on Antarctic benthic microbial communities. *Journal of Experimental Marine Biology and Ecology*, **322**: 53–65.

Roling, W.F.M., Milner, M.G., Jones, D.M., Fratepietro, F., Swannell, R.P.J., Daniel, F. and Head, I.M. 2004. Bacterial community dynamics and hydrocarbon degradation during a field-scale evaluation of bioremediation on a mudflat beach contaminated with buried oil. *Applied Environmental Microbiology*, **70**: 2603–2613.

Rooney-Varga, J.N., Anderson, R.T., Fraga, J.L., Ringelberg, D. and Lovley, D.R. 1999. Microbial communities associated with anaerobic benzene degradation in a petroleum-contaminated aquifer. *Applied Environmental Microbiology*, **65**: 3056–3063.

Taketani, R., Franco, N., Rosado, A. and van Elsas, J. 2010. Microbial community response to a simulated hydrocarbon spill in mangrove sediments. *Journal of Microbiology*, **48**: 7–15.

Tecon, R., Beggah, S., Czechowska, K., Sentchilo, V., Chronopoulou, P.-M., McGenity, T.J. and van der Meer, J.R. 2010. Development of a multistrain bacterial bioreporter platform for the monitoring of hydrocarbon contaminants in marine environments. *Environmental Science and Technology*, **44**: 1049–1055.

Uad, I., Silva-Castro, G.A., Pozo, C., González-López, J. and Calvo, C. 2010. Biodegradative potential and characterization of bioemulsifiers of marine bacteria isolated from samples of seawater, sediment and fuel extracted at 4000 m of depth (*Prestige* wreck). *International Biodeterioration and Biodegradation*, **64**: 511–518.

Young, L.Y. and Phelps, C.D. 2005. Metabolic biomarkers for monitoring *in situ* anaerobic hydrocarbon degradation. *Environmental Health Perspectives,* **113**: 62–67.

APPENDIX 7

Key considerations when collecting dead and live birds

Dead casualties

Dead casualties need to be collected and stored at a central location with a system for logging them. If there are going to be a large number, then a freezer lorry/container should be made available at a suitable assembly point. On arrival, the number of each species from each location needs to be recorded and the legs of the birds checked for rings. Ring numbers should be reported to the BTO regularly so that identification of the populations involved can be assessed as the incident progresses. It is important that there is a later systematic rechecking for rings and that biometrics be taken to aid identification of populations and age structure of affected birds. Even when experienced people check for rings on heavily oiled birds, some rings are missed when the number arriving is more than a few individuals per day. Although we have a reasonably good knowledge of the locations of concentrations of birds at sea, we often do not know the locations of their associated breeding colonies. This is especially true outside the breeding season, although, using new technologies, we are finding that breeding birds may travel long distances on feeding trips. The location of affected populations is important for future monitoring of changes in population size and breeding success.

Live casualties

Ensuring that all birds are taken to recognised cleaning centres where a proper triage procedure can be carried out is important. In the final reporting of an oil spill (or of a chemical that coats plumage), the number of birds taken into care is often taken as a measure of the effectiveness of the response. In reality, it is the number that are released and survive to re-enter the breeding population that is important. This can only be gauged over the long-term by ringing all birds released and undertaking an analysis of the recoveries a decade later. Those that die in captivity or are euthanased should be added to the dead casualties.

APPENDIX 8

Assessing marine invertebrate communities: summary of Water Framework Directive data requirements provided by the Environment Agency

Environment Agency
Asiantaeth yr Amgylchedd

Assessing Marine Invertebrate Communities: Summary of Water Framework Data Requirements

External Data Guidance **040311**

1 Introduction

The Water Framework Directive (WFD) requires ecological monitoring and status assessment of our coastal and transitional (TraC) waters. To ensure the best possible confidence in our status assessments we aim to utilise as much suitable data as possible. The Environment Agency (EA) has established a WFD marine ecological monitoring programme but a significant amount of monitoring done by external organisations (e.g. consultancies undertaking environmental impact assessment, research projects etc.) could also be used. These data would greatly improve our evidence base and hence improve management decisions in the waterbodies.

This document describes the requirements when supplying WFD compliant **macrobenthic invertebrate data** for TraC waters.

