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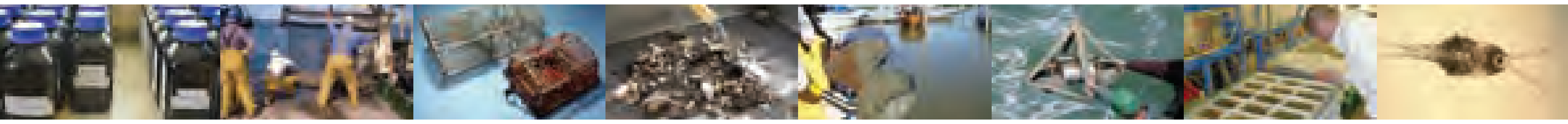

GUIDELINES FOR THE ENVIRONMENTAL MONITORING AND IMPACT ASSESSMENT ASSOCIATED WITH SUBSEA OIL RELEASES AND DISPERSANT USE IN UK WATERS

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GUIDELINES FOR THE ENVIRONMENTAL MONITORING AND IMPACT ASSESSMENT ASSOCIATED WITH SUBSEA OIL RELEASES AND DISPERSANT USE IN UK WATERS

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This guideline document has been developed with reference to the monitoring principles set out as part of the Premiam initiative (see www.cefas.defra.gov.uk/premiam).

Premiam (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) is a cross UK government initiative with strong links to industry and other stakeholders aimed at promoting best practice in the application of integrated science and management for post-incident monitoring following oil or chemical spills in the marine environment.

Cefas

This guideline document has been primarily developed by marine monitoring experts at Cefas (Centre for Environment, Fisheries and Aquaculture Science) in consultation with the Premiam partner organisations, including Marine Scotland.

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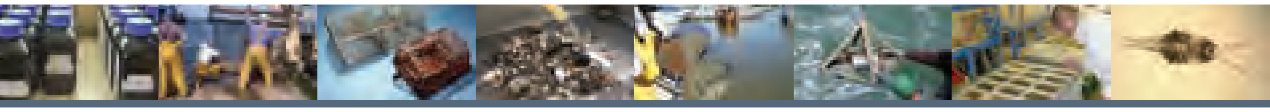

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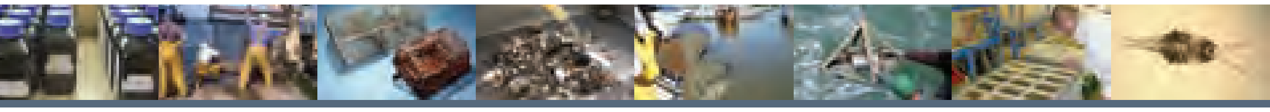


1 Objective of the Guideline

The main objective of this document is to guide the reader through what monitoring is required in order to understand the environmental impacts of a subsea oil release.

In 2011 overarching post-incident monitoring guidelines (Law et al., 2011) were published by the cross-government group Premiam (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) providing a best practice framework for the conduct of post-spill monitoring. However, as part of the OSPRAG/OSRF initiative, lead by Oil & Gas UK, it was recommended that more specific guidelines with a focus on the necessary monitoring associated with a subsea oil release incident and its potential treatment with dispersants would be beneficial. This document, closely aligned with the overarching Premiam principles and associated technical guideline documents is aimed at addressing that recommendation.

In order for regulators to confidently decide on dispersant use issues, they need to be reassured that a prompt and effective environmental monitoring programme can be conducted following that decision. The development of guidelines for environmental monitoring helps to provide this reassurance, and can act as the basis of an agreed approach between regulators and offshore operators. This guideline, does not, however, address the issue of decision making itself. What it does do is to give guidance regarding the type of data which would be desirable in order to assist in that decision making process.

As well as an approach to provide the underpinning information needed for operational decision making, these guidelines (together with associated technical guidelines, see Annex 1) also suggest the principles on which a monitoring programme to assess longer term damage and recovery can be based. This is an essential consideration for authorities responsible for marine conservation and a range of other stakeholders.

Finally, advance preparedness is essential if an effective monitoring programme is to be promptly initiated, and this can only be achieved if there is an agreed approach/framework for the activity. This guideline aims to provide this, and to identify the requirements with respect to skills and equipment. Knowing the principles enables preparedness and can also provide the basis for future preparedness audits.

While there is some information regarding the tracking of oil plumes within this document, this is primarily focussed on informing the monitoring strategy, and does not constitute guidance on oil plume tracking techniques per se.

2 Background

As a result of the Macondo/Deepwater Horizon incident in the Gulf of Mexico in 2010 global focus was drawn towards improving the ability to respond appropriately to similar subsea oil releases in the future. Primary considerations were the improvement of safety for personnel and to establish the capability to stop oil flow and treat any subsequent environmental pollution. Many national and international groups have made great improvements on this front but these types of incident also provide a major challenge with respect to the conduct of prompt and effective environmental monitoring and impact assessment.

Historically, in the United Kingdom, guidance pertaining to counter pollution response, clean-up and preparedness has been provided through the National Contingency Plan (NCP) (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/275054/ncp-shipping-offshore-installations.pdf, accessed 29 July 2014) and the guidance provided by the Department for Energy and Climate Change (DECC) for Oil Pollution Emergency Plans (DECC, 2012), which all offshore operators need to put in place. However, although these documents refer to the need for environmental monitoring they do not provide a clear framework for how they should be effectively conducted. The Premiam guidelines published in 2011 (Law et al., 2011), provide this overarching framework providing guidance on initiating, designing and determining the scope of a post-incident monitoring programme designed to facilitate environmental impact assessment.

