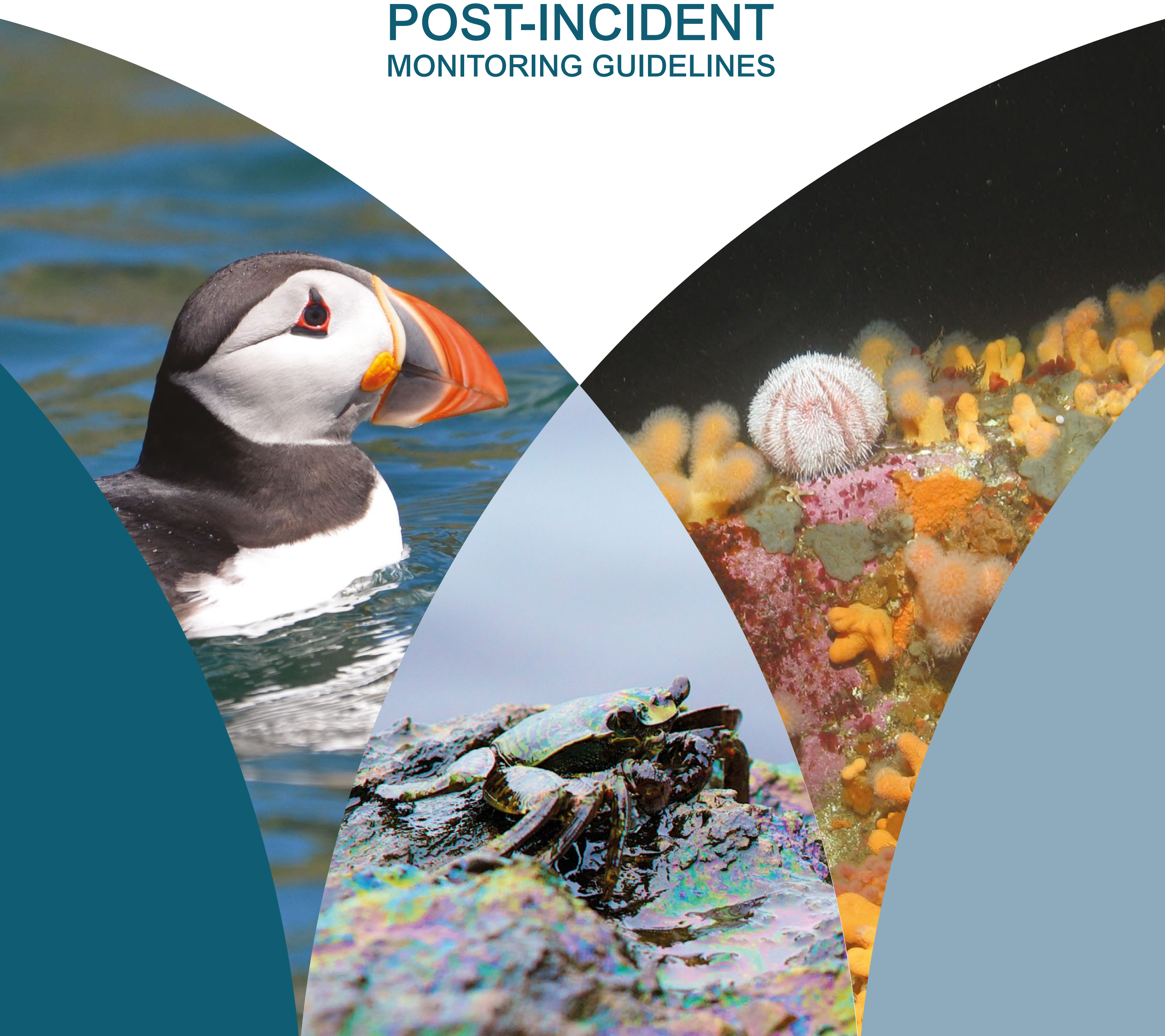
premiam

POLLUTION RESPONSE IN EMERGENCIES

MARINE IMPACT ASSESSMENT AND MONITORING

POST-INCIDENT MONITORING GUIDELINES



Editors
Kirby, M.F.[1]; Brant, J.[1]; Moore, J.[2] and Lincoln, S.[1]

Contributors
Lyons, B.[1]; Briggs, K.[1]; Whittle, J.[1]; Parker, J.[1]; Aldridge, J.[1]; Williams, O.[1]; Patel, M.[3]; Van Wyk, M.[4]; McGenity, T.[5]; McKew, B.[5]; Harold, P.[6]; Holland, R.[7]; Connal, G.[7]

Also contributed
Archer, S., Banks, A., Cariglia, N., Carter, F., DellaMea, C., Edmonds, P., Gallego, A., Graves, B., Harold, P., Holland, R., Hull, T., Lamb, M., Law, R., Mellor, A., Merckel, D., Proudfoot, R., Saunders, I., Williams, N., Ware, S.

Origin
These guidelines were produced for Defra, as a deliverable within project Marine Emergency Response Research 2 (MERR2): "PREMIAM Guidelines: 2nd Edition".

Citation
The report should be cited as:
Kirby, M.F., Brant, J., Moore, J., Lincoln, S., (eds.) 2018. PREMIAM – Pollution Response in Emergencies – Marine Impact Assessment and Monitoring: Post-incident monitoring guidelines. Second Edition. Science Series Technical Report. Cefas, Lowestoft, 176 pp.

A full PDF copy of the guidelines can be downloaded from https://www.cefas.co.uk/premiam.

Acknowledgements
Photograph of puffin (FC) © Mark Lewis, Photograph of coral (FC) ©JNCC, Photograph of dolphin on page 101 © Sarah Canning, Photographs of beach surveys on page 94 and 111 © Marine Scotland and are used with permission. Photographs of: oil on sand shore (page 12); thick fuel oil on rocks, with 10cm scale (page 14); otter with fish (page 18); surveyor on rocky shore (page 30); puffin with fish in mouth (page 52); oil sheen on water between boulders (page 58); oil cleanup on sand beach, with men & vac truck (page 64); orange boom across channel to lagoon (page 68); stranded bivalves with tar balls (page 76); bleached coralline algae on rocky shore (page 82); sampling of kelp holdfast (page 116); orange soft coral (page 122); cormorant colony (page 140); sand dune, with village in distance (page 145) © Jon Moore are used with permission. Photograph of Shipek grab (page 35, Figure 6 right) © Wildco Science First. All remaining photographs are British Crown copyright.

[1] The Centre for Environment, Fisheries and Aquaculture Science (Cefas), Cefas Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT
[2] Coastal Assessment, Liaison and Monitoring (CALM) Ltd., Ti Cara, Point Lane, Cosheston, Pembrokeshire SA72 4UN
[3] The International Tankers Owners Pollution Federation Ltd. (ITOPF), 1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, UK
[4] Marine Management Organisation (MMO), Lancaster House, Hampshire Court, Newcastle upon Tyne NE4 7YH
[5] School of Biological Sciences, University of Essex, Colchester, Essex CO4 3SQ
[6] Public Health England (PHE), Centre for Radiation, Chemical and Environmental Hazards c/o Wales Regional Office, Cardiff Metropolitan University Western Avenue, Cardiff CF5 2YB
[7] Oil Spill Response Limited (OSRL), Lower William Street, Southampton SO14 5QE

Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Spillages of oil and chemicals at sea can be high profile events and can result in significant environmental impacts. Effective response to marine spills is essential if risk to the public and the marine environment is to be minimised and effective clean up and recovery options initiated. In general, requirements for key response activities such as the initiation of counter pollution measures, situational awareness, clean up and recovery are established within international conventions and implemented through national contingency plans. However, the key element of environmental monitoring and impact assessment is rarely included and it is to facilitate best scientific practice and management in post-spill monitoring that these guidelines have been developed.

The importance of prompt and effective environmental monitoring is an important part of an integrated spill response as it is only through this that the risks and impacts to the human food chain, the marine ecosystem and commercial marine resources can be ascertained. Furthermore, it is only through monitoring that we can gather the data necessary to establish the effectiveness of the response operations and any subsequent actions taken to mitigate impacts or promote recovery. It is therefore imperative that scientifically robust approaches, methods, and processes are considered in developing a monitoring plan so that it can be implemented in a prompt and cost-effective manner and to ensure that the results are fit for purpose and adhere to scientific standards. In the United Kingdom, the cross-government Premiam (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) initiative works to promote effective post-spill monitoring and these guidelines, now referred to in the UK National Contingency Plan, form a key deliverable.

The guidelines begin by outlining the key principles of an environmental monitoring programme by establishing the key aims and the fundamental answers to why, where, when, what and how we need to monitor. Understanding these key aims is essential to the planning process outlined in this guide which then proceeds to provide the necessary detail on sample collection and management, key monitoring techniques and strategies for a range of ecological habitats and marine resources. Finally, the guide highlights the importance of data management, communication and reporting in order to enable effective dissemination from the programme.

While these guidelines have been developed from a UK perspective the key aims, principles and many of the approaches are applicable to the implementation of marine monitoring plans for any spill. They aim to provide essential guidance in the event of a spill but should also be considered as an important source of reference for pre-planning and preparedness so that appropriate authorities can implement appropriate monitoring as effectively as possible.

THE PREMIAM GUIDELINES HAVE BEEN PRODUCED IN CONSULTATION WITH MANY MAJOR GOVERNMENT STAKEHOLDERS ACROSS THE UNITED KINGDOM, INCLUDING:

1. 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, 2017) because of improved practices and prevention, there are still occasional large, high-profile incidents (e.g. Deepwater Horizon and Hebei Spirit). Also, small spills, which can nevertheless have significant localised impacts, and 'near-miss' potential spills occur on an almost daily basis. It is against this background that national authorities 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 environmental monitoring programme, facilitated by clear guidance as presented in this guideline, will ensure that:

- Key stakeholders, including government and the 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.

For example, under the UK National Contingency Plan (NCP) (Maritime and Coastguard Agency, 2014), 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. Under these arrangements, an Environment Group (EG) may be established to provide operational advice to the response centres, and will also advise on and encourage the collection and evaluation of data for the assessment of the environmental impact of the incident. A further role of the EGs, between incidents, is to record data concerning the pre-existing baseline conditions within their designated area, for use as baseline information and reference points during an incident. However, for major incidents, impact assessment projects and monitoring or survey studies may need to be commissioned and managed separately. The International Petroleum Industry Environmental Conservation Association (IPIECA)[1] (2011, 2015) 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 to achieve net environmental benefit analysis (NEBA) and further relevant material are published by the US National Research Council (1999, 2005). However, these documents focus on response options and do not fully cover the principles of environmental monitoring and impact assessment.

In the UK, an appropriate government department, or devolved administration, responsible for managing environmental quality for the waters in which an incident occurs (e.g. the Department for Environment, Food and Rural Affairs – Defra) would take the lead in co-ordinating the commissioning of such work, to ensure that it is linked with any existing marine monitoring and assessment activities. The NCP suggests establishing a Premiam Monitoring Coordination Cell (PMCC) or equivalent at an early stage, working closely with the EG but allowing that group to focus on providing advice to the response cells (see further information regarding the PMCC in Appendix 1, including responsibilities, membership, links to other groups etc.). The PMCC would also be charged with establishing and managing the funding for the impact assessment (including any impacts on public health, see Appendix 2) and long-term monitoring programmes. The NCP does not, however, go into further detail regarding the scientific framework and principles of any specific monitoring activities nor does it consider the co-ordination of the group and its activities.

These guidelines, therefore, aim to provide important preparedness and capability information with respect to establishing and conducting an effective post-incident monitoring programme. They set out expert, best-practice principles for the planning and conduct of post-incident monitoring and impact assessment and, since their original publication in 2011, are widely referred to in public and private sector documentation.

[1] *IPIECA is the global oil and gas industry association for environmental and social issues (http://www.ipieca.org/about-us/)*

These guidelines constitute an important output from the cross-government Premiam initiative which has also established mechanisms for overseeing the practical aspects of any programme (e.g. survey design, sampling, analysis and interpretation).

Implementation of the principles set out in these guidelines aims to strengthen monitoring and impact assessment activities in terms of:

- Speed – providing a faster response 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 document acknowledges the difficulty of obtaining absolute statistical proof that a spill 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. Some of the most useful and informative impact assessment studies have resulted from opportunistic situations, where very recent and good-quality baseline data are available for an impacted resource; or where someone with appropriate expertise and capability is available and immediately begins studies on a sensitive resource. These situations are rare and most assessments generally work with inadequate baseline data. The literature also highlights the useful insights on environmental impact/change that can come from good natural-history observation activities as well as 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 impact assessments should aim to accumulate a weight of evidence using a range of methodologies, each of which will need to be tailored to the circumstances.

It is also recognised that designing a monitoring programme is not a one-off event. Circumstances will change as an incident proceeds, particularly if it is protracted (e.g. as in the Deepwater Horizon incident) 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;
- Environmental conditions: survey timing will need to take account of both predictable (e.g. tides and currents) and less predictable (e.g. weather) environmental conditions;
- Access to sites: survey and sampling sites may be in areas that are difficult to access or where permission is required;
- Licence: some species are protected by law, and studies may require a licence from the relevant agency for any handling or collection.

Finally, while these guidelines set out the core principles of the design and conduct of an effective post-spill monitoring and impact assessment programme, and describes some of the key techniques and approaches, it should be recognised that the ability to plan and undertake effective monitoring relies on a range of factors including the availability of appropriate expertise and equipment, access to funding and integrated aims across stakeholder organisations. These guidelines help to set out what needs to be done and how this can be achieved, including the importance of quality assurance, data management and effective communications. However, authorities with monitoring responsibility need to ensure an appropriate level of preparedness if the programme is to be implemented promptly and effectively and a means of assessing preparedness has been described by Kirby et al. (2014) and is reproduced in Table 11, Appendix 3 of this guide.

PART 2

The principles of a monitoring plan

2. The principles of a monitoring plan

2.1 WHEN DO WE NEED TO MONITOR?

When an incident is expected to have the potential for a significant environmental impact. This is influenced by the nature of the oil and/or chemical spilled, or potentially spilled, the quantity, the location and the resources at risk locally (Hook et al. 2016).

Whether the impact from an incident is likely to be significant is a question that generally needs to be assessed using scientific inputs from modellers, chemists and eco-toxicologists backed up by natural and fisheries resource information from appropriate conservation fisheries management agencies. This advice and expertise will likely reside in a range of government departments/agencies and therefore current personnel details and effective emergency response contact processes are essential for prompt decision making. The decision should consider physicochemical properties of the spilled, or potentially spilled, substance (density, solubility, volatility, ability to bind to particles, persistence and reactivity), inherent toxicity to both wildlife (including aspects such as smothering and bio-accumulative capacity) and humans, and the likely movement of the material, whether as a coherent slick, a plume or in solution, in relation to the resources threatened. Initially, information on the actual scale of the incident may not be available. While even very severe incidents rarely see a total loss of cargo and bunker fuel, this worst-case scenario may be a good starting point for early modelling until more accurate information is available. This process will also begin to focus the aims and extent of the monitoring programme depending on the expected impacts or implications. Monitoring on some scale will certainly be initiated:

- 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 food-chain is likely;
- When an incident may have other human health implications.

2.2 WHY DO WE MONITOR?

Possible aims might be:

- To assess the impact on species/habitats of nature conservation importance (e.g. in relation to the EU Birds and Habitats Directives, OSPAR);
- To assess the impact on commercial stocks of fish and shellfish;
- To assess the impact on the wider ecosystem and its functionality;
- To assess the impact on the human food chain;
- To inform fishery closure/re-opening;

- To assess the efficacy of chosen response and clean-up options;
- To assess any impact on the local human population;
- To provide evidence to support subsequent compensation or insurance claims;
- To provide public reassurance.

However clear the direction of the monitoring programme is, there will also be several overlapping aspects to consider. Clouds of volatile chemicals close to centres of population with an onshore wind point impacts on the local human population, but may also impact species of nature conservation importance (e.g. fisheries and birds). 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?” or “Is it safe to go to the beach?” are perfectly legitimate questions and should be answerable in a straightforward manner, backed up by monitoring data. Finally, in many countries or regions there is a statutory duty to undertake monitoring. For example, in the UK, for transitional and coastal waters as defined by the Water Framework Directive (WFD[2]), there is 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. Similarly, under the Marine Strategy Framework Directive (MSFD[3]), for waters at a greater distance from shore, there is an obligation to investigate the occurrence, origin and extent of significant acute pollution events and their impact on biota physically affected by this pollution, to assess the impact of the pollution events on Good Environmental Status (GES) within the affected region or sub-region.

2.3 WHAT DO WE MONITOR?

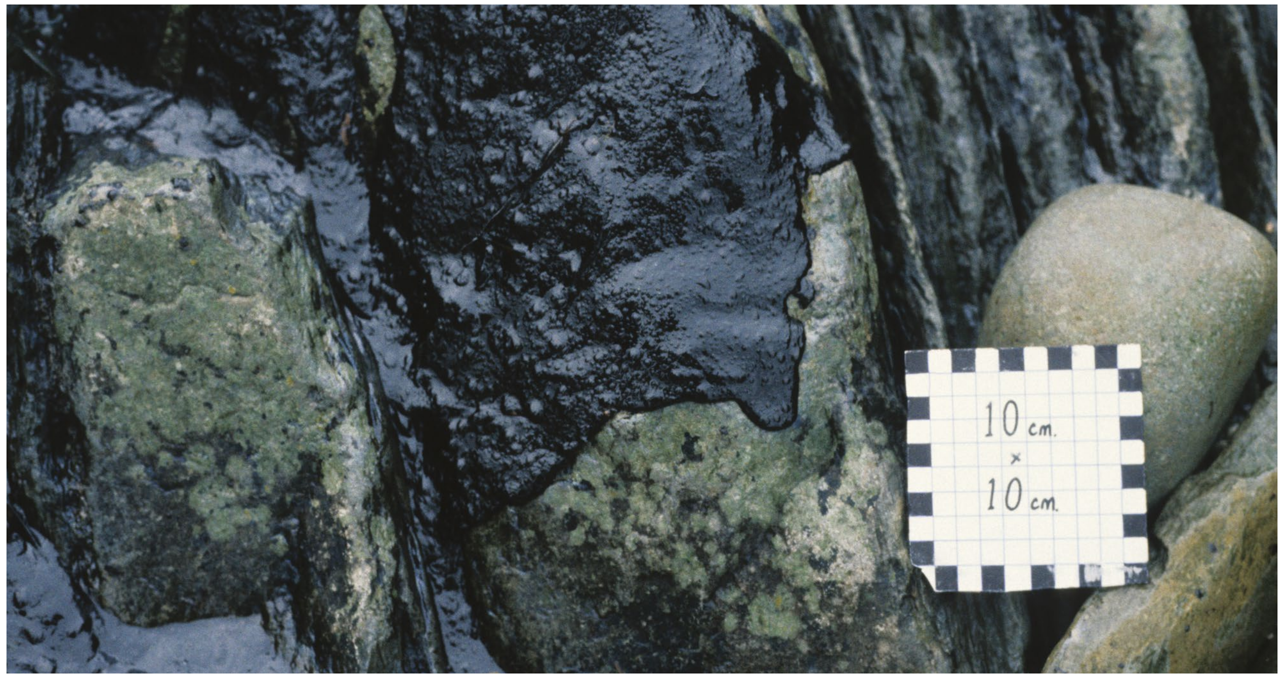
The exact elements that are included within a monitoring programme may need to be limited, especially in the first hours of an incident or where resources and funds are restricted or uncertain. Therefore, monitoring effort may need to be prioritised and decisions made by an expert (or expert cell) on what is included to ensure best use of resource. Ultimately, this will depend on the nature of the incident and will be determined on a case-by-case basis. However, typical elements for consideration in the planning of the monitoring programme could include:

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

The ultimate focus of the monitoring effort is dependent on the concerns identified above and resource priorities.

“*The exact elements that are included within a monitoring programme may need to be limited, especially in the first hours of an incident or where resources and funds are restricted or uncertain.*”

[2] http://ec.europa.eu/environment/water/water-framework/index_en.html
[3] http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm



A wildlife licence may be necessary for monitoring activities involving certain protected species. Guidance on this issue and the current list of protected species can be found in Appendix 4.

2.4 WHERE DO WE MONITOR?

Fundamentally the key geographical areas for sampling and monitoring activity will fall into three categories:

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

All impacted areas should be considered for monitoring. Hence the geographic scale of the incident will generally drive the spatial scale of the monitoring programme. Also, the use of fate and transport modelling to predict oil/chemical behaviour helps to identify sites likely and unlikely to be impacted as the incident develops, which in turn will help to define areas outside the currently impacted area which may be at risk later. These should also be incorporated into the monitoring plan. The extent to which oil or chemicals might be transported will define the maximum size of the impacted area for the incident. Areas outside the potentially impacted area, that are similar to those inside (in relation to sediment characteristics, species of fish and shellfish present, etc.), can be considered as reference areas. Identification of such areas is particularly important where little background information exists from within the impacted area before the incident occurred. Comparisons between impacted sites and reference sites or background information allow the impacts of an incident to be inferred and characterised. 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.

During an oil incident response which is likely to impact the coastline (and possibly also during a chemical incident response, depending on the nature of the chemical), Shoreline Clean-up 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 in the late 1980s, following the Nestucca and Exxon Valdez oil spills, the SCAT approach has been used on many occasions worldwide. In the UK, a SCAT manual is available from the Maritime and Coastguard Agency (2007). See also NOAA (2003, 2013b).

2.5 HOW FREQUENTLY DO WE MONITOR?

There are several drivers affecting the frequency of monitoring. Monitoring should be carried out:

- Frequently enough to follow changes in status;
- Infrequently enough to keep within the funding constraints;
- Sufficiently frequently to ensure that conservation status/objectives are maintained for designated species/habitats of conservation importance in Marine Protected Areas (MPAs);
- For a long enough period that sufficient time-series measurements at multiple sites are generated. These are very valuable in following the development of impacts resulting from an incident, and subsequent levels of recovery resulting from the mitigation measures applied.

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, and 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.

2.6 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 and subsequent rates of recovery 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, differently impacted sites, 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 logical endpoint. 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, and many other regions globally, 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 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 areas likely to be impacted prior to the arrival of the spilled oil or chemicals;
- Collecting and analysing samples taken from outside the likely impacted areas but in areas thought to have similar levels of contaminant load before the incident.

“Designing a damage assessment study for an ecological resource must be undertaken with considerable attention to detail.”

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 several techniques, a study group within the International Council for the Exploration of the Sea (ICES, 2011) 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 have developed advice to OSPAR on integrated chemical and biological effects monitoring, which reflects the current state of the art guidance (ICES, 2011). This advice was based upon the work of the joint ICES/OSPAR Study Group on Integrated Monitoring of Contaminants and Biological Effects.

The aim of ecological monitoring is to follow the progress of biological recovery from the effects of the spill, particularly for sensitive species/habitats or those 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.

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

- The re-established healthy community may not have 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 points arise from the fact that ecosystems are naturally in a constant state of flux, even in the absence of spilled oil or chemicals.

2.7 SURVEY DESIGN

Designing a damage assessment study for an ecological resource must be undertaken with considerable attention to detail. Many decisions need to be taken which 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. Hook et al. 2016; Moreira et al. 2007; Robertson, 2001).

After careful prioritisation, each damage assessment study would typically be based on:

- selected biological features and key indicators, chosen according to their ecological significance and their sensitivity;
- essential environmental parameters (chemical/physical characteristics of the habitat which 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 toward baseline level).

It is not usually necessary to investigate all of the ecosystem’s components to build-up a picture of the damage caused by the accident. Sometimes indicator species can be selected which will give a general indication of the scale and extent of the impact. In general, amphipods (a diverse group of small shrimp-like crustacean 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. Where appropriate, the biological element most sensitive to the pressure caused by the incident should be monitored.

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 Funds). Appendix 5 provides a useful summary of UK regulations in terms of compensation for oil spill damage from ships.

It should also be noted that survey design is an iterative process, particularly in long-running incidents (such as may result from a subsea blowout on an oil platform), as concerns will change as the incident evolves.

There are three main strategies to damage 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) analysing post-incident data monitored over a period of time to identify a 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.

2.7.1 Comparison of post-and pre-incident data

Pre-incident data are very valuable to damage assessment studies, so this is the best strategy 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 – i.e. there will be a level of uncertainty if the pre-incident data are old, are from a site that was not badly impacted, don't include some important parameters (such as PAHs, background hydrocarbon levels, etc. in the case of an oil spill) or are from a location that cannot be identified 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 additional evidence.

2.7.2 Data comparison from impacted and reference sites

This is the most common strategy for assessing post-incident damage 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 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, a statistically balanced design would provide samples from several impacted locations and the same number of reference locations. In practice, researchers often reduce the number of reference sites and a typical scenario would have ten impacted sites and five reference sites, though the appropriate level of sampling differs based on the circumstances of each incident. After statistical analysis, even this number of samples may be found to be inadequate to detect an impact, but that level of sampling effort typically provides a practical compromise that takes account of available time, financial budgets and statistical rigour. 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.

2.7.3 Longer-term analysis of data for trend and recovery

If pre-incident data are not available and the impacted resource is discrete (e.g. it is not possible to collect data from many sites and no suitable reference sites are available), 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 damage must have occurred. Distinguishing impact recovery from natural trends 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 damage. 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; e.g. aquaculture, where it may be possible 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.

2.8 CO-ORDINATION AND AN INTEGRATED APPROACH

Significant spillages of oil and chemicals into the marine environment can be high-profile events and likely to give rise to adverse environmental and/or public health impacts. It is likely that the response will require a multi-agency/stakeholder approach. Therefore, national plans should include clear guidance on how the related environmental monitoring activities are to be co-ordinated and managed, in both the immediate aftermath of a spill and the longer-term recovery phase of an incident.

> *"It is important that the choice of approach adopted, the species selected for monitoring and any biological and/or chemical assays are relevant and that they contribute towards a fully integrated post-incident assessment."*

A fully efficient monitoring programme will be characterised by effective integration and co-ordination of relevant activities from a range of sources. In most cases, the core effort will primarily be delivered by government departments/agencies but this could still involve several organisations. This is especially the case where responsibilities for different 'at threat' resources and zones are not addressed by one body.

For example, monitoring may be required to assess impacts associated with fisheries, environmental/conservation issues or human health (from food and/or leisure exposure) in both coastal and/or offshore environments.

The breadth of methods and species that can be considered during any post-spill monitoring is wide and thus gives a level of flexibility within any programme. However, it is important that the choice of approach adopted, the species selected for monitoring and any biological and/or chemical assays are relevant and that they contribute towards a fully integrated post-incident assessment. For example, guidance on integrated biological effects and chemical monitoring has recently been produced by ICES (Davies and Vethaak, 2012). While aimed at non-spill related chemical monitoring programmes, the general principles and approaches are easily transferred to post-spill assessment strategies. 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 regarding 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.

While core government bodies with statutory responsibilities will likely lead any monitoring response, it is recommended that other relevant activities are also incorporated into the monitoring programme. Other sources of monitoring activity might include:

- Routine sampling as part of national or regional environmental quality monitoring (these can be an important source of baseline information);
- Academic studies; universities will often use real incidents as an ideal opportunity to deploy developmental techniques if funding is available;
- Industry/Commercial; if the 'polluter' is identified they may well initiate monitoring activities of their own;
- Voluntary/public activities; local and national groups such as wildlife and conservation associations can provide an important source of local knowledge and may well instigate their own monitoring activities.

It is recommended that efforts are made to integrate these alternative sources of monitoring information into the overall programme. An example of Detailed guidance on how the process monitoring process is co-ordinated is the management and co-ordination in England and Wales via the Premiam Monitoring Co-ordination Cell (PMCC) along with links into the standing Environment Groups is outlined in Appendix 1.

PART 3

Survey planning

3. Survey planning

3.1 PURPOSE

The questions in Table 1 are the typical questions that a post-spill environmental monitoring survey needs to address and therefore the questions that may be asked at the start of an ecological damage assessment process for an oil or chemical spill.

Table 1. *List of questions to help define the purpose of a survey.*

Question	Limitations and issues
Describing the acute impact of the spill	
1. Has the spill impacted the ecological resource?	What characteristics of the resource are of interest? Consider distribution, extent, abundance, productivity, biodiversity, protected status, reproductive capacity etc.
2. How many individuals were killed by the spill?	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 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 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 subtler 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 and chemicals, but study methods are often not designed to sample or distinguish them from adults.
6. Has the spill had sub-lethal 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 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 risk-based 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 clean up activity 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 (if useful) 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 responses are 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.

3.2 ESTABLISHMENT OF BASELINE DATA AND INFORMATION

Information on pre-existing baseline environmental data should be gathered in advance if possible. For example, this is one of the roles between incidents of the Environment Groups in the UK. National monitoring programmes (e.g. CSEMP in the UK) undertaken by the relevant environmental regulator may also yield useful information. Relevant surveys and studies may also have been undertaken by local nature conservation agencies, universities and research institutes.

A range of data repositories are often publicly available, and can provide an excellent source of pre-existing data, or directions to where monitoring organisations hold relevant information. Some examples from the UK include:

- Magic [interactive mapping of the natural environment from across government];
- Merman [holds UK data collected to fulfil the UK's mandatory monitoring requirements under OSPAR JAMP. These data are used in support of EC directives and national assessments, such as Charting Progress 2 and are also supplied to EMODNET];
- United Kingdom Directory of Marine Observing Systems (UKDMOS) [internet-based searchable database of marine monitoring conducted by UK organisations];
- Cefas Data Hub [online portal accessible to the public and UK businesses to explore, download and reuse Cefas data for their own research];
- MEDIN Data Archive Centres (DACs), e.g. DASSH [UK Data Archive Centre for marine biodiversity data for both species and habitats];
- Data.Gov.UK [data published by government departments and agencies, public bodies and local authorities].

The availability of pre-incident monitoring data, and how it can be accessed, is one of the topics any Environment Group or monitoring co-ordination cell in each area should aim to address. In the absence of pre-existing baseline information, samples (sediments and biota, preferably) can be collected from selected locations and stored frozen against future need for analysis. Based on the spill modelling carried out by emergency responders, these baseline samples could be collected from locations in the predicted trajectory of the spill that can be reached and sampled pre-oiling. This will be particularly useful in the case of chemicals (Hazardous and Noxious Substances or HNS) where, for most chemicals transported by sea, there is very little likelihood of data having been collected before. Ideally, sampling locations should be chosen to represent both reference sites, those which are unlikely to be impacted during the incident, and sites which are likely to be impacted. Also, the characteristics of the samples taken from the two sets of locations should be similar wherever possible – e.g. muddy sediment; mussels or fish/invertebrates of the same species. When selecting species, 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 and/or habitats of significant nature conservation importance should be considered for inclusion.

> *“a range of data repositories are often publicly available, and can provide an excellent source of pre-existing data, or directions to where monitoring organisations hold relevant information.”*

3.3 DESIGN PROCESS

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

A. Identify the natural resource for which there is concern (the use of spill models can be valuable to identify areas most likely to be impacted). Carry out reconnaissance surveys (see Section 5.3.3.1), as necessary, to assess the spatial extent and level of exposure to oil or chemicals;

B. Define aims and objectives of the study – first understand clearly what question(s) you want answered. Examples of typical questions and their associated limitations are given in Table 1;

C. 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 limitations of budget, resources 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;

D. Examine existing information from studies of the resources in the affected area or elsewhere (see Section 3.2) to evaluate whether the methodologies used are appropriate for application to impact assessment of the oil or chemical(s) involved, whether a modified methodology would work, or whether a new methodology needs to be devised. Evaluation of the pre-incident data from the affected area should also be made to assess its usefulness as a baseline;

E. With the above in mind, select suitable parameters and/or attributes for measurement – 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;

F. Select or design an appropriate method to obtain the necessary data, including preparation of detailed protocols to ensure quality, consistency and statistical robustness;

G. Analyse existing pre-incident data from the site or from similar resources elsewhere (see Section 3.2) to understand the potential levels of natural variability (temporal fluctuations and spatial patchiness);

H. Decide on the level of accuracy that is required. 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 will be used as part of a claim for compensation or could be challenged in a legal or scientific forum;

I. 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 2.7;

J. Consider the likely data analytical requirements – it is often advisable to obtain guidance on appropriate statistical methods and computer software packages before collecting data (see Section 3.5);

K. 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 H above);

L. 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;

M. Define procedures for storing and tracking samples/data and other chain-of-custody requirements (see Sections 4.4 and 4.5);

N. 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. It should also be noted that various authorisations may need to be in place for sampling (especially for protected areas/species);

O. Prepare recording forms and database (see Section 6.2);

P. Select sites, to represent the different levels of impact, taking account of confounding factors and logistical issues. See Sections 3.4 and 5.2.4.7;

Q. Test and thoroughly review the methodology;

R. Initiate survey.

[4] www.emodnet-seabedhabitats.eu

[5] At the time of producing these guidelines, JNCC indicated that guidance on benthic habitats monitoring was to be published soon. For further information visit: http://jncc.defra.gov.uk/

Biological and chemical sampling and ecological 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 can often result in a lack of co-ordination between the collection of biological and chemical data, with consequent difficulties for comparison and correlation. It is obviously advisable that liaison between the relevant personnel is established at an early stage in the planning, in order that the two datasets can be assessed in an integrated manner later. This co-ordination has been discussed in more detail in Section 2.8.

3.4 SITE SELECTION

Selecting sites and stations for environmental surveys and monitoring programmes will depend on the occurrence of the resource chosen to sample/record. Sub-sections within Section 5.4 provide references to sources of distribution data for biological resources. Habitat maps will also aid site selection and are available for many intertidal and subtidal areas, at various scales, from the statutory conservation agencies or online (EMODnet[4] or higher resolution if available[5]). Site selection 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 damage will be detected from 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, select stations with very similar environmental conditions;
- **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 allowing easy and frequent access without being too easy for members of the public 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 and a GPS.