2 Assessment Tool – Infaunal Quality Index (IQI)

For the WFD, the soft sediment macrobenthos is assessed in terms of abundance, diversity and pollution-sensitive taxa, using the Infaunal Quality Index. The IQI combines an AZTI marine biotic index (AMBI) score, Simpson's diversity (1 – λ') and the number of taxa (S).

Individual components (metrics) have been weighted and combined in order to best describe the changes in the benthic invertebrate community due to anthropogenic pressure. The IQI operates over a range from zero (bad status (azoic)) to one (high status (reference)). Each metric is normalised to a maximum value related to the reference condition for a specific habitat (sediment type/depth/salinity regime).

For further information see UKTAG guidance "UKTAG Coastal Water Assessment Methods: Benthic invertebrate fauna – Invertebrates in soft sediments (Infaunal Quality Index (IQI))" at www.wfduk.org/UKCLASSPUB/.

3 Data requirements

Our assessment uses standard macrobenthic data and supporting parameters (EN ISO 16665: 2005 Water quality – Guidelines for quantitative sampling and sample processing of marine soft-bottom macrofauna (ISO 16665: 2005)). Table 1 lists the data collected by the EA for WFD macrobenthic invertebrate sampling. If the parameters listed as "essential information" are collected, the IQI can be calculated from the data (the reference models are more accurately applied if particle size analysis data are available, but qualitative descriptions, e.g. Folk classification, are adequate). Taxa are identified to the lowest possible taxonomic level, and taxon lists are based on the World Register of Marine Species (WoRMS, www.marinespecies.org).

Table 1
Data requested for macrobenthic invertebrate assessment.

ESSENTIAL INFORMATION	(PER REPLICATE/SAMPLE TAKEN)
Infaunal abundance	Taxa present and abundance.
Sample type	e.g. Day Grab 0.1 m^2 (**must** specify surface area sampled)
Mesh size of sieve	e.g. 1 mm, 0.5 mm
Sample position	Lat/Long (specify OSGB36/WGS84) or Easting/Northing
Date of sampling	Date sample taken
Sediment description	Folk e.g. mS – muddy Sand
Salinity	Essential for estuarine samples (can be assumed for coastal surveys) so that the correct habitat-specific reference conditions can be applied. Ideally a bottom salinity
Water depth	Measured or estimated from charts
DESIRABLE INFORMATION	
Particle size analysis	Any fractions reported and/or summary statistics [EA reported fractions – Grain Size Inclusive Mean (mm), Inclusive graphic skewness (SKI), Grain Size Median (mm), Grain Size Inclusive Kurtosis, Sorting coefficient, Grain Size Fractions (%) > 8,000 µm, 4,000–7,999 µm, 2,000–4,000 µm, 1,000–2,000 µm, 500–999 µm, 250–499 µm, 125–249 µm, 62.5–124 µm, < 63 µm]
Digital image of sediment	Digital image of sediment in grab/sediment surface which supports the sediment description
Chart datum	Chart depth at sample site used to show whether community represents littoral or sublittoral communities. NB drying areas should be negative.
Time of sampling	Time sample taken
Depth of sediment	Depth of sediment in grab/core (cm)

4 Quality Assurance

Quality assurance procedures should be indicated. If data have no documented quality assurance, it may still be possible to utilise them but a low confidence will be associated with the classification outcome. For further information on quality assurance see www.nmbaqcs.org/

5 More information

For more detailed information on how to plan a fully compliant WFD survey, the EA has an Operational Instruction "Water Framework Directive (WFD) Transitional and Coastal Waters: Macrobenthic Invertebrate Sampling" that can be supplied.

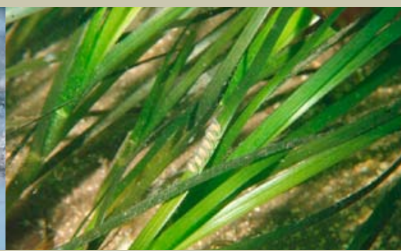
Requests for further information should be made to enquires@environment-agency.gov.uk

Cefas

Head Office
Centre for Environment,
Fisheries & Aquaculture Science
Pakefield Road, Lowestoft,
Suffolk NR33 0HT, UK

Tel +44 (0) 1502 56 2244
Fax +44 (0) 1502 51 3865
Web www.cefas.defra.gov.uk
Cefas is an executive agency of Defra






ISSN 0308-5589