It is generally accepted that the appropriate treatment of an oil spill/release with chemical dispersants can result in the protection of sensitive environmental resources. This can be as a result of the removal of oil from the sea surface to avoid the oiling of sensitive coastal environments that would have been impacted without treatment. Furthermore, the use of dispersants can promote biodegradation of oil by creating a larger surface area with potential benefits in terms of longer term impacts. This also holds true for the injection of dispersant into subsea releases of oil. The level of underpinning scientific knowledge with respect to the deeper water environments however is lower than for surface application in more familiar marine environments. This is especially true in respect to the fate of oil/dispersant subsea. The ability to provide timely and scientifically sound fate and effects information is essential to support the regulators (e.g. The department for Energy and Climate Change (DECC), Marine Scotland (MS) and the Marine Management Organisation (MMO)) in their decision making role when approving the initial use of dispersants and whether to continue or cease their use during the incident.

Within the UK, there are well embedded and comprehensive arrangements for the provision of environmental advice to response cells during oil and chemical spill incidents. These are based upon a network of Standing Environment Groups (SEGs), covering the whole of the UK coastline. Each of these has an appointed chair and an assigned membership. During an incident, their primary role is to provide environmental advice to groups established by the Maritime and Coastguard Agency (MCA) to oversee salvage, response and clean-up. They meet periodically within their own groups between incidents and the chairs also meet annually with the MCA to discuss their work and preparations. In the event of a Scientific and Technical Advice Cell being established under Civil Contingency arrangements to provide advice to the Gold Commander (usually a senior police officer), as happened during the *MSC Napoli* container ship grounding incident in 2007, then a means of ensuring liaison between this group and the relevant EGs convened for a specific incident and location has been developed. This ensures that conflicting advice is not being given in the two fora in relation to the same incident.

An incident of the type considered in this document (a subsea release of oil with dispersant treatment at or close to the source of the release) is most likely to fall within the remit of the Scottish Environment Group and Marine Scotland Science, for reasons of location and bathymetry. In the event of such an incident, it is important to note that there is no guarantee that an application to conduct dispersant injection or application at or close to a wellhead will be approved. Both the regulators and their scientific advisors will need to be convinced that a net environmental benefit would result before approval could be given. Subsequently, the regulators will require robust evidence that the application of dispersant is proving effective in dispersing the oil, in order to approve the continuation of treatment. Appropriate monitoring would be required to confirm or refute this.

If a marine pollution incident is expected to have a significant environmental impact, the NCP states that arrangements should be made to begin to monitor, in order to assess the long-term, as well as the short- and medium-term, environmental impacts. As part of the Premiam initiative, as well as post-incident monitoring guidelines, the concept of a PMCC (Premiam Monitoring Coordination Cell) was introduced. This group takes the lead co-ordinating role as set out in the NCP.

3 Survey Design and Management

3.1 INITIAL ACTIONS

3.1.1 Establish area likely to be impacted and document its resources at risk

As soon as the likely scale of an incident is established, an initial estimate of the scope of the monitoring programme needs to be made in order that survey design and resource allocation can begin. Monitoring cannot be undertaken in an effective manner until survey design including all necessary elements has been defined.

To some extent, the area in which a sub-sea release is most likely, from an exploration or production well in deep water, can be predicted and therefore some pre-planning for monitoring should be achieved. On the UK continental shelf (UKCS), the area to the west of the Shetland Islands, including the Faroe-Shetland channel, and the east Shetland basin are the areas where exploration occurs in the deepest waters. They are therefore the most likely regions in which a subsea release and dispersant treatment is envisaged but other regions on the UKCS should not be discounted. Specific areas at high risk of impact might include sensitive coastlines or areas of seabed in the vicinity of the incident. The early use of spill trajectory modelling (see section 3.2.1) in pre-planning and during an incident can help to establish any specific areas at high risk of impact and which, therefore, need to be an area of focus for monitoring activity.

Resources at risk can include a wide variety of species of both commercial fisheries and nature conservation importance. Information on commercial fisheries can be found in the annual publications of fisheries statistics by the Marine Management Organisation (that for 2014 is at: https://www.gov.uk/government/statistical-data-sets/monthly-sea-fisheries-statistics-april-2014 accessed 29 July 2014), in Scotland's Marine Atlas (Baxter et al., 2011: http://www.scotland.gov.uk/Topics/marine/science/atlas accessed 29 July 2014) and in the report published by AFEN (2001). The AFEN report also contains information on non-commercially exploited species which occur in the Atlantic Frontier area, some of which may need to be considered for study as being of conservation importance. Access to site specific documents such as the environmental statement (ES) or the oil pollution emergency plan (OPEP) would also offer valuable information.

3.1.2 Ensure appropriate technical instructions/SOPs are in place

Before monitoring is undertaken, to ensure that valid data are generated during the monitoring programme, standard operating procedures (SOPs) or equivalent agreed approaches should be in place. The availability of agreed protocols that can be followed in all areas of the monitoring programme will allow robust datasets to be generated for dispersant efficacy and impact assessment. This ensures that only data which are fit for purpose are used in assessments of dispersant effectiveness and the impact of the incident. It also ensures that resources are not wasted on data which are not fit for purpose. In association with this document, technical guidelines for some of the key processes to be undertaken (e.g. water or sediment sampling) are provided. The associated quality assurance procedures to be followed to assure the collection of robust data, of whatever sort, should also be included. The process by which the data should be validated and archived should also be described as part of a monitoring plan. More detail on data quality can be found in Annex 2.

3.1.3 Collect appropriate background samples and store

FIGURE 1
Sample jars

In the absence of adequate data to establish a baseline prior to a spill, it is suggested that surveys and sampling are conducted. Key types of samples to inform such a baseline could include sediments (both coastal and sub-tidal), water, biota (especially commercially exploited fish and shellfish and species of nature conservation importance) and photographic/video footage of the seabed and coastline against which later images can be compared. It is preferable, however, to possess good baseline data for the area, collected in advance of an incident. One of the tasks of the EG between incidents is to maintain knowledge of those baseline data that are available and to ensure that these can be accessed rapidly once an incident commences. Once the area which may be impacted has been established (see section 3.1.1 above) then additional appropriate baseline samples can be taken for storage and analysis as required. It may also be cost-effective to collect samples and store appropriately on an opportunist basis for future needs.