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:

- **Co-ordinate biological and chemical sampling** – it will be much easier to interpret the results if biological impacts and chemical concentration data are recorded from the same locations and within a similar timeframe;
- **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 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 area of study will also aid later interpretation;
- **Identify 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;
- **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 location 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 Global Positioning System (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.

3.5 STATISTICAL CONSIDERATIONS

The monitoring study needs to be designed so that it can answer the main questions required of it. Generally, the main decisions will be in terms of the number of locations to monitor and the frequency of monitoring at each location. Typical things that may need to be determined are:

Aim 1: Whether mean levels of pollutants (or other measured parameters) at the contaminated site are 'similar' to those at a reference site (we could define 'similar' to be 'within X units');

Aim 2: Whether levels of pollutants (or other measured parameters) are reducing/increasing at the contaminated site. That is, is there a downward or upward trend of magnitude in measured parameters at the contaminated site? Such a trend at the contaminated site might well be examined relative to any trend at the reference site;

Aim 3: Whether biological communities are recovering or deteriorating at the impacted sites as compared to a reference site or sites.

For these aims, the concept of statistical power is important. There is a need to ensure that there are sufficient sampling stations and sufficient frequencies of temporal measurements to be able to demonstrate effects with a high degree of certainty. For determining mean differences (Aim 1), there will need to be a compromise between the sample size and the magnitude of difference to be determined such that the probability of being able to determine the difference is sufficiently high (for example 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 (Aims 2 and 3), the statistical design of the monitoring programme should ensure that it affords sufficient power of detection of the 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 powerful (and hence fewer measurements are needed) as the variability becomes lower. The use of good techniques to collect and analyse 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 tests. However, it is often more appropriate to estimate levels of pollutants at the 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 to achieve some agreed level of precision in our results.

Another concept that will be useful when comparing levels of pollutants at a contaminated site with some reference level is the use of tests that demonstrate that the levels of pollutants in the contaminated area are below some threshold. 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 general, these principles of statistical power in monitoring design hold as best practice for all types of measured parameters (e.g. not just for contaminant measurements).

PART 4

Sample collection and management

4. Sample collection and management

4.1 INTRODUCTION

Sampling should include both impacted (or at risk of impact) and reference (unimpacted) sites, ideally with similar characteristics as outlined in Section 3.4 above.

The range of sample types to be collected can vary, and can include water, subtidal and intertidal sediments, subtidal and intertidal biota, commercial fish and shellfish, and samples of the spilled oil or chemical(s) from the sea surface or beaches depending on the incident in question. The way that samples are collected can have a large impact on the analysis, and there will undoubtedly be several organisations involved in the monitoring effort for any major spill event. Standard procedures should be agreed in advance and followed to assure the quality of the data collected by eliminating (as far as possible) the possibility of contamination/cross-contamination, the possibility of contamination/cross-contamination and loss of samples.

4.2 SAMPLING

4.2.1 Sampling Equipment/containers

Figure 1.

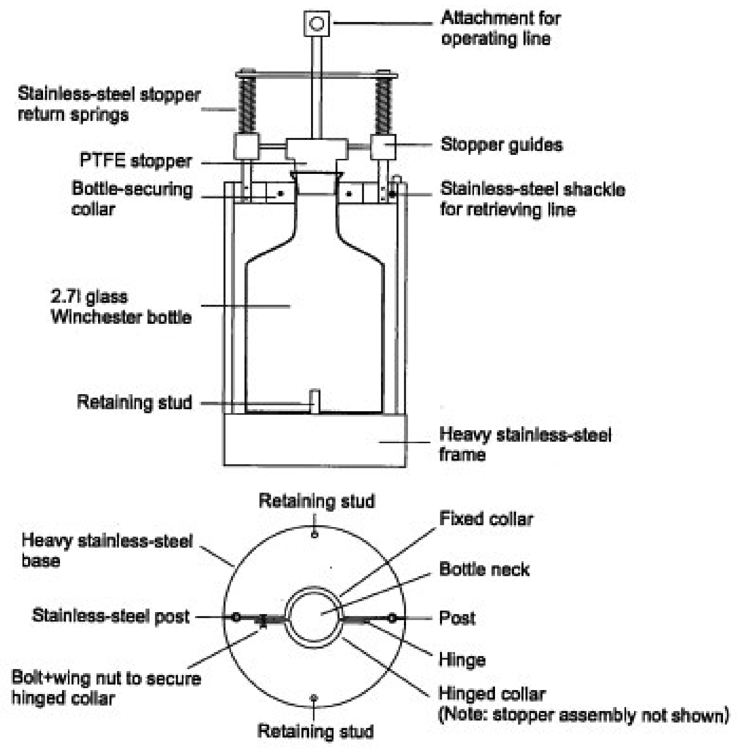
Cefas sub-surface water sampler rigged for use. The sampler is lowered using the white rope, and opened and closed using the red rope. Note the clips and stabilising vane for deployment from a hydro-wire

Results can be impacted by the containers and equipment that are used to collect samples, particularly in the case of analytical chemistry and ecotoxicological studies. For example, since dissolved concentrations of contaminants are usually very low even during marine incidents, when chemical analysis is required, great care must be taken in the selection of sampling devices, their cleaning and decontamination prior to use and the avoidance of cross-contamination. Most organisations conducting routine analysis will have their own protocols for sample container selection. Plastics are generally not suitable materials for samples which are to be analysed for organic compounds. Many plastics are not resistant to solvents commonly used to clean sampling devices, and phthalate esters added as plasticisers (substances added to plastics to increase their flexibility, transparency, durability, and longevity) can leach into samples, causing analytical issues. In addition, organic compounds can adsorb to plastic containers, reducing the concentration in the sample. For analysis of organic compounds this usually means that glass is used, although sometimes metal containers are used for sediments, and other inert (but robust) materials such as Polytetrafluoroethylene (PTFE) at depth. Sample containers should be rigorously cleaned with solvent before use.

Some analytical determinands, such as PAHs, are also sensitive to degradation by Ultraviolet (UV) light. When samples are collected for this type of analysis it is important that light is excluded from these samples as far as possible after collection by use of amber glassware or by wrapping samples in foil. Where samples are to be stored at very low temperatures (-80 or -196 °C), vials capable of withstanding these temperatures must be used.

Figure 2.

Design of a Cefas sub-surface water sampler.



4.2.2 Water sampling

Detailed information for collection of water samples can be found on the Water Sampling guidelines (TG01) available from the Post-Incident Monitoring Guidelines: Subsea Oil Releases and Dispersant Use in the Premiam website[6].

Water samples are normally used to assess concentrations of dissolved oil or chemicals in the water column, but may also be required for assessing the bacterial species present (to look for elevation in hydrocarbon degraders) or for toxicity testing. Samples may be required from a variety of depths, but for surface spills will usually be at relatively shallow depths. Samples should be collected in appropriate bottles (usually glass, see Section 4.2.1 above) below any surface films. This can be done using apparatus such as that described in Kelly et al. (2000) (Figures 1 and 2). This example uses a glass Winchester solvent bottle (2.7 litres volume), 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 can be resealed when full, being open therefore only during sample collection, and sealed during deployment and recovery. With the addition of mounting clips and an aluminium vane to prevent spinning (see Figure 2), these samplers can be deployed from a hydro wire and used to a depth of at least 50m without imploding (Law and Whinnett, 1993). The sampler (particularly the stopper) should be cleaned with solvent 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.

[6] https://www.cefas.co.uk/premiam/publications/post-incident-monitoring-guidelines-subsea-oil-releases-and-dispersant-use

Figure 3.
A van Veen grab in the cocked position, ready for sampling

At depths greater than 50m, water sampling for oil and chemicals can be undertaken using hydrographic sampling bottles, preferably with a PTFE internal lining. This is most easily undertaken with a rosette sampler (deployed by hydro-wire) which allows the bottles to be closed at a specific sampling depth using either a messenger or by signal from the deploying vessel. This also enables sampling at several depths at a (GPS) single location. In calm conditions with a small amount of drift over a flat seabed rosette can sample to within 1m of the bottom. In rough seas, or with a rocky seabed, the rosette will need to be further from the seabed (2-5m). For examples of the use of these methods during the Deepwater Horizon incident, see Camilli et al. (2010) and Hazen et al. (2010).

Water samples can also be obtained by remotely operated or underwater autonomous vehicles (ROVs or AUVs). This might be appropriate where the risks associated with sampling immediately over the plume are deemed to be high in terms of worker safety. The number of samples that can be obtained tends to be fewer than by rosette sampler for example. The principles however remain the same. Sampling vessels should be clean and pre-rinsed with solvent. They should be prevented from opening near the surface so that the sea surface microlayer is not sampled, and should be triggered at a depth that is appropriate to the survey design. Oil concentrations can also be monitored semi-continuously using various fluorimetry devices. The use of sensors and remote sampling devices is discussed in Section 5.6.

4.2.3 Sediment sampling

There are two main purposes of sediment sampling following an oil or chemical spill. The first is to establish whether the oil/chemical is entering the sediments due to the spill. The second is to obtain samples which can be used to study changes in benthic communities and so determine the degree and area of the impact of the spill on the seabed.

Sediment samples can be collected using grabs or coring devices, or by means of ROVs deployed and controlled from a surface vessel. This section relates only to grabs and corers. Further information regarding use of ROVs can be found in Section 5.6.

In intertidal areas, sediment samples can be collected by hand. The use of stainless steel or Teflon 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.

A van Veen grab is shown in Figure 3. Small versions can be operated by hand from small boats, jetties, quaysides, etc. (see Figure 5 opposite).

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. Corers are generally used to remove a core from the seabed to establish contaminant changes over time. If samples are taken from stable sediment areas, then increasing depth in the sediment (down the core from the sediment surface) represents an increase in time since the sediment was deposited.

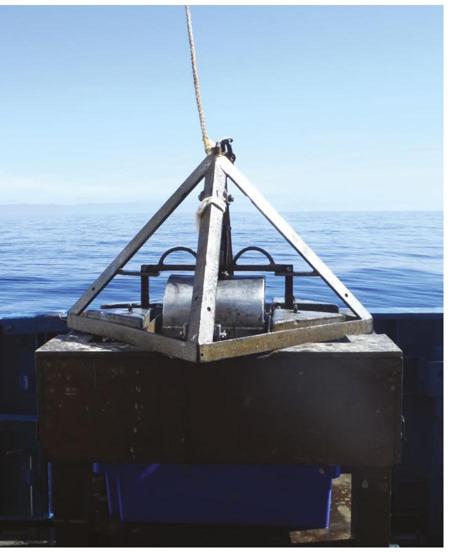


Figure 4.
Day grab (0.1 m^2).

Figure 5.
A hand-held van Veen grab used for sampling in estuaries from wharves, jetties or small boats, showing the sediment collected.

Sediment core slices can be dated by determination of the 210Pb content, up to around 150 years. In a post-spill situation though, it is the recent history which tends to be of interest, so grab samplers which sample the top few cm of the sediments are most often used.

A 0.1m^2 modified Day grab is a good general-purpose grab (Figure 4), but in sediments which 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 (Figure 6). In coarse, gravel dominated sediments, a Hamon grab is generally more effective. Where little is known regarding the sediment types likely to be encountered, the use of a Hamon grab is recommended to reduce the likelihood of failed sampling across the entire range of sediments present within any given site (Figure 7).

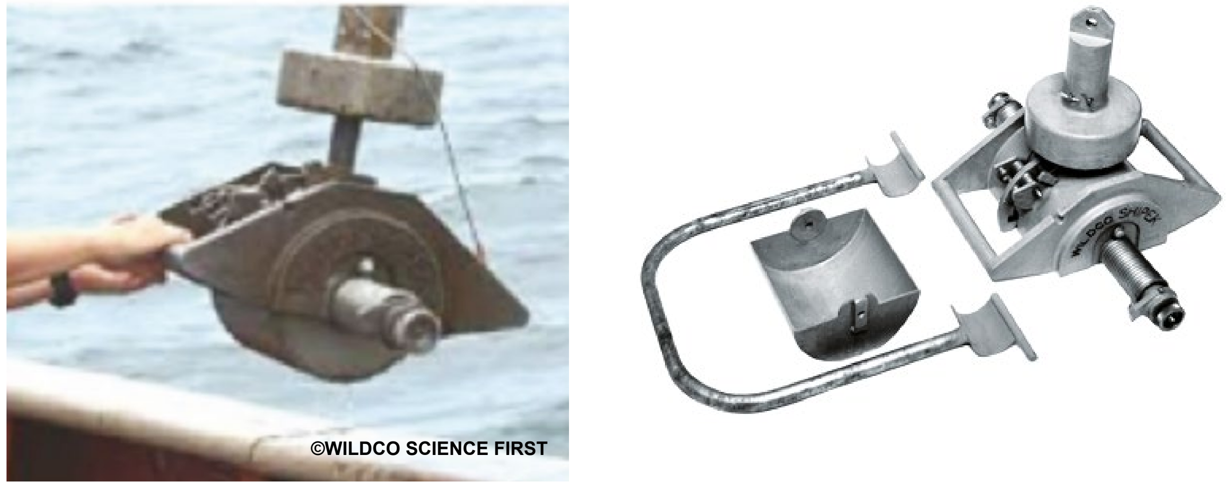


Figure 6.
Shipek grab

Figure 7.
Mini-Hamon grab (fitted with video system), the combined gear being known as HamCam.

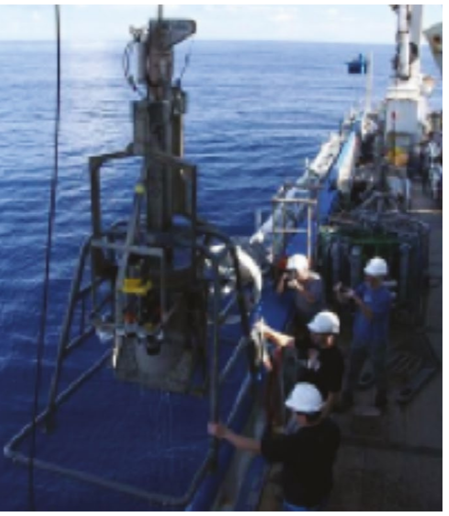


Figure 8.
Nioz corer.

Whilst the selection of grabbing gear employed is largely driven by the nature of the targeted sediment type, there are several implications associated with the use of the different gear types. Firstly, due to the action of the Hamon grab, the whole sample is 'mixed' during the process of collection and retrieval, thereby precluding the examination or sub-sampling of an undisturbed sediment surface. Therefore, sub-samples of sediment obtained from a Hamon grab sample comprise an integrated sediment sample which is representative of the sediments present throughout the entire depth of the sample. Another implication associated with the sub-sampling of Hamon grab samples for Particle Size Analysis (PSA) is the likely under-representation of the sediment fractions comprising large grain sizes.

Conversely, the Day grab does allow access to the undisturbed sediment surface during subsampling. In this instance, the sediment sub-sample collected for subsequent PSA is considered adequate given that this sampling device should only be employed in areas of relatively uniform, homogenous sediments. If an undisturbed sediment core is required, then a benthic corer can be used. An example of a benthic corer is the Nioz corer (Figure 8). The retrieval of undisturbed cores permits in-situ biogeochemical processes to be investigated. It also allows investigation of the different sediment layers, in particular the depth of the REDOX discontinuity layer. An overview of common sampler types is provided in Table 2.

Table 2. *Overview of sampler types*

	Nioz Corer	Day Grab	Shipek Grab	Hamon Grab
Soft sediments	•	•	•	•
Stony ground			•	•
Unknown substrate				•
Advantages	Historic information, redox layer	Retained surface layer, PSA relevance	Good for less homogenous samples	Limited sampling failures
Disadvantages	Limited applicability in spill incidents. Limited to use on larger vessels with sufficient lifting capability.	Sampling failures on stony substrates.	Mixed sample (no surface layer).	Mixed sample. PSA can be unrepresentative. Limited to use on larger vessels with sufficient lifting capability.

Surface sediment samples for chemical analysis should be taken from the upper 2cm of an undisturbed sample and transferred to an aluminium or glass container. 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 in the laboratory. Core samples should be extruded and sliced at 2cm intervals, and then the slices stored in a similar manner. Samples for PSA are taken with a plastic scoop or syringe and stored in a tub or bag at -20°C. Samples for infaunal analysis are sieved on board and preserved in formalin.

Murdoch and MacKnight (1994) provide comprehensive guidance on sampling procedures for collection of bottom sediments, suspended particulate material and sediment pore water. A detailed description of sediment sampling can be found in the Benthic Grabbing guidelines (Technical Guideline No. 2) available from the Post-Incident Monitoring Guidelines: Subsea Oil Releases and Dispersant Use in the Premiam website[7].

4.2.4 Biota sampling

The collection of macro biota (primarily fish and shellfish) as a result of an emergency can be for a number of reasons, to include assessing the immediate impact on population density or individual contamination. The methods used for sampling biota will vary depending on the species of interest and the habitats with which they are associated. Pelagic fish move throughout the water column and so provide an assessment of the impact of pollution within the water column, whilst demersal fish (especially flatfish which live on the seabed) are more closely associated with pollution of seabed sediments. Shellfish, especially bivalve molluscs, but including crustaceans, can be found in coastal and offshore locations and, due to their relatively sessile nature, tend to accumulate hydrocarbons and so should be prioritised for sampling. In coastal areas where aquaculture activities are significant, farmed fish/shellfish should also be prioritised for sampling. Purchasing fish from retail outlets (such as fish markets) is not recommended as point-of-origin records are notoriously unreliable. When sampling for assessment of human health risk, local consumption habits should be considered. For example, following the Sea Empress oil spill in 1996, three seaweed species were included within the monitoring programme as these were eaten locally (Law and Kelly, 2004). Further information on biota sampling can be found in the Biota Collection guidelines (Technical Guideline No. 3) available from the Post-Incident Monitoring Guidelines: Subsea Oil Releases and Dispersant Use in the Premiam website.

Pelagic and demersal fish are best collected using commercial fishing gears at preselected locations using fishing or research vessels. While research vessels may be better equipped to undertake this type of sampling, utilising the knowledge of the fishermen themselves regarding suitable and safe areas to fish is invaluable, and may often prove to be the better option. 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 being transported to a laboratory for analysis should be whole, and 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 (see Section 4.5). Individual fish should be wrapped in solvent rinsed foil to prevent contamination, degradation and dehydration before placing in a plastic bag. 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 uncertainty. The number of each species needed to provide a "representative" sample should be established regarding the level of variability for the contaminants of concern, as described in the OSPAR Joint Assessment and Monitoring Programme (JAMP) Guidelines for monitoring contaminants in biota (see OSPAR, 2012).

[7] https://www.cefas.co.uk/premiam/publications/post-incident-monitoring-guidelines-subsea-oil-releases-and-dispersant-use
[8] https://www.cefas.co.uk/premiam/publications/post-incident-monitoring-guidelines-subsea-oil-releases-and-dispersant-use

Fish may also be required to be dissected ahead of storage, if being analysed for certain biomarkers such as Ethoxyresorufin-O-deethylase (EROD). Dissection should be carried out in accordance with standard protocols and samples stored in liquid nitrogen at -190°C (usually in a dry cryogenic shipper).

Of prime importance is the avoidance of contamination of the biota samples during collection and transport to the analytical laboratory. Whilst on board, this could include contamination from sampling gear, shipboard fuels, lubricants and greases, engine exhaust and overboard discharges as well as the decks and surfaces. The deck area and fish reception areas aboard vessels should be washed regularly and nets and buckets used for collection and transfer of fish and shellfish should be cleaned regularly. The gloves worn by personnel sorting the catch should not have been used for general deck duties. Smoking must not be allowed in areas in proximity to those locations where samples are handled as smoke contains PAHs that may contaminate samples. Surfaces and sampling equipment must be visually inspected for signs of contamination i.e. surface oil sheen, and scrubbed clean where necessary. Sea water used to wash equipment must be remote from the spill site and free from contamination.

4.3. SAMPLE PREPARATION

It is also important to prevent contamination of samples (and loss of analytes) during storage, preparation and analysis. 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, cross-contamination and loss of analytes 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. In this instance, amber glassware should also be for any stage of the procedure where samples will be stored for over 24h. 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 positive pressure in the laboratory (to prevent dust from entering the laboratory) and an input of filtered air. For this reason, preparation of samples should be undertaken in a laboratory rather than field setting where possible. Sometimes this will not be possible, for example where time between collection and dissection is critical, or the number of samples to be taken will make the transport of whole fish impractical.

"*The avoidance of contamination of the biota samples during collection and transport to the analytical laboratory is of prime importance.*"

4.4 SAMPLE LABELLING AND TRACKING

The appropriate labelling and tracking of samples is an important step in ensuring robust and defensible data. Good chain of custody procedures is required so that the identity and integrity of the specimen from collection through to reporting of the test results can be guaranteed, and should be applied in post-spill monitoring studies. Most scientific organisations will already have these procedures in place, but a common practice should be agreed at the beginning of an incident. Chain of custody 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. 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. An example of a chain of custody form for registering changes of stewardship of samples is given in Yender et al. (2002).

The type of information that should be gathered as metadata for each sample is listed below, as an example of logsheet and chain of custody form (Table 3).

Table 3. *Example of chain of custody form.*

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:	

4.4.1 Sample tracking using barcodes and barcode readers

Keeping track of many samples requires effective methods of labelling and organisation. One very successful and simple technique involves the addition of a barcode label to a sample at the time of collection, linked to a database holding full information about the sample via a portable digital assistant (PDA). Such sample tracking is an important aspect of quality assurance, and 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.

Storage locations (cupboards, freezers, shelves etc.) can also be barcoded, scanned when samples are moved and the new location recorded. User names and passwords are required to change the person currently responsible for the sample, therefore providing chain of custody information.

4.5 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 (for instance, part way through an extended sampling programme) then priority delivery can be used to transport the samples. Couriers should be sourced that are able to transport the samples in an appropriate condition, for example ensuring that they stay frozen during transit and do not come into contact with possible sources of contamination. In a major and protracted incident, it is likely that any laboratories involved in storage and analysis will need to procure additional freezer capacity to hold all the samples generated. If samples cannot all be analysed immediately, priority should be given to the analysis of samples directly relevant to the management of fishery closures or other decision making, with samples related to the overall impact assessment banked in freezers until the initial pressure on the analytical facility eases as (e.g.) segments of the fisheries are re-opened.

PART 5

Key methodologies

5. Key methodologies

5.1 CHEMICAL ANALYSIS

The analytical methods deployed in any spill situation will depend on the incident itself. The chemical(s) spilled, their potential effects, and changes that may occur on mixing with other substances, including breakdown in seawater need to be considered. In the case of oil spills, the choice of analytical determinands is effectively predetermined. Oil is composed of a complex mixture of hydrocarbons, including aliphatics, one-ring aromatics, usually known as BTEX (benzene, toluene, ethylbenzene and xylenes) and the polycyclic aromatics (PAH: two to six fused aromatic rings). To get an overall picture of the level of contamination by hydrocarbons, a 'total hydrocarbon' measurement can be carried out. This can be done in situ using fluorimeters attached to ships or autonomous vehicles (see Section 5.6), or in the laboratory following solvent extraction. Samples are extracted into solvent (usually pentane) and analysed using UV fluorescence spectroscopy as per Kelly et al. (2000). This is a rapid way to understand the level of contamination, and should be used to gain an understanding of which areas may have been impacted. More in depth analytical procedures are available if identification of sources or determination of potential toxicity are required. PAHs formed by combustion processes comprise principally parent (non-alkylated) PAHs whilst, in oils, alkylated PAHs predominate and the mixture is much more complex. This means that, while analytical methods based upon high-performance liquid chromatography (HPLC) methodologies can be used satisfactorily to determine the smaller number of combustion PAHs, the available resolution using this technique is inadequate for the analysis of oil-derived PAHs and gas chromatography-mass spectrometry (GC-MS) is the preferred technique. 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.

This also yields the possibility for the investigation of aliphatic hydrocarbons and biomarker compounds (e.g. n-alkanes, pristane and phytane; steranes and triterpanes – see Section 5.2.1 below) in the same samples used for PAH determination. The development of methodology for the determination of PAHs has been outlined (de Boer and Law, 2003) and the recent status summarised elsewhere (Law et al. 2011). Further, White et al. (2016) describe the various techniques employed during the Deepwater Horizon incident, which highlighted techniques such as two-dimensional gas chromatography (GC x GC) which offers greater specificity over traditional GC methods, but is less readily available and can take months to derive meaningful results.

Many methods have been developed utilising different extraction and clean-up techniques, but one which has been used in oil spill studies and other monitoring programmes historically is described in Kelly et al. (2000). In practice, a combination of techniques will probably be required. Low selectivity but rapid turnaround techniques such as in situ fluorimetry will enable a prompt assessment of contamination, while the more time-intensive methods intensive methods which elicit more detailed data will be required to confirm sources and toxicity profiles.

Spills of HNS can be more complex from an analytical perspective, as a very wide range of chemicals are transported in either bulk or packaged form and so may be lost from vessels. Metals (including mercury) can be readily determined using inductively-coupled plasma-mass spectrometry (ICP-MS) (Wilbur and Jones, 2015; Helaluddin et al. 2016). Atomic absorption/emission spectroscopy (e.g. GF-AAS, ICP-OES) techniques can also be used for the determination of a wide range of elements at trace level. Other more specific techniques include X-ray fluorescence, cold-vapour atomic absorption spectrophotometry, atomic fluorescence spectrometry and anodic stripping voltammetry.

The techniques mentioned above may be useful for the determination of specific chemicals, depending upon their physico-chemical properties, but the combination of 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 the possible spilled chemicals, as most are not included in routine monitoring programmes, but efforts should be made to ensure that validated methods are used, or at least that quality procedures are followed and documented. In some programmes (e.g. those operated in coastal waters by the Environment Agency in England), screening techniques are deployed to detect and semi-quantify non-target compounds, with the aim of identifying those which may merit future inclusion in the full programme because of environmental concerns. These approaches may be appropriate in a chemical spill scenario to identify chemicals which warrant further attention. Methods employed typically involve a combination of GC-MS and LC-MS techniques, usually with passive sampling devices (PSD) used for sample collection purposes. PSDs have the advantage that time-weighted average concentrations can then be derived by deploying them for several weeks and calculating back to water concentrations.

Passive samplers are less useful in the early stages of an emergency, due to the relatively long equilibration and deployment times (of the order of weeks) required to obtain usable data, but may be more usefully deployed to assess recovery or return to background levels. Passive samplers are being investigated for use in monitoring across Europe (Booij et al. 2016; Miège et al. 2015), and are now included in the QUASIMEME suite of techniques to provide the quality assurance that will be required for future inclusion in the OSPAR Coordinated Environmental Monitoring Programme (CEMP)[9].

[9] www.quasimeme.org

5.1.1 Chemical fingerprinting

Environmental forensics can sometimes be deployed to provide a better understanding of the source of contamination. Environmental forensics has been defined as the systematic and scientific evaluation of physical, chemical and historical information for developing defensible scientific conclusions relevant to the liability for environmental contamination (Murphy and Morrison, 2015). Chemical fingerprinting can be used as part of this approach, employing a variety of methods and target biomarker compounds, and has been widely applied to oil spills of both known and unknown origin (for example, 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. 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 which form a background contaminant pattern, as well as accounting for changes in spilled oil due to weathering over time. The application of these types of source allocation techniques following the Exxon Valdez spill in Alaska can be found in e.g. Short et al. (1999), Boehm et al. (2001) and Burns et al. (2006), and an overview is given in Bence et al. (2007). The oil spill fingerprinting to determine sources has been reviewed by Christensen and Tomasi (2007).

> *"Chemical fingerprinting can be used as part of environmental forensic approaches, employing a variety of methods and target biomarker compounds, and has been widely applied to oil spills of both known and unknown origin."*

Coupled high-resolution GC-MS is the most commonly used technique (Stout and Wang, 2007). However, developments in the field of comprehensive two-dimensional gas chromatography (GC x GC) have enhanced forensic oil spill investigations due to the increased resolving power which allows the separation of many more compounds in complex mixtures than can be made with traditional (one-dimensional) gas chromatography, as described following its use in the Deepwater Horizon spill (White et al. 2016). 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 (ToF MS), to form a GC x GC-ToF MS system. Eiserbeck et al. (2012) compared GC x GC with various 1D GC techniques and found that GC x GC coupled to ToF MS was a particularly valuable tool in separating compounds with identical molecular masses and similar fragmentation patterns. This technique was used extensively following the Deepwater Horizon spill to investigate weathering (Hall et al. 2013 and Gros et al. 2014). In GC-MS, both low resolution (quadrupole or ion-trap MS) and high resolution MS instruments can be used satisfactorily. Suitable instrumental conditions for chemical fingerprinting using GC-MS can be found in US EPA standard method 8270D (US EPA, 1998).

Whereas combustion PAHs consist primarily of parent (unalkylated) PAH compounds, oils contain mainly alkylated PAHs. 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 many isomers and the distribution of these will vary in different oils, so the PAH isomer profiles can be used for comparative purposes and matching of spill samples and potential (or known) source oils.

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, b; 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 sources, so the ratio of pristane/phytane can be used to identify whether there are natural inputs or just those derived from a spill. These branched chain hydrocarbons are more resistant to biodegradation than the normal straight chain alkanes, and so tracking reductions in the ratios of C_{17}/pristane and C_{18}/phytane 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 Wang et al. (2007). These compounds can be observed by extracting from mass chromatograms fragments with a molecular mass (or mass to charge ration – m/z) 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 a wide range of illustrative material indicating oil to oil variations and the use of pattern matching to distinguish sources.

5.1.2 Taint-testing

Another way to determine hydrocarbons in seafood is taint testing. The use of a trained sensory assessment 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, taint-testing was used as a component of the management of the fisheries closures. In the former case, taint-testing was used extensively; in the latter case, when PAH concentrations had returned to background, representative samples of fish or shellfish were taint-tested as a final proof that the fishery sector could be reopened. Taint testing should only be carried out by a panel of suitably trained personnel, who regularly undergo monitoring of performance. This panel assesses samples of cooked fish using a numerical scale to indicate the intensity of taint.

More information regarding the use of taint-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). Guidance on the sensory assessment of seafood following an oil spill was published by the National Oceanic and Atmospheric Administration (NOAA) in 2001 (Reilly and York, 2001).

5.2 ECOTOXICOLOGY IN POST-INCIDENT MONITORING

5.2.1 General Introduction

One of the most important potential impacts of accidental spills 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; Radovi et al. 2012). This section provides 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.

5.2.1.1 Pertinent Questions

When deciding whether it is appropriate to deploy ecotoxicological techniques in post-incident monitoring, there are several 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 near 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?
- Is there concern over 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?

5.2.2 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, will depend on the matrix selected for investigation, and will broadly fall into four categories:

- Water
- Sediment
- Biota
- Chemicals

> *The use of transplanted or caged biota (such as mussels) may be considered where any of the above concerns exist but where naturally occurring specimens are difficult to obtain.*

5.2.2.1 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 regarding Section 4.2.2. Recommended standard water exposure tests are listed in Table 4.

5.2.2.2 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 therefore more likely to become associated with sediments.

Sediment samples to be used in ecotoxicological studies should be taken regarding Section 4.2.3. Recommended standard sediment exposure tests are listed in Table 4.

5.2.2.3 Biota

There are a number of situations in which biota, collected in the vicinity of a spill (e.g. wild or farmed), can be obtained and assessed for evidence of exposure or impact as part of a monitoring programme:

- Where there is a concern that in-situ biota could have been affected by the contamination (the water/sediment may be still 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 sea grass beds).
- Where there is 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 where naturally occurring specimens are difficult to obtain.

Biomarker and specific biota tests are listed in Table 4.

5.2.2.4 Chemicals

Efforts should be made to source relevant toxicological hazard information from the literature or from relevant chemical hazard databases (e.g. Gesamp, 2015) before resorting to novel data generation. Alternatively, modelling approaches such as QSARs (Quantitative structure-activity relationship) (e.g. EPA EPISUITE or OECD QSAR toolbox) can be used to predict ecotoxicological properties of chemicals of known structure. However, on occasion there may 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.

Table 4 and Table 5 describe techniques which can be used to test specific chemicals.

5.2.3 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 (OSPAR, 1997; OSPAR, 2003).

Table 4 and Table 5 overleaf outline a suggested baseline approach.

5.2.3.1 Bioassays

Table 4. *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) Oyster embryo development (*Crassostrea gigas* 24 hr EC50) Algal growth inhibition test (*Skeletonema costatum* 72 hr EC50)	ISO, 1999. ISO 14669:1999(E) Water quality -- Determination of acute lethal toxicity to marine copepods (Copepoda, Crustacea) Leverett, D. and Thain, J. 2013. Oyster embryo-larval bioassay (Revised). ICES Techniques in Marine Environmental Sciences No. 54. 34 pp. 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, Polychaete whole sediment bioassay (*Arenicola marina* 10 d LC/EC50)	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. 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.
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

5.2.3.2 Biomarkers (short-term)

Table 5. *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 activity PAH metabolites in bile AChE (Acetylcholinesterase activity Comet assay (genotoxic damage)	Stagg, R., McIntosh, A., and Gubbins, M. J. 2016. Determination of CYP1A-dependent mono-oxygenase activity in dab by fluorometric measurement of EROD activity in S9 or microsomal liver fractions. ICES Techniques in Marine Environmental Sciences No. 57. 21 pp. 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. 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. Bean, T. P. and Akcha, F. 2016. Biological effects of contaminants: Assessing DNA damage in marine species through single-cell alkaline gel electrophoresis (comet) assay. ICES Techniques in Marine Environmental Sciences no. 58. 17 pp.
Invertebrates – Molluscs Mussel (Mytilus edulis)	Lysosomal stability Scope for growth Comet assay (genotoxic damage)	Martínez-Gómez, C., Bignell, J. and Lowe, D. 2015. Lysosomal membrane stability in mussels. ICES Techniques in Marine Environmental Sciences No. 56. 41 pp. 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. Bean, T. P. and Akcha, F. 2016. Biological effects of contaminants: Assessing DNA damage in marine species through single-cell alkaline gel electrophoresis (comet) assay. ICES Techniques in Marine Environmental Sciences no. 58. 17 pp.

5.2.4 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. Such approaches have been recently discussed by Martínez-Gómez et al. (2010) and Radovi et al. (2012). Some examples where other techniques should be considered are outlined below.

5.2.4.1 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 PAH bile metabolites (Ariese et al., 2005) which become elevated due to exposure to certain polycyclic aromatic hydrocarbons (PAH), 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), delta-aminolevulinic acid dehydratase (ALAD) (for Pb) (Johansson-Sjobeck and Larsson, 1978) and acetylcholinesterase 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.

5.2.4.2 Mixtures

A 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 often involve the simultaneous release of a wide 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).

5.2.4.3 Habitat specific

Specific ecotoxicological techniques can also be extremely valuable in assessing the impact, or potential impact, of spills in certain habitats. Where a habitat is at threat or already damaged, it would be beneficial in the assessment of impact and recovery to be able to use sentinel species that are representative of that environment. Published ecotoxicological methodologies using habitat-representative species are manifold and examples might include the use of periwinkles (*Littorina littorea*) 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. This species was also successfully used as a sentinel species following the Sea Empress oil spill (Lyons et al. 1997; Harvey, 1999). 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 salting pools on sandy or muddy shores. Its food consists mainly of small crustaceans.

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.

"*Many of the recommended baseline biomarkers can be modified or are equally relevant for a wide range of other fish and invertebrates.*"

5.2.4.4 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. Some of these screening assays, such as those for Microtox (Zwart and Sloof, 1983) are now highly portable with a few manufacturers offering field-based kits that can generate ecotoxicological data without the need for sophisticated laboratory facilities.

5.2.4.5 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 (Table 4 and Table 5) have been selected 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. 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, miconucleii and comet assay) can act as indicators for the potential of 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).

5.2.4.6 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 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. 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.

5.2.4.7 Confounding factors

It is important, when using biological effects biomarkers and assays, to appreciate the 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 and 2003) should be followed. Additional guidance on the supporting parameters that should be considered when undertaking biological effects monitoring in fish and shellfish has been published by ICES (Balk et al. 2012).

5.3 ECOLOGICAL ASSESSMENT – GENERAL GUIDANCE

5.3.1 General recording of conspicuous impacts

Reliable records of conspicuous impacts to wildlife, particularly corpses, provide the most persuasive evidence of ecological damage. Some caution is necessary to ensure that the impacts are caused by the contaminants 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 daily and then less frequently).

Collection of dead wildlife for possible autopsies, 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, 2014) (see also Section 5.2.6).

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 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.

"Prioritisation of assessment studies is appropriate ... the considerable knowledge and experience available from previous spills can be used to assess the value of proposed studies."

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 whether the animals were impacted by the spill or by a natural event. Other conspicuous signs of impact of the spill may also appear over time, 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 initiated following the Exxon Valdez oil spill in Alaska in 1989[10].

5.3.2 Selecting/prioritising subjects for study

Reviews of historical oil spill damage 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 (Moore, 2005). While it may be politically useful to show to the public that a natural resource was not damaged, this can waste a limited monitoring budget. 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).

- **Importance of resource**:

  Nature conservation importance;

  Rarity and distribution;

  Ecological/functional importance;

  Profile of resource – public/scientific expectations.

[10] Currently 15 years in length, available at: http://oceanservice.noaa.gov/education/stories/oilymess/downloads/photo_series.pdf [accessed 14 January 2011]

- **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, licensing, etc.

  Available budget and cost effectiveness; it is expected that the costs of data collection will be included in any cost recovery and therefore such cost must be, reasonable, proportionate and relevant so a suitable budget is to be set to cover justifiable costs.

While the factors listed above will need to be considered in relation to the specific characteristics of the spill event, experience from previous spills provides considerable information on the sensitivity and vulnerability of different resources and their potential for natural recovery. The following generalisations may help to decide which resources deserve a higher priority. However, it is important to appreciate that they are only generalisations, primarily based on information from oil spill studies (data from chemical spills is limited) and may not always be appropriate.

- 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 toxic hydrocarbons are dispersed into the water column (either naturally or by the application of chemical dispersants), the resulting damage 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 or there is particular concern for a very important population or community;
- Contaminants reaching the marine environment in high amounts as a result of spills or leakage during transport constitutes an important pollution source directly affecting microbial populations. A summary of the current state of knowledge in this area is provided in Section 5.4.2.9, although they are not considered a high priority for study for most incidents;
- Planktonic communities have generally been observed to show no more than transient impacts from oil or chemical spills and are rarely studied for damage assessments, although during the 2010 Deepwater Horizon oil well blow-out in the Gulf of Mexico the US NOAA studied the impacts of the spill on productivity, nutrient cycling and species composition near and offshore habitats, which included plankton sampling;

- Most species of fish will avoid contaminated waters if they can, so fish kills are unlikely in open coast spill situations and have not been reported in offshore spill situations;
- In shallow water or in the case of sunken oil/chemical(s), mobile marine species (nekton) are less at risk of contamination than 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 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. This is likely similar for chemical spills, but data is limited;
- Some intertidal habitats where oil/chemical(s) may become trapped are more vulnerable to effects and may suffer longer-term damage. Many of these habitats are also important for their species richness. These include rock pools, 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 substantial toxic effect on the lower and middle shore habitats. Behaviour of spilled chemicals will be very dependent on their intrinsic properties;
- Oil tends not to penetrate 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 dependent on their intrinsic 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 the protection provided by 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 also a number of additional factors which should be considered. For example, it is important to understand the 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.

5.3.3 Planning for ecological monitoring surveys

5.3.3.1 Reconnaissance

Early reconnaissance is appropriate for selected intertidal priority habitats (e.g. saltmarsh, seagrass beds and other features and sites of 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 (see Section 2.4 and Moore, 2007), but in addition to oil/chemical distribution mapping the survey should include:

- basic biotope/NVC[11] mapping of contaminated areas (this is a primary purpose of the reconnaissance but the level of detail only needs to be adequate to identifying potential study areas);
- numerous photographs (view shots with adequate geo-referencing, habitat shots (with appropriate scaling and geo-referencing) and close-ups) (mark location on map or geo-reference with handheld 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);
- brief assessment of the condition of any known populations of protected species (conspicuous species only, e.g. plants);
- 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.); and
- brief assessment of potential for follow-up surveys (incl. practical and logistical constraints).

Reconnaissance of small areas of selected shallow subtidal priority conservation habitats (e.g. maerl beds, *Zostera marina* beds, lagoons) may also be appropriate if particularly high concentrations of hydrocarbons or chemical contaminants in water have been recorded in the vicinity. The primary aim here is to make ecological observations of condition of plants and animals and assess potential for follow-up surveys, though photography would also be useful.

[11]National Vegetation Classification

The principles of a monitoring plan
Survey planning
Sample collection and management
Key methodologies
Data quality and management
Communications and reporting
Appendices

5.3.3.2 Biological features and parameters

The range of biological features that could be considered for post-spill damage assessment study 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 spilled oil or chemicals 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 of use in improving our understanding of spill impacts on wildlife describe the temporal pattern of mortality, extent/distribution of mortality, and causes/ mechanisms of mortality in given species. 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 (sub-lethal) 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, egg-laying success 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 sub-lethal effects of pollutants in the tissues of individual animals, sometimes referred to as biomarkers[12]. See Section 5.2.3 and Section 5.2.4 for information on biomarker methodologies. However, even if sub-lethal 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 as a whole may not be apparent.

Toxicity and bioassay tests – see Section 5.2.3.1 Table 3.

[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.

5.3.3.3 Selecting and developing methods and protocols

While standard methodological protocols are available for some habitats and species, most will require at least some modification to make them appropriate to the characteristics of the resource affected and the spill conditions. Section 5.4 includes references to standard methodological texts for surveying and monitoring biological resources. 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, 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 assurance and quality control measures. The choice of survey and laboratory personnel will require certain minimum levels of qualifications and experience.

The amount of data required 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). The logistical and statistical implications of this should be discussed with your statistician. Site selection guidance is given in Section 3.4.

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.

The relevant international and national standards and best-practices must be followed during samples collection and analysis to avoid or at least reduce the risk of later queries and challenges.

Methodological references on ecological survey planning: AMSA (2003); AMSA (2003b); Davies et al. (2001); Moore (2007); NOAA (2013b).

[12] *Biomarkers – this term has two very different uses, both of which are relevant in this document: 1) a specific sub-lethal biochemical or physiological measurement which 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.*

5.4 ECOLOGICAL ASSESSMENT – SPECIFIC RESOURCES: HABITATS AND WILDLIFE

The guidance provided in the following sections is primarily derived from experience gained from studies carried out 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 physicochemical properties and behaviours of chemicals will affect the applicability of the guidance depending on the chemical(s) spilled.

[Note: several habitats and species groups described in the following sections may include populations of protected species of conservation importance. Any surveys that could affect those species will therefore require licensing via an emergency wildlife licence (for more details see the MMO website).]

5.4.1 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 impacts to terrestrial maritime habitats from spills, and fewer have detected any notable impacts. The Braer oil spill was one of the few incidents 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 at 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 that impacts are unlikely to be detected unless visibly coated with oil. No such studies have been undertaken to date following chemical spills.

Coastal habitats, above the level of spring high tides, may be damaged 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 fore dune communities of sand dunes and vegetated shingle ridge communities.

Damage assessment methods and strategy – The lack of an aqueous medium, removing surface contamination and impacted vegetation, makes post-spill damage assessment a lot easier than on intertidal areas, although the initial scorching and dieback effects may disappear when new growth begins (in the following spring/summer). There is likely to be at least a few weeks to document the area of contamination, analyse soil samples for contaminants, conduct initial surveys and devise a scientifically valid damage assessment methodology which includes the following elements:

1. Reconnaissance: taking note of scorching and dieback effects; and
2. 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.

The detailed strategy for the assessment of damage should consider the following points:

- If good quality pre-incident data exists from the impacted area – -establish previous survey sites and use 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 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; and
- QA/QC – measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

References on post-spill studies of oil on terrestrial vegetation: Bayfield and Frankiss (1997); Evans (1998); Little et al. (2001); Wolseley and James (1997).

5.4.2 Saltmarshes

Known vulnerability and sensitivity – saltmarshes are generally considered to be very vulnerable to oil spills. This is 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 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 the most difficult habitat to clean, due to the soft muddy substratum. Attempts to clean up these areas are not recommended without specialist advice. Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

“*several habitats and species groups may include populations of protected species of conservation importance... surveys that could affect those species will require licensing.*”

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. AURIS (1994), Baker et al. (1996), Sell et al. (1995) and Michel and Rutherford (2014) have reviewed the literature on impacts and recovery of saltmarshes following several 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 or all 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 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 effects of sub-surface oil, and recovery is prolonged. Areas of vegetation may die completely. Sediment erosion may occur if re-colonisation does not start within a year; and
- Thick deposits of viscous oil or mousse on the marsh surface. Vegetation is likely to be killed by smothering, and recovery delayed because persistent deposits inhibit re-colonisation.

A classification of different saltmarsh plants according to their recovery potential after oil spills, based on field experiments in British marshes, is also provided 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 killed quickly 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* and *Salicornia*). 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*, *Iva*, *Baccharis*) 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*, *Puccinellia*). 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*, 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*) 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*, *Limonium* and *Plantago*). 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 several occasions to cause considerable long-term damage; and it is now well recognised amongst professional oil spill responders that natural recovery is the best option for most areas of contaminated saltmarsh (Michel and Rutherford, 2014 and Zengel et al. 2015). 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. Michel and Rutherford (2014) and NOAA (2013) provide guidance on clean-up options for those situations where there is an imperative to respond.

Damage assessment methods and strategy – Spatial patchiness and temporal variability are not as high in saltmarshes 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, damage to saltmarsh communities may be best assessed by methodically monitoring their condition over the following weeks, months and possibly years; and using the same methods in uncontaminated reference sites. It is recommended that aerial photographs (or multispectral scans) are acquired as soon as possible of the contaminated marsh and surrounding areas. If the oil or chemical causes plants to die or lose their leaves, the aerial photographs/images will provide a baseline for assessing and monitoring the extent of damage; although this will need to take account of natural seasonal dieback. Initial focus of the assessment should consider the following elements:

1. Recording dead wildlife: counts of recently dead crabs and snails will provide useful evidence of damage;
2. Reconnaissance: taking note of the condition of contaminated plants (signs of decay in leaves, shoots, and roots; evidence of new growth; reproductive status); which parts of the plants are contaminated; any evidence of long-term natural trends (signs of natural dieback; 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; and
3. Biological survey attributes: some of the more likely potential indicators include 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 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.

The detailed strategy for the assessment of damage should consider the following points:

- 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) or chemical;
- 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 contamination may be possible within spatially extensive marshes;
- Comparison between stations on different marshes will be strongly influenced by other environmental factors;
- An alternative option may be to monitor changes in some of the above attributes at temporal intervals (e.g., bimonthly) from early stages of spill for at least one 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;
- QA/QC – measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. Identification of epibiota (e.g. saltmarsh snails and algae) will require specialist training. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

Key methodological references: Dalby (1987); JNCC (2004a); RPI (2002).

Other references on saltmarsh monitoring and impacts of oil: AURIS (1994); Baca et al. (1987), Baker et al. (1996), Bell et al. (1999); Getter et al. (1984); Hester et al. (2016); IPIECA (1994); IPIECA (2016); Michel and Rutherford (2014); NOAA (2013); Sell et al. (1995); Zengel et al. (2016).

Sources of data: Magic[14] : Coastal saltmarsh (England), Saltmarsh (Wales)); UK Data Gov Open Portal[15] ; individual statutory conservation agencies.

5.4.3 Seagrass beds

Known vulnerability and sensitivity – Two distinctly different forms of seagrass bed are found around UK coasts – intertidal beds (comprising of either *Zostera noltii* or *Z. angustifolia*) and shallow subtidal beds (comprising of *Zostera marina*). 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 spill impacts on temperate *Zostera* beds (AURIS, 1995; Fonseca et al. 2017), 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. Seahorses and their habitat are protected under the Wildlife and Countryside Act 1981 and subtidal seagrass beds are their prime habitat; specific consideration may therefore be required if there is any potential that seahorses are present.

The vulnerability of subtidal seagrass communities to dispersed oil or chemical will depend greatly on the flushing rate of seawater through the bed and the depth of water and the way in which the contaminants are 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 dieback.

[14] www.magic.gov.uk
[15] https://data.gov.uk/

Clean-up activity can have impacts on seagrass beds, particularly physical damage from trampling and vehicles. 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).

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Seahorses may be found in seagrass and may require specific consideration (see Section 2.3.1 which provides further detail relating to protected species and habitats) during clean-up activities or for post-incident monitoring, and authorisations from the MMO may be required. As is the case with fish, birds, seals, turtles and cetaceans, seahorses may also attract a great deal of public and media interest if impacted by the incident.

Damage 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 uncontaminated 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 greater levels of spatial patchiness and temporal variability. Detecting impacts in populations of these sensitive species (e.g. snails and small crustacean) is likely to require considerable efforts to collect data from numerous contaminated sites and numerous comparable reference sites. Unsworth et al. (2014) review seagrass bed monitoring methodologies in a UK context and suggests that the initial focus of the assessment should consider the following elements:

A. Intertidal seagrass beds

1. Recording dead wildlife: counts of dead biota (e.g. bivalves) will provide useful evidence of damage;
2. Reconnaissance: taking particular note of condition of *Zostera* and presence of molluscs (e.g. *Hydrobia*, *Littorina* and *Cerastoderma*). Aerial photographs (preferably vertical views and geo-referenced) will help to define the area of impact and may be useful for site selection;
3. 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.

The detailed strategy for the assessment of damage should consider the following points:

- 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 contamination may be possible on very extensive beds;
- An alternative option may be to monitor changes in some of the above attributes at temporal intervals (e.g. bimonthly) from early stages of spill for at least one year at selected sites;
- Effects of clean-up: the most likely impacts are from physical damage (trampling, vehicle traffic); damage assessment should be based on basic mapping of damage features, ecological observation and seagrass coverage in relation to damage features.

B. Subtidal seagrass beds (and extreme lower intertidal)

1. Recording dead wildlife: counts of washed-up bivalves, urchins etc. will provide useful evidence of damage.
2. Reconnaissance: by snorkelling, taking note of condition of *Zostera* plants, epifauna on blades (including amphipods in tubes and snails) and speed of retraction of bivalve siphons in sediment.
3. 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.

The detailed strategy for the assessment of damage should consider the following points:

- 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 contamination by toxic concentrations of oil or chemical 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).
- 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 one year at selected sites.

> *“Detection of conspicuous impacts on the condition of the seagrass plants may be possible if monitoring begins early enough and includes some uncontaminated reference sites.”*

- Effects of clean-up: potential impacts are from physical damage (trampling of beds at extreme low water), contaminated water run-off (from intertidal flushing operations) and chemically dispersed oil. Damage assessment of the former should be based on basic mapping of damage features, ecological observation and seagrass coverage in relation to damage features. Damage assessment of contaminated water run-off and chemically dispersed oil could be similar to the methods above, but it will be difficult to separate clean-up effects from other spill effects unless an experimental approach (incl. pre-clean-up recording) is applied.

[Note: Some seagrass beds are known to hold populations of seahorses, which are protected species. Surveys may therefore require licensing via an emergency wildlife licence.][16]

- QA/QC: measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. In-situ identification of epifauna and epifloral will require specialist training. Repeat recording and data checks by other surveyors will also be appropriate. Sediment sampling and analysis should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: Burdick et al. (1993); Davis et al. (2001) for guidelines on intertidal sediment core sampling, subtidal quadrat sampling, subtidal coring by diving, suction sampling and subtidal fish surveys; WFD-UKTAG (2014a).

Other references on seagrass bed monitoring and impacts of oil: AURIS (1995); Davison and Hughes (1998); Dean et al. (1998); Fiocco and Lewis (1999); Fonseca et al. (2017); den Hartog and Jacobs (1980); Hodges and Howe (1997); Howard et al. (1989); Jacobs (1980); Jewett et al. (1999); Unsworth et al. (2014); Zieman et al. (1984).

Sources of data: Magic17: Seagrass (Wales), Marine Recorder database of benthic survey data18; individual statutory conservation agencies.

5.4.4 Intertidal sediments

Known vulnerability and sensitivity – Sedimentary shores range from coarse shingle shores exposed to wave action to soft mud flats in sheltered bays. There are number of physical and biological characteristics of sedimentary shores that can influence their vulnerability and sensitivity to oil or chemical 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 relative sparsity of fauna present 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. Oil can persist and remain toxic in sheltered muddy sediments for many years (decades), particularly in unoxygenated sediments. AURIS (1985) reviews the effects in intertidal sediments from many spills and experimental studies. IPIECA (1999, 2016) summarise information on their sensitivity and recovery potential.

[16] *For more details see the MMO website: https://www.gov.uk/guidance/understand-marine-wildlife-licences-and-report-an-incident*
[17] *www.magic.gov.uk*
[18] *http://jncc.defra.gov.uk/page-1599*

Adverse effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

As on all shores, bulk oil tends to concentrate along the strandline; 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 faunal communities associated with sedimentary habitats are more sensitive to oil than 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 several oil spills. Some other species of fauna which are associated with intertidal sediments may opportunistically increase following oil spill impacts. These include small polychaetes such as *Capitella* spp.

Meiofaunal species associated with intertidal sedimentary habitats 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 two years later.

Damage assessment methods – Detecting impacts on communities associated with sedimentary shores can be difficult, even with good pre-incident information. This is due to the spatial patchiness and high temporal variability exhibited by intertidal communities; and the fact that impacts are, in some cases, relatively subtle so that laborious sampling and laboratory analysis is usually required. However, some conspicuous impacts may be evident in the first weeks following the incident (e.g. stranded bivalves), so early reconnaissance is recommended. Subsequent assessment of population effects is likely to require sampling from numerous contaminated 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.]

> "whole-sediment bioassays 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."

The initial focus of the damage assessment conducted for sedimentary intertidal habitats should consider the following elements:

1. Recording dead wildlife: counts of dead cockles, etc., will provide useful evidence of damage.
2. Reconnaissance: taking note of drainage features; presence of seagrass, surface grazing snails, cockles and other large bivalves (particularly on the lower shore), lugworm casts, large burrows, areas that would be very difficult to core into (due to subsurface coarse material), presence and character of strandline debris.
3. Biological survey attributes: some of the more likely potential indicators include 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 fluctuations and patchiness may confuse effects beyond a few months. The development of a method to assess sediment toxicity from natural copepod egg viability may become useful. The Infaunal Quality Index (IQI), developed under the WFD, is designed to assess sediment community health in response to organic enrichment and contaminant effects and should therefore identify notable impacts of the oil or chemical.

The detailed strategy for the assessment of damage should consider the following points:

- 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 contamination 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 one year at selected sites may show stages in impacts and recovery;
- 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;
- Effects of clean-up: potential impacts are from physical disturbance and burial of oil (particularly from trenching), and contaminated water run-off (from intertidal flushing operations). Such operations are most likely on firm sand beaches. Damage assessment could be similar to the methods above, but it will be difficult to separate clean-up effects from other spill effects unless an experimental approach (incl. pre-clean-up sampling) is applied. Physical disturbance effects are more likely if these operations can occur on sheltered muddy sediments; and monitoring of the infaunal communities should be able to detect impacts and follow recovery; and
- QA/QC: Sediment sampling and analysis should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: Baker and Wolff (1987); Davis et al. (2001): for guidelines on intertidal sediment core sampling; JNCC (2004c); WFD-UKTAG (2014b).

Other references on intertidal sediment monitoring and impacts of oil: AURIS (1995); Elliott et al. (1998); EPA (1994); Gesteira and Dauvin (2000); Holme and McIntyre (1984); IPIECA (1999); Kingston et al. (1997); Lee et al. (1999); Lindley et al. (1998); Moore et al. (1997); Rostron (1998); Shackley and Llewellyn (1997); Shigenaka (2014); Thomas (1978).

Sources of data: Marine Recorder database of benthic survey data[19].

5.4.5 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 large numbers of rockpools and crevices (Baker et al. 1996).

There is a considerable body of literature on the impacts of oil spills and on spill clean-up on rocky shores. IPIECA (1995, 2016) summarise 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 on the effects of the 1967 Torrey Canyon oil spill by Southward and Southward (1978) 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 (on a decadal scale) 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 three 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 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.

[19] http://jncc.defra.gov.uk/page-1599

The principles of a monitoring plan
Survey planning
Sample collection and management
Key methodologies
Data quality and management
Communications and reporting
Appendices

Several conclusions on sensitivity and appropriate survey methodologies can be drawn from the various studies of oil spill impacts on rocky shores and these are summarised below:

- 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 the development of appropriate survey/sampling/analysis techniques;
- Mortality of barnacles, primarily by smothering rather than chemical toxic effect, is likely where oil covers rocks; but 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. Sub-lethal 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 rock pool 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*); and
- 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.

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage 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 high degree of spatial patchiness and temporal variability. Early reconnaissance of contaminated 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 contaminated sites and numerous comparable reference sites.

The initial focus of the damage assessment conducted for rocky shores should consider the following elements:

1. Recording dead wildlife: counts of dead/moribund limpets and other gastropods will provide useful evidence of damage.
2. 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.
3. 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 sub-lethal 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 damage.

The detailed strategy for the assessment of damage should consider the following points:

- 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 contaminated and uncontaminated 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 contaminated and uncontaminated sites, or along a gradient of increasing distance from source, may be very useful. Such studies should preferably start soon (within a few weeks) after the spill, and be repeated at intervals to allow recovery processes to be assessed;
- Monitoring changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least one year (more for longer living species) at selected sites, may show development of effects and then the subsequent 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; and
- QA/QC: in-situ identification of epifauna and epiflora will require training. Measures of percentage cover can be subjective and require training and survey aids to ensure consistency of recording. Repeat recording and data checks by other surveyors will also be appropriate. Analysis of amphipods and other infauna from algal samples should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: Baker and Crothers (1987); JNCC (2004d); Murray et al. (2006).

Other references on rocky shore monitoring and impacts of oil: AURIS (1994), Baker et al. (1996); Barillé-Boyer et al. (2004); Chamberlain (1997); Crump et al. (1998); Crump and Emson (1998); Cullinane et al. (1975); Emson and Crump (1997); Hill et al. (1998); IPIECA (1995), Kingston et al. (1997); Little et al. (2001); Ryland and de Putron (1998); Somerfield and Warwick (1999), Southward and Southward (1978).

Sources of data: Marine recorder database of benthic survey data.

5.4.6 Lagoons

Known vulnerability and sensitivity – No cases of oil or chemical spills contaminating lagoons in UK or northwest 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 the 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.

[20] http://jncc.defra.gov.uk/page-1599

Damage assessment methods – The initial focus of the damage assessment conducted for lagoons should consider the following elements:

1. Reconnaissance: along shore and by snorkelling, taking particular note of condition of lagoon vegetation and conspicuous presence of species for which the lagoon is known to be important.
2. Biological survey attributes: some of the more likely potential indicators include 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).

The detailed strategy for the assessment of damage should consider the following points:

- If pre-incident data are available: resurvey 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 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 one 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 damage, but are likely to include basic ecological observation and vegetation mapping. If a lagoon is protected from oil or chemical 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;

[Note: Some lagoons are known to hold populations of protected species. Surveys may therefore require licensing via an emergency wildlife licence (for more details see the MMO website[21]).]

- QA/QC: measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. Identification of epibiota (e.g. snails and algae) will require training. Repeat recording and data checks by other surveyors will also be appropriate. Sediment sampling and analysis should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: Bamber et al. (2001); Bamber (2004); JNCC (2004b).

Other references on lagoon monitoring and impacts of oil: SEEEC (1998).

Sources of data: Marine Recorder database of benthic survey data individual statutory conservation agencies[22].

[21] https://www.gov.uk/guidance/understand-marine-wildlife-licences-and-report-an-incident
[22] http://jncc.defra.gov.uk/page-1599);

5.4.7 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 on the infaunal communities associated with the seabed sediments have been described after several 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. For example, oil particles preferentially adsorb onto fine particles of silt and clay, so higher concentrations are normally found in muddy sediments.

While it is generally considered unusual for notable quantities of oil from surface oil spills to reach depths greater than 10m, 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 11,320 ppm) a considerable distance to the west and south of Shetland in depths of at least 100 m (Kingston et al. 1997). Sub-surface spills, caused by releases from offshore oil installations during exploration, have greater potential for contamination and impacts to seabed communities, as shown by the Deepwater Horizon spill (Beyer et al. 2016) (also considered in Section 5.2.5.9 on deep-water habitats).

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.) and burrowing urchins (e.g. *Echinocardium cordatum*) have been identified as being particularly sensitive to the effects 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 may be that sediment contamination is not a requirement for, or indeed the main cause of, the effects on filter feeders described above. Transitory 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. Following the 1996 Sea Empress spill, analysis of seabed sediments in Carmarthen Bay, where large numbers of torpid bivalves stranded, found hydrocarbon concentrations within background levels (Lunel and Elliott 1998). If the sediment is contaminated it may influence recovery of those populations.]

Some other species of infauna may opportunistically increase following oil spill impacts, particularly small polychaetes.

While macrofaunal communities associated with shallow subtidal sediments are likely to be very sensitive to oil spills, they have been the subject of few post spill studies to date, due to the difficulties of sampling. The work by Jewett et al. (1999) in shallow subtidal *Zostera marina* 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 (Moore et al., 1997), although reductions in abundance or diversity are likely.

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage assessment methods – The initial focus of the damage assessment conducted for subtidal sediments should consider the following elements:

1. Recording dead wildlife: counts of washed-up bivalves, urchins, etc. will provide useful evidence of damage.
2. 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.
3. Biological survey attributes: some of the more likely potential indicators include 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); and while reliable techniques for spill impact assessment have not yet been developed, they may be useful for following short- to medium-term effects. The IQI, developed under the WFD, is designed to assess sediment community health and should therefore identify notable impacts of the oil or chemical.

[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.).]

The detailed strategy for the assessment of damage should consider the following points:

- Initial emphasis should be placed on areas where near-seabed concentrations or oil or chemical 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 contaminant 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 or chemicals from the spill are identified, it may be easier to establish viable reference sites or a series of sites along transects. However, 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 allow an assessment of recovery processes;
- If pre-incident data are unavailable, use evidence of stranded fauna to identify sites and consider small scale macrofauna or meiofauna sampling programme with increasing distance from source, re-surveyed at seasonal intervals for one or two 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 would only be appropriate in very unusual circumstances; and
- QA/QC: sediment sampling and analysis should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: JNCC Marine Monitoring Handbook (Davis et al. 2001): guidelines for subtidal coring by diving, suction sampling and fish on sediments; Holme and McIntyre (1984); JNCC (2004e); WFD-UKTAG (2014b).

Other references on subtidal sediment monitoring and impacts of oil: Beyer et al. (2016); Dauvin (1998); EPA (1994); Gesteira and Dauvin (2000); Jewett et al. (1999); Kingston et al. (1997); Moore et al. (1997), Nikitik and Robinson (2003); Rostron (1997); Rutt et al. (1998).

Sources of data: Marine Recorder database of benthic survey data[23]. UK benthos database of offshore environmental survey data[24].

[23] https://www.gov.uk/guidance/understand-marine-wildlife-licences-and-report-an-incident
[24] http://jncc.defra.gov.uk/page-1599);

5.4.8 Subtidal rock

Known vulnerability and sensitivity – Very few studies have explored oil or chemical 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 physical substrata that could retain a persistent contamination means that any impacts are only likely to be due to the acute effects of the dispersed oil or chemical, unless chronic contamination seeps down from an intertidal source.

As described in Section 5.4.7 on subtidal sediments (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 occurred. Various infaunal species of 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 sub-lethal 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 (c.f. references cited in Environment Agency 2004).

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

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.

Damage assessment methods – The initial focus of the damage assessment conducted for subtidal rock should consider the following elements:

1. Reconnaissance: possibly useful in very shallow areas, possibly by snorkelling (after surface pollution has gone); taking particular note of presence of amphipods and snails and any unusual behaviour (suggesting narcotisation) of any mobile fauna.
2. 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.

“*Very few studies have explored oil or chemical spill impacts on the epibenthic communities of rocky subtidal habitats.*”

The detailed strategy for the assessment of damage should consider the following points:

- 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 concentrations of contaminant 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 one 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 would only be appropriate in very unusual circumstances; and
- QA/QC: in-situ identification of epibenthic invertebrates and fish will require training. Repeat recording and data checks by other surveyors will also be appropriate. Analysis of amphipods and other infauna from algal samples should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: Rees (2009); JNCC (2004d); JNCC Marine Monitoring Handbook (Davis et al. 2001): guidelines on subtidal quadrat sampling.

Other references on subtidal rock monitoring and impacts of oil: Dean et al. (1996a); Dean et al. (1996b); Kingston et al. (1997); Rostron and Bunker (1997).

Sources of data: Marine Recorder database of benthic survey data[25].

5.4.9 Deep water habitats

Known vulnerability and sensitivity – Deep water habitats, i.e. beyond the continental shelf, between 200 and 1500 m depth, will not be vulnerable to surface oil spills, but may be vulnerable if a subsea oil leak occurs during oil exploration and production activities. Potentially vulnerable resources include benthic invertebrates, living on and in the seabed, and benthic and demersal species of fish, living on or close to the seabed. Our knowledge of the sensitivity of these invertebrates and fish to oil is very limited, primarily from studies following the 2010 Deepwater Horizon spill and some laboratory experiments. Dispersed oil from Deepwater Horizon contaminated a large area of seabed around the well, which resulted in notable impacts. Impacts on infaunal species diversity and community composition (Montagna et al., 2013), diversity and abundance of epibenthic and demersal megafauna (Valentine et al., 2013) and health of deep sea corals (Fisher et al., 2016) have been described, and that work is continuing. It is known that many deep-sea species (including corals) are long-lived and slow growing, suggesting that recovery from impacts may be slow (Beyer et al., 2016).

[25] http://jncc.defra.gov.uk/page-1599

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage assessment methods – Law et al. (2014) provide a framework and much detailed guidance for post-spill studies. The following provides some additional suggestions on relevant attributes and strategies.

Given the inevitable logistical challenges of mobilising surveys in deep water habitats it is unlikely that surveys of biological resources can be initiated very rapidly, so they should wait for information on the distribution of near-seabed contaminant concentrations (from water sampling or modelling). Survey of populations and communities on hard substrata, particularly deep-water corals, will require video sampling techniques.

1. Biological survey attributes: some of the more likely potential indicators include mega-fauna abundance, macro-fauna and meiofauna diversity and abundance. The polychaete/amphipod ratio has been suggested as an oil spill 'bioindicator' (Gesteira and Dauvin, 2000) and may also apply to the deep sea. The nematode/copepod ratio has been used in Deepwater Horizon studies (Baguley et al., 2015). Indices of impact on sessile epibenthic invertebrates (e.g. corals and sponges) may be developed from the frequency of tissue necrosis and other signs of ill health in video and still images. Measures of diversity and abundance of species associated with deep sea corals may also be developed from analysis of video and stills.