Relatively little baseline information is available for much of the sea area to the west of Shetland and other deeper regions of the UKCS. The largest collection of data in this region took place during the Atlantic Frontier programme (AFEN, 2001), which produced a wealth of useful information despite now being several years old. In addition, Marine Scotland Science conducts regular fishing surveys and has published PAH contaminant data for fish and shellfish from the waters around Scotland (Webster et al., 2009; 2011), and benthic data can be found in the benthos and wider area surveys 2005-2009 (http://www.oilandgasuk.co.uk/knowledgecentre/additional_surveys.cfm). Information may also be available from industry conducted surveys. To supplement this information, it will be necessary, as soon as possible after an incident begins, to collect additional background samples (e.g. seawater, sediments and appropriate biota) which can be stored and analysed at a later date in order to generate a view of the pre-incident baseline against which impacts can be assessed.

The area west of Shetland is one of complex and dynamic hydrography. Therefore, additional baseline data are needed for assistance with impact assessment of any future incident in this area. Marine Scotland Science has a project entitled "Monitoring and Research in Scottish Deepwater Environments" running during 2014-2017 as well as NERCs FASTNEt (http://www.nerc.ac.uk/research/funded/programmes/shelfedge/fastnet-summary.pdf) 2011-2015 which should make a substantial contribution to the physical and biological datasets available to inform baseline assessments of waters deeper than 200 m, in the Faroe-Shetland Channel to the NW of the Shetland Isles and the Rosemary Bank Seamount to the NW of the Outer Hebrides. These baseline data are primarily intended to be used in assessment of Good Environmental Status under the EU Marine Strategy Framework Directive, but will be available in the event of an oil spill. In the event of a spill, additional detailed hydrographic baseline data are required to characterise the current structure and dynamics of the water column in order to feed into a suite of predictive models tailored to the local area and the waters between that area and the Scottish mainland and islands to the east. Predictive oil spill models, fed with predicted current and weather forecasts, can then be used to establish the area that may be impacted by both surface oil and any subsea plumes generated and their subsequent response to dispersant use. Areas in the general vicinity of the spill which are unlikely to be impacted should be considered for use as reference areas against which to compare changes observed in the impacted zones but good pre-spill baseline data is the preferred comparator for post-spill impacts assessment (Law et al 2011).

3.1.4 Obtain sample of source oil and dispersants to be used

For fingerprinting and tracking of oil, it is important to obtain authentic samples of the oil being released and any dispersants which are to be used during the response. This allows analysts to confirm that oil and dispersant chemicals seen in environmental samples arise from the incident and not from other sources. This process should be facilitated by the operator of the installation involved and the response organisation conducting the dispersant application. All of the dispersants to be applied **MUST** appear on the list of approved dispersants published by the Marine Management Organisation. These have been screened for efficacy and toxicity within the regulatory procedure in force within the UK and reference samples of the dispersants used should also be sourced (for a list of approved products see https://www.gov.uk/government/publications/approved-oil-spill-treatment-products (accessed 29 July 2014). A flowchart of the dispersant use approval process can be found at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307676/oil-spill-treatment-products-approval.pdf (accessed 29 July 2014) and further guidance is available at http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/62990/6202-reg-treat-products.doc (accessed 16 April 2014). Similarly, approval for use in Scottish waters will require permission from Marine Scotland and, if the oil is from an offshore installation, DECC.

In a major incident it is likely that a number of dispersant products will be used, as stockpiles are limited. All of the samples described above are to be collected for scientific purposes, in addition to any collected by regulatory authorities for evidential and potential prosecution purposes, as they are intended primarily to support the monitoring programme.

Guidance on chemical fingerprinting of oil to confirm its source is given in the Premiam guidelines (Law et al., 2011; appendix 5). This appendix includes a list of relevant references to the scientific literature.

3.2 SURVEY DESIGN

A survey must be robustly designed before being commenced to ensure that monitoring is undertaken effectively and includes all areas and resources which need to be assessed. It should address both the assessment of impact and of the effectiveness of any dispersants used to treat the oil.

Within the Premiam guidelines (Law et al., 2011) a series of questions were outlined to be asked before implementing a post-incident (oil or chemical spill) monitoring programme. These were:

- When do we need to monitor ?
- What do we monitor ?
- Where do we monitor ?
- How frequently do we monitor ?
- Why do we monitor ?

For a subsea release, the monitoring programme will include two components relevant for subsea release and treatment scenarios.

Firstly, surveying the immediate area downstream of the subsea dispersant application in order to determine the efficacy of dispersant treatment in dispersing the oil being released. This may not be a trivial task, as current directions in deeper regions may flow in different directions in different layers of the water column, and so locating subsea plumes of dispersed oil might become complicated. The ability to model the transport of oil within the water column effectively will be key to locating these, as it will allow appropriate locations and depths to be targeted for study.

Secondly, to develop a wider survey plan which will facilitate the impact assessment of the incident as a whole. Following a major release, the survey area may include inshore areas and potentially impacted coastlines, as oil could persist, both on the sea surface and subsea, and be transported to these areas.

In the case of assessing dispersant effectiveness, the initial focus will be close to the point of dispersant injection and immediately downstream. This is in line with the American Petroleum Institute (API) industry recommended subsea dispersant monitoring plan (API, 2013), which outlines in a step by step manner how to monitor the effectiveness of dispersant use once applied at a subsea well head. This describes three phases of monitoring subsea dispersant application, which would ideally be started simultaneously but which may have to be sequential, largely due to the more complicated logistics of phases 2 and 3. The phases are:

1. Confirmation of dispersant effectiveness by visual observation at the site of dispersant injection, and by observation of reductions in the size of the surface slick and concentrations of volatile organic compounds close by.