The detailed strategy for the assessment of damage should consider the following points:

- It is likely that at least some pre-incident data on fish populations and benthic communities will be available from environmental assessment studies, so re-surveys should be a priority;
- Establishing comparative reference sites or looking for trends with distance from spill site may also be appropriate, using designs that are commonly used for studying offshore oil well impacts (OSPAR, 2004). The relative homogeneity of deep water sediments across large areas will hopefully make it easier to distinguish natural trends from contaminant impacts;
- Monitoring changes in some of the above attributes at intervals may allow subsequent assessment of the recovery processes;
- 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; and
- QA/QC: sediment sampling and analysis should follow NMBAQC standards and guidelines. See Section 6.2.

Recommended references

Key methodological references: Law et al. (2014); OSPAR (2004).

Other references on deep water monitoring and impacts of oil: Baguley et al. (2015); Beyer et al. (2016); Fisher et al. (2016); Klif (2011); Montagna et al. (2013); Valentine et al. (2013).

5.4.10 Plankton

Known vulnerability and sensitivity – Planktonic organisms include marine algae and fauna (including adults and larvae of invertebrates and larval stage of vertebrates), which 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 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; but 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.

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. Tas et al. (2011) studied phytoplankton following the oil spill from the Volgoneft-248 in Turkey in 1999, and observed 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 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 which can provide data, which are logged continuously whilst the vessel is on passage[26].

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage assessment methods – The initial focus of the damage assessment conducted for plankton should consider the following elements:

1. Biological survey attributes: there are no attributes of plankton that are considered worthy of special attention.

The detailed strategy for the assessment of damage should consider the following points:

- 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 ongoing or recent plankton studies have got pre-incident data, then re-survey and comparison with that data is appropriate.

[26] For further information see www.ferrybox.org accessed 20 March 2017

Recommended references

References on plankton monitoring and impacts of oil: Batten et al. (1998); Kelly-Gerreyn et al. (2007); National Academy of Sciences (1985); Tas et al. (2011).

Sources of data – UK Data Gov Open Portal[27]. Continuous Plankton Recorder data[28].

5.4.11 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, however, high concentrations of freshly dispersed oil may kill some fish and have sub-lethal effects on others. Juvenile fish, larvae and eggs are most sensitive to the oil toxicity; 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; but 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. IPIECA (1997) summarises information on the sensitivity and recovery potential of fish and fisheries.

Damage assessment methods – Fish populations are characterised by considerable natural fluctuations, making it difficult to distinguish pollution effects, even if baseline data are available for comparison. Post-incident surveys of fish stock sizes/densities are extremely unlikely to provide any information suitable for a damage assessment. The only exception would be where detailed recent pre-incident population data exists for species.

1. Reconnaissance: collect samples of selected fish species of nature conservation importance for analysis (including PAH analysis in the case of oil spills, to facilitate assessment of risks to human consumers of commercial species).
2. Biological survey attributes: Biomarkers including hepatic EROD activity, PAH metabolites in the bile and DNA damage in sampled fish are likely to be the best measure of oil exposure (Martínez-Gómez et al., 2010; Radovic et al., 2012). 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 sub-lethal stress in fish tissues and may be useful for monitoring their recovery, but may not provide a reliable measure of the health of the affected population.

[27] https://data.gov.uk/
[28] https://www.sahfos.ac.uk/

The detailed strategy for the assessment of damage should consider the following points:

- Comparison between pre- and post-incident data on EROD activity, followed by monitoring to show recovery will provide the best evidence of sub-lethal 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; and
- QA/QC: see Procedural Guidelines listed in Section 6.2.

Recommended references

Key methodological references: JNCC Marine Monitoring Handbook (Davis et al. 2001): guidelines on fish in subtidal rock habitats, fish in vegetative cover, fish on sediments and fish in rockpools.

Other references on marine fish monitoring and impacts of oil: IPIECA (1997); Kirby et al. (2000); Law et al. (1998); Lyons et al. (1997); Wright et al. (1997).

Sources of data: UK Government Open Portal[29]

5.4.12 Seabirds

Known vulnerability and sensitivity – There is a considerable wealth of literature on the effects of oil spills on seabirds; which are taken here to include auks, terns, gulls, gannets, fulmars, petrels, shearwaters, kittiwakes, skuas, cormorants and shags. Partially marine water birds, such as sea ducks and divers are covered in the next section. Summaries of the effects of oil spills on seabirds are provided in NOAA (1992) and Clark (1984). Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

"There is a considerable wealth of literature on the effects of oil spills on seabirds."

Seabirds feeding or resting on the sea surface are vulnerable to water-borne pollution, and the periods 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). Sensitivity to pollutants will also be affected by the condition of the birds, so winter food shortages could increase the sensitivity of many birds.

[29] https://data.gov.uk/

The sensitivity and vulnerability of seabirds to floating oil is species specific and a variety of sensitivity indices have been developed. Webb et al. (2016) describe a recent index that has been developed for use on oil sensitivity maps of UK waters (see Table 6). The most sensitive species are those which spend a substantial period of their lives on the water surface, particularly divers, shag, guillemots, puffins and razorbills. Other factors that contribute to the calculation of the species-specific index are the proportion of tideline corpses oiled, habitat flexibility, the proportion of the biogeographical population present in the UK, the status on the list of Birds of Conservation Concern and in Annexes to the EC Birds Directive, the potential annual productivity and the adult survival rate.

Table 6. *Species specific seabird oil sensitivity index. Win. and Sum. are Winter and Summer values. From Webb et al. (2016).*

Species		Win.	Sum.
Great Northern Diver	*Gavia immer*	0.976	0.865
European Shag	*Phalacrocorax aristotelis*	0.851	0.823
Black-throated Diver	*Gavia arctica*	0.845	0.845
Common Guillemot	*Uria aalge*	0.843	0.902
Atlantic Puffin	*Fratercula arctica*	0.843	0.874
Red-throated Diver	*Gavia stellata*	0.808	0.808
Razorbill	*Alca torda*	0.799	0.865
Slavonian Grebe	*Podiceps auritus*	0.726	0.726
Black Guillemot	*Cepphus grylle*	0.721	0.721
Common Scoter	*Melanitta nigra*	0.712	0.667
Velvet Scoter	*Melanitta fusca*	0.657	0.657
Little Auk	*Alle alle*	0.655	0.655
Common Eider	*Somateria mollissima*	0.651	0.651
Common Goldeneye	*Bucephala clangula*	0.597	0.555
Red-necked Grebe	*Podiceps grisegena*	0.597	0.597
Great Cormorant	*Phalacrocorax carbo*	0.579	0.521
Long-tailed Duck	*Clangula hyemalis*	0.57	0.57
Greater Scaup	*Aythya marila*	0.561	0.529
Balearic Shearwater	*Puffinus mauretanicus*	0.534	0.534
Black-legged Kittiwake	*Rissa tridactyla*	0.484	0.429
Great Skua	*Stercorarius skua*	0.472	0.523
Manx Shearwater	*Puffinus puffinus*	0.472	0.547
Common Gull	*Larus canus*	0.467	0.429
Great Crested Grebe	*Podiceps cristatus*	0.463	0.463
Great Black-backed Gull	*Larus marinus*	0.459	0.459
Black-legged Kittiwake	*Rissa tridactyla*	0.436	0.471
Goosander	*Mergus merganser*	0.427	0.427
Red-breasted Merganser	*Mergus serrator*	0.396	0.396
Northern Fulmar	*Fulmarus glacialis*	0.391	0.421
Northern Gannet	*Morus bassanus*	0.391	0.447
Herring Gull	*Larus argentatus*	0.389	0.389
Mediterranean Gull	*Larus melanocephalus*	0.382	0.382
Lesser Black-backed Gull	*Larus fuscus*	0.379	0.407

Species		Win.	Sum.
Arctic Skua	*Stercorarius parasiticus*	0.377	0.392
Little Tern	*Sternula albifrons*	0.374	0.389
Roseate Tern	*Sterna dougallii*	0.339	0.35
Common Tern	*Sterna hirundo*	0.326	0.339
Black-headed Gull	*Chroicocephalus ridibundus*	0.312	0.312
Long-tailed Skua	*Stercorarius longicaudus*	0.306	0.306
Little Gull	*Larus minutus*	0.305	0.278
Cory's Shearwater	*Calonectris diomedia*	0.28	0.28
Great Shearwater	*Puffinus gravis*	0.28	0.28
Common/Arctic Tern	*Sterna hirundo/ Sterna paradisaea*	0.271	0.282
Sandwich Tern	*Sterna sandvicensis*	0.271	0.291
Arctic Tern	*Sterna paradisaea*	0.268	0.279
Sooty Shearwater	*Puffinus griseus*	0.266	0.266
Pomarine Skua	*Stercorarius pomarinus*	0.244	0.244
Sabine's Gull	*Larus sabini*	0.236	0.236
Glaucous Gull	*Larus hyperboreus*	0.208	0.208
European Storm-petrel	*Hydrobates pelagicus*	0.144	0.148
Leach's Storm-petrel	*Oceanodroma leucorhoa*	0.144	0.144
Black Tern	*Chlidonias niger*	0.124	0.124
Grey Phalarope	*Phalaropus fulicarius*	0.063	0.063

Maps showing the sensitivity of seabird concentrations to oil pollution for each month of the year have been prepared from algorithms that combine the species-specific scores with estimates of seabird densities (Webb et al, 2016). These density estimates have been calculated from seabird survey data collected over many years and using a variety of techniques: primarily boat-based line transects, visual aerial line transects and digital video strip transects. The resulting sensitivity maps are essential for environmental assessments of new developments and oil spill contingency planning, but Webb et al. (2016) highlight the age of much of the survey data. They include maps that show an index of confidence in the sensitivity assessment and recommendations for areas that should be prioritised for survey.

Within the last 30 years, oil spills in the northwest Atlantic (Braer, Sea Empress, Erika, Prestige, Tricolor) killed large numbers of seabirds, particularly guillemots and razorbills, 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 most 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.

Although the apparent impact of oil spills on seabirds is 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[30], and there are more and better monitoring data for these species than any other vulnerable (to oil and chemical spills) species of mammal, invertebrate or plant. Comparison of reliable colony count data from pre- and post-incident surveys (e.g. Heubeck, 1997 and 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 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 availability) 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 several years may provide a better indication, but it is now recognised that that still doesn't 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 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 damage to the populations and will rely on counts of corpses. The greatest concerns will always be for species that are both vulnerable and uncommon.

Theoretically, data on densities/distribution of seabirds at sea may also be used to compare pre- and post-spill populations, but annual variation can be considerable and data for many areas of sea are relatively sparse and dated.

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 sub-lethal 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) below). 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).

[30] http://jncc.defra.gov.uk/page-1550

Damage assessment methods – The initial focus of the damage assessment conducted for seabirds should consider the following elements:

1. Recording dead wildlife: Camphuysen et al. (2007) provide detailed methodologies for post-incident surveys. Counts of dead and contaminated birds will provide the best evidence of actual damage; 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. Carcass recovery experiments (preferably using dummy birds or drift blocks (wooden blocks with steel plate ballast, designed to mimic seabird carcass drift patterns, Munilla et al., 2011) 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 details to the British Trust for Ornithology (BTO). Other data to collect from corpses and live contaminated birds include a range of biometric measurements (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. It may provide useful data to support assessments, including indicating which colonies are likely to be most adversely affected.
2. Biological survey attributes: the priority should be to mobilise seabird at sea surveys to assess the locations of seabird concentrations liable to be impacted by drifting oil or chemical. Surveys will depend on suitable weather conditions and are usually carried out most efficiently from the air. The existing Seabird Monitoring Programme[31] 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, using digital aerial survey techniques, (Thaxter and Burton, 2009; Buckland et al., 2012). 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 sub-lethal 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.]*

The detailed strategy for the assessment of damage should consider the following points:

- 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;

[31] *http://jncc.defra.gov.uk/page-1550*

- Comparison of data on sub-lethal 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 is unlikely to provide proof without pre-incident data and will be a low priority for study; and
- QA/QC: identification and counting of seabirds, at breeding sites, at sea and in digital video, will require training. Accredited courses are available. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

Key methodological references: Buckland et al. (2012); Camphuysen et al. (2007); Gilbert et al. (1998); JNCC (2004f); Thaxter and Burton (2009); Walsh et al. (1995) and Webb et al. (2016).

Other references on seabird monitoring and impacts of oil: Baines and Earl (1998); Birkhead (2001); Bretagnolle et al. (2004); Camphuysen and Heubeck (2001); Camphuysen and Leopold (2004); Camphuysen et al. (2002); Castège et al. (2000); Clark (1984); Grantham (2004); Haycock et al. (1998); Heubeck (1997); Heubeck (2000); Irons (1996); JNCC (2015); Mavor et al. (2008); Mitchell and Parsons (2007), Monaghan and Turner (1997); Monaghan et al. (1997); Munilla et al. (2011), National Research Council (2003); NOAA (1992); O'Hara and Morandin (2010); Piatt and Anderson (1996); RPI (2001); SEEEC (1998); Shore and Wright (1997); Votier et al. (2005).

Sources of data: Magic[32] (Seabird Nesting Counts – British Isles – GIS); Seabird colony data[33]; Seabird Oil Sensitivity Index[34].

5.4.13 Inshore waterbirds

Known vulnerability and sensitivity – Inshore waterbirds are taken here to include eider, scaup, long-tailed duck, scoter, goldeneye, divers, grebes, goosanders and mergansers. They are considered separately here from seabirds because they mainly have an inshore distribution in the non-breeding season, very few breed in UK (most wintering sea duck breed in the 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 molluscs, or small fish/invertebrates, 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). Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Inshore waterbirds are extremely vulnerable to water-borne pollution, and the three species of divers are within the top six most sensitive 'seabird' species (refer to Table 6 of seabird oil sensitivity index in Seabird Section 5.4.12 above). Ecologically highly significant numbers of sea duck and divers have been killed by oil spills in the UK, including Braer (Heubeck 1997) and Sea Empress (SEEEC, 1998; Banks et al., 2008). Changes in distribution of inshore waterbirds may also result, perhaps in response to impacts on supporting habitats or prey (Castege et al., 2004; Banks et al., 2008).

[32] *www.magic.gov.uk*
[33] *http://jncc.defra.gov.uk/page-4460*
[34] *http://jncc.defra.gov.uk/page-7373*

Although the apparent impacts on these birds may be obvious when contaminated 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 Research Council, 1985) that the high reproductive potential of many sea duck may allow more rapid recovery of their populations compared to many seabirds, and evidence from the UK supports relatively rapid recovery (Banks et al., 2008). Scoter and diver concentrations at sea have been surveyed, and to a certain extent monitored, in some locations around UK, including within marine Special Protection Areas (Carmarthen Bay, Liverpool Bay and Outer Thames Estuary SPAs). Future monitoring data may also become available for a new suite of marine SPAs around the UK (in consultation at the time of writing), when classified. Standardised techniques have been developed, and digital aerial surveys are typically quick, targeted and precise (e.g. Thaxter and Burton, 2009; Buckland et al., 2012).

Studies of sub-lethal and indirect effects of oil or chemicals on sea duck and divers are not known from UK, but studies following the Exxon Valdez oil spill in Alaska did suggest effects on body mass (Esler et al., 2002).

Damage assessment methods – The initial focus of the damage assessment conducted for inshore waterbirds should consider the following elements:

1. 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 damage; 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 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 contaminated 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.
2. Biological survey attributes: priority should be to mobilise seabirds at sea surveys to assess location of concentrations of sea duck and divers liable to be impacted by drifting oil or chemical. 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 yet flexible (e.g. Thaxter and Burton, 2009; Buckland et al., 2012). 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 exists. Other sub-lethal effects indices might also be useful if good pre-incident data happens to be available. *[Note: catching and taking samples from birds will require an official licence.]*

“...priority should be to mobilise seabirds at sea surveys to assess location of concentrations of sea duck and divers liable to be impacted by drifting oil or chemical.”

The detailed strategy for the assessment of damage should consider the following points:

- 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.
- QA/QC: identification and counting of water birds, at breeding sites, at sea and in digital video, will require training. Accredited courses are available. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

Key methodological references: Thaxter and Burton (2009); Buckland et al. (2012).

Other references on inshore waterbird monitoring and impacts of oil: Banks et al. (2004); Banks et al. (2008); Camphuysen et al. (2004); Camphuysen et al. (2007); Castege et al. (2004); Clark (1984); Esler et al. (2002); Heubeck (1997); NOAA (1992); SEEEC (1998).

Sources of data: Seabird Oil Sensitivity Index[35]; individual statutory conservation agencies.

5.4.14 Wetland birds

Known vulnerability and sensitivity – Wetland birds, including waders, ducks, 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 primary concern for wetland birds during oil spills is the effects of the oil and the clean-up on their feeding and roosting resources (Henkel et al., 2014). 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 sub-lethal impacts.

Impacts on the food resource; i.e. 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 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.

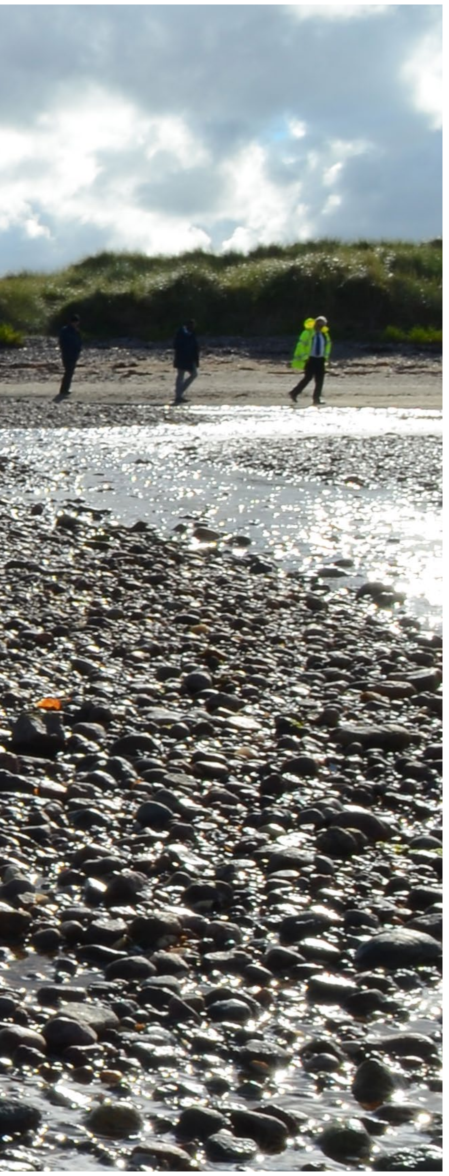
A variety of sub-lethal physiological effects from birds feeding on contaminated prey and building up a body burden of toxic hydrocarbons, have been shown from experimental studies (National Research Council 2003), but few field-based studies have shown evidence of population effects (c.f. black oystercatcher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

[35] http://jncc.defra.gov.uk/page-7373

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage assessment methods – The initial focus of the damage assessment conducted for wetland birds should consider the following elements:

- 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 damage; therefore, require 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, contaminated 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.
- 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[36]. These can show changes in numbers of birds visiting affected feeding areas, but 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[37], 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 prey population that was shown to be badly affected by the incident was the primary food source of a particular bird population.
- Sub-lethal 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 licence.]*



[36] See online WeBS report for survey data and methods http://app.bto.org/webs-reporting/
[37] See online WeBS report: http://app.bto.org/webs-reporting/

The detailed strategy for the assessment of damage should consider the following points:

- 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 damage 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; damage assessment should be based on standard survey methods described above and basic ecological observation; and
- QA/QC: identification and counting of wetland birds will require training. Training courses are available. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

Key methodological references: JNCC (2004f); Gilbert et al. (1998); BTO Wetland Bird Survey website[38].

Other references on wetland bird monitoring and impacts of oil: Andre (1999); Armitage et al. (1997); Armitage et al. (2000); Burton et al. (2004); Camphuysen et al. (2007); Musgrove et al. (2004); National Research Council (2003); Pollitt et al. (2003); Sharp et al. (1996); US EPA (2002).

Sources of data: BTO Wetland Bird Survey website[35]; individual statutory conservation agencies.

5.4.15 Affected birds

Birds affected by oil or chemicals can be divided into those which are alive and require rehabilitation if thought appropriate, and those which are dead and need to be stored for possible future necropsy and/or other studies. Statistics on contaminated birds also feeds into any overall impact assessment of an incident. 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 which 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 some initiatives to this end.

[38] www.bto.org/volunteer-surveys/webs

An active network of oiled wildlife responders has now been established across Europe, consisting of coastal rehabilitation groups, veterinarians, scientists, universities and national NGOs (now known as EMPOWER[39]). At a global level, the International Alliance 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 practice have also been published (IPIECA, 2014; Nijkamp, 2007).

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). Natural England and the Joint Nature Conservation Committee developed guidelines for the collection and study of dead oiled birds which are given below.

The rehabilitation of wildlife is a specialised area and should be undertaken by specialists. The Royal Society for the Prevention of Cruelty to Animals (RSPCA) 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 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 Standing Environment Group network during 2011. The RSPCA wishes to be more proactive than in the past and to form more formal relationships with the regional Standing Environment Groups.

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

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 biometric measurements be taken to aid identification of populations and age structure of affected birds. Even when experienced people check for rings on heavily contaminated 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, it is evident 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.

[39] *For further information see http://www.sea-alarm.org/*

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. However, 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 euthanised should be added to the dead casualties.

5.4.16 Seals

Known vulnerability and sensitivity – Geraci and St. Aubin (1990) summarise evidence on the impacts of oil on seals. Adults 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.

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.

Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage assessment methods – The initial focus of the damage assessment conducted for seals should consider the following elements:

1. Recording dead/contaminated wildlife: counts of dead or contaminated or sick seals will provide the best evidence of actual damage, although reasonable steps/analysis should be taken to check that death/oiling/sickness was caused by the 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 the Cetacean Strandings Investigation Programme operated by the Institute of Zoology on behalf of Defra. 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.
2. Biological survey attributes: some of the more likely potential indicators include in-situ recording of respiratory symptoms (and other signs possibly related to oil or chemical contamination 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 are the primary measure for population effects and standardised census methods are well developed, although annual fluctuations will greatly limit the detection of any impacts (e.g. Westcott 2002).

[Note: aerial surveys are widely used for seal counts (adults and pups), but ground-based surveys are generally considered more reliable in some steep coastlines where the pups are often hidden in small coves and caves.]

The detailed strategy for the assessment of damage should consider the following points:

- 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 from oil spill effects;
- Comparison of data on respiratory symptoms between different haul-outs (contaminated and uncontaminated, or along a gradient of contamination) is likely to provide the best evidence of short-term impacts, if 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 (contaminated and uncontaminated) may be useful in severe cases (and when contamination 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; and

[Note: seals are protected species so a licence would be required for survey work using invasive techniques – contact relevant statutory conservation agency.]

- QA/QC: measures of seal stress can be subjective and require training and survey aids to ensure consistency of recording. Counting seals, from ground-based or aerial surveys, will also require training. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

“measures of seal stress can be subjective and require training and survey aids to ensure consistency of recording.”

Recommended references

Key methodological references: Duck (2003); JNCC (2005).

Other references on seal monitoring and impacts of oil: CCW (1998); Conroy et al. (1997); Duck et al. (1993); Geraci and St Aubin (1990).

Sources of data: UK Data Gov Open Portal[40]; Sea Mammal Research Unit[41]; individual statutory conservation agencies.

[40] https://data.gov.uk/
[41] http://www.smru.st-andrews.ac.uk/

5.4.17 Otters

Known vulnerability and sensitivity – Otters are undoubtedly sensitive to oil (Geraci and S. 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.

Damage assessment methods – Detecting and monitoring of any impacts to otters from oil or chemical spills will be extremely difficult. Even if there is considerable contamination 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. The initial focus of the damage assessment conducted for otters should consider the following elements:

1. Recording dead otters: counts of dead or contaminated or sick otters will provide the best evidence of actual damage, although reasonable steps/analysis should be taken to check that death/oiling/sickness was caused by the oil or chemical spill.
2. 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 (e.g. Crawford, 2011)); records of otter sightings at known sites close to the spill area.

The detailed strategy for the assessment of damage should consider the following points:

- 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 contaminated and uncontaminated areas is very unlikely to be of any value, due to natural variation; and

  [Note: Otters are a protected species so a licence would be required for survey work using invasive techniques – contact relevant statutory conservation agency.]

- QA/QC: otter survey techniques will require training. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

Key methodological references: JNCC (2004g); Crawford (2011).

Other references on otter monitoring and impacts of oil: Conroy et al. (1997); Geraci and St Aubin (1990); SEEEC (1998).

Sources of data: JNCC website[42] (pages on Otter), individual statutory conservation agencies.

[42] http://jncc.defra.gov.uk

5.4.18 Cetaceans: whales, dolphins and porpoises

Known vulnerability and sensitivity – Geraci and St Aubin (1990) and Gubbay and Earll (2000) summarise the limited evidence for impacts of oil on cetaceans up to and including studies from the 1989 Exxon Valdez spill in Alaska. More recently, studies following the 2010 Deepwater Horizon spill have suggested notable impacts on dolphins in the Gulf of Mexico. 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 near oil spills, sometimes being attracted to the spill area by the response activity, and may therefore come into contact with oil. While their skin is not thought to be particularly sensitive to oil, any accidental ingestion or breathing of oily fumes could cause physiological stress (Takeshita et al., 2017). However, until the recent Deepwater Horizon studies, very few examples of actual injury to cetaceans had been reported and much of the evidence of injuries from spills is circumstantial. Some 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) describe notable reductions in the numbers of two pods that had been observed near the spill and showed that they did not follow the population increases shown by other Alaskan pods. Some reviewers have suggested other possible causes for the reductions, but the debate continues.

When the Deepwater Horizon spill occurred in 2010, a team of marine mammal researchers began studies on several cetacean populations. Those studies soon highlighted unusual rates of mortality in certain populations that could be linked to the spill. Further, comparisons between resident populations of bottlenose dolphins in areas with different levels of oiling identified significant health issues in a population from the most heavily oiled area (Barataria Bay, Lousiana). The population showed several indicators of poor health, including pulmonary disease, and low reproductive success (Lane et al., 2015; Takeshita et al., 2017). As is typical with studies of marine mammals, there are several confounding factors that cast some doubt on the conclusions; however, the studies clearly identify exposure to oil, a potential mechanism for effects and some moderately convincing evidence of injury. Continued studies will hopefully describe recovery.

Notwithstanding the Deepwater Horizon evidence, current evidence does not suggest more than a low sensitivity to oil for most cetaceans, but resident populations of some species may be both vulnerable and sensitive to large oiling events. Effects can also be expected from exposure to spilled chemicals but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Damage assessment methods – The Deepwater Horizon spill, and subsequent cetacean studies, were exceptional. In most spill situations, it will be very difficult to prove an impact on cetacean populations, or indeed to provide much information suitable for a damage assessment, even if pre-incident data exist. The exception would be if a well-studied and very stable species population is normally present in the spill area. All cetaceans are highly mobile, difficult to study in the wild and protected by law. Detailed damage assessment studies are therefore not normally recommended unless such exceptional circumstances suggest a higher priority.

The detailed strategy for the assessment of damage should consider the following points:

- 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 casual sightings of ill animals are reported;
- 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 operated by the Institute of Zoology on behalf of Defra. 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;
- Acoustic survey methods that are currently being developed may be available in the future for estimating abundances of cetaceans in 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; and
- QA/QC: Identification and counting of cetaceans, and sea and from digital video, will require training. Accredited Marine Mammal Observer courses are available. Repeat recording and data checks by other surveyors will also be appropriate. See Section 6.2.

Recommended references

Key methodological references: JNCC (2005); Evans and Hammond (2004).

Other references on cetacean monitoring and impacts of oil: Baines et al. (1997); Geraci and St Aubin (1990); Gubbay and Earll (1999); Gubbay and Earll (2000); Lane et al. (2015); Matkin et al. (2008); Ridoux et al. (2004); Takeshita et al. (2017).

Sources of data: Atlas of cetacean distribution[43].

[43] http://jncc.defra.gov.uk/page-3881

5.4.19 Microbial communities

Monitoring microbes affected by marine oil spills

Oil spills dramatically alter the composition of marine microbial communities, generally resulting in a large decrease in species richness and diversity, and an increase in the abundance of hydrocarbon-degrading bacteria (Head et al., 2006; McGenity et al., 2012; Joye et al., 2016). However, the application of microbial community analysis for post-spill monitoring is in its infancy. Generally, it provides supportive evidence that bioremediation is taking place. For example, in marine waters, the increased relative abundance of sentinel genera such as *Alcanivorax*, *Thalassolituus*, *Oleispira* and *Oleibacter* (primarily alkane-degrading) and *Cycloclasticus* (primarily PAH-degrading) indicates that these components of crude oil are being biodegraded and that the community has the capacity to naturally attenuate the oil (assuming that nutrients, such as N, P and Fe, do not become limiting).

However, the selection for particular sentinel species and their abundance are influenced by numerous factors including: oil composition, degree of weathering (Head et al., 2006), proximity to the oil phase (Chronopoulou et al., 2015), temperature (Coulon et al., 2007), nutrient availability and extent of dispersion (McKew et al., 2007b). The process of biodegradation is also successional, so the community composition will depend on the amount of time since the oil was spilt. This temporal change in microbial community composition may be caused by various factors, such as decreasing nutrient concentration, changing bioavailability of hydrocarbons, and preferential accumulation of those hydrocarbons that are more resistant to degradation. Moreover, while we can say with certainty that the aforementioned genera are hydrocarbon degraders, this is not the case with more versatile genera such as Marinobacter. Although these factors can complicate the interpretation, and thus value, of microbial monitoring, some may also be advantageous. For example, it is well established that there is niche-partitioning between species in the utilisation of different hydrocarbon components (McKew et al., 2007a), which could inform on the status of a spill, i.e. changes in oil composition over time as particular hydrocarbon substrates are removed (generally proceeding from low- to high-molecular weight hydrocarbons).

Microbial community analysis is performed by nucleic acid extraction from the environment followed by analysis of phylogenetic or functional genes or transcripts. The most typically applied method is high-throughput sequencing, which can inform on the diversity and relative abundance of taxa, to demonstrate overall shifts in community composition (Dumbrell et al., 2016), and the selection of oil-degrading genera. Illumina next-generation-sequencing, lab-based platforms are most commonly used, but in-situ sequencing could be achieved with portable devices such as Oxford Nanopore Technologies real-time MinION sequencer. Quantitative PCR is a more targeted approach that can, for example, measure the change in relative abundance of sentinel genera, such as Alcanivorax (McKew and Smith, 2017). The 16S rRNA gene is the most commonly used phylogenetic gene; and a range of functional gene primers (e.g. targeting the alkane hydroxylase gene, alkB) can be employed for both aerobic (Scoma et al., 2017) and anaerobic (Leuders and von Netzer, 2017) hydrocarbon-degradation pathways.

In addition to identifying taxa that increase in abundance in response to an oil spill, an alternative approach is to detect or quantify genes or transcripts belonging to species that may be inhibited by oil fractions dissolved in the water column, e.g. the otherwise ubiquitous SAR-11 group (Chronopoulou et al., 2015). However, the absence of a species cannot easily be attributed to the presence of oil, as such microbes may be susceptible to diverse pollutants and it is difficult to differentiate relative or absolute decreases in abundance of such taxa owing to the simultaneous increase in abundance of oil-degrading bacteria. Moreover, their decrease in abundance may be attributed to direct toxic effects from oil (Paul et al., 2013) and/or treatments, or due to being outcompeted for available resources by specialist hydrocarbon-degrading bacteria.

Microeukaryotes may provide another source of sentinel species for oil spills. For example, Brussaard et al. (2016) showed that certain micro-phytoplankton and microzooplankton taxa declined during a relatively small, rapidly dissipating spill. Using 18S rRNA gene sequencing Bik et al. (2012) saw major shifts in the eukaryote communities in oil-impacted sediments surrounding the Gulf of Mexico, with Fungi becoming dominant in several locations, potentially playing a role in degradation. For Archaea, no consistent effects of oil on their community composition have been observed (Sanni et al., 2015).

Approaches such as microplate Most Probable Number enumeration have proven useful for measuring changes in abundance of hydrocarbon-degrading bacteria (Johnsen, 2017). Metabolite detection can also inform on the extent and mechanism of hydrocarbon degradation (Bonifay et al., 2016).

Lozada et al. (2014) proposed and tested an ecological index of hydrocarbon exposure based on microbial community composition determined by 16S rRNA gene sequences. They allocated phylotypes according to whether they were from genera that had been shown to include hydrocarbon-degrading species. The index may be improved further by better understanding taxonomy-trait relations and by incorporating knowledge gained about the function of uncultivated bacteria, e.g. obtained through methods like single-cell genomics (Mason et al., 2012), DNA stable-isotope probing (Gutierrez et al., 2013) or epicPCR (Emulsion, Paired Isolation and Concatenation PCR) (Spencer et al., 2016) and other approaches as outlined by Röling and van Bodegom (2014). Given that we have an ever-growing understanding of hydrocarbon catabolic pathways, the genetic information relating to these pathways can be used to assess the microbial capacity to respond to hydrocarbon degradation, or, using gene expression analysis, to quantify the actual response (McKew and Smith, 2017). However, judicious selection of target genes and primers is essential (Scoma et al., 2016).

It is important to be able to rapidly quantify the bioavailability of hydrocarbons, because it provides a measure of the capacity of hydrocarbons to enter cells, and thus of their potential toxicity or biodegradability. Bacterial bioreporters provide quantitative assays to measure the bioavailability of various oil fractions, such as short- and long-chain n-alkanes, BTEX (benzene, toluene, ethylbenzene and xylenes) or low molecular weight polycyclic aromatic hydrocarbons and derivatives (naphthalene, methylnaphthalene, phenanthrene) (van der Meer and Belkin, 2010). Bacterial bioreporters have been successfully deployed at sea during experimental spills, demonstrating their applicability for oil-spill monitoring (Tecon et al., 2010; Brussaard et al., 2016). For example, bioreporters indicated that dissolved oil components, such as BTEX, were immediately available to biota just two hours after an oil spill and 8m below the spill; and the bioreporters also enabled hydrocarbon bioavailability to be monitored over time (Brussaard et al., 2016).