2. Characterisation of dispersed oil concentrations at depths in the water column.

3. Detailed chemical characterisation of water samples.

Phase 1 should be as close to the source of the release as restrictions (e.g. exclusion zones implemented for operational and safety reasons) permit. Video observation at the site of application, using cameras deployed on an ROV, can assist in this assessment by monitoring changes in the colour of the visible oil cloud, as the dispersant generates finer oil droplets. In phase 2, activity will centre on the identification and location of subsea plumes of dispersed and/or undispersed oil, using acoustic and other techniques, and the acquisition of samples from within the plumes for subsequent analysis either on board the sampling vessel or in onshore laboratories (phase 3). Concentration profiles across the plumes and at different depths within them will also need to be established, using fluorimeters towed by a research vessel or attached to ROVs or AUVs. Acoustic devices, e.g. multibeam echosounders and acoustic Doppler current profilers (ADCPs), may also provide useful information in this regard. These will allow oil concentrations to be determined and the volume of oil being transported within the plumes to be estimated. Comparisons between the estimates of the amount of oil being released and of that entrained in subsea plumes will allow the efficacy of dispersant treatment to be estimated. Samples taken from within the subsea plumes can also be analysed to see whether or not dispersant is present, and so whether the oil has been chemically or naturally dispersed.

FIGURE 2
ADCP

The wider impact assessment is much more complicated since it involves the assessment of impact in and on a much wider range of species, resources and locations. Key to the development of this survey plan will be transport modelling of both surface and subsea dispersed oil and the assessment of all of the resources at risk. Certainly this will relate to the immediate vicinity of the incident itself, but potentially as far as adjacent coastlines many miles from the incident, and possibly beyond, depending on the persistence of the oil. This could include inshore areas and aquaculture operations, as well as commercial fisheries and the human food chain, seabirds and other species and habitats of nature conservation importance and the presence of oil pollution in sediments, where there may be a major risk of persistence. The constructed monitoring programme should gather data to allow the assessment of all of the relevant environmental compartments and of the environmental damage which results, both due to the oil and the use of any chemicals, and the length of time for which it persists in each of the compartments considered.

Adaptability is key to a successful monitoring programme, therefore the initial survey plan developed will need to be subject to periodic review by the PMCC Chair as the coordinator, in conjunction with others from the organisations conducting the monitoring, to ensure that it continues to address all relevant issues as the incident progresses and circumstances change.

A flowchart describing a logical process for the designing of a survey of a natural resource was given in the Premiam guidelines (Law et al., 2011; pages 21-23) and is reproduced here in Annex 3.

3.2.1 Modelling

To produce potential trajectories of sub-surface and surface oil plumes, an integrated modelling system is required to produce accurate and timely forecasts for use by responders and regulators. The ability to predict the movement of oil within a complex hydrographic area is key to the definition of the areas likely to be impacted and to direct monitoring activities to these and to other areas to be investigated for comparison reference purposes. If possible, suitable models should be constructed prior to an incident for areas at most risk and the input parameters defined for the models used. If this cannot be done, then it should begin as soon as the likely scale of the incident can be assessed. More detail on model parameterisation can be found in Annex 4.

Successful modelling of oil transport feeds directly into survey design, as it allows areas of high and low risk of impact to be identified. Both high and low risk areas are likely to be included within the monitoring programme, as affected and reference areas need to be compared. To improve model predictions, data for the actual movement of oil should be gathered during an incident and fed back into the models. This updated modelling data should then assist in the modification of the monitoring programme survey design so that it can adapt as circumstances change and the incident develops. The PMCC will meet on a regular basis during an incident to ensure that the survey design is still fit for purpose.

3.2.2 Data Handling

It is important that the data gathered by diverse organisations is coordinated and drawn together for assessment. The PMCC are responsible for overseeing that this is done. This ensures that resources are most efficiently deployed, and that all of the data gathered is used. Data should be securely stored in one database for ease of access and traceability. More detail is given in Annex 2.

3.2.3 Communications

The findings from the monitoring programme need to be communicated to stakeholders. This will include the responders (who may modify their response activities as a result), the media, the general public, government and non-governmental organisations. This again needs to be coordinated and managed. More detail is given in Annex 2.

4 Sampling and Monitoring

In order to successfully obtain samples for monitoring, it is important to have the appropriate vessels, equipment and personnel in place. Information on requirements of vessels and personnel can be found in Annex 5. Techniques described here are those which have been used extensively for monitoring of spills. For further information on techniques deployed during the Deepwater Horizon incident, see Annex 6.

4.1 WATER SAMPLING

4.1.1 Purpose

The purpose of water sampling is many fold and includes:

- Measuring the concentrations of oil in the water column as a result of the spill in relation to concentrations at a distance from the source
- Determining the presence of subsea plumes of chemically dispersed or undispersed oil, their extent in three dimensions, and the oil concentrations within them
- Investigating the potential and extent of biodegradation of the oil.

In order to establish hydrographic conditions, water mass boundaries and the presence or absence of stratified layers within the water column which may affect the behaviour of the oil, deployed sensors are required. This is further discussed in section 4.5.

4.1.2 Relevance

Released oil is transported within the water column and partly dissolves, leading to enhanced concentrations of the more soluble hydrocarbons (primarily BTEX (1 ring aromatic hydrocarbons) and low molecular weight (2 – 3 ring) polycyclic aromatic hydrocarbons (PAH). BTEX fairly rapidly vent into the atmosphere but the PAH will persist for longer periods. Establishing the concentrations of both these compounds and of chemically and naturally dispersed oil in water allows fate and likely impacts on organisms to be predicted.

4.1.3 Timing

Water sampling should begin as soon as practicable following the start of the incident. This will be constrained by the logistics of placing a suitable vessel within the study area.

4.1.4 Procedure for water sampling

Seawater oil concentrations can be determined using both discrete sampling and *in-situ* methods. See TG01 for more detail on discrete sampling methods (http://www.cefas.defra.gov.uk/premiam/publications). In shallow waters, custom-made and designed samplers intended to collect water samples uncompromised by contamination from surface films on the sea surface can be deployed (Kelly et al., 2000) to depths of at least 50 m (Law and Whinnett, 1993). Surface film samplers (e.g. Garrett screens or other devices) (Garrett et al., 1965; Guitart et al., 2004, 2008) can also be deployed to characterise any surface films present. Pad samplers can also be used to establish the thickness of sea surface oil films in the µm to mm range (Cormack, 1982).