In order to make such tools more applicable, whether we are considering bioreporters or any of the nucleic-acid-based methods to monitor microbes – sentinel species or functional groups that increase or decrease in abundance, ecological indices based on community analysis, genes indicative of hydrocarbon degradation – there is a lot of scope for developing rapid and simple tools for nucleic acid extraction and analysis, as well as coupling to mobile or static monitoring devices in the marine environment (van der Meer, 2016; McQuillan and Robidart, 2017).

5.5 MODELLING

At present computer modelling of oil or chemical spills is used either prior to an incident, in a planning or risk assessment role, or during an incident to inform response decisions. However, there can also be a role for modelling in post-incident monitoring. This section outlines the use of spill models in that role, as well as briefly describing the capabilities and data requirements of existing oil and chemical spill models.

5.5.1 Existing spill model types, data requirement and capabilities

A prerequisite for models used in oil or chemical spill incidents is speed and convenience. This has implications for the degree of sophistication of the physical and chemical processes that can be included, although advances in computer technology mean a standard PC can now be used to run quite complicated models at relatively high spatial resolution. The availability of menu driven graphical user interfaces (GUIs) and graphical output helps to make these models relatively easy to use. However, the correct use of these modelling tools needs an appreciation of the limitations of the model by a user who can interpret the output from the model in the light of expert knowledge. All commonly used models represent spills as a collection of particles that move with the water currents and under wind influence. This provides fast predictions of the movement of material but is less satisfactory for predicating concentrations (of chemical components, for example). Various commercially available models are presently available, including OSCAR, OilMap, and OSIS for oil spills, and Chemmap and DREAM for chemical incidents.

Most were designed to deal with surface spills typically arising from ship groundings or collisions. However, since the Deepwater Horizon incident, many of these models have been extended to include deep water release capabilities. Spaulding (2017) provides a recent review of models. Table 7 provides a checklist of considerations for model selection.

Table 7. *Model choice checklist.*

Support	Model Flexibility	Ease of use	Cost	Track record
Is the model undergoing active improvement? Is there technical support and training available?	Can model use data from a wide range of sources and provide a range of relevant outputs?	GUI interface, display of results. Flexibility may come at a cost of interface complexity.	Models with similar capabilities may nevertheless have widely differing purchase or licence costs.	Is the model widely used with example applications of real world use and published results?

Data required to run the model includes geographical information such as coastlines, seabed depths and (optionally) seabed sediment types. Usually these are pre-prepared covering the region of potential use so the necessary inputs to the model can be generated automatically when an incident occurs. For surface slicks, the wind plays a dominant role and these are generally obtained from meteorological model forecasts provided by national weather forecasting organisations. Also required are water currents, which may also may be obtained from publicly or commercially available 3D model forecasts (for example the EU Copernicus site), although such data may not be available in all regions or at sufficient resolution. An alternative is a database of pre-prepared tidal information that can allow higher resolution near the shore but will not include non-tidal currents such as those driven by wind or density differences. How far into the future oil or chemical spills can be predicted will clearly be limited by the length of the wind or current forecast used. A summary of the key data requirements for setting up a model simulation are:

- Bathymetry – Pre-prepared data base.
- Coastline – Pre-prepared data base.
- Winds – Automatic access to forecasts required.
- Currents – Access to ocean/coastal model outputs and/or database of tidal information.
- Other/Optional – e.g. Seabed sediments, biological species.

The most basic output from spill models typically consists of oil or chemical trajectories on the water. However, most models now provide a wide range of more sophisticated output such as estimates of oil or chemical concentrations in a variety of phases e.g. suspended or dissolved in the water, or (where information on suspended sediment concentration is available) adsorbed onto particles (Figure 9). Models also generally estimate the quantity attached to the seabed and shore-line, as well as the amount that has evaporated and some models also allow the calculation of the airborne trajectory of evaporated chemical components. At the most sophisticated level estimates of concentrations in biota may be calculated.

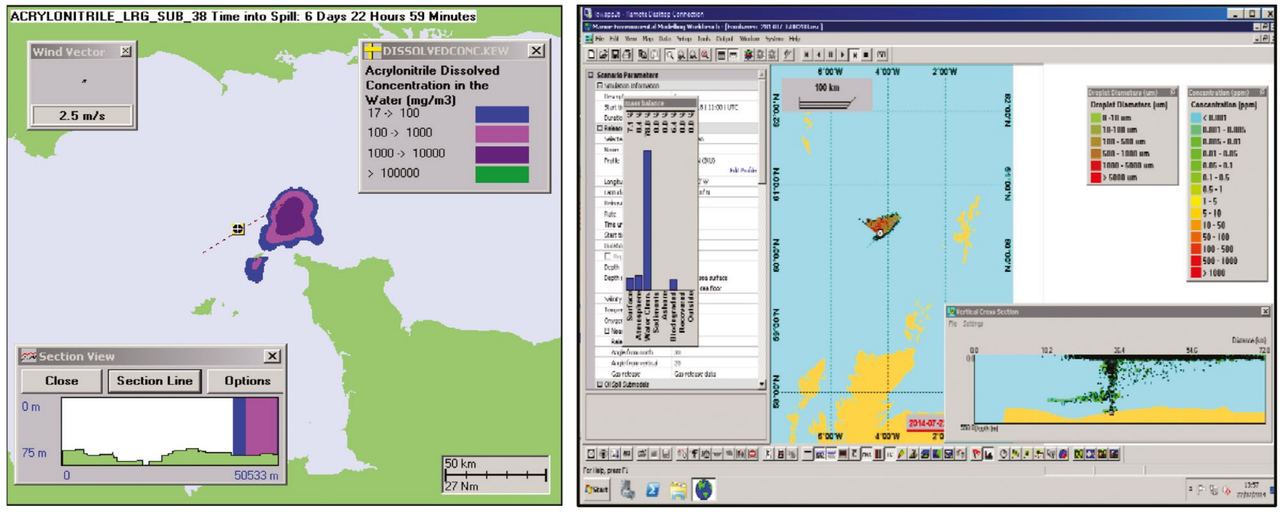


Figure 9.

Output from a chemical spill model (left panel) and oil spill model (right panel) showing example outputs. These include average water concentrations displayed as both plane view and a slice through the water column. Similarly, the representation of the oil spill (right panel) also includes a summary histogram of the proportion of oil in: the water column, evaporated, on the shore, and in the sediments..

5.5.2 Post-spill monitoring: use of models during an incident

Standard spill modelling aimed at predicting the path of contaminants during an incident will also suggest areas unlikely to be impacted, giving an early indication of potential unimpacted reference sites for post-spill monitoring. The same modelling could, in principle, also identify sites likely to be impacted within the next 48 hours (for example), allowing the chance to take samples immediately prior to impact. This, however, places some faith in the accuracy of predictions that may not be achievable for a given incident. More broadly, modelling at this stage of an incident can give an indication of the relative partitioning of contaminants between atmosphere, water column, sediments and shoreline, providing an early indication of where monitoring resources need to be focused. For example, model indications of the quantity of material attaching to seabed sediments would help guide decisions on seabed sampling. Similarly, some models can provide estimates of contaminant concentrations in biota (e.g. fish) and this will inform decisions on whether to monitor these organisms. In practice however, this relatively sophisticated modelling is more likely to be done in a post-spill context. In all these applications, it is highly desirable that model results can be readily incorporated into a Geographical Information System (GIS), enabling them to be combined with other information such as locations of environmentally or commercially sensitive areas.

5.5.3 Post-spill monitoring: use of models post incident

Post-spill, the chance to run a greater range of scenarios and include additional data collected during the incident allows more refined modelling and increased confidence in results. It is at this point that modelling is most likely to be used to help in the identification of priority and reference sites for survey planning purposes, including whether there is a need to monitor seabed sediments.

Predictions of biota concentrations might be attempted, although in practise the uncertainties involved and adoption of a precautionary approach might dictate this, irrespective of modelling results.

Potential use of model outputs is summarised in Table 8. For large incidents, and if sufficient funding is available, there may be justification in commissioning bespoke modelling to understand longer-term impacts. Rather than the spill models used for short term predictions, this would be likely to require different types of ecosystem and chemical transport models that can simulate effects over longer periods of months to years.

Table 8. *Model choice checklist.*

Particle trajectories	Water Concentrations	Sediment concentrations	Biota concentrations (if available)
Advance indications of shoreline sites of high and low impact.	Guide monitoring locations for potential biological impacts.	Guide decisions on need to take sub-tidal sediment or monitor benthic species.	Guide decisions on possible impacts to fish and human health if consumed.

5.6 REMOTE SENSING, AUTONOMOUS PLATFORMS AND OTHER TECHNOLOGIES

Due to the development of technologies and their associated enhanced applications, it is now possible to utilise a wealth of resource to undertake post-spill environmental monitoring, impact and recovery assessment.

5.6.1 Satellite observations

5.6.1.1 Observing a slick

Satellite observation data can be used in the post-spill monitoring of oil slicks, particularly their detection and subsequent development over time (with respect to extent, thickness and dispersion).

Synthetic Aperture Radar (SAR) looks at the backscatter signal from the Earth's ocean, which is dampened with the presence of oil on the surface, and is the primary method of oil spill monitoring from space because of its all-weather (i.e. it can penetrate cloud cover) and day-night capability (Fingas and Brown, 2014).

One of the drawbacks for SAR is the problem of distinguishing oil slicks from other natural phenomena including (but not limited to) natural films/slicks, grease ice, and wind effects that dampen the short waves and create dark patches on the surface (Brekke and Solberg, 2005).

Whilst ocean colour data from satellites can be used to detect oil spills, it can also assist in the detection of natural slicks through the determination of Chlorophyll-a presence. However, the acquisition of such data can be compromised by the requirements for line-of-sight and in daylight, with data availability therefore subject to environmental and astronomical factors.

Oil thickness can be interpreted using Infrared (IR) images due to oil absorbing solar radiation and re-emitting long-wave (8-14 μm) radiation, however the thickness at which these detections occur are poorly understood, so cannot be relied upon (Fingas and Brown, 2014). Whilst thin oil and sheens are not detected by IR images (Fingas and Brown, 2014), sheens can be detected using ultraviolet sensors due to the high reflectance of sunlight in the ultraviolet range, however this technique is not used extensively due to the fact that thicknesses are not relevant to the oil spill countermeasures (Fingas and Brown, 2014).

Two specific sensors that show potential are the passive microwave radiometer for measuring thickness at sea, and the laser fluorosensor for a variety of sensing applications, however both sensors require some more development and extensive commercialisation before being used extensively in this area (Fingas and Brown, 2014).

5.6.1.2 Additional observations

In addition to the observation of the oil slick itself, knowledge of meteorological and oceanographic conditions can enable a more effective and informed management process to be adopted. Complementing in-situ terrestrial and marine observations, satellite remote sensing facilitates a synoptic view of such parameters, and together can assist in the assignment of resources and the refinement of models.

5.6.1.3 International Charter

The International Charter "Space and Major Disasters" was initiated by the European and French space agencies (ESA and CNES), and aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters (e.g. tropical cyclones and oil spills respectively) through Authorised Users. In reality, this means that in addition to a country's own satellites, through invoking the Charter they are able to access data from all other Charter members, with situations arising where other members' satellites may be switched on specifically to collect data when transiting over the area of interest (Figure 10).

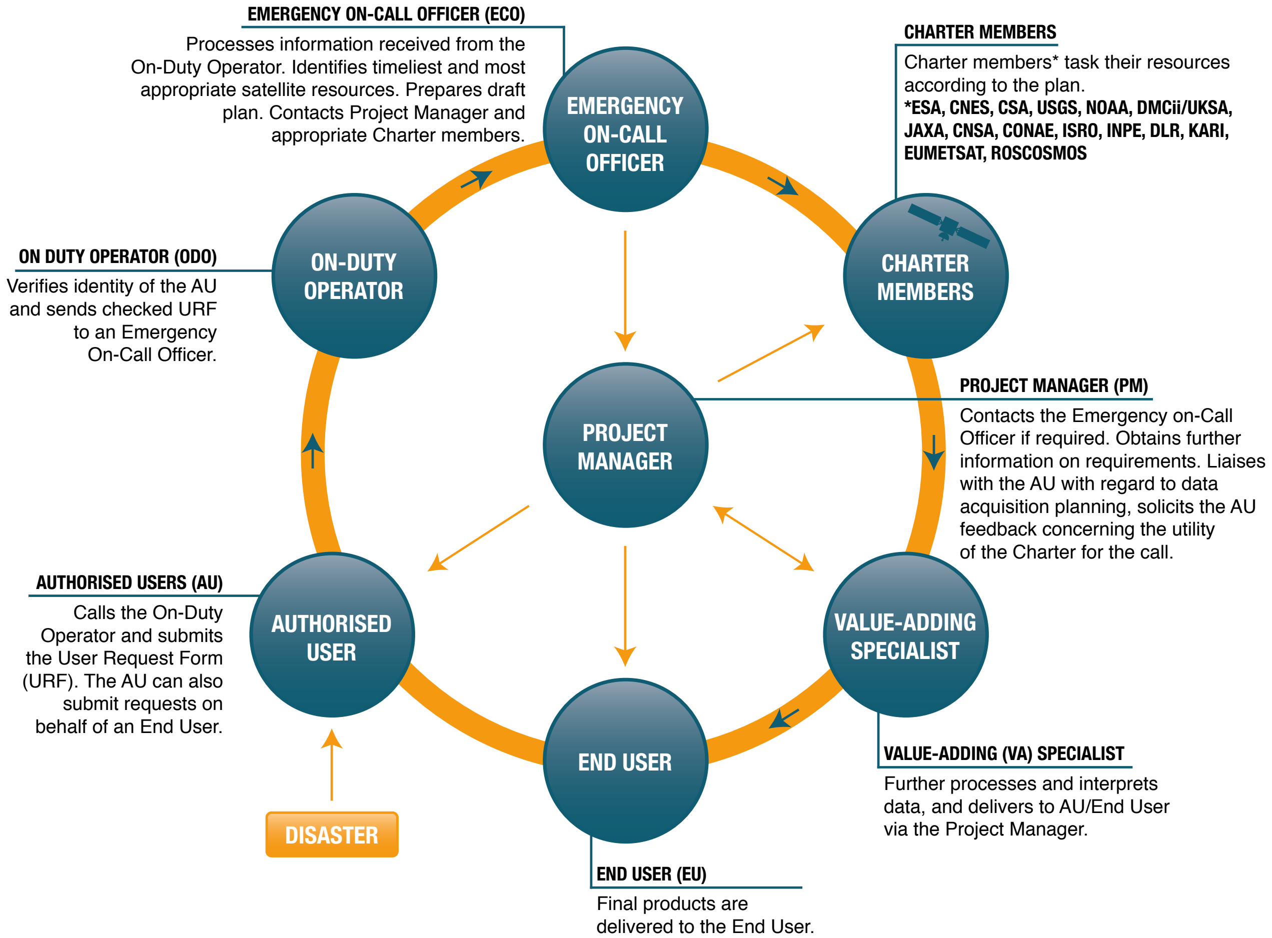


Figure 10.
Charter Operational Loop (Source: www.disasterscharter.org).

For each disaster type the Charter has identified the most appropriate satellite sensors and their usage to obtain the most useful data. For example, imaging radar, with its all-weather capability, has been utilised for the detection of oil spills in bad weather conditions as well as the monitoring of floods and landslides. Optical imagery at medium resolutions has been used for creating an overview of damage following a disaster while high resolution optical data can be utilised for identifying damage to roads and individual buildings.

Since the charter became operational in 2000 there have been 499 disasters covered in 118 countries, of which 16 have related to oil spill incidents, and the most recent of these surrounding a Vietnamese oil spill in 2015.

The Charter members have now adopted the principle of 'Universal Access'. This means that any national disaster management authority will be able to submit requests to the Charter for emergency response. A registration process is available for national authorities with an interest in the Charter with explanations provided on the activation of the Charter in case of a major disaster and testing of the procedures.

5.6.2 Aerial observations – manned and unmanned

5.6.2.1 Detection

Synthetic Aperture Radar (SAR) and Side-Looking Airborne Radar (SLAR) are both radar methods which can be employed on aerial platforms, and whilst an older technology, SLAR has pre-dominated airborne oil spill remote sensing because of its cheaper cost.

5.6.2.2 Impact and Recovery

Aerial imagery offers the ability to undertake coastline and intertidal environmental monitoring in a cost and time efficient way, and in areas where oil spills have already impacted, manage human exposure risks. The use of aerial imagery also removes the requirement for direct access to the site which in many intertidal and coastal areas may be limited and/or dangerous.

In addition to the above referenced radar methods, visible spectrum (RGB) images can be used to identify the presence of the slick, and together with infrared (IR) outputs, can be used to assess the impact of a slick on the coastal and intertidal environment, however acquisition of such data would be restricted to line-of-sight and daylight operations only.

In the past, these methods have been used to identify changes in both the extent and health of coastal macrophyte (seaweeds/seagrasses) communities post event. Utilising both the RGB and IR data allows assessments to be made on the quality of the macrophytes and identify areas which have been directly or indirectly impacted by a spill. However, to ensure such environmental monitoring is a consistent manner, a robust post-spill monitoring methodology is required.

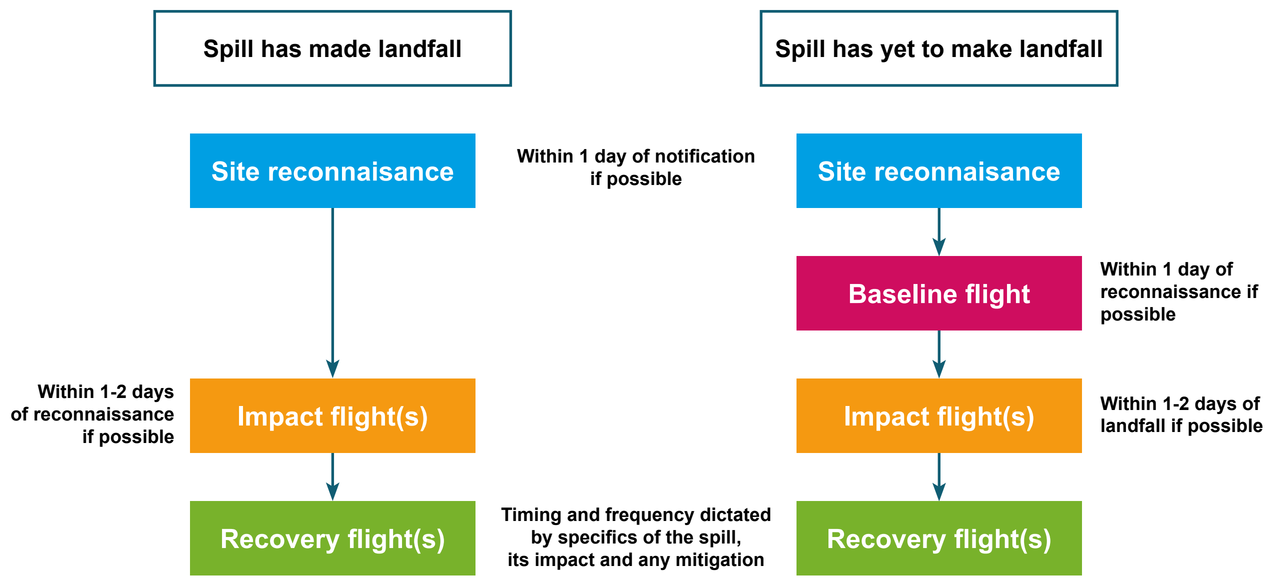


Figure 11.
Schematic of the emergency response deployment strategy. Response times are given for each type of survey flight; all timings will be influenced by site and spill characteristics and health and safety considerations. (Source: Bremner et al. (2016).

Associated with the development of technology and legislation around unmanned aerial vehicles, it is anticipated that such monitoring can be most efficiently delivered using remotely piloted aircraft (RPA), with the above schematic (Figure 11) representing a draft methodology for the use of RPAs for such monitoring.

In contrast to manned aerial systems, RPAs offer greater flexibility through the ease of mobilisation, with surveys being possible during times of cloud cover (due to the flying altitude of the systems), and the ease of survey repeatability offers the ability to assess the recovery of the coastal habitat on a short temporal scale. However, payload capacity and endurance requirements will be critical factors in determining an RPA's suitability for monitoring.

5.6.3 In-Situ observations

Aerial and satellite data acquisition can be complemented by in-situ autonomous environmental monitoring, either through static or mobile platforms acquiring data from the seabed, throughout the water column, and at the sea surface. Such data can also act to calibrate aerial satellite observations, and validate oil spill models.

5.6.3.1 Platforms

Static platforms enable the measurement of parameters in a fixed location. Such platforms include, but are not limited to:

- Fixed infrastructure (e.g. oil and gas platforms);
- Buoys;
- Instrument moorings;
- Seabed frames.

Benefits of such systems is that they allow the ability to detect change over time with only a minimal spatial variable (drift of a buoy on its mooring), with majority of surface deployed platforms offering the ability to telemeter data in real-time and facilitate effective management, however some platforms (particularly sub-surface) may be limited in this capability.

In contrast, mobile platforms enable the measurement of parameters at varying spatial and temporal scales. Such platforms include, but are not limited to:

- Unmanned Surface Vehicles (USVs);
- Undulating gliders;
- Autonomous Underwater Vehicles (AUVs);
- Remotely Operated Vehicles (ROVs).

These mobile systems can be targeted at specific areas of interest (latitude, longitude and depth), which may change over the post-spill monitoring period. Additionally, due to their mobile nature, they can act as sentries around sensitive marine and coastal habitats, providing alerts and informing management of the associated risk.

As with static platforms, majority of mobile platforms offer the ability to telemeter data, however real-time telemetry is most reliable using surface vehicles (or those directly linked to the surface – e.g. ROVs), with sub-surface vehicles mostly relying on time at surface to telemeter data packages of their recent profiles.

5.6.3.2 Key parameters for measurement

Hydrocarbon sensors are tuned for a particular a functional group of hydrocarbons, and knowledge of what has been spilt allows the correct filters to be used and the correct calibration coefficients to be applied. Otherwise any measurements would just be a relative measure. These sensors typically fall into two categories, crude and refined oils (typically using Chrysene as the reference material).

Most hydrocarbon sensors will struggle in coastal waters due to interference from other compounds which fluoresce at similar wavelengths (CDOM). Turbidity can also interfere with these sensors and should also be measured. Another common issue is fouling, for example in the case of a vehicle travelling through a slick oil, which will adhere and contaminate the sensors.

“hydrocarbon sensors are tuned for particular functional group of hydrocarbons, and knowledge of what has been spilt allows the correct filters to be used and the correct calibration coefficients to be applied.”

In addition to hydrocarbon sensors, other parameters which impact the degradation and mixing of oil are of key interest during post-spill monitoring. These include (in order of priority):

a. Surface wind (speed and direction);

b. Currents (speed and direction) – profiles preferable where available;

c. Water temperature – profiles preferable where available;

d. Wave height (significant and maximum) and direction (peak);

e. Salinity – profiles preferable where available;

f. Suspended sediment concentration (seabed and surface);

g. Seabed composition (particle size analysis);

h. Chlorophyll;

i. Water depth.

Additionally, acquisition of water samples for subsequent analysis in the laboratory can offer additional confidence in the sensor and aerial measurements.

PART 6

Data quality and management

6. Data Quality and Management

6.1 GENERAL CONSIDERATIONS

The data generated needs to be of high quality to ensure that robust and defensible decisions can be made. The control of sample collection, transport, storage and analysis are all key to this level of quality being achieved. For example, all laboratories should have a quality manual which is adhered to always during sampling, storage and analysis of samples. For some other services, further requirements are expected for safety reasons. 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 (Table 9). When procurement of external services is necessary, 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 certification or the use of UKAS accredited techniques). Further evidence of quality control (QC) could be provided by participation in and adherence to the principles of QC proficiency testing schemes such as QUASIMEME (Quality Assurance of Information for Marine Environmental Monitoring in Europe[46]), BEQUALM (Biological Effects Quality Assurance in Monitoring Programmes[47]) and NMBAQC (National Marine Biological Association Quality Control[48]). Individuals may also be accredited, e.g. in the UK in the case of marine mammals, JNCC offer accreditation as an approved observer.

6.2 QUALITY CONTROL CONSIDERATIONS

Management of data supporting post-spill reporting and monitoring presents a unique set of issues and requires careful consideration for it to be effective and efficient. Time must be invested in creation and maintenance of post-spill response mechanisms, including availability of experts, relevant guidance and appropriate tools to be used when an incident occurs.

Ad-hoc data collection and processing, without earlier preparation and structures put in place, will lead to data collected to worse quality standards, coverage and, with that, less reliable.

As part of the UK drive to data openness, information made available directly by the monitoring programmes undertaken by relevant environmental regulators (e.g. the EA in England and Wales and the Scottish Environment Protection Agency (SEPA) in Scotland) may also yield useful information, as may the UK's national marine monitoring programme (CSEMP).

[46] www.quasimeme.org
[47] www.bequalm.org
[48] www.nmbaqcs.org

Table 9. *International quality standards and protocols, specific to the different technical service.*

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	Digital aerial survey
	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

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 or openly published and may require some effort to unearth.

6.2.1 Pre-incident data management best practice

Fast and effective response to an incident will rely on availability and accessibility of relevant baseline data for the affected site. It will also rely on experts in spill and incident management being available to access and utilise this data with minimal delay.

Current direction to make scientific data openly available and accessible to all, works in favour of any future work related to spill incidents. Whilst each event will present a unique set of issues and requirements with regards to data, knowledge of existing sources of national and regional datasets would be invaluable.

On a European scale, many initiatives, such as the introduction of INSPIRE Directive, support openness and availability of environmental data across the EU. A vast number of internet data portals on a European, national, and local scale are available to offer, if not direct access to data, then at least access to metadata describing available resources. To support management of any future incidents, standing response teams should monitor availability of data relevant to their area of responsibility.

The list below points out some of the UK portals, which could be consulted to identify national level data relevant to a site and type of an incident:

- Metadata[49] and direct links to data from UK government bodies.
- Marine Environmental Data and Information Network[50] (MEDIN), metadata portal specifically for marine metadata from government (and some commercial) sources.
- UK Directory for marine monitoring metadata[51].

Teams responsible for the collection of post-spill monitoring data and its use as part of an impact assessment (e.g. PMCC's or equivalent in the UK) should use such portals (alongside any other resources they deem appropriate) to enhance their overall knowledge about data availability as well as a source of points of contact for specialist data areas. Even if directly relevant data is not immediately available, contacting creators and custodians of data similar in nature or geographical extent may lead to further information and data being discovered (even if, for various reasons, it may not have been published yet).

6.2.2 Data Governance

Data collected in response to an incident will vary in terms of its source (e.g. type of measurement undertaken), quality, level of completeness and suitability for the assessment or monitoring purpose. Due to the complex nature of incident response, data will also be provided by a variety of participating organisations, resulting in disparate data standards and collection protocols being used.

This monitoring coordination cell (or equivalent) would benefit from nominating a designated incident data manager/co-ordinator, whose role would be to co-ordinate provision and management of data required in post-incident monitoring and impact assessment. Those fulfilling the incident data manager role should be identified and mobilised immediately (by the monitoring cell chair) in the event of a spill (some incidents may require multiple data managers to be made available depending on complexity/severity).

The nominated data manager would be responsible for:

- Co-ordinating data and information related to the location and status of any data and samples being used and processed;
- Overseeing the quality assurance and quality controls to be put in place;
- Advising on which data standards should be used in collection;
- Data structures (folder structures, etc.);
- Naming conventions; a clear and meaningful method should be established for the naming of folders, datasets, samples etc. The method should include location of sample/dataset collection, time/date, data type. Other features such as collecting organisation may also be included;
- Metadata; ensuring that data suppliers include all relevant details of methodological protocols, particularly for bespoke and novel techniques, before archiving;

[49] http://data.gov.uk
[50] http://www.oceannet.org/finding_data/search/full
[51] http://www.ukdmos.org/

- Formats; finalised data retained in the central repository should be in simple, non-proprietary formats; and
- Acceptable quality control to allow finalised data to be stored in the long-term repository.

To streamline data and sample collection during the initial response, incident response teams should put in place templates for station data collection, including information such as: sample ID numbers/codes; site name; geolocation; date/time; description of the item surveyed; physical parameters measured (e.g. temperature, water depth); filenames and location of related materials (e.g. photographs).

The information gathered as part of this initial data collection exercise would be complementary of the information included in the sample Chain of Custody forms (see Table 2).

These templates could made be available as printable forms which can be used in the field or as online forms/apps for use on laptops/tablets/smartphones. This would enhance the homogeneity and quality of data collected and ensure that critical information is consistently collected.

6.2.3 Data quality

To enhance quality and consistency of data collected in response to an incident, use of recognised data standards is recommended, as well as introduction of data collection forms, where possible, and implementation of quality control procedures. These measures should be put in place before incident occurs and made available to any data gathering entity as soon as sampling and monitoring activity is in progress. Any documents or data guidelines and forms should be available online to allow responders in any geographical locations to access relevant information.

Several recognised marine data standards are available worldwide. These could be used directly or amended/simplified to achieve a better fit with emergency response situations. For example, in the UK, a set of marine data guidelines is provided by MEDIN[52].

These can be used to ensure maximum consistency and interoperability of data gathered or incident response and monitoring.

Equally, building on expertise gathered during previous incidents, there could be a reason to create simple, incident response tailored guidance, ensuring that at least a minimum level of data is collected consistently. Whichever ption is chosen (using existing standards, or creating a designated emergency response one) these should be created and made available in preparation for any future emergency work.

In addition to quality data, high quality metadata should be obtained alongside the data to provide clear evidence of provenance (quality, spatial and temporal resolution, points of contact, etc.), as well as detailed information on collection methods. This will enable the accurate and appropriate inclusion of pre-existing data into the incident management evidence base.

[52] http://www.oceannet.org/marine_data_standards/medin_data_guidelines.html

> An efficient response to an incident requires data to be collected and processed by a number of potentially dispersed individuals and organisations, provision of centralised, accessible data storage space could support both quality of data and efficiency of use.

Creation of detailed metadata and adherence to existing standard operating procedures/data standards will help ensure high quality data and information is gathered throughout any post-incident monitoring work. The MEDIN metadata standard[53] can be used in recording detailed metadata for data created and gathered post-incident. If specialised software is not available, metadata can be recorded using a simple spreadsheet containing, as a minimum, the following information:

- Dataset title.
- Description.
- Lineage (notes on methodology and equipment/tools used to collect/generate data).
- Dates between which dataset has been collected (start date and end date).
- Data formats used.
- Spatial reference system used.
- Links to any additional sources of information regarding the dataset (published reports, websites, etc.).
- Data ownership and handling information:
  - Data originator – name of the entity providing data.
  - Data originator point of contact – name of an individual or a team in the originating body, who would be able to answer questions regarding data attributes, quality, collection methods, provenance, etc.
  - Access and reuse conditions – notes on whether data are provided as open data, or whether any limitations/conditions are in place for future reuse.

The above list is provided as an example and a starting point for creating an incident metadata template and should be expanded to document any other information about data useful to the specific situation.

6.2.4 Data use conditions

Information on potential confidentiality/sensitivity as well as use/reuse conditions should be gathered from all data owners when receiving existing data. Ideally this information would already be included as part of the metadata. Equally the same aspects of data use should be considered for any data collected post incident and recorded alongside (or as part of) the metadata. It is essential that data use conditions are followed when it comes to any subsequent publication of reports and/or data.

[53] http://www.oceannet.org

6.2.5 Data storage

An efficient response to an incident requires data to be collected and processed by a number of potentially dispersed individuals and organisations; provision of centralised, accessible data storage space could support both quality of data collected (giving the incident data manager overview of all data available, allowing for monitoring of data quality, processing steps and completeness) and efficiency of how this data is used in subsequent analysis and reporting (easy access to definite set of available data).

Such centralised data storage space should be made available to all involved in the emergency response work to collate and process data created and gathered as soon as possible after an incident occurs and the response team is brought together. Indeed, as part of preparation for monitoring activities, the system for data storage and access should be agreed and considered in advance.

Cloud based solutions could be considered to maximise the ability to share data across a spatially distributed incident team. Another benefit of the use of cloud based technology is the relative ease of mobilisation – avoiding the need for extensive physical infrastructure to be put in place.

If the cloud solutions are not a viable option, a physical central repository should be created, allowing direct access for data generators and users.

6.2.6 Post-incident data curation

Once post spill monitoring and impact assessment activities have been completed, data created and used for reporting (including raw data sheets, wherever possible) should be retained for future use and in support of any future legal proceedings relating to the incident (data use agreements must be adhered to).

The incident data manager should ensure that all metadata is finalised. Once this is achieved, the entire incident dataset should be deposited in non-proprietorial long-term storage formats in the relevant data repository for long term curation.

There is high potential value in publishing metadata for data collected and created during the incident and, where possible, of publishing the data itself. As well as adding to scientific understanding of the post-spill ecosystem recovery, it could also support prevention and management of future spills/incidents.

6.2.7 Future planning – summary

As part of preparation for future incidents, organisations responsible for future incident response should consider preparation of the following package of items, to function as a data 'response kit'.

- A list of individuals who are prepared to take on the role of Incident Data Manager;
- A list of relevant data collection and processing organisations and points of contact;
- Relevant data collection SOPs/guidance;
- A centralised data storage area;
- Metadata recording templates/software;
- Station data recording templates/software; and
- Sample Tracking template/software.

PART 7

Communications and reporting

7. Communications and reporting

7.1 INTRODUCTION

Key findings from an environmental monitoring programme may need to be communicated effectively to appropriate stakeholders. This will include (but not be limited to) the responders (who may modify their response activities as a result), the media, the public, government and non-governmental organisations, and all communications will need to be managed in a co-ordinated way. Communications may take place through a range of channels, and there should be agreement at the outset on who/which bodies are responsible for communicating with the various interested stakeholders.