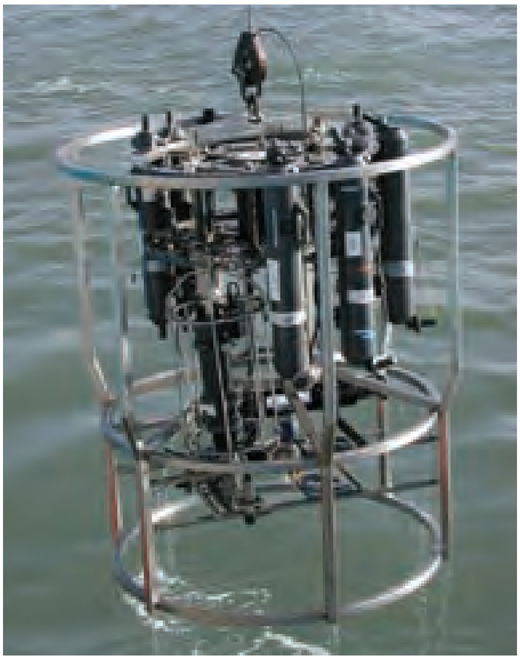


FIGURE 3
CTD rosette

In deeper waters, the sampling devices used are most likely to be oceanographic rosette samplers intended primarily for defining CTD (conductivity (a proxy for salinity), temperature, depth) profiles and the identification of water masses and the presence or absence of stratification within the water column. Sampling bottles fitted to a rosette sampler can be operated remotely by signals from a surface vessel, and these can be suitable for hydrocarbon sampling if Teflon-lined. Fluorimeters operating in the UV range and attached to the rosette samplers can assist in identifying appropriate depths at which to sample, by indicating the presence of hydrocarbons within discrete layers of the water column.

4.2 SEDIMENT SAMPLING

4.2.1 Purpose

There are two main purposes of sediment sampling. The first is to establish whether oil is entering the sediments as a result of the spill, and its concentration in relation to distance from the source. 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 oil and / or dispersant on the seabed

4.2.2 Relevance

In support of the overall assessment of the impact of the incident sediment samples are needed to assess the impact of oil on the seabed and upon sediment dwelling species. Substantial quantities of oil can reach sediments following oil spills. It has been estimated that 30,000 tons (36 %) of the oil spilled from the *Braer* in Shetland in 1993 was deposited in sediments. This includes naturally dispersed oil that was carried for almost 100 km to be deposited in a sedimentary sink SE of Fair Isle (Law and Moffat, 2011). Oil can persist for many years in sediments, particularly if they are low in oxygen, and, in deep waters, where the oil is not likely to be remobilised by wave action during storms.

4.2.3 Timing

Monitoring should begin as soon as the likely scale of the incident can be assessed, and will continue at intervals throughout the monitoring programme unless no seabed impacts are observed.

4.2.4 Procedure for sediment sampling

Sediment samples should be collected using suitable devices for the depth and type of bottom sediments to be expected offshore and the sampling depth. Technical guideline TG02 (http://www.cefas.defra.gov.uk/premiam/publications) gives further details on specific methods and considerations. Grabs and/or corers may be suitable, but it is likely that a large and heavy coring device such as a Reineck box corer or a vibrocorer would be most likely to sample successfully given the depths likely to be encountered, especially in poor weather conditions. An initial survey of the area using a multi-beam echosounder and camera sledges or drop cameras, or cameras mounted on ROVs or AUVs, would be helpful in order to identify areas which are too hard to sample, informed by backscatter profiles and video/still camera images (Schinaia and Callaway, 2013).

FIGURE 4
Camera sledge on deck

FIGURE 5
Recovering drop camera

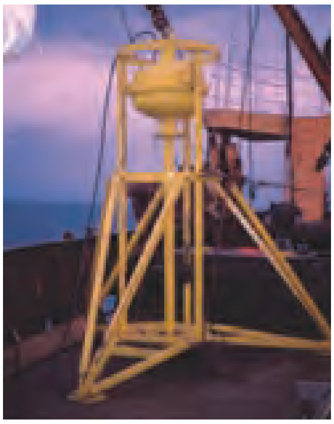


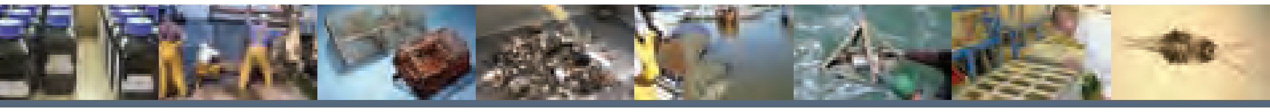
FIGURE 6
Vibrocorer

FIGURE 7
NIOZ corer being deployed

FIGURE 8
Van Veen grab

Surface sediment samples should be taken from the upper 2 cm of an undisturbed sample and transferred to an aluminium or glass container for storage frozen at -20 °C for chemical and particle size analysis in the laboratory. Core samples should be extruded and sliced at 2 cm intervals, and then the slices stored in a similar manner. In shallow or intertidal areas, sediment samples may be collected by hand using stainless steel or Teflon spoons, or using hand-held grabs such as a Van Veen from small boats, jetties, etc.

All samples should be analysed for hydrocarbons and PAH using UV fluorescence spectrometry as a screening technique in order to prioritise samples for analysis, followed by gas chromatography – mass spectrometry (GC-MS) analysis of a suite of PAH compounds (Kelly et al., 2000). This is further described in section 5.1. For the samples in which PAHs or geochemical biomarker compounds are to be determined, analyses of supporting parameters (total organic carbon and particle size analysis) should also be conducted to aid interpretation of the results obtained. Sediment samples should also be collected for assessment of benthic infauna. This process is described in section 5.3.