Information resulting from an environmental monitoring and impact assessment will be of substantial interest and, informing as it does on human health, food safety and environmental impact, could also be very sensitive and have the potential to be misinterpreted if taken out of context. In the UK, clear communications links and the production of reports and updates is a key responsibility of the PMCC or equivalent (see Appendix 1). The monitoring coordination cell will have responsibility for collating and packaging information but will need to fit into an overall communications plan as part of the incident command and control process. Reporting and communication lines and responsibilities need to be clearly established early during (preferably in advance of) an incident.

7.2 COMMUNICATION OBJECTIVES

7.2.1 Monitoring team communications

Any cell responsible for co-ordinating post-spill monitoring may use communications to ensure stakeholders:

- Remain informed on incident developments and aware of exceptional events;
- Exchange knowledge to build collective capability;
- Raise support for the monitoring aims (to enable more stakeholder engagement for a more accurate and effective programme); and
- Share knowledge of monitoring activities and experiences to reassure stakeholders that an appropriate programme is in place, and avoid the spread of misinformation.

7.2.2 Stakeholders communications

A range of stakeholder groups will be interested in the monitoring activities being carried out, and any specific events/notifications which arise because of the monitoring programme. A selection of the main stakeholders includes:

- Incident responders: need to be informed of monitoring results to allow modification of response activities and preparedness for emerging issues;
- Industry regulators: for example, BEIS, MCA etc. These organisations need to ensure that regulatory responsibilities are adhered to as appropriate, and they also need to be made aware of and able to share developments in best practices and the Premiam guidelines, which need to be followed (further information about evidence needs and statutory requirements for government departments and agencies in Appendix 1);
- Environmental regulators: need to be updated on contravention of Health and Safety or Environmental regulations, or if environmental damage has occurred and so whether prosecution is appropriate;
- Other monitoring/research organisations: able to offer their expertise as appropriate, and avoid duplication of effort whilst offering chances for collaboration;
- National media: to reassure as appropriate that there is a co-ordinated, comprehensive monitoring programme in place which works to protect the marine environment. Also, ensure they are kept updated on exceptional events through press releases and interviews as necessary;
- General public: need to be able to access information on the monitoring programme as appropriate and be reassured that it has been well planned and is effective.
- Government/ministers: need to be updated and briefed on progress/status of the monitoring programme as necessary;
- NGOs: to reassure that there is a co-ordinated, comprehensive monitoring programme in place which works to protect the marine environment;
- Local media: may be interested in specific monitoring areas. Reassuring those in a concerned area that measures are being taken to monitor the situation as appropriate; and
- Industry and industry media: building support for the importance of the programme and industry role in it. Ensuring industry's voice is heard and they feel informed and engaged during the monitoring process.

7.3 COMMUNICATIONS MEDIA

Several communications media are available and can be used to communicate the findings from the monitoring programme to relevant stakeholders; see a summary in Table 10 below. The use of communications media needs to be managed as part of a communications plan to enable stakeholders to access the information in an appropriate manner.

Table 10. *Targeted communications media that could be used to inform the findings from the monitoring programme to relevant stakeholders.*

Designated website	Regular progress notifications could be posted on a designated website (could also be updated when a specified monitoring event such as a high reading occurs, although exceptionally high readings will require careful management). This would enable the monitoring process to be followed, explaining mitigations when concerns are high and reassuring stakeholders when returned to normal levels.
Exceptional wider press releases	In select cases, there may be a need to communicate an exceptional monitoring event to the wider public (e.g. due to a particularly high reading or misinformation about such). A wider press release could be distributed to local, regional and trade media.
Industry outreach contact list	Certain aspects of the monitoring are mostly of interest to affected industry, and it will be important that industry is made aware of it and understands these aspects in a timely manner. An email contact list of key industry contacts could be used to ensure that an individual with responsibility for their input into the monitoring progress is kept up to date with the latest relevant developments. This will also enable a two-way conversation with these partners so they can raise concerns quickly and effectively.
Social media	To respond quickly to concerns raised by the public, social media messages could be drafted and distributed via the social media accounts of partners as appropriate. These messages will not have the same level of detail as the notifications set, but will offer a rapid reassurance that measures are being developed, as deemed necessary by any monitoring coordination cell. Social media will also serve a useful role in monitoring and avoiding the spread of incorrect information.
Industry forums	Like social media, posts on industry forums could be used as deemed necessary by any monitoring coordination cell to provide timely updates and avoid misinformation.

7.4 COMMUNICATIONS RECOMMENDATIONS

There are a range of media available for a monitoring coordination cell to reach different stakeholders. Table 11 below summarises how different media channels may be used to reach different stakeholders.

Table 11. *Summary of the use of different media to reach different stakeholders.*

Stakeholder	Information required				Media			
	Treatment effectiveness	Safety concerns	Detailed scientific results	Impact on resource	Email/phone (direct)	Database	Social media/ internet	Interviews
Responders	X	X			X			
Regulators	X		X	X	X	X		
Other monitoring/ research organisations			X			X		
Media		X		X	X		X	X
General public		X					X	X
Government/ ministers	X	X	X	X	X			
NGOs	X			X	X		X	X
Volunteers		X			X		X	

7.4.1 Communications on the application of mitigation techniques

Information concerning the effectiveness of the dispersant application could be reported as soon as appropriate to core stakeholders, to inform the continuing response operation and inform decisions relating to the continuation/cessation of the operation. These updates may be required on an hourly or at least daily basis to begin with, when different mitigations techniques may be being trialled. To assist with rapid dissemination of information, a template could be used to ensure that relevant information is captured on each occasion. These templates would be distributed primarily through the database, but particularly significant findings may eventually be communicated more widely through the notification website or interviews.

> *Major spills in the public eye will also be discussed within government, to ensure that any response options are fully justified and that monitoring is of the highest standard while still being affordable and efficient.*

7.4.2 Communications on monitoring results

Results generated from any monitoring programme are of importance to a range of stakeholders. Effective access to the right information enables stakeholders to assimilate a better understanding for the need for any actions taken (e.g. fishery closures), and the rationale for reopening them. For example, during the Sea Empress incident, data from the monitoring programme (PAH concentrations in fish and shellfish) were reported on a weekly basis to all stakeholders, which included anyone who had expressed an interest in the results (including fishermen, NGOs and members of the public), along with an explanation of the policy implications, especially in relation to the fishery closures (Law and Kelly, 2004).

The major advantage of this approach was that when various fishery restrictions, whether for species or areas, were lifted, they were seldom challenged. This reporting could be done primarily through the notification website, and through the direct contact list to interested organisations.

7.4.3 Exchange of monitoring data and information

There will be many organisations involved in the collection of data for post spill monitoring, and the results of any analysis needs to be co-ordinated to ensure that duplication is avoided and that all results are considered when decisions about fishery closures, future monitoring and ongoing response options are made. The handling of that data is discussed in more detail in the Data Management Section 6., but alongside a shared database and the notification website, regular meetings (be they virtual or face to face) could be conducted to ensure that all relevant information is shared appropriately.

7.4.4 Regular reporting to policy makers and government ministers

Any major spill which is in the public eye will also be discussed within government, to ensure that any response options are fully justified and that monitoring is of the highest standard while still being affordable and efficient. Briefings to ministers would highlight the benefits (and limitations/risks) of the monitoring effort in ensuring ongoing protection of the environment and the minimisation of impact on the local and national economy. This may include fishery closure, loss of income to businesses due to beach closures, or loss of other amenities.

7.4.5 Wider reporting of monitoring outputs

To aid lead response authorities, the environmental monitoring team should consider the likely types of information necessary to ensure information from the monitoring programme is as accessible as possible to a wider range of stakeholders (including the public).

Potential questions and brief responses could be offered in a simple document, which can be shared widely and updated as the incident progresses. This could:

- Set out any specific information about the monitoring approach/ breadth: e.g. the samples being obtained and tested; the monitoring timeline: what will be happening when? How long is this likely to take? What are the next steps?
- Distil key (technical) points: e.g. why dispersants are being used (as opposed to other options); what experience has shown to be effective; how dispersants work; pros/cons of their usage, etc. including an explanation of any acronyms or complex science.

A regularly updated monitoring report template could be a useful tool for effective dissemination. Report frequency and the level of detail required will differ depending on the type and scale of the incident and should be agreed by key parties as part of the monitoring communications plan. The monitoring progress report could cover key elements such as:

- Location;
- Samples collected;
- Analysis status and projected delivery schedule;
- Evidence of impacts on marine resources (e.g. commercially exploited fisheries); and
- Other results of relevance to the impact assessment.

A "key facts" box containing brief facts and figures to enable media engagement as appropriate.

A simple, visual representation of information focusing on the core messages will facilitate understanding in non-specialists as well as provide clear, unambiguous information to specialists who wish to remain aware of progress. A traffic light (green, amber, red) or arrows (up, down, ongoing) system showing progress or impact degree could help to communicate trends. An example of this approach is demonstrated in the MCCIP (Marine Climate Change Impacts Partnership) report card[54]. Making reports accessible digitally means that interactive links to supporting maps, photos ("before" and "after" shots) and infographics can also be used.

[54] *See http://www.mccip.org.uk/media/1301/mccip-arc2013.pdf*

Other channels of communication, where appropriate, may also be considered. Notifications, events, meetings, and specialist articles could all be useful to reach different relevant audiences at different times. However, it is envisioned that the use of a clear Monitoring Report template could form the basis for any additional interactions and would ensure that consistent and current information is available regarding monitoring activity and results.

7.4.6 Social media use

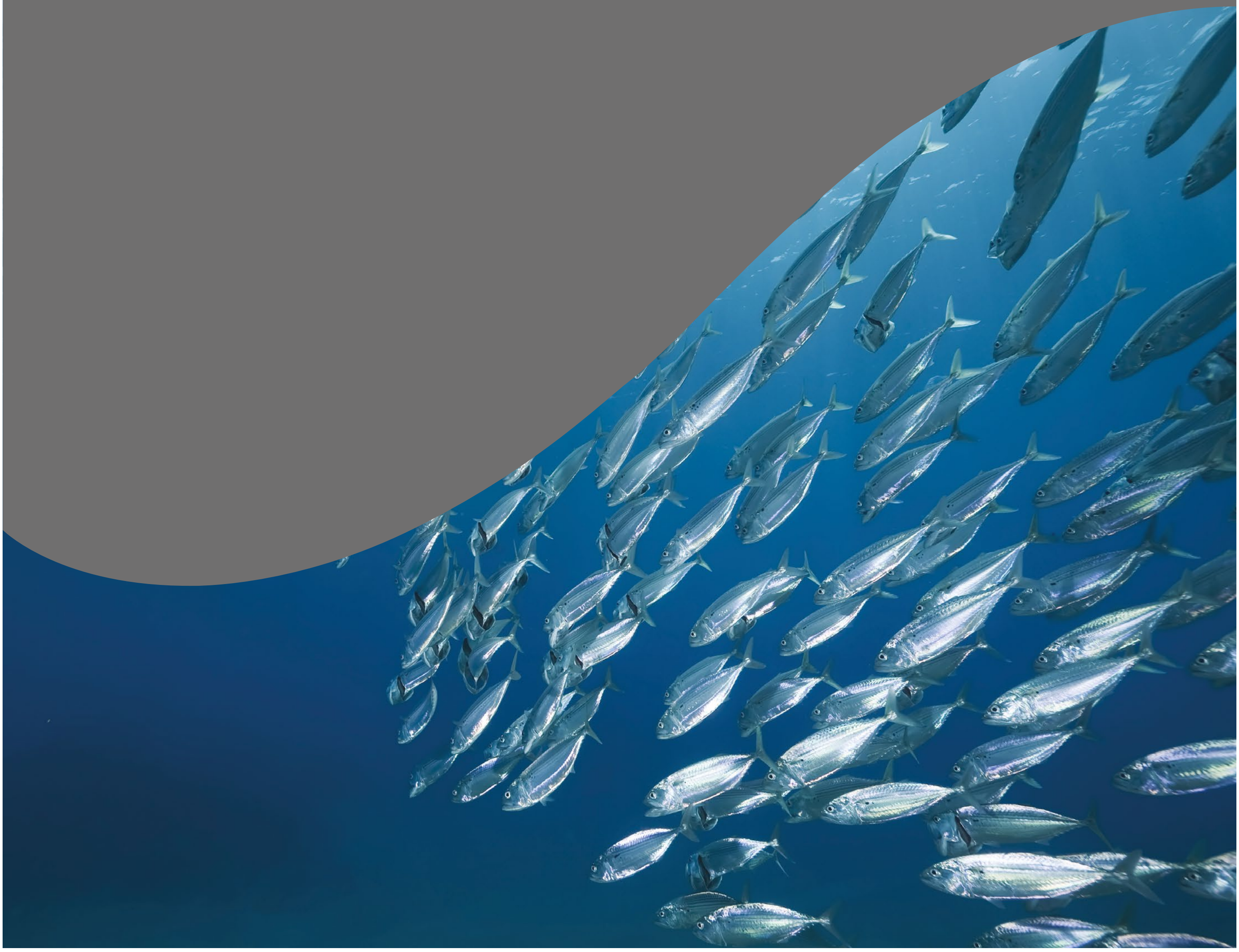
Both organisations and individuals are increasingly making use of different forms of social media to stay up to date on news and scientific developments. Therefore, it offers an alternative, up to the minute form of proactive communication. However, incorrect information can also spread quickly through social media, meaning that everything should be done to make sure that correct information is put into the public domain before rumours gain traction. For example, as well as proactive communication of information, it may be appropriate to task a team to be responsible for monitoring and responding to social media releases from outside of the core monitoring group to ensure that the impact of incorrect messages is minimised.

7.5 OVERALL REMARKS

The number of responders acting, stakeholders concerned and mediums needed to distribute the right information at the right time means that co-ordination of messages will be critical.

This section thus sets out guidelines for how a monitoring coordination cell could use communications in an organised and coherent manner, to ensure that the technical measures set forth in the previous section receive the right level of support and engagement from the stakeholders listed above.

APPENDICES



1. The Premiam Monitoring Co-ordination Cell

INTRODUCTION

In order to facilitate the promptness in monitoring initiation the decision-making process for the mobilisation of initial sampling and analysis needs to be straight forward with clear responsibilities identified. In addition, it needs to be recognised that any initial mobilisation, sampling or analysis will incur costs and therefore a pre-considered mechanism for funding this initial activity is essential.

A programme of marine monitoring for a significant incident can be extremely complex as it may need to co-ordinate many service contributors and take account of an ever-changing scenario. Therefore, under the auspices of the Premiam group it is recommended that, for significant incidents, a Premiam Monitoring Co-ordination Cell (PMCC) is formed, often on a virtual basis. The role of the PMCC is outlined in this guidance as well as its important links to the standing EG process.

This guidance is the result of a series of workshop/meeting(s) involving the key UK government bodies with responsibilities for: i) taking the decision to initiate/continue/cease monitoring activities; and, ii) funding monitoring activities. It aims to detail the decision making and funding process with respect to post-spill monitoring and how that process is managed and developed as the incident proceeds. As such it forms a deliverable from the Premiam group aimed at clarifying and improving post-spill monitoring processes across the UK. This document forms the agreed guidance for England. Complementary versions have been developed for Wales, N. Ireland and Scotland to reflect any national and organisational differences.

PREMIAM MONITORING CO-ORDINATION CELL (PMCC)

The Premiam Monitoring Co-ordination Cell will be the group responsible for the overall conduct and integrated co-ordination of monitoring and impact assessment activities following a marine incident. In this respect, it provides a distinct but complementary role to an EG.

Its specific responsibilities will include:

- The initiation and development of a co-ordinated monitoring programme in line with the Premiam post-spill monitoring guidelines;
- The formation and management of a ‘monitoring team’ to undertake the monitoring activities;
- The maintenance of strong communication links to any formed EG and other response and advisory cells as necessary including a Scientific Advisory Group for Emergencies (see Appendix 6 for situation report template to add the communication strategy);
- The management and maintenance of financial and expenditure records pertaining to any initial monitoring activities (including liaison with and payment of any sub-contractors used); and

- Overseeing the generation and publication of reports as necessary. These will include i) regular/routine updates for Premiam partner organisations and the EG, and ii) interim and final monitoring and impact assessment reports.

The initial PMCC will be formed within minutes/hours of an incident because of key individuals being informed through the already established emergency response notification procedures (e.g. POLREPs etc.). The formation of the PMCC will be the responsibility of the pre-identified chair and/or deputy chair. The chair and deputy chair will be drawn from the organisations with primary responsibility for the conduct of marine monitoring in England; Cefas and Environment Agency.

The membership of the PMCC will be driven by the nature of the incident, including geographic position, and the nature of the resources that form the focus of the monitoring activity (e.g. fisheries, food, conservation, amenities etc.) and government stakeholder ‘evidence needs and statutory requirements’ will be the main driver in the design of the monitoring programme. The membership will also evolve as the group moves from considering initial, through to ongoing and cessation of activities.

PMCC Membership (England)

Permanent members [Note: The preparedness levels allocated to each scenario are indicative only and have not been derived through thorough expert consultation]

- Cefas (Chair)
- Environment Agency (Deputy Chair)

Other potential members

- Food Standards Agency (where focus of monitoring is food/human health issues)
- Marine Management Organisation (where focus is fisheries or to monitor the use of oil spill treatment products)
- Inshore Fisheries Conservation Authorities (where focus is fisheries)
- Natural England/JNCC (where focus is conservation issues – especially if MPAs, e.g. SPA, SAC, MCZs are under threat)
- Maritime and Coastguard Agency (where focus is effectiveness/ impacts of counter pollution and clean-up activity)
- BEIS (Department for Business, Energy and Industrial Strategy; if the incident involves an offshore installation)
- Local Government Authority (if focus is contamination of local amenities)
- Defra (as government department with overall environmental responsibility)

The initial (0-96 hours) membership of the PMCC will be managed by the PMCC chair in consultation as necessary. As any incident evolves input to the PMCC might be sought from a wide range of potential organisations and individuals including; Public Health England, identified scientific or local experts, industry representatives, suppliers of significant effort into the monitoring programme, RSPB, local wildlife associations etc.

Links with the Environment Group

It will be essential for the PMCC to have strong communication links with any formed EG as the expert environmental advice being generated by the EG will provide key input to the development and evolution of the monitoring programme. The Premiam process will act as a fast and effective route through which the EG's recommendations, with respect to monitoring, can be actioned. Furthermore, the EG will need to have prompt and effective feedback from the outputs of the monitoring programme to inform and update their advice.

To facilitate this relationship and the flow of advice and information between the groups a Premiam liaison officer will form part of the EG membership. It will be their specific role to facilitate the links and flow of information between the groups (a schematic of the group links is shown in Figure 12). The EG chair will be responsible for nominating a liaison officer. The PMCC should develop regular situation reports (sitreps) (see Appendix 6 for template) to help facilitate communication between the group and relevant stakeholders. These sitreps will include information on the operational activities taking place, issues encountered, partnerships that have been established and funding mechanisms currently in place. The reports also act as an auditable track record of the decision-making process that the PMCC has gone through to develop its post spill monitoring plans.

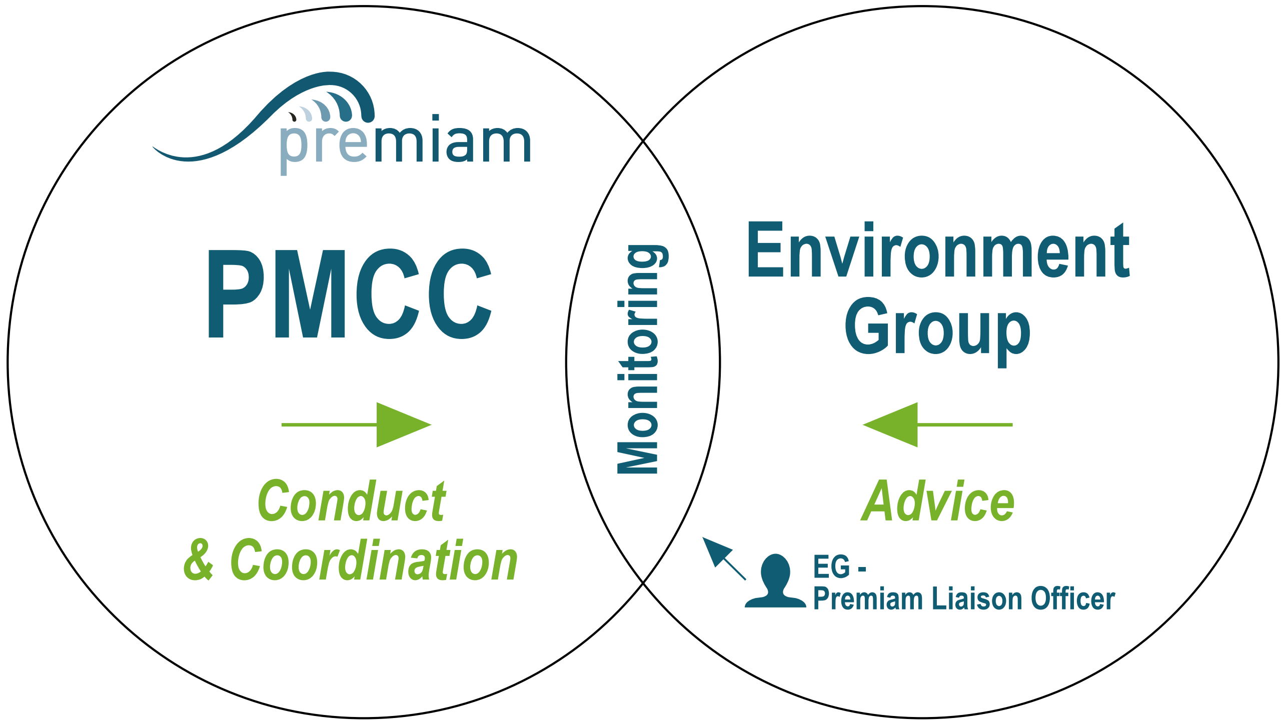


Figure 12.
The integrated relationship between the PMCC and EG.

Monitoring Phases

A. Initial Response Phase (0-96 Hours)

Decision to initiate monitoring activity

In order to facilitate the prompt and effective decision to initiate monitoring (which may need to be taken within minutes to allow baseline samples to be collected or relevant datasets to be identified and accessed) the responsibility for making the initial decision is delegated to the PMCC chair (on behalf of the responsible authorities, e.g. Defra, EA, FSA). In order to ensure that an effective and prompt decision is made it is necessary to invest this responsibility in a previously identified individual. However, in the vast majority of cases it is anticipated that the PMCC chair will be able to make this decision after necessary consultation (e.g. with the EG chair and other government authorities).

Funding

The decision to initiate monitoring activity in the event of an incident can only be taken in the knowledge that appropriate budget will be available to cover necessary start up costs. Therefore, the pre-authorised availability of initial funds has been identified as set out in Table 12 below.

Table 12. *Pre-authorised availability of initial funds.*

Funder	Mechanism/Fund	Pre-authorised limit
Defra	Via Cefas allocated Defra funding	£50,000
Environment Agency	Via internal Estuarine and Coastal Monitoring and Assessment Service to support fieldwork and sample analysis (as appropriate)	£50,000
Food Standards Agency	Incident Response (support) Programme Budget	£50,000
Any identified polluter	Maritime and Coastguard Agency to request monitoring support funds from any identified polluter [Note: The polluter will be given the option, at the earliest opportunity, to propose and deliver a monitoring programme. However, monitoring is likely to be initiated before there is confidence that the polluter has this in hand]	-
	Total initial fund	£50-100,000 + (depending on monitoring drivers)

The principles of a monitoring plan
Survey planning
Sample collection and management
Key methodologies
Data quality and management
Communications and reporting
Appendices

Management and Co-ordination

Initial management and co-ordination will be overseen by the PMCC chair using input and support from other PMCC members as necessary.

B. Ongoing Phase (96 hours onwards)

Decision to maintain/expand/reduce activity

If an incident requires continuation of monitoring activity beyond the first few days a more consultative procedure for decision making will be initiated. The overall decision making process will continue to be overseen and managed by the PMCC chair but it is anticipated that time will allow full consultation with the other PMCC members, the EG chair and the identified monitoring funders.

Funding

If a decision has been made and supported that requires extended (e.g. weeks) or significantly expanded monitoring activity it is assumed that, in parallel, additional funding sources have been identified as required. Any sources of funding for an extended and/or expanded monitoring and impact assessment programme will be separate to, (or in addition to) those identified as pre-authorised funds to initiate monitoring activities. The potential need for an extended/expanded environmental monitoring programme will be communicated to potential funding authorities by the PMCC chair as early as possible so that potential funding streams can be identified in advance.

It is anticipated that those government departments/agencies already identified as providing funds in the initial monitoring phase (see above) are likely to be contributors to any required funds for any ongoing monitoring phase. In particular, it is probable that Defra will fund ongoing monitoring, however, time will now allow for other funding sources to be sought and identified and these might include other government departments/agencies and industry/private bodies. For significantly extended monitoring programmes where a polluter has been identified cost recovery may also be sought by authorities under the ‘polluter pays principle’ to recover appropriate and proportional costs.

Management and Co-ordination

Overall co-ordination of any extended environmental monitoring programme will continue to be undertaken through the PMCC. However, any ongoing programme will be professionally managed on a project basis with full planning and will include identification and tracking of deliverables to time, quality and budget, in order to meet any specific requirements that identified funders may have.

Where a programme extends/expands to necessitate management as described above a suitably experienced and qualified project manager will be appointed. This will most likely not be the PMCC chair or any existing member of the PMCC (who will not have been included for their project management skills). When appointed the project manager will automatically become a member of the PMCC. They will be responsible for the maintenance of project plans and the tracking of delivery to time, quality and budget. They will also provide financial updates and information to the PMCC and funders as well as providing projections for potential future spend requirements.

C. Monitoring Cessation Phase

Decision to cease activity

It is a primary aim of the Premiam process to deliver high quality but cost-effective monitoring and impact assessment processes. This can be delivered by ensuring full integration and co-ordination of the activities so that unnecessary activity is cut out, duplication of activity is minimised and quality, through adherence to the Premiam guidelines, is maximised.

The decision to cease monitoring activity will be considered and made as part of the PMCC responsibilities (with full consideration of any EG recommendations). In any complex monitoring programme it is likely that cessation of activities will be a phased process but it will be a principle of the PMCC to not extend any monitoring activity beyond that which is necessary. Specific monitoring activities will not be completely ceased until all government stakeholder evidence needs and statutory requirements are fully met.

Funding

Any residual financial issues following cessation of a monitoring programme will be handled by the project manager.

Interim reporting

In the event of a major pollution incident which has had a major adverse impact on sensitive coastal or marine habitats, interim reports will also need to be produced. These will help form the strategy for the longer term management and restoration of these sites.

Final Reporting

Once a monitoring programme has ceased a final monitoring report, covering all issues as required by government stakeholders, will be prepared. Its production will be overseen by the PMCC chair (or delegated as necessary) and its timely delivery tracked by the project manager. As part of this the PMCC chair will carry out a post-incident review to ensure any learning is embedded into future response activities.

Evidence Needs and Statutory Requirements for Government Departments/Agencies

Defra

- Overview assessment of risks to and impacts on human health and the environment;
- Assessment should consider potential impacts on the full range of ecosystem goods and services; and
- In a major incident evidence may need to be updated rapidly, e.g. twice daily in immediate aftermath.

Environment Agency

The EA is the leading public body for protecting and improving the environment in England. As an environmental regulator, with a wide range of roles and responsibilities, it responds to many different types of incident affecting the natural environment, human health or property.

The EA's main priorities, during the response and recovery phases of an incident are to:

- prevent or minimise the impact of the incident;
- investigate the cause of the incident and consider enforcement action; and
- seek remediation, clean-up or restoration of the environment.

In the event of a pollution incident the EA will seek to prevent/control and monitor the input of pollutants to the environment. In emergencies involving air pollution the EA will co-ordinate a multi-Agency Air Quality Cell (AQC) to provide interpreted air quality information.

In addition, the EA is the competent authority for the WFD which requires the EA to set out requirements for basic measures to be complied with to prevent and/or reduce impact of accidental pollution and to take all appropriate measures to reduce risk to aquatic ecosystems (rivers, lakes, groundwater, estuaries and coastal areas). For WFD this extends out to one nautical mile for ecological status and twelve nautical miles for chemical status. Natural Resources Wales (NRW), SEPA and NIEA are the competent authorities for WFD in Wales, Scotland and Northern Ireland respectively.

In the event of major accidental pollution, the EA is required to undertake investigative monitoring for WFD to ascertain the magnitude and impacts of the pollution. This will inform the establishment of a programme of measures for the achievement of the environmental objectives and specific measures necessary to remedy the effects of the pollution.

Marine Management Organisation

- Evidence relating to the impact of the use of dispersants and other oil spill treatment products;
- Evidence of impact on commercial fish stocks; and
- Evidence which will inform any potential enforcement action under the Environmental Damage Regulations.

Food Standards Agency

- Evidence relating to actual or potential threats to the safety of food or animal feed that could require intervention to protect consumers;
- Evidence of impact on fish and shell fish farms; and
- Evidence of impact on seaweed beds harvested for animal feed, fertilizer and human consumption.

Natural England

Natural England is the government's advisor on the natural environment and provides practical advice, grounded in science, on how best to safeguard England's natural wealth for the benefit of everyone.

Natural England requires information on:

- Location and sensitivities of designated sites and species;
- Potential impacts of marine pollution events;
- Priorities for site/species protection; and
- Suitability of clean up techniques.

Maritime and Coastguard Agency

The Maritime and Coastguard Agency (MCA) implements the government's maritime safety policy in the UK and works to prevent the loss of life on the coast and at sea.

The MCA provides a 24-hour maritime search and rescue service around the UK coast and in the international search and rescue region through HM Coastguard and inspect and survey ships to ensure that they are meeting UK and international safety rules. The MCA also provides certification to seafarers, register vessels and respond to pollution from shipping and offshore installations.

Joint Nature Conservation Committee

The Joint Nature Conservation Committee (JNCC) is the statutory advisor to government on nature conservation issues for UK marine areas, outside of territorial waters (12nm), and we work closely with devolved authorities, statutory bodies and stakeholders to ensure that conservation objectives are met at a national and international level.

In the event of a marine pollution event JNCC would require evidence to inform our advice on the following areas:

- Location and sensitivities/vulnerabilities of designated sites and species;
- Priorities for site/species protection;
- Suitability of response approach; and
- Impacts of marine pollution events.

2. Impacts on Human Health

As well as having significant ecological impact, maritime incidents involving oil or chemicals can also impact upon human health. As such, it is important to initiate post spill monitoring for human exposure at an early stage to inform the risk assessment process. As in the classical paradigm (WHO[55]) risk assessment for human health is based upon the source-pathway-receptor approach requiring information on the nature of the pollution released, the likely human receptors and the routes by which pollution can reach these.

The nature of the spill will define the main routes of exposure, so for example volatile oils and chemicals will pose greatest risk via airborne exposure, while those that sink may pose a greater threat to benthic communities and ultimately to human health via the food chain. Likewise, pollutants floating or dissolving in the water column may pose greater risks via direct exposure or indirectly via contact with contaminated wildlife.

In all cases it is imperative to have an initial understanding of the pollutant behaviour in the environment. In addition, where mixtures of chemicals have been released it will be important to determine if these may react to form products with new characteristics. Likewise, if incidents involve fires then products of the combustion need to be considered both from the perspective of airborne exposure and deposition on crops and soils etc.

Any post spill monitoring will need input from agencies responsible for public health and food and fisheries. For example, UK response plans define establishment and operation of Environment Groups during incidents[56] 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 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; and
- Advise on requirements for monitoring of threat to public health.

[55] http://apps.who.int/iris/bitstream/10665/44127/1/9789241598149_eng.pdf
[56] https://www.gov.uk/government/publications/scientific-technical-and-operational-advice-notes-stop-notes
[57] https://www.gov.uk/guidance/emergency-contacts-public-health
[58] http://www.food.gov.uk/

As well as core membership from Public Health England[57], (Public Health Wales, Health Protection Scotland, or Public Health Agency Northern Ireland for devolved regions), membership can be augmented with additional relevant expertise and may include:

- Local authority Environmental Health departments
- Public Health Services
- Local Health Boards
- Occupational Health advisor
- Food Standards Agency[58] in England and Wales and Food Standards Scotland[59]
- Chemical Hazards Advisory Group (convened by the Maritime and Coastguard Agency)
- The National Chemical Emergency Centre (at AEA Technology[60])

Issues related to crops, foodstuffs and fisheries would be covered as part of the EG input and with the direct technical involvement of the FSA or relevant IFCAs when required. Should human health issues be on any standard agendas, these would also be covered by agencies including FSA and broader Health Agencies on attendee lists as part of the technical groups.

Such technical groups can further aid risk assessment for airborne, foodborne and shoreline contaminants, including interpretation against exposure standards, advice on personal protective equipment, medical and evacuation advice, decontamination and disposal of waste.

Agencies within these groups in the UK can request the initiation of mobile monitoring facilities, to obtain data on airborne pollutants rapidly. This can also be supplemented by monitoring capabilities provided by specialist FRS teams and spill contractors.

In addition, such groups can often request and interpret fate and transport modelling. In the UK, 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 although this can be requested providing sufficient data are available regarding the pollutant source and ambient concentrations. 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 PHE, EA in England and NRW in Wales, and other relevant advisors.