4.3 BIOTA SAMPLING

4.3.1 Purpose

Biota samples are surveyed and collected for a multitude of purposes, this includes determining their presence, population size, community structure, functional effectiveness and for sensory assessment and chemical analysis to establish their contaminant status, in this case in relation to oil and PAHs.

4.3.2 Relevance

Oil spills can often result in contamination of fish and shellfish in the locality by PAHs contained in the oil. If the contamination is such that regulatory food limits, recommended by the European Food Safety Authority for benzo[*a*]pyrene and PAH4 (the sum of the concentrations of benzo[*a*]pyrene, benz[*a*]anthracene, chrysene and benzo[*b*] fluoranthene) (5 µg kg^{-1} wet weight and 30 µg kg^{-1} wet weight, respectively, in bivalve molluscs) (EU, 2011) are, or are likely to be breached, then fishery closures are likely to be implemented in order to protect human consumers. A monitoring programme will then need to be implemented to advise on changes in concentrations over time, in order that restrictions can be removed as contamination levels decline to below the regulatory limits. In the UK, it is usual to have samples tested for taint prior to restrictions being lifted. The regulatory authority in the UK is the food standards agency.

Fish are often used as sentinel species for assessing the impact of contaminants through biological effects measurements, but in the acute phase of a severe oil spill they are likely to move away from the affected area, unless they are prevented from doing so (e.g., salmon in aquaculture cages, in which case serious contamination can result, as was observed following the *Braer* spill in Shetland in 1993 (Law and Moffat, 2010)). Fish are not, therefore, ideal species for monitoring the immediate impact of a spill, although they are useful for monitoring longer-term impacts.

Some biological effects measurements (e.g., assessment of genotoxic damage) can be undertaken in non-mobile species (e.g., macrobenthos) and used to assess the toxic impact of spilled oil on these species. Spilled oil can also impact populations of marine organisms, reducing populations of some species, particularly those which are very sensitive to oil, such as amphipods. These species reductions may, particularly among the benthos, change the communities which are living in and on the seabed, leading to increases in hardier and more opportunistic species. Benthic ecology encompasses the study of these effects – see example in section 6 on impact assessment in subtidal sediments.

4.3.3 Timing

Sampling of biota should begin as soon as practicable. Samples of harvested bivalve mollusc species (e.g. mussels, oysters, scallops) likely to be affected should be taken both from commercially exploited shellfish beds and from any wild populations, the former to assess possible contamination of the human food chain and the latter to feed into the assessment of impact on the species' populations. Commercial species should be sampled on a weekly basis initially and then at a lesser frequency once the rate of change in concentrations has been established. No similar restrictions apply to collection of sediment benthos for study of abundance, diversity and community structure.

4.3.4 Procedure for biota sampling

Intertidally, biota samples can be collected by hand. Below the low water mark, they can be collected using a variety of nets, grabs, dredges or pots (for crustaceans, primarily). For more detail on collection of biota, and for specific detail on plankton sampling, see TG03 and TG04 respectively (http://www.cefas.defra.gov.uk/premiam/publications). Sampling vessels may be owned by the sampling organisation or chartered from a range of providers, including fishermen (particularly where fishery closures are in force). Following collection, samples should be preserved in a manner appropriate to their final use (e.g. preserved in formalin, frozen at -20 °C or live and maintained in an aquarium attached to a laboratory). See Section 4.8.2 for information on storage of samples.

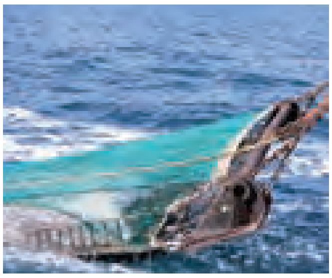


FIGURE 9
Beam trawl in water

FIGURE 10
Day grab

FIGURE 11
Shellfish dredge recovery

FIGURE 12
Lobster and crab pots

FIGURE 13
Benthos sieving

4.4 HYDROCARBON TRACKING

4.4.1 Purpose

Hydrocarbon tracking is required in order to document where the oil released during the incident has been transported to, both at the sea surface and subsea. This information will be fed into the models to improve their parameterisation, and improved predictions from these will allow reassessment of the areas likely to be impacted and allow the monitoring programme to adapt to meet changing needs.

4.4.2 Relevance

Knowledge of the oil transport allows the evolution of the incident to be established. This information feeds directly into the overall impact assessment of the incident and allows a link of causation ("Pathway" in US damage assessment parlance) to be made between the impacts and the incident. This will be a strict requirement if compensation is to be sought under the international conventions relating to this.

4.4.3 Timing

Continuously during and immediately following the incident, until the oil has dissipated or reduced to levels, agreed by the monitoring team and regulators, as a threshold below which no further or a reduction in monitoring is required. However, consideration should be given to the potential for remobilisation of oil and for the needs to monitor longer-term levels.

4.4.4 Procedure for hydrocarbon tracking

4.4.4.1 Sea surface coverage of oil

A variety of methods can be used to establish the size and location of surface oil slicks, including visual observation from vessels, visual observation and imagery from surveillance aircraft, and satellite observations using synthetic aperture radar (SAR), and other techniques (Klemas, 2010; 2012). IR and UV imagery from aircraft is a reliable technique as it relies on the inherent chemical constituents of the oil and their physical properties for identification. SAR is inherently less reliable as it is essentially measuring the smoothness of the sea surface (oil slicks damp capillary waves and so make the sea surface smooth) and so can be prone to false positive detections due to wind shadowing, especially along elevated coastlines with winds coming from the shore, as was seen during the *Sea Empress* spill in 1996. All observations should, however, be recorded with accurate date/time/location information, and transferred to a Geographic Information System (GIS), so that the history of oil slick evolution and transport can be logged and investigated at a later date.

4.4.4.2 Subsea oil plumes

Within the Deepwater Horizon response and monitoring activities published to date, this process has not been well defined in terms of which techniques proved successful and which not. Acoustic techniques (e.g. multibeam echosounders, side-scan sonar) should be deployed to see whether they are successful in locating and defining subsea plumes as these techniques can rapidly be deployed over considerable areas from a suitably equipped vessel. Fluorimeters, operating in the ultraviolet range, which will unequivocally detect oil against a low background signal, due to low-level hydrocarbon/ PAH contamination present in all of our seas, can also be used, and are the preferred technique if the plume characteristics are such that acoustic techniques are unsuccessful. More detail regarding deployment of fluorimeters can be found in TG05 (http://www.cefas.defra.gov.uk/premiam/publications). These may be deployed from vessels (as towed units, e.g. UV Aquatracka) or attached to rosette water samplers (in order to generate vertical concentration profiles), ROVs or AUVs. Rosette water samplers can also be used to retrieve samples from within the plume for analysis; other units (ROVs, AUVs, gliders) may also be able to do this depending upon how they are configured. Once the plume has been located and its depth established, towed and/or dipped (see section 4.5) units can be used in order to establish the configuration of the plume, its extent and the variations in concentrations of oil across it and with depth within the plume.

4.5 IN-SITU PHYSICAL MEASUREMENTS

4.5.1 Purpose

Physical measurements are made in the sea in order to gather data which will allow the structure of the water column to be established, as this will affect the transport of oil within the water column. Separate water masses may behave differently and any stratification of the water column, as is seen in many UK sea areas seasonally, may affect the movement of oil vertically in the water column. Finally, they will aid in parameterisation and further development of transport models. Current directions at different depths can also be determined using acoustic techniques.

4.5.2 Relevance

During any incident, prediction of the potential pathways of the released material relies on knowledge of the local oceanographic or hydrographic conditions. These datasets can be used in two modes: firstly, calibration of the models to ensure they are as accurate as possible, and secondly, for use in validation of the model predictions, where observations can be compared with models. The “Hydrographic conditions” definition can be split into three main components:

- Bathymetry
- Vertical and horizontal temperature and salinity structure
- Flow regime in 3 Dimensions

The local and regional bathymetry is a key parameter as this is a base requirement of the numerical models. Resolution should be sufficient to identify key bathymetric features, such as the shelf break, seamounts, canyons etc. In areas of rapidly changing bathymetry, the spatial resolution of the bathymetric data should reflect the rapidly changing bathymetric gradients.

In the event of any release of oil close to the seabed, two types of plume are hypothesised – a sub-surface plume, in which the oil droplet density is equivalent to that of local seawater, and a surface slick, where the oil droplet density is less than the local seawater surface density. In addition, in the dynamic waters to the west of Shetland (the Faroe-Shetland Channel), there is the potential for some of the undispersed oil to be entrained in deep water masses due to the complex hydrography of the area. These may be moving in different directions, and these 3 dimensional flow and density fields will also need to be input into the oil spill models. Therefore, characterisation of the vertical density profile (i.e. temperature and salinity) and variability in space and time is a key requirement for our ability to provide advice to regulators and responders. Whilst not all incidents will necessarily involve a sub-surface plume, the large variation in density structure observed in the area West of Shetland would facilitate the formation of sub-surface plumes.

In order to predict the fate of any sub-surface or surface oil plume, the time evolving 3 dimensional velocity field is required to estimate the trajectory of oil droplets and gas bubbles. Note that knowledge of the vertical velocities is important in order to estimate the depth of any sub-surface plume, and also to establish whether the gas bubble plume will reach the sea surface and/or gas hydrates are formed. The application of dispersants near to or at the release site will impact on the size of the oil droplets, as chemically dispersed droplets are smaller than those formed during natural dispersion due to wave action. This affects their rise velocity (as smaller droplets rise more slowly than large ones) and their eventual fate in either sub-surface or surface plumes.

4.5.3 Timing

Physical measurements should be undertaken as soon as possible after the incident occurs, and continue until the oil has dispersed. A key advantage of physical monitoring systems is that they can be deployed from existing organisations or commercial contractors within a short time period of an incident. Once deployed monitoring system can telemeter data via satellite systems to shore or vessel based control centres. Sub-surface telemetry systems tend to transit summary information due to the low acoustic communicating rates, whereas surface systems can transit very regularly (from hourly to minutes) with 2-way communication allowing modification of sampling regimes. Depending on the sampling regime, durations for deployment are normally limited by battery life and the need for servicing, which will be at intervals between monthly and yearly.

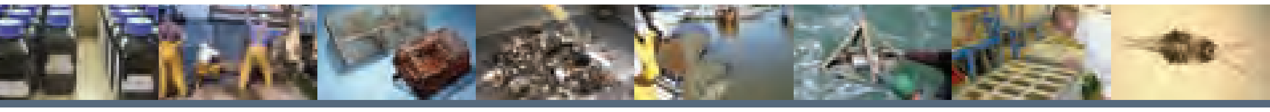
4.5.4 Procedure for physical measurements

To establish the hydrographic conditions at a release site there are a variety of techniques, platforms and instruments that can collect oceanographic data suitable for use during marine emergencies. Table 1 shows a high level assessment of these different platforms and techniques and describes some of their advantages and disadvantages. Further detail on deployment of current meters can be found in TG06 (http://www.cefas.defra.gov.uk/premiam/publications).

Table 1. High level assessment of monitoring techniques for hydrographic conditions.