Depending upon the scale and type of incident, short- or longer-term health surveillance (for responders and/or members of the 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, the Braer incident in Shetland in 1993, the Prestige incident in Spain in 2002, the Erika incident in France in 1999, the Exxon Valdez incident in Alaska in 1989, the Nakhodka incident in Japan in 1997 and the Hebei Spirit incident in Korea in 2007. Post spill monitoring activities undertaken following a number of incidents have been reviewed, and health impacts of the Deepwater Horizon oil spill in the Gulf of Mexico have also been considered recently, and long-term health studies of personnel involved in the response are being undertaken as part of the GuLF Project by the US Department of Health[61].

[59] http://www.foodstandards.gov.scot/
[60] http://the-ncec.com/
[61] https://gulfstudy.nih.gov/en/index.html

3. Preparedness Matrix

There are three core elements that constitute a fully effective post-incident monitoring capability; i) Science Quality, ii) Co-ordination and Organisation, and iii) Preparedness and Responsiveness. If any one of these is missing or sub-standard then the ultimate programme and the information it produces may be flawed and the overall effectiveness compromised.

As part of the UK Premiam initiative several key principles, representative of an effective post-spill monitoring programme, have emerged. These eight principles are:

1. Scientific Guidance;
2. Skills & Knowledge;
3. Equipment;
4. Funding;
5. Responsibility & Management;
6. Integration & Co-ordination;
7. Support & Buy-in; and
8. Practice.

For a more detailed description of these principles refer to Kirby et al. (2014). However, these elements can be used as the basis for the assessment of preparedness to undertake post-incident monitoring.

In considering preparedness in this context, stakeholders might ask a number of questions including:

- Do we know what to do?
- Can we respond quickly enough?
- Do we know what our responsibilities are and those of other stakeholders?
- Do we have or have access to the right expertise and knowledge?
- Is the necessary sampling and monitoring equipment available and ready for use?
- Can we manage the necessary logistics and communications involved?
- Do we have the necessary support and funding to do this properly?
- Is our pre-planned response to environmental monitoring proven to work?

The monitoring preparedness assessment matrix (or MPAM, see Table 13) is a tool that puts these types of preparedness questions into an organised framework for assessment purposes. Each of the eight principles of effective monitoring programmes is considered in the matrix as indicators of preparedness level against which the user can judge their own situation/scenario. The preparedness levels are rated on a 1 to 5 scale, representing a range of situations from underprepared to fully prepared, respectively. The preparedness level assignments for each of the principles can then be summed to provide an overall Monitoring Preparedness Assessment Score (MPAS) ranging between 8 and 40. The MPAS value can be considered as an overall indication of the preparedness level for the situation/scenario under consideration but, more importantly, the process can highlight specific areas in which improvement is needed.

Examples of how a monitoring preparedness assessment score (MPAS) is derived are shown in Table 14 by referring to several scenarios for illustrative purposes. Using a red-amber-green (RAG) approach in the assessment also allows a more visual representation to be generated which is useful for comparing several scenarios on a qualitative basis.

Table 13. *The Monitoring Preparedness Assessment Matrix (or MPAM, adapted from Kirby et al. 2014).*

No.	Principle	Preparedness level 1	Preparedness level 2	Preparedness level 3	Preparedness level 4	Preparedness level 5
1	**Scientific Guidance**	No guidance identified/available.	No specific guidelines, with access to relevant guidance available but not necessarily agreed by all stakeholders.	No specific guidance in place but identified source(s) disseminated and agreed by stakeholders.	Fully comprehensive general principles and guidance available. Agreed by stakeholders as the 'standard' to be used.	Fully comprehensive guide(s) relevant to specific scenario(s). Agreed by stakeholders as the 'standard' to be used.
2	**Skills & Knowledge**	Major gaps in availability in several key skills and knowledge areas.	Substantial gaps in availability in several key skills and knowledge areas.	Some uncertainty regarding skills availability but expected to be sufficient.	Providers of all necessary skills identified, but not necessarily fully engaged.	Providers of all necessary skills identified and fully engaged.
3	**Equipment**	Major gaps in sources and availability of key monitoring equipment.	Substantial gaps in source and availability of key monitoring equipment identified. Basic sampling equipment sources available.	Sources of key monitoring equipment identified. Uncertainty around equipment for specialised functions or extended programmes.	Sources of all monitoring equipment identified but uncertainties about availability.	Sources of all monitoring equipment identified with guarantees of short-notice availability.
4	**Funding**	No promptly accessible funding source identified. Key potential funders do not accept responsibility to fund.	No agreed up-front funding identified. Likely sources known but some uncertainty around access and responsibility to fund.	No up-front funding identified, but parties responsible for funding agreed. Possible uncertainty around prompt access to funding and the size of funding available.	Up-front funding identified and promptly accessible. Potential uncertainty for funding of monitoring on a very large scale or over the long-term.	Promptly accessible and fully sufficient funding set aside with clear responsibility.
5	**Responsibility and Management**	No clarity on which body has responsibility for making decisions regarding monitoring.	Generally understood which organisations would manage the monitoring programme, but some uncertainty over roles and responsibilities.	Generally understood which organisation would manage the monitoring programme, with an expectation that a clear process would be put in place promptly.	Clear process for decision making and management of monitoring programme, but no named individuals or co-ordinating group identified.	Clear process for decision making and management of monitoring activity, with named individuals identified for important roles.
6	**Integration & Co-ordination**	Little integration. Different stakeholders likely to act in isolation.	Substantial gaps in communication between key bodies. Some uncertainty on how monitoring would be co-ordinated effectively.	Good general links between key bodies. Expected to 'pull together' during an incident.	Full integration between key government authorities. All other sources of monitoring activity identified but not necessarily engaged.	Fully integrated programme with good links between government, industry and academia.
7	**Support & Buy-in**	Relevant systems and processes conflict with no agreement between key parties.	No declared support from across all stakeholder groups. Some disagreement/uncertainty but no obvious conflict.	Substantial agreement and support amongst key bodies (i.e. government authorities). No major support sought across all stakeholder groups.	General support and buy-in across stakeholders with strong support from key bodies (i.e. government authorities). Some activity on wider stakeholder engagement.	Full support and buy-in across all stakeholders for the process, including declarations of support. Regular activity promoting broad stakeholder engagement.
8	**Practice**	Monitoring activity not included in emergency response exercises. Little or no links between the responsible bodies.	Inclusion of monitoring in exercises 'in principle' but no specific activity to date.	Included as part of scheduled emergency response exercises. But not recently (> 1 year ago).	Integration into regular emergency response exercises (but not necessarily including physical deployment of assets).	Full integration of monitoring and communications into regular emergency response exercises (including physical deployment of assets).
	Overall Monitoring Preparedness Assessment Score (MPAS)	**8 - 12**	**13-20**	**21-28**	**29-35**	**36-40**
	Level	**Underprepared**	**Low preparedness**	**Prepared (but with weaknesses)**	**Generally Prepared**	**Fully Prepared**

Table 14. *Illustrative examples of monitoring preparedness assessments for a range of scenarios demonstrating how the Monitoring Preparedness Assessment Score (MPAS) is derived. [Note: The preparedness levels allocated to each scenario are indicative only and have not been derived through thorough expert consultation].*

No.	Scenario	Scientific Guidance	Skills & Knowledge	Equipment	Funding	Responsibility & Management	Integration & Co-ordination	Support & Buy-in	Practice	MPAS
1	**Sea Empress 1996**	2	3	3	2	2	3	2	1	18
2	**MSC Napoli 2007**	2	3	3	3	3	3	3	1	21
3	**Sea Empress equivalent 2014**	4	4	3	3	3	3	3	2	25
4	**MSC Napoli equivalent 2014**	4	3	3	4	4	4	4	2	28
5	**Subsea release – West of Shetland 2014**	3	2	2	2	4	4	2	2	21
6	**Small localised oil spill near English coast 2014**	4	5	4	5	5	4	5	2	34

APPLICATIONS OF THE PROCESS

The assessment process described above, using the MPAM to generate MPAS values, can be used for a number of purposes that can help in emergency response preparedness assessment, planning and monitoring.

i. National/regional/local assessment

Using a generic scenario, or one that is recognised as of highest risk/likelihood of occurring, the MPAM can be used to understand the general post-spill monitoring preparedness level in a country, region or local area. Generating the MPAS should be done in consultation with all the main relevant stakeholders for the nation, region or local area in question.

ii. Organisation/team assessment

Similarly to the use outlined above, using an appropriately selected relevant scenario, the MPAM can be applied to a single organisation or discrete team that has a responsibility pertaining to the management and/or conduct of post-spill environmental monitoring. This can be useful for understanding where investment and/or training is required and for identifying issues on which the organisation needs to engage more actively with other stakeholders.

iii. Specific scenario assessment

Every marine spill scenario is different and the nature of the required monitoring programme will depend on many factors including; what has been spilled (oil, HNS etc.), the size of the spill, the location of the incident and the nature/sensitivity of the receiving environment. The MPAM can be used, therefore, to investigate preparedness levels for a range of spill scenarios and, in conjunction with risk assessment and probability analysis, provide a strong tool to focus training and investment.

iv. Preparedness auditing and improvement monitoring

The MPAM and the generated MPAS values can be used as part of a preparedness auditing process. Furthermore, if conducted periodically and compared the MPAS values and profiles can be used to monitor improvements in preparedness or to highlight where a degradation of preparedness level is evident.

v. Preparedness perception and reassurance

The MPAM can also be used to measure the level of preparedness that is perceived by different individuals or groups. Most monitoring programmes will require the co-ordinated efforts of several organisations and their effectiveness as a team will be affected by their collective understanding of roles, responsibilities and resource availability. If the MPAS is generated by all relevant stakeholders for a common scenario the differences between their assessments can highlight areas where there are gaps in the collective understanding that could lead to misunderstandings or uncertainty in the event of a real incident. This process would be useful as part of response exercises. The MPAM and the eight principles can also be used as the basis on which to explain to key stakeholders (e.g. the public) the level of preparedness and thus can be used as part of a communications and reassurance strategy.

4. List of protected species, England and Wales

Protected species, as well as protected habitats, should be given careful consideration within monitoring plans, as there may be wildlife licensing needs to be resolved prior to carrying out monitoring work. This would be important in order to avoid committing offences as part of monitoring work.

An example list of protected species in England and Wales is provided below in Table 15. Further information on UK-wide priority habitats and species can be found in a number of reports and publications from JNCC[62].

A list of features that could be afforded protection under a marine protected area can also be found on the Marine Conservation Zone Ecological Network Guidance by JNCC and Natural England[63].

Table 15. *Protected species in England and Wales is provided below [Note: This list was updated at the time of writing these guidelines].*

	Species	Regulations
FISH		
1	Common sturgeon (Acipenser sturio)	Regulations 39 & 41 of Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007, 12–200nm. Regulations 41 & 43 of Conservation of Habitats and Species Regulations 2010 (as amended). Sections 9(4)(b), (c) and 9(5) of Wildlife and Countryside Act 1981 (as amended) 0-12 nm.
2, 3	Allis shad (Alosa alosa) Twaite shad (Alosa fallax)	Regulations 41(shad) of Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007, 12-200nm. Sections 9(1) & 9(4)(a) for shad of Wildlife and Countryside Act 1981 (as amended), 0-2nm.
4	Houting (Coregonus oxyrinchus)	Regulations 42(8)(d) of Conservation of Habitats and Species Regulations 2010 (as amended). Regulations 40(5)(d) for houting of Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007, 12-200nm.
5, 6	Giant goby (Gobius cobitis) Couch's goby (Gobius couchi)	Section 9 of Wildlife and Countryside Act 1981 (as amended).
7, 8	Spiny seahorse (Hippocampus histrix) Short-snouted seahorse (Hippocampus hippocampus)	Wildlife and Countryside Act 1981 (as amended).
9, 10	Basking shark (Cetorhinus maximus) Angel shark (Squatina squatina)	Wildlife and Countryside Act 1981 (as amended), Section 9.
BIRDS		
11	All species of wild birds are protected	Wildlife and Countryside Act 1981. Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007. Birds Directive (Annex 1 has species list).
INVERTEBRATES		
		Wildlife and Countryside Act 1981 (as amended), 0-12nm.
12	Pink sea fan (Eunicella verrucosa)	Section 9(1), 9(2) and 9(5)
13	Starlet sea anemone (Nematostella vectensis)	Section 9
14	Ivell's sea anemone (Edwardsia ivelli)	Section 9
15	Marine hydroid (Clavopsella navis)	Section 9
16	Northern hatchet shell (Thyasira gouldi)	Section 9
17	Trembling sea matt (Victorella pavida)	Section 9
18	Tentacled lagoon worm (Alkmaria romijni)	Section 9(4)(a)
19	Lagoon sand shrimp (Gammarus insensibilis)	Section 9(4)(a)
20	De Folin's lagoon snail (Caecum armoricum)	Section 9
21	Lagoon sea slug (Tenellia adspersa)	Section 9
22	Lagoon sand worm (Armandia cirrhosa)	Section 9
23	Fan mussel (Atrina fragilis)	Section 9(1), 9(2) and 9(5)
CETACEANS		
24	All species of whales, dolphins and porpoises are protected	Regulations 39 & 41 of Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007,12-200nm. Regulations 41 & 43 of Conservation of Habitats and Species Regulations 2010 (as amended). Sections 9(4)(a) & 9(5) of Wildlife and Countryside Act 1981 (as amended), 0-12nm.
MARINE TURTLES		
25	All species of turtle are protected	Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (as amended). Conservation of Habitats and Species Regulations 2010 (as amended). Wildlife and Countryside Act 1981 (as amended) – flatback and olive ridley turtles only.
SEALS		
26	All species of seals are protected	The Conservation of Seals Act 1970. Conservation of Seals (England) Order 1999. Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (as amended). Conservation of Habitats and Species Regulations 2010 (as amended). Wildlife and Countryside Act 1981 (as amended).

[62] *Marine Habitats, JNCC: http://jncc.defra.gov.uk/page-1529*
[63] *Marine Conservation Zone Project: Ecological Network Guidance, by JNCC and Natural England: http://publications.naturalengland.org.uk/file/1737273*

5. Compensation for oil spill damage from ships and Environmental Regulations

The UK is a signatory to two international conventions governing claims and compensation following oil spills from tankers carrying persistent oil as cargo: the International Convention on Civil Liability for Oil Pollution Damage (1992 CLC) and the 1992 International Convention on the Fund for Compensation for Oil Pollution Damage (1992 Fund Convention). The UK has also ratified the Supplementary Fund Protocol which provides an additional layer of compensation in states that are members of the 1992 Fund Convention.

In addition to the above instruments covering spills of persistent oil from tankers, the UK is also a signatory to the 2001 International Convention on Civil Liability for Bunker Oil Pollution Damage (Bunker Convention 2001). This convention establishes liability for spills of oil carried as fuel in ship's bunkers and applies to all types of ships.

With regard to chemical spills, since the shipping convention of the International Maritime Organisation's International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea is yet to enter into force, at the moment of producing these guidelines there was no international convention covering compensation for chemical spills, with the exception of LLMC 76 (where applicable) which establishes limits.

Developed under the auspices of the IMO, these conventions provide compensation for environmental damage resulting in loss of profit and the costs of reasonable measures of reinstatement. The costs of suitably tailored post-incident studies fall within the definition of reinstatement measures.

The handling of claims generated by a given incident is typically undertaken by the ship-owner's Protection and Indemnity (P&I) insurer in cases falling under the Bunker Convention 2001 and the 1992 CLC. In cases where the ship owner's liability under the CLC is either not applicable or exceeded, the Secretariat of the International Oil Pollution Compensation Funds (IOPC Funds), the organisation that administers the 1992 Fund and Supplementary Fund, will handle claims.

It is typical for the ship owner's insurer and/or IOPC Funds to appoint experts to provide input on various technical aspects following an incident, including the planning, design and implementation of post-incident studies. Early engagement and close liaison between the PMCC and the ship owner's insurer and/or IOPC Funds and their experts is therefore encouraged.

Detailed guidance on the preparation and submission of claims for incidents involving the IOPC Funds is available on the IOPC Funds website[64]. Information on how the IOPC Funds assesses claims for environmental damage and environmental studies can be found on the 1992 Fund Claims Manual, 2016.

[64] *http://www.iopcfunds.org/publications/iopc-publications*

Additionally, a guidance document by IOPC for presenting claims for environmental damage is currently being drafted and is expected to be adopted by the IOPC Funds' Governing Bodies in the near future. Similarly, the IOPC Funds have published a guidance document for Member States on the criteria for imposing and lifting fisheries closures, which is also available at the URL mentioned above.

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; examples of the largest sites in England (larger than 100 hectares (or 1km^2) can be found in Wikipedia.

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.

[65] *List of the largest Sites of Special Scientific Interest in England: http://en.wikipedia.org/wiki/List_of_the_largest_Sites_of_Special_Scientific_Interest_in_England*

6. PMCC Situation report

Introduction

Premiam Co-ordination Cell (PMCC) Situation report – [response name]

Sitrep no. (version no.)

Completed by	Name/role
Approved by	Name/role
Date	
Time	

Highlights

- 3-5 bullet points only.
- If no progress since last Sitrep clearly state here.

Situation to date (what has happened)

- Brief summary of "start-up details" – date, place, time, who is involved.
- Ensure old information is deleted, and do not just add new/additional info to each newly issued Situation report (Sitrep).
- Image if required (e.g. model output, map of sampling locations).

Operation update

- Brief summary of sampling activities (underway or planned).
- Assets required and/or in place.
- Where operation expects to be in next 24hrs etc. (or time frame for when next Sitrep is to be issued).

Issues

- Present brief description of issue(s) that are known/reasonably expected to arise before the next Sitrep is issued e.g. a shortage of a given resource, a significant H&S concern etc.
- Acknowledgement of significant achievements, failures etc. can be given here.

Partnership and co-ordination

- Describe make up on core PMCC cell members.
- State time last PMCC meeting was held.
- List ad-hoc members who contributed since last Sitrep issued.
- List significant developments in terms of cross agency/department efforts in relation to monitoring.

Funding update

- To update if additional monitoring funds requested and points of contact with Gov. (likely to be required for longer running monitoring efforts).

Media communication

- List PMCC media communication points of contact.
- List any press or comms related activity that EG should be aware of.

Abbreviations:

Note to aid drafting:

- Information in the Sitrep should be factual and largely without interpretation and conjecture.
- The information in a Sitrep should cover the period between the last issued Sitrep and the next Sitrep.
- Aim to keep Sitreps brief (read in <3-5 mins).
- Sitreps should be specific to the activities of the PMCC, and not present information that is outside the specific operational area.
- It is acceptable for a Sitrep to be issued that states no change since last Sitrep (see last Sitrep for information).
- A map and other graphic can be part of a Sitrep – ensure date/time of the graphic is shown on it, and there is a reference between the graphic and the Sitrep.
- Each electronically produced Sitrep should be saved as a new file, and all saved to the same folder.
- Ensure the information (Sitrep number, response title, Sitrep version date) is updated in the footer.

ACKNOWLEDGEMENTS

Photograph of Puffin (FC) ©Mark Lewis, Photograph of Coral (FC) ©JNCC, photographs on page 94 and 111 ©Marine Scotland and are used with permission. All remaining photographs are British Crown copyright.

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-Gutierrez, J., Figueras, A., Albaiges, J., Jimenez, N., Vinas, 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.

AMSA, 2003. Oil spill monitoring background paper. Australian Maritime Safety Authority, Canberra. https://www.amsa.gov.au/environment/marine-pollution-response/scientific-info/dispersants/Documents/Oil_Spill_Monitoring_Background_Paper.pdf. [accessed 17 February 2017].

AMSA, 2003b. Oil spill monitoring handbook. Australian Maritime Safety Authority, Canberra. https://www.amsa.gov.au/environment/marine-pollution-response/scientific-info/dispersants/Documents/Oil_Spill_Monitoring_Handbook.pdf [accessed 17 February 2017].

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].

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://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times39/TIMES39.pdf [accessed 3 January 2017].

Armitage, M., Burton, N. and Rehfisch, M., 1997. The Abundance and Distribution of Waterfowl within Milford Haven after the Sea Empress Oil Spill, 1 Year Report. Report to CCW from the British Trust for Ornithology, Thetford. 124 pp.

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. 85 pp.

AURIS, 1994. Scientific criteria to optimise oil spill clean-up operations and effort. A report by AURIS Environmental, Aberdeen. 56 pp plus 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. 148 pp.

Australian Maritime Safety Authority, 2003. Oil spill monitoring handbook. AMSA, Canberra. http://www.amsa.gov.au/marine_environment_protection/national_plan/contingency_plans_and_management/research_development_and_technology/Oil_Spill_Monitoring_Handbook.pdf [accessed 6 February 2017].

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.

Baca, B. J., Lankford, T. E., Gundlach, E. R. (1987). Recovery of Brittany coastal marshes in the eight years following the Amoco Cadiz incident. Proceedings of the 1987 International Oil Spill Conference. In International Oil Spill Conference Proceedings: April 1987, Vol. 1987, No. 1, pp. 459–464.

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. 67 pp.

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. 77 pp.

Baker, J.M. and Crothers, J.H, 1987. Intertidal rock. In: J.M. Baker and W.J. Wolff (editors.), Biological Surveys of Estuaries and Coasts, Estuarine and Brackish Water Sciences Association Handbook, University of Cambridge Press, Cambridge, UK, pp. 157-197.

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. 89 pp.

Baker, J.M. and Wolff, W.J. (editors), 1987. Biological Surveys of Estuaries and Coasts. Estuarine and Brackish Water Sciences Association Handbook, University of Cambridge Press, Cambridge. 472 pp. ISBN-10 0 52 131191 8 ISBN-13 978 0 52 131191 5.

Balk, B., Martínez-Gómez, C., Gubbins, M., Thain, T. (2012). Technical Annex: supporting parameters for biological effects measurements in fish and mussels p. 191- 196. In Davies, I. M. and Vethaak, A. D. 2012. Integrated marine environmental monitoring of chemicals and their effects. ICES Cooperative Research Report No. 315. 277 pp.

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. CCW Marine Monitoring Report No. 12. 41 pp.

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

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.

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. 160 pp plus figures and tables.

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. The Stationery Office Limited, Edinburgh, pp. 52-62.

Bean, T. P. and Akcha, F. 2016. Biological effects of contaminants: Assessing DNA damage in marine species through single-cell alkaline gel electrophoresis (comet) assay. ICES Techniques in Marine Environmental Sciences. no. 58. 17 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times58/TIMES%2058.pdf [accessed 04 January 2017].

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 plus 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. Wang, Z. and Stout, S.A. Oil Spill Environmental Forensics: Fingerprinting and Source Identification. Elsevier, Inc. 554 pp. ISBN10 0 12 369523 6; ISBN13 978 0 12 369523 9. Chapter 15, pp. 449-487.

Beyer, J., Trannum, H.C., Bakke, T., Hodson, P.V. and Collier, T.K. 2016. Environmental effects of the Deepwater Horizon oil spill: A review. Marine Pollution Bulletin, 110(1), 28-51.

Bik, H.M., Halanych, K.M., Sharma, J. and Thomas, W.K., 2012. Dramatic shifts in benthic microbial eukaryote communities following the Deepwater Horizon oil spill. PLoS ONE 7(6), e38550.

Birkhead, T.R. 2001. Skomer Guillemot Studies 1999-2001 - Three year Report. Unpubl. 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. 22. 12 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times22/TIMES22.pdf [accessed 03 January 2017].

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.

Bonifay, V., Aydin, E., Aktas, D.F., Sunner, J. and Suflita, J.M. 2016. Metabolic profiling and metabolomic procedures for investigating the biodegradation of hydrocarbons. In Hydrocarbon and Lipid Microbiology Protocols: Genetic, Genomic and System Analyses of Communities. McGenity, T.J., Timmis, K.N., Nogales, B. (eds). Springer, Berlin, pp. 111-161.

Booij, K., Robinson, C.D., Burgess, R.M., Mayer, P., Roberts, C.A., Ahrens, L., Allan, I.J., Brant, J., Jones, L., Kraus, U.R., Larsen, M.M., Lepom, P., Petersen, J., Pröfrock, D., Roose, P., Schäfer, S., Smedes, F., Tixier, C., Vorkamp, K. and Whitehouse, P., 2016. 'Passive Sampling in Regulatory Chemical Monitoring of Nonpolar Organic Compounds in the Aquatic Environment. Environmental Science & Technology, vol 50, no. 1, pp. 3-17. DOI: 10.1021/acs.est.5b04050.

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

Brekkea, C. and Solbergb A.H.S. (2005). Oil spill detection by satellite remote sensing. Remote Sensing of Environment 95, 1-13p.

Bremner, J., Smith, A., Biermann, L., Downie A. and Dolphin, T. (2016). Coastal imaging, mapping and algal health assessment using remotely piloted aircraft. Marine Emergency Response Research Technology Transfer Programme, Reference Code C5905. Cefas Report to Defra.

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.

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.

Brussaard, C.P., Peperzak, L., Beggah, S., Wick, L.Y., Wuerz, B., Weber, J., Arey, S.J., van der Burg, B., Jonas, A., Huisman, J. and van der Meer, J.R., 2016. Immediate ecotoxicological effects of short-lived oil spills on marine biota. Nature Communications 7, 11206.

BTO Wetland Bird Survey website: https://www.bto.org/volunteer-surveys/webswww.bto.org/webs [accessed 23 February 2017].

Buckland, S. T., Burt, M. L., Rexstad, E. A., Mellor, M., Williams, A. E. and Woodward, R. (2012). Aerial surveys of seabirds: the advent of digital methods. Journal of Applied Ecology, 49: 960–967.

Burdick, D. M., Short, F. T. and Wolf, J. (1993). An index to assess and monitor the progression of wasting disease in eelgrass Zostera marina. Marine Ecology Progress Series 94:83-90.

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, accessed 23 February 2017].

Camphuysen, C.J. and Leopold, M.F. 2004. The Tricolor spill: characteristics of seabirds found oiled in The Netherlands. Atlantic Seabirds 6(3): 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, 37 pp.

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.

CCW, 1998. Grey seal pup production and monitoring studies following the Sea Empress oil spill. Summary report prepared for SEEEC.

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. 30 pp plus 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.

Chronopoulou, P-M., Sanni, G.O., Silas-Olu, D.I., van der Meer, J.R., Brussaard, C.P.D., Timmis, K.N. and McGenity, T.J., 2015. Generalist hydrocarbon-degrading bacterial communities in the oil-polluted water column of the North Sea. Microbial Biotechnology 8, 434-447.

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, C.F., 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. The Stationery Office Limited, Edinburgh, pp. 106-120.

Coulon, F., McKew, B.A., Osborn, A.M., McGenity, T.J. and Timmis, K.N., 2007. Effects of temperature and biostimulation on oil-degrading microbial communities in temperate estuarine waters. Environmental Microbiology 19, 177-186.

Countryside Council for Wales, 1998. Grey seal pup production and monitoring studies following the Sea Empress oil spill. Summary report prepared for the Sea Empress Environmental Evaluation Committee.

Crawford, A., 2011. Fifth otter survey of England, 2009-2010. Environment Agency, Technical Report. 125 pp.

Crump, R., 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: Edwards, R. and Sime, H. (Editors.) The Sea Empress Oil Spill. Proceedings of a conference held in Cardiff, 11-13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management. pp. 207-222.

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: Edwards, R. and Sime, H. (Eds.) The Sea Empress Oil Spill. Proceedings of a conference held in Cardiff, 11-13 February 1998. Published for SEEEC by The Chartered Institution of water and Environmental Management. pp. 423-435.

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. Chapter 3 Salt marshes. In: J.M. Baker and W.J. Wolff (eds.), Biological Surveys of Estuaries and Coasts, Estuarine and Brackish Water Sciences Association Handbook, University of Cambridge Press, Cambridge, UK, pp. 38-80.

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.

Davies J., Baxter J., Bradley M., Connor D., Khan J., Murray E., Sanderson W., Turnbull C. and Vincent M., (editors.), 2001. Marine Monitoring Handbook. JNCC, Peterborough, 405 pp. http://www.jncc.gov.uk/page-2430 [accessed 17 February 2017].

Davies, I. M. and Vethaak, A. D. 2012. Integrated marine environmental monitoring of chemicals and their effects. ICES Cooperative Research Report No. 315. 277 pp. http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/crr315/CRR315_Integrated%20Monitoring_final.pdf [accessed on 05 January 2017].

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. and Vincent, M. (2001). Marine Monitoring Handbook, 405 pp. Joint Nature Conservation Committee. Procedural Guideline No's 4-1, 4-2, 4-3 & 4-4.

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. http://www.ukmarinesac.org.uk/publications.htm [accessed 17 February 2017].

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., 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.

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, held in Anchorage, Alaska, 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, held in Anchorage, Alaska, February 1993. American Fisheries Society Symposium 18, 412-423.

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. 28 pp.

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. Cambridge, Sea Mammal Research Unit.

Eiserbeck, C., Nelson, R.K., Grice, K., Curiale, J., Reddy, C.M., 2012. Comparison of GC-MS, GC-MRM-MS, and GC× GC to characterise higher plant biomarkers in Tertiary oils and rock extracts. Geochimica et Cosmochimica Acta 87, 299-322.

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). 151 pp. www.ukmarinesac.org.uk/publications.htm [accessed 23 February 2017].

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 and Orielton Field Centre, Pembroke.

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. http://www.epa.gov/waterscience/library/sediment/marinemethod.pdf [accessed 2 July 2010].

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. 20 pp plus appendices.

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

Fisher, C.R., Montagna, P.A. and Sutton, T., 2016. How Did the Deepwater Horizon Oil Spill Impact Deep-Sea Ecosystems? Oceanography, 29(3), 182-195.

Fonseca, M., Piniak, G. and Cosentino-Manning, N., 2017. Susceptibility of seagrass to oil spills: A case study with eelgrass, Zostera marina in San Francisco Bay, USA. Marine Pollution Bulletin, 115, 29-38.

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. Wang, Z. and Stout, S.A. Oil Spill Environmental Forensics: Fingerprinting and Source Identification. Elsevier, Inc. 554 pp. ISBN10 0 12 369523 6; ISBN13 978 0 12 369523 9. Chapter 5, pp. 169-206.

Geraci, J.R. and St. Aubin, D.J., 1990. Sea Mammals and Oil: Confronting the Risks. Academic Press. 282 pp.

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.

GESAMP, 2015. Group of Experts on the Scientific Aspects of Marine Environmental Protection. GESAMP Composite List. Issued as PPR.1/Circ.2. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/ChemicalPollution/Documents/GESAMP%20CompList%202015.pdf [accessed 16 March 2017].

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. Chapter 3 In: Cairns, J.J. and Buikemea, J. (eds.), Restoration of habitats impacted by oil spills. Massachusetts: Butterworth Publishers, Boston, MA. USA, pp. 65-113.

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. 464 pp. ISBN: 1 90 193003 3.

Grantham, M.J. 2004. Age structure and origins of British and Irish Guillemots Uria aalge recovered in recent European oil spills. Atlantic Seabirds 6(3): 95-108.

Gros, J., Reddy, C.M., Aeppli, C., Nelson, R.K., Carmichael, C.A., Arey, J.S., 2014. Resolving biodegradation patterns of persistent saturated hydrocarbons in weathered oil samples from the Deepwater Horizon disaster. Environmental Science & Technology 48 (3), 1628-1637.

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. http://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. 34 pp. Available at: www.morayfirth-partnership.org, [accessed 23 February 2017] http://www.snh.org.uk/pdfs/publications/review/003.pdf [accessed 11 March 2011].

Gutierrez, T., Singleton, D.R., Berry, D., Yang, T., Aitken, M.D. and Teske, A., 2013. Hydrocarbon-degrading bacteria enriched by the Deepwater Horizon oil spill identified by cultivation and DNA-SIP. ISME Journal 7, 2091–2104.

Hall, C., Frysinger, G.S., Aeppli, C., Carmichael, C.A., Gros, J., Lemkau, K.L., Nelson, R.K., Reddy, C.M., 2013. Oxygenated Weathering Products of Deepwater Horizon Oil Come From Surprising Precursors. Marine Pollution Bulletin 75(1–2), 140–149

Hall, M., 1997. The Braer: environmental health problems associated with the spill. In.: J.M. Davies, G. Topping (Editors). The Impact of an Oil Spill in Turbulent Waters: the Braer. The Stationery Office, London. ISBN 0 11 495798 3.

Harvey, J.S., Lyons, B.P., Page, T.S., Stewart, C., Parry, J.M. (1999). An assessment of the genotoxic impact of the Sea Empress oil spill by the measurement of DNA adduct levels in selected invertebrate and vertebrate species. Mutation Research - Genetic Toxicology and Environmental Mutagenesis, 441 (1), pp. 103-114.

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.

Head, I.M., Jones, D.M. and Röling, W.F.M., 2006. Marine microorganisms make a meal of oil. Nature Reviews Microbiology 4, 173-182.

Hegazi, A.H. and Andersson, J.T., 2007. Characterization of polycyclic aromatic sulphur heterocycles for source identification. In. Wang, Z. and Stout, S.A. Oil Spill Environmental Forensics: Fingerprinting and Source Identification. Elsevier, Inc. 554 pp. ISBN10 0 12 369523 6; ISBN13 978 0 12 369523 9. Chapter 4, pp. 147-168.

Helaluddin, ABM,. Saadi Khalid, R., Alaama, M. and Atif Abbas, S. (2016). Main Analytical Techniques Used for Elemental Analysis in Various Matrices. Tropical Journal of Pharmaceutical Research 15(2): 429.

Henkel, J. R., Sigel, B. J. and Taylor, C. M. (2014), Oiling rates and condition indices of shorebirds on the northern Gulf of Mexico following the Deepwater Horizon oil spill. J. Field Ornithol., 85: 408–420. doi:10.1111/jofo.12080

Hester, M.W., Willis, J.M., Rouhani, S., Steinhoff, M.A., Baker, M.C. 2016. Impacts of the Deepwater Horizon oil spill on the salt marsh vegetation of Louisiana. Environmental Pollution, 216, 361-370.

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.

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. The Stationery Office Limited, Edinburgh, pp. 73-90.

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). 84 pp. http://www.ukmarinesac.org.uk/publications.htm [accessed 2 July 2010, 17 February 2017].

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. 13 pp plus tables and maps.

Holme, N. A. and McIntyre, A. D. (editors), 1984. Methods for the Study of Marine Benthos, 2nd edition. IBP Handbook, No.16. Oxford, Blackwell Scientific Publications for International Biological Programme.

Hook, S., Batley, G., Holloway, M., Irving, P. and Ross, A. (eds) 2016. Oil spill monitoring handbook. CSIRO Publishing, Australia. 288 pp.

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. Editor: B. Dicks. John Wiley & Sons, Chichester.

Howgate, P., 1999. Tainting of food by chemical contaminants. In.: Environmental Contaminants in Food. (C.F. Moffat, K.J. Whittle (eds). Sheffield Academic Press/ CRC Press. 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, 2011. Report of the Study Group on Integrated Monitoring of Contaminants and Biological Effects (SGIMC). ICES Document CM 2011/ACOM:30 Ref. OSPAR.

Inshore Sublittoral Rock Habitats. Version August 2004. 27 pp. http://www.jncc.gov.uk/ page-2236 [accessed 2 July 2010].

International Oil Pollution Compensation Fund, 2016. Claims manual. IOPC Funds, London. 43 pp. http://www.iopcfunds.org/uploads/tx_iopcpublications/IOPC_ Funds_Claims_Manual_ENGLISH_WEB.pdf [accessed 18 November 2016].

IPIECA, 1991. Guidelines on biological impacts of oil pollution. IPIECA Report Series Volume 1, International Petroleum Industry Environmental Conservation Association, London, 15pp. http://www.ipieca.org/system/files/publications/Vol1_ BioImpacts.pdf [accessed 2 July 2010].

IPIECA, 1994. Biological Impacts of Oil Pollution: Saltmarshes. London: International Petroleum Industry Environmental Conservation Association. IPIECA Report Series, Volume 6. 20pp. http://www.ipieca.org/system/files/publications/Vol6_ Saltmarshes_0.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, 20 pp. http://www. ipieca.org/system/files/publications/Vol10_NEBA_1.pdf [accessed 2 July 2010].

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

IPIECA, 2011. Sensitivity mapping for oil spill response, OGP Report Number 477, 39 pp. http://www.oilspillresponseproject.org/wp-content/uploads/2016/02/GPG- Sensitivity-Mapping.pdf [accessed 2 July 2010].

IPIECA, 2012. Sensitivity mapping for oil spill response. IOGP Report No. 477. International Petroleum Industry Environmental Conservation Association. London. 24pp. www.oilspillresponseproject.org/planning [accessed 17 February 2017]. IPIECA, 1996. Sensitivity mapping for oil spill response. IPIECA Report Series, Volume 1. International Petroleum Industry Environmental Conservation Association. London. 24pp. www.ipieca.org/publications/publications_summary. php?id=41 [accessed 2 July 2010].

IPIECA, 2014. Wildlife response preparedness. IOGP Report No. 516. www. oilspillresponseproject.org/response/International Petroleum Industry Environmental Conservation Association, London, 58 pp. [accessed 17 February 2017] IPIECA, 2004. A guide to oiled wildlife response planning. IPIECA Report Series, Volume 13, International Petroleum Industry Environmental Conservation Assocation, London. 52 pp. http://www.ipieca.org/activities/oilspill/downloads/ publications/reports/english/Vol13_Oiled_Wildlife.pdf [accessed 24 May 2010].

IPIECA, 2015. Impacts of oil spills on marine ecology. IOGP Report No. 525. www. oilspillresponseproject.org/impacts/International Petroleum Industry Environmental Conservation Association, London, 52 pp. [accessed 17 February 2017].

IPIECA, 2015b. Response strategy development using net environmental benefit analysis (NEBA). IOGP Report No. 527. www.oilspillresponseproject.org/strategy/ International Petroleum Industry Environmental Conservation Association, London, 39 pp. [accessed 17 February 2017].

IPIECA, 2016. Impacts of oil spills on shorelines. IOGP Report No. 534. www.oilspillresponseproject.org/impacts/International Petroleum Industry Environmental Conservation Association, London, 53 pp. [accessed 17 February 2017].

IPIECA, 2016b. Economic assessment and compensation for marine oil releases. IOGP Report No. 524. www.oilspillresponseproject.org/impacts/International Petroleum Industry Environmental Conservation Association, London, 54 pp. [accessed 17 February 2017].

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

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.

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.

ITOPF, 2017 tanker spill statistics 2017 at: http://www.itopf.com/fileadmin/data/Photos/ Publications/Oil_Spill_Stats_2016_low.pdf [accessed 2 July 2010].

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, 2004a. Common Standards Monitoring Guidance for Saltmarsh Habitats. Version August 2004. 23pp. http://www.jncc.gov.uk/page-2204 [accessed 16 February 2017].

JNCC, 2004b. Common Standards Monitoring Guidance for Lagoons. Version August 2004. 38 pp. http://www.jncc.gov.uk/page-2236 [accessed 16 February 2017].

JNCC, 2004c. Common Standards Monitoring Guidance for Littoral Sediment Habitats. Version August 2004. 33pp. http://www.jncc.gov.uk/page-2236 [accessed 16 February 2017].

JNCC, 2004d. Common Standards Monitoring Guidance for Littoral Rock and Inshore Sublittoral Rock Habitats. Version August 2004. 27 pp. http://www.jncc.gov.uk/ page-2236 [accessed 16 February 2017].

JNCC, 2004e. Common Standards Monitoring Guidance for Inshore Sublittoral Sediment Habitats. Version August 2004. 27 pp. http://www.jncc.gov.uk/page-2236 [accessed 16 February 2017].

JNCC, 2004f. Common Standards Monitoring Guidance for Birds. Version August 2004, Online only. 50 pp. http://www.jncc.gov.uk/page-2224 [accessed 16 February 2017].

JNCC, 2004g. Common Standards Monitoring Guidance for Mammals. Version August 2004, Online only. 51 pp. http://www.jncc.gov.uk/page-2229 [accessed 16 February 2017].

JNCC, 2005. Common Standards Monitoring Guidance for Marine Mammals. Version May 2005, Online only. 36 pp. http://www.jncc.gov.uk/page-2228 [accessed 16 February 2017].

JNCC, 2015. Seabird Population Trends and Causes of Change: 1986-2014 Report (http://www.jncc.defra.gov.uk/page-3201). Joint Nature Conservation Committee. Updated October 2015 [accessed 16 February 2017]

Johansson-Sjobeck, M.-L. and Larsson, A., 1978. The effect of cadmium on the haematology and on the activity of aminolevulinic acid dehydratase (ALAD) in blood and haemopoetic tissues of the flounder Pleuronectes platessa L. Environmental Research 17, 191-294.

Johnsen, A.R., 2017. Introduction to microplate MPN enumeration of hydrocarbon degraders. In Hydrocarbon and Lipid Microbiology Protocols: Microbial Quantitation, Community Profiling and Array Approaches. McGenity, T.J., Timmis, K.N., Nogales, B. (eds.). Springer, Berlin, pp. 17-33.

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

Joye, S.B., Kleindienst, S., Gilbert, J.A., Handley, K.M., Weisenhorn, P., Overholt, W.A. and Kostka, J.E. 2016. Responses of microbial communities to hydrocarbon exposures. Oceanography 29, 136-149.

Kelly, C.A., Law, R.J., 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. http://www.cefas.co.uk/publications/aquatic/aepam12.pdf [accessed 1 February 2017].

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. The Stationery Office Limited, Edinburgh, pp. 209-233.

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., 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, 30 pp.

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.

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.

Klif, 2011. Guidelines for offshore environmental monitoring: The petroleum sector on the Norwegian Continental Shelf. Norwegian Climate and Pollution Agency. http://www.miljodirektoratet.no/old/klif/publikasjoner/2849/ta2849.pdf.

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 Professionnelles 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.

Lane, S.M., Smith, C.R., Mitchell, J., Balmer, B.C., Barry, K.P., McDonald, T., Mori, C.S., Rosel, P.E., Rowles, T.K., Speakman, T.R., Townsend, F.I., Tumlin, M.C., Wells, R.S., Zolman, E.S. and L.H. Schwacke (2015). Reproductive outcome and survival of common bottlenose dolphins sampled in Barataria Bay, Louisana, USA, following the Deepwater Horizon oil spill. Proceedings Royal Society B 282:1994-2001.

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.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: Edwards R. and Sime H. (Editors) The Sea Empress Oil Spill: Proceedings of the International Conference held in Cardiff, 11-13 February 1998. Chartered Institute of Water and Environmental Management, London, pp. 109-136.

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, Cefas, Lowestoft, 61: 36pp. http://www.cefas.co.uk/publications/aquatic/aemr61.pdf [accessed 26 May 2010].

Law, R., Brant, J, Kirby, M., Lee, J., Morris, D. and Rees, J., 2014. Guidelines for the environmental monitoring and impact assessment associated with subsea oil releases and dispersant use in UK waters. Science Series Technical Report. Cefas, Lowestoft, 153. 58 pp.

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., 1980. Changes in the composition of oil from the "Amoco Cadiz". The Science of the Total Environment 15, 37-49.

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., Webster, L., Theobald, N., Rumney, H.S. and de Boer, J., in press 2011. Organic micropollutants. In.: Chemical Marine Monitoring - Policy Framework and Analytical Trends. P. Roose, G. Verreet, P. Quevauviller (Editors). Wiley-Blackwell, Chichester, 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. Chapter 6, pp. 161-196 (P. Roose, G. Verreet, P. Quevauviller Eds). Wiley-Blackwell, Chichester, UK.

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 D.C. #432, 5 pp.

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.

Leverett, D. and Thain, J. 2013. Oyster embryo-larval bioassay (Revised). ICES Techniques in Marine Environmental Sciences No. 54. 34 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times54/TIMES%2054%20web.pdf [accessed 03 January 2017].

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. 124 pp. plus 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.

Lozada, M., Marcos, M.S., Commendatore, M.G., Gil, M.N. and Dionisi, H.M., 2014. The bacterial community structure of hydrocarbon-polluted marine environments as the basis for the definition of an ecological index of hydrocarbon exposure. Microbes and Environments 29, 269–276.

Lunel, T. and Elliott, A.J., 1998. Fate of Oil and the Impact of the Response. In: Edwards, R. and Sime, H. (Editors.) The Sea Empress Oil Spill. Proceedings of a conference held in Cardiff, 11-13 February 1998. Published for SEEEC by The Chartered Institution of Water and Environmental Management. pp. 51-72.

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 2007. The UK SCAT Manual: A Field Guide to the Documentation of Oiled Shorelines in the UK. Maritime and Coastguard Agency, Southampton, UK, 47 pages + vi. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297968/ukscatman.pdf

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

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

Maritime and Coastguard Agency, 2014. The National Contingency Plan. A Strategic Overview for Responses to Marine Pollution from Shipping and Offshore Installations. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/478676/1501120_NCP.pdf [accessed 20 February 2017].

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

Martínez-Gómez, C., Bignell, J. and Lowe, D. 2015. Lysosomal membrane stability in mussels. ICES Techniques in Marine Environmental Sciences No. 56. 41 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times56/TIMES%2056.pdf [accessed 03 January 2017].

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.

Mason, O.U., Hazen, T.C., Borglin, S., Chain, P.S.G., Dubinsky, E.A., Fortney, J.L., Han, J., Holman, H.Y., Hultman, J., Lamendella, R., Mackelprang, R., Malfatti, S., Tom, L.M., Tringe, S.G., Woyke, T., Zhou, J., Rubin, E.M. and Jansson, J.K., 2012. Metagenome, metatranscriptome and single-cell sequencing reveal microbial response to Deepwater Horizon oil spill. ISME Journal 6, 1715–1727.

Matkin, C.O., Saulitis, E.L., Ellis, G.M., Olesiuk, P. and S.D. Rice. 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., Schmitt, S. and Parsons, M. 20062008. Seabird numbers and breeding success in Britain and Ireland, 20052006. Peterborough, Joint Nature Conservation Committee. (UK Nature Conservation, No.3031)

McGenity, T.J., Folwell, B.D., McKew, B.A. and Sanni, G.O., 2012. Marine crude-oil biodegradation: a central role for interspecies interactions Aquatic Biosystems 8, 10.

McKew, B.A. and Smith, C.J., 2017. Real-time PCR approaches for analysis of hydrocarbon-degrading bacterial communities. In: Hydrocarbon and Lipid Microbiology Protocols: Microbial Quantitation, Community Profiling and Array Approaches. McGenity, T.J., Timmis, K.N., Nogales, B. (eds). Springer, Berlin, pp. 45-64.

McKew, B.A., Coulon, F., Osborn, A.M., Timmis, K.N. and McGenity, T.J., 2007a. Determining the identity and roles of oil-metabolizing marine bacteria from the Thames estuary, UK. Environmental Microbiology 9, 165-176.

McKew, B.A., Coulon, F., Yakimov, M.M., Denaro, R., Genovese, M., Smith, C.J., Osborn, A.M., Timmis, K.N. and McGenity, T.J., 2007b. Efficacy of intervention strategies for bioremediation of crude oil in marine systems and effects on indigenous hydrocarbonoclastic bacteria. Environmental Microbiology 9, 1562-1571.

McQuillan, J.S. and Robidart, J.C., 2017. Molecular-biological sensing in aquatic environments: recent developments and emerging capabilities. Current Opinion in Biotechnology 45, 43–50.

Merv Fingas, M. and Brown C., (2014). Review of oil spill remote sensing. Marine Pollution Bulletin 83:1, 9-23p. http://dx.doi.org/10.1016/j.marpolbul.2014.03.059.

Michel, J. and Rutherford, N. (2014). Impacts, recovery rates, and treatment options for spilled oil in marshes. In Marine Pollution Bulletin, Vol. 82, Issues 1–2, pp. 19–25

Michel, J., Zengel, S., Hinkeldey, H. and Helton, D., 2003. Ephemeral data collection during the emergency phase of a spill: Protocols on design and methods. Proceedings of the 2003 International Oil Spill Conference, 1139-1145.

Miège, C., Mazzella, N., Allan, I., Dulio, V., Smedes, F., Tixier, C., Vermeirssen, E., Brant, J., O'Toole, S., Budzinski, H., Ghestem, J-P., Staub, P-F., Lardy-Fontan, S., Gonzalez, J-L., Coquery, M., Vrana, B., 2015. Position paper on passive sampling techniques for the monitoring of contaminants in the aquatic environment – Achievements to date and perspectives, Trends in Environmental Analytical Chemistry, vol 8, 20-26 pp. http://dx.doi.org/10.1016/j.teac.2015.07.001.

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.

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. 12 pp. + 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. The Stationery Office Limited, Edinburgh, pp. 91-105.

Montagna P.A., J.G. Baguley, C. Cooksey, I. Hartwell, L.J. Hyde, J.L. Hyland, R.D. Kalke, L.M. Kracker, M. Reuscher, and A.C.E. Rhodes. 2013. Deep-sea benthic footprint of the Deepwater Horizon blowout. PLoS ONE 8(8).

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. 79 pp.

Moore, J. (2007) The UK SCAT Manual. A Field Guide to the Documentation of Oiled Shorelines in the UK. Maritime and Coastguard Agency, Southampton. 47 pp. + vi. https://www.gov.uk/government/publications/shoreline-clean-up-assessment-techniques-scat [accessed 23 February 2017].

Moore, J.J., Hill, A.S., 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.

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].

Morales-Caselles, C., Riba, I. and Ángel DelValls, T, 2002. 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. and Guilhermino, L., 2007. EROCIPS Report for Task 7.3.5: Environmental monitoring report. 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. Second edition. CRC Press, Boca Raton, Florida, USA. ISBN-10 1 56 670027 2; ISBN-13 978-1 56 670027 6. 256 pp.

Munilla, I., Arcos, J.M., Oro, D., Álvarez, D., Leyenda, P. M. and Velando, A. 2011. Mass mortality of seabirds in the aftermath of the Prestige oil spill. Ecosphere 2(7):art83.

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.

Murphy, B.L. and Morrison R.D. (eds) (2015). Introduction to Environmental Forensics. Third Edition. Elsevier. http://dx.doi.org/10.1016/B978-0-12-404696-2.01001-8.

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

Musgrove, A.J., Langston, R.H.W., Baker, H. and Ward, R.M. (editors), 2004. Estuarine Waterbirds at Low Tide, The WeBS Low Tide Counts 1992-93 to 1998-99. pp 316.

National Research Council, 1999. Spills of Nonfloating Oils: Risk and Response. Committee on Marine Transportation of Heavy Oils. National Academy Press, Washington D.C. 88pp. http://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 Academy Press, Washington D.C. 601pp. http://www.nap.edu/catalog/10388.html – includes online reading/search facility [accessed 23 February 2017].

National Research Council, 2005. Oil Spill Dispersants: Efficacy and Effects. Committee on Understanding Oil Spill Dispersants. National Academy Press, Washington D.C. 378pp. http://www.nap.edu/catalog.php?record_id=11283 [accessed 23 February 2017].

National Research Council Academy of Sciences, 1985. Oil in the Sea: Inputs, Fates and Effects. National Academy Press, Washington D.C. 601 pp. ISBN 0 309 03479 5.

Nijkamp, H., (ed.) 2006. Preparedness and response to oiled wildlife incidents in Europe. http://www.interspill.com/pastevents/cp8.htm [accessed 24 May 2010] http://www.interspill.org/previous-events/2006/wildlife.php, [accessed 23 February 2017].

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. 28 pp. http://www.oiledwildlife.eu/publications, [accessed 23 February 2017] http://www.oiledwildlife.eu/files/Rehabilitation%20of%20Oiled%20Birds%20in%20the%20aftermath%20of%20an%20Oil%20Spill%20Incident%20-Handbook-2007.pdf [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. National Oceanic and Atmospheric Administration, Report No. HMRAD 92-4. [Chapter 4 Biological Resources]. http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills, [accessed 23 February 2017].

NOAA, 2003. The coastal resource coordinator's bioassessment manual. Office of Response and Restoration, National Oceanic and Atmospheric Administration. 260pp + appendices. https://docs.lib.noaa.gov/rescue/NOAA_E_DOCS/E_Library/ORR/general/bioassessmentmanual_rev2003.pdf, [accessed 23 February 2017].

NOAA (2013). Oil Spills in Marshes. Planning & Response Considerations. National Oceanic and Atmospheric Administration, Office of Response and Restoration. 125pp. http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/oil-spills-marshes.html, [accessed 17 February 2017].

NOAA (2013b). Shoreline Assessment Manual. National Oceanic and Atmospheric Administration, Office of Response and Restoration. 154pp. http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/shoreline-assessment-manual.html, [accessed 17 February 2017]

Nyyssönen, M., Kapanen, A., Piskonen, R., Lukkari, T. and Itaevaara, 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.

O'Hara, P. D. and Morandin, L. A. (2010). Effects of sheens associated with offshore oil and gas development on the feather microstructure of pelagic seabirds. In Marine Pollution Bulletin, Volume 60, Issue 5, pp. 672-678.

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. Ref. 1997-7.

OSPAR (2003). Guidelines for contaminant specific biological effects monitoring. Oslo and Paris Commissions, London. Ref. 2003-10.

OSPAR (2004). OSPAR Guidelines for Monitoring the Environmental Impact of Offshore Oil and Gas Activities. Oslo and Paris Commissions, London. 19 pp.

OSPAR (2012). OSPAR JAMP Guidelines for Monitoring Contaminants in Biota (Agreement 1999-02, revised 2012). https://www.ospar.org/documents?d=32414 [accessed 17 March 2017].

Owens, E.H. and Sergy, G.A., 2000. A Field Guide to the Documentation and Description of Oiled Shorelines. Second edition. Environment Canada, Ottawa.

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.

Paul, J. H., Hollander, D., Coble, P., Daly, K.L., Murasko, S., English, D.F., Basso, J., Delaney, J., McDaniel, L and Kovach, C.W., 2013. Toxicity and mutagenicity of Gulf of Mexico waters during and after the Deepwater Horizon oil spill. Environmental Science and Technology 47, 9651–9659.

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, New Jersey, USA. ISBN10 0130867527; ISBN13 978-0130867527.

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. 492 pp. ISBN10 0521786975; ISBN13 978-0521786973.

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. 704 pp. ISBN10 0521039983; ISBN13 978-0521039987.

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, held in Anchorage, Alaska, 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. http://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(ssimilarities) to risk society theory. In. Cohen, M.J. (Ed.). Risk in the Modern Age: Social Theory, Science and Environmental Decision-Making. Palgrave Macmillan Publishers. pp. 143-170. ISBN-10 0-312-22216-5 ISBN-13 978-0-312-2216-5. 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. Eds. Braund, S.R. and Kruse, J. 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. http://www.wwt.org.uk/images/upload/pub/49.pdf [accessed 2 July 2010]. https://www.bto.org/volunteer-surveys/webs/publications, [accessed 23 February 2017].

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.

Radovi, J.R., Rial, D., Lyons, B.P., Harman, C., Viñas, L., Beiras, R.,. Readman, J.W., Thomas, K.V., Bayona, J.M. (2012). Post-incident monitoring to evaluate environmental damage from shipping incidents: Chemical and biological assessments. Journal of Environmental Management, 109, 136-153.

Rees, H.L. (ed.) 2009. Guidelines for the study of the epibenthos of subtidal environments. ICES Techniques in Marine Environmental Sciences no. 42. 12 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times42/TIMES42.pdf [accessed 16 February 2017].

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. American Petroleum Institute, Washington D.C., pages 1545-1548.

Röling, W.F.M. and van Bodegom, P.M., 2014. Toward quantitative understanding on microbial community structure and functioning: a modeling-centered approach using degradation of marine oil spills as example. Frontiers in Microbiology 5, 125.

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. 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. 35 pp.

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. 27 pp. plus 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. 51 pp. plus appendices.

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/wp-content/uploads/2012/10/Bird.Injury.pdfhttp://www.researchplanning.com/services/nrda/Bird.Injury.pdf [accessed 16 February 2017].

RPI (2002). Salt Marsh reconnaissance: http://www.researchplanning.com/services/nrda/saltmarsh.recon.pdf http://www.researchplanning.com/wp-content/uploads/2012/10/saltmarsh.recon_.pdf [accessed 16 February 2017].

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: Edwards R. and Sime H. (Editors), The Sea Empress Oil Spill: Proceedings of the International Conference held in Cardiff, 11-13 February 1998. Chartered Institute of Water and Environmental Management, London, pp. 189-206.

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. 86 pp.

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.

Sanni, G.O., Coulon, F. and McGenity, T.J., 2015. Dynamics and distribution of bacterial and archaeal communities in oil-contaminated temperate coastal mudflat mesocosms. Environmental Science and Pollution Research 22: 15230-15247.

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-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. Chapter 4. Biological Resources. In: NOAA report: Introduction to Coastal Habitats and Biological Resources for Spill Response. http://response.restoration.noaa.gov/oilaids/monterey/monterey.html [accessed 2 July 2010].

Scoma, A., Hernandez-Sanabria, E., Lacoere, T., Junca, H., Boon, N., Pieper, D.H. and Vilchez-Vargas, R. 2016. Primers: Bacterial genes encoding enzymes for aerobic hydrocarbon degradation. In Hydrocarbon and Lipid Microbiology Protocols: Primers. McGenity, T.J., Timmis, K.N., Nogales, B. (eds.). Springer, Berlin, pp 23-37.

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. 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. Proceedings of the 1995 International Oil Spill Conference. American Petroleum Institute, Washington D.C. pp. 595-610.

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. 29 pp plus 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, held in Anchorage, Alaska, February 1993. American Fisheries Society Symposium 18, 748-758.

Shigenaka, G. (2014). Twenty-Five Years after the Exxon Valdez Oil Spill: NOAA's Scientific Support, Monitoring, and Research. National Oceanic and Atmospheric Administration (NOAA), Office of Response and Restoration. 78 pp.

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, Monkswood. 40 pp.

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. 19 pp. plus appendices.

Spaulding, M. L. (2017). State of the art review and future directions in oil spill modeling, Marine Pollution Bulletin, 115, 1–2.

Spencer, S.J., Tamminen, M.V., Preheim, S.P., Guo, M.T., Briggs, A.W., Brito, I.L., Weitz, A.D., Pitkänen, L.K., Vigneault, F., Juhani Virta, M.P. and Alm, E.J., 2016. Massively parallel sequencing of single cells by epicPCR links functional genes with phylogenetic markers. ISME Journal 10, 427–436.

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].

Stagg, R., McIntosh, A., and Gubbins, M. J. 2016. Determination of CYP1A-dependent mono-oxygenase activity in dab by fluorimetric measurement of EROD activity in S9 or microsomal liver fractions. ICES Techniques in Marine Environmental Sciences No. 57. 21 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times57/TIMES%2057.pdf [accessed 02 March 2017].

Stout, S.A. and Wang, Z., 2007. Chemical fingerprinting of spilled or discharged petroleum – methods and factors affecting petroleum fingerprints in the environment. In. Wang, Z. and Stout, S.A. Oil Spill Environmental Forensics: Fingerprinting and Source Identification. Elsevier, Inc. 554 pp. ISBN10 0 12 369523 6; ISBN13 978 0 12 369523 9. Chapter 1, pp. 1-53.

Takeshita, R., Sullivan, L., Smith, C., Collier, T., Hall, A., Brosnan, T., Rowles, T., Schwacke, L. 2017. The Deepwater Horizon oil spill marine mammal injury assessment. Endangered Species Research, 33, 95-106.

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.

Ta, S., Oku, 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. 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://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times29/TIMES29.pdf [accessed 03 January 2017].

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://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times28/TIMES28.pdf [accessed 03 January 2017].

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 http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times11/TIMES11.pdf [accessed 16 February 2017].

Thaxter, C.B. and Burton, N.H.K. (2009) High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols. British Trust for Ornithology Report Commissioned by Cowrie Ltd. www.thecrownestate.co.uk/energy-minerals-and-infrastructure/downloads/cowrie [accessed 16 February 2017].

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.

U.S. EPA (2002) Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-023. http://www.epa.gov/waterscience/criteria/wetlands/13Birds.pdf [accessed 2 July 2010] https://www.epa.gov/sites/production/files/documents/wetlands_13birds.pdf [accessed 23 February 2017].

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 4000m of depth (Prestige wreck). International Biodeterioration and Biodegradation 64, 511-518.

Unsworth RKF, Bertelli CM, Bull JC., 2014 Options for long-term seagrass monitoring at Porthdinllaen, Wales. Produced by Swansea University on behalf of Gwynedd Council.

US EPA, 1998. Method 8270D (SW-846): Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS), Revision 4 https://www.epa.gov/sites/production/files/2015-07/documents/epa-8270d.pdf [accessed 1 February 2017].

Valentine, M.M., and M.C. Benfield. 2013. Characterization of epibenthic and demersal megafauna at Mississippi Canyon 252 shortly after the Deepwater Horizon oil spill. Marine Pollution Bulletin 77:196–209,

van der Meer, J.R. and Belkin, S., 2010. Where microbiology meets microengineering: design and applications of reporter bacteria. Nature Reviews Microbiology 8, 511–522.

van der Meer, J.R., 2016. Towards improved biomonitoring tools for an intensified sustainable multi-use environment. Microbial Biotechnology 9, 658–665.

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.

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.

Wang, Z. and Stout, S.A., 2007. Oil Spill Environmental Forensics: Fingerprinting and Source Identification. Elsevier, Inc. 554 pp. 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. Wang, Z. and Stout, S.A. Oil Spill Environmental Forensics: Fingerprinting and Source Identification. Elsevier, Inc. 554 pp. ISBN10 0 12 369523 6; ISBN13 978 0 12 369523 9. Chapter 3, pp. 73-146.

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. Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response 1, pp. 1-30

Webb, A., Elgie, M., Irwin, C., Pollock, C. and Barton, C. 2016. Sensitivity of offshore seabird concentrations to oil pollution around the United Kingdom: Report to Oil & Gas UK. Document No HP00061701. http://jncc.defra.gov.uk/page-7373 [accessed 23 February 2017]

Webb, A., Stronach, A., Tasker, M.L. and Stone, C.J., 1995. Vulnerable concentrations of seabirds South and West of Britain. Joint Nature Conservation Committee, Peterborough.

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.

WFD-UKTAG, 2014a. UKTAG Transitional and Coastal Water Assessment Method: Angiosperm: Intertidal Seagrass Tool. Water Framework Directive – United Kingdom Technical Advisory Group. 23 pp.

WFD-UKTAG, 2014b. UKTAG Transitional & Coastal Water Assessment Method: Benthic Invertebrate Fauna Infaunal Quality Index. Water Framework Directive – United Kingdom Technical Advisory Group. 20pp. www.wfduk.org/resources%20/coastal-and-transitional-waters-benthic-invertebrate-fauna.

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

White, H.K., Conmy, R.N., MacDonald, I.R. and Reddy C.M., 2016. Methods of oil detection in response to the Deepwater Horizon oil spill. Oceanography 29(3): 76–87, http://dx.doi.org/10.5670/oceanog.2016.72.

Whittle, K.J., Anderson, D.A., Mackie, P.R., Moffat, C.F., Shepherd, N.J., McVicar, A.H., 1997. The impact of the Braer oil on caged salmon. In.: J.M. Davies, G. Topping (Editors). The Impact of an Oil Spill in Turbulent Waters: the Braer. The Stationery Office, London. 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. 30 pp. http://ices.dk/sites/pub/Publication%20Reports/Techniques%20in%20Marine%20Environmental%20Sciences%20(TIMES)/times40/TIMES40.pdf [accessed 03 January 2017].

Wilbur, S. and Jones, C. (2015). Simple, reliable analysis of high matrix samples according to US EPA Method 6020A using the Agilent 7700x/7800 ICP-MS. Agilent Application Note.

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

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. The Stationery Office Limited, Edinburgh, pp. 161-181

Yender, R., Michel, J. and Lord, C. (2002). Managing seafood safety after on oil spill. Seattle: Hazardous Materials Response Division, Office of Response and Restoration, National Oceanic and Atmospheric Administration. 72 pp. http://response.restoration.noaa.gov/sites/default/files/managing-seafood-safety-oil-spill.pdf [accessed 1 February 2017].

Young, L.Y. and Phelps, C.D. (2005). Metabolic biomarkers for monitoring in situ anaerobic hydrocarbon degradation. Environmental Health Perspectives 113, 62-67.

Zengel S, Bernik BM, Rutherford N, Nixon Z, Michel J (2015) Heavily Oiled Salt Marsh following the Deepwater Horizon Oil Spill, Ecological Comparisons of Shoreline Cleanup Treatments and Recovery. PLoS ONE 10(7)

Zengel, S., Weaver, J. Pennings, S.C., Silliman, B., Deis, D.R., Montague, C.L., Rutherford, N., Nixon, Z., Zimmerman, A.R. (2016). Five years of Deepwater Horizon oil spill effects on marsh periwinkles Littoraria irrorata. Mar. Ecol. Prog. Ser.

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. (Cairns, J and Buikema, A.L., editors). Butterworth Publishing Co., pp. 108-126.

Zwart, D.D. Sloof, W. (1983). The Microtox as an alternative assay in the acute toxicity assessment of water pollutants. National Institute for Water Supply. Aquatic Toxicology 4, 129-138.

ACRONYMS AND ABBREVIATIONS

AChE	Acetylcholinesterase
AFBI	The Agri-Food and Biosciences Institute in Northern Ireland
ALA-D	δ-amino levulinic acid dehydratase
AQC	Air quality cell
AR CALU X	Androgen-responsive chemically activated luciferase gene expression
AURIS	Aberdeen University Research & Industrial Services
AUV	Autonomous Underwater Vehicle
BEQUALM	Biological Effects Quality Assurance in Monitoring Programmes
BTEX	Benzene, toluene, ethylbenzene and xylenes
BTO	British Trust for Ornithology
CEDR	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 CALU X	Dioxin-responsive chemically activated luciferase gene expression
DTAPS	Disposable Toxicological Agent Protective System
EA	Environment Agency (England)
EG	Environment Group
EMDC	Environmental Monitoring Data Coordinator
ER-CALU X	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
GC	Gas Chromatography
GC x GC	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
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
IFCA	Association of Inshore Fisheries and Conservation Authorities
IMO	International Maritime Organization
IOPC Funds	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
MCZ	Marine Conservation Zone
MEDIN	Marine Environmental Data and Information Network
MMO	UK Marine Management Organisation
MMSI	Maritime Mobile Service Identity
MNR	Marine Nature Reserve
MPA(s)	Marine Protected Area(s)
MPAM	Monitoring Preparedness Assessment Matrix
MPAS	Monitoring Preparedness Assessment Score
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
NRW	Natural Resources Wales
NVC	National Vegetation Classification
OSPAR	Oslo and Paris Commissions
OSPAR CEMP	OSPAR Coordinated Environmental Monitoring Programme
PACs	Polycyclic aromatic compounds
PAH	Polycyclic aromatic hydrocarbons
PCA	Principal Component Analysis
PCBs	Polychlorinated biphenyls
PDA	Portable digital assistant
PHE	Public Health England
PSA	Particle Size Analysis
PSD	Passive sampling device
PTFE	Polytetrafluoroethylene
QUASIMEME	Quality Assurance of Information for Marine Environmental Monitoring in Europe
RIB	Rigid inflatable boat
ROV	Remotely Operated Vehicle
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
ToF MS	Time of Flight Mass Spectrometry
TraC Waters	Coastal and Transitional Waters
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
UV	Ultraviolet light
WeBS	Wetland Bird Survey
WFD	EU Water Framework Directive
YAS	Yeast androgen screen
YES	Yeast estrogen screen

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