SENSOR TYPE	PARAMETER	PLATFORM	ADVANTAGES	DIS-ADVANTAGES
Current Profiler (Acoustic Doppler Current Profiler: ADCP)	3D Current regime	Seabed (frame), Surface (buoy) or mobile	75kHz long range ADCP can profile to 600m depth	Only surface mounted unit routinely capable of data return by near real-time telemetry.
CTD profiling	Temperature, Salinity, Suspended sediment, Fluorometers and particle size sensors (LISST) and water samples using a rosette sampler.	CTD mounted on Research Vessel	Full water column	Only mounted on Research Vessel or fitted to Utility vessel. Management of safety zone around incident site.
Underway instrumentation	Acoustic sensors (Swath bathymetry (including water column detection), Fisheries acoustics)	Research vessel and potentially AUVs, ROVs or autonomous surface vehicles (ASVs)	Full water column with telemetry	Management of safety zone around incident site.
Tethered Instrumentation	As CTD and highly adaptable	ROV	Standard Oil Industry platform. Highly controllable. Can remain close to incident site for long durations	Need utility vessel or RV to deploy. Management of safety zone around incident site.
Drifters	Position and profiles	Lagrangian sensor e.g. Argo floats	Near real-time telemetry	Number of drifters in incident area?
Active Platforms	Position and profiles	AUV/ASV	Programmable and adaptive mission plans. Near real-time telemetry of data for ASVs and at surface for AUVs	Specialised vehicles – limited supply? Management of safety zone around incident site.
HF Radar	Surface currents and potentially waves	Mounted remotely on islands or platforms	Good surface coverage.	Needs to be established before the incident.
Aerial (Aircraft mounted)	Temperature, Suspended sediment, Backscatter, Oil distributions using multi spectral sensors (usually IR or UV)	Aircraft	Large survey area	Weather dependent. Limited number with oil sensors fitted.
Satellite sensors	Temperature, Suspended sediment, Backscatter, Oil distributions using multi spectral sensors, synthetic aperture radar		Frequency of overpasses and swath coverage variable. Good geographical coverage.	Weather dependent (clouds)

During any incident, responders and regulators will need to visualise and assess oceanographic data and numerical model predictions in real-time in order to provide robust and suitable management decisions. For instance, the NOAA ERMA (Emergency Response Management Application – http://gomex.erma.noaa.gov/ accessed 15 April 2014), is one potential type of web portal.



4.6 MICROBIAL SAMPLING

4.6.1 Purpose

The purpose of microbial sampling is to investigate the occurrence and rate of biodegradation of oil in the water column and sediments, particularly in relation to any subsea plumes of chemically or naturally dispersed oil. Species of hydrocarbon-degrading bacteria, naturally present in the water column as a result of oil seeps and earlier hydrocarbon inputs, would be expected to increase in numbers in response to the presence of what is, to them, a new food and energy source. This would increase their overall respiration rates, and could be monitored by measuring decreases in levels of dissolved oxygen.

4.6.2 Relevance

A review of the literature relating to hydrocarbon-induced impacts on microbial communities following oil spills up to 2011 was presented in the Premiam guidelines (Law et al., 2011). It has been observed that, especially, marine hydrocarbon degraders like *Alcanivorax* sp. or *Cyclostaticus* sp. increase as a result of oil contamination. This is accompanied by an increase in overall bacterial abundance and in enzyme activities (Cappello et al., 2007).

4.6.3 Timing

Samples for microbial sampling can be taken during the same water sampling events which are being used to take samples for characterisation of subsea dispersed oil.

4.6.4 Procedure for microbial sampling

The use of dispersants to treat oil spilled at sea leads to a predominance of oil droplets of a smaller size than those which result from natural dispersion due to wave action alone. This means that chemically dispersed oil droplets have a larger surface area, and so the oil is biodegraded more rapidly by indigenous hydrocarbon-degrading bacteria. The process can be followed by collecting water samples from within the plume and looking at the bacterial species present (see section 4.2.4). It can also be followed by monitoring dissolved oxygen levels, e.g. during CTD profiling casts, as the hydrocarbon-degrading bacteria operate aerobically and so their consumption of hydrocarbons depresses oxygen levels locally (see section 4.4.4.2). By taking samples in vertical and horizontal planes across and through the plume, the overall degree of activity can be estimated.

4.7 PASSIVE SAMPLING METHODS

4.7.1 Purpose

FIGURE 14
Passive samplers attached to an instrument buoy

Both biological and chemical passive samplers can be used to accumulate oil related contaminants following an oil release. In some scenarios, fish may display avoidance behaviour in the early stages of a spill scenario and therefore may not be available for collection to determine potential effects on the foodchain or be representative of bioaccumulation potential at a fixed point. Deployment of mussels for contaminant analysis is a good substitute to obtaining local fish, and can also be used for biomarker assessment. Chemical passive samplers can also be deployed and later analysed for contaminants.

4.7.2 Relevance

Passive samplers accumulate organic contaminants (including oil derived hydrocarbons) from water over time. They can be deployed in order to mimic the uptake in biota, assess likely bioaccumulation, or to calculate a time weighted average concentration of contaminants in the water column. They can also be used in laboratory experiments to reproduce environmental conditions in toxicity testing. Because passive samplers take at least 2 weeks to give meaningful results they would be used to assess recovery of an area rather than to assist in real time decision making. Passive samplers can also be used to assess the degree of pollutant pressure in sediments, both in field-collected sediments returned to the laboratory and *in-situ*. These samplers can also be used as contaminant sources for toxicity experiments. Mussels can also be deployed to calculate uptake of hydrocarbons, and this can be assessed alongside biomarkers of health such as lysosomal stability and scope for growth. The disadvantages of this approach are that, in highly contaminated areas, the mussels may not survive.

4.7.3 Timing

Both mussels and passive samplers take time (2-4 weeks) to accumulate sufficient contaminants to give an accurate interpretation of the local situation. They should therefore be deployed when a time weighted assessment is required, rather than to observe peaks in exposure.

4.7.4 Procedure for passive sampling methods

Both mussels and passive samplers have been used to monitor the marine environment, and can be deployed at various depths to assess the water column as a whole. However, the limitation in this scenario is that both need a fixing point. Commonly, close to shore, navigation buoys have been used and, if a spill were to happen close to an installation, this structure could be used to secure the samplers and mussels. In relatively shallow water (50 m depth or less), a buoy can be deployed with ground tackle to serve as a platform for securing samplers, mussels and other instrumentation. In deeper waters, where no existing fixing points are present, these techniques cannot be deployed easily, although subsea moorings or seabed landers and tripods have also been used as fixing points for the deployment of passive samplers or caged organisms. In deep waters, however, it is likely that only the passive samplers would be deployed on the sea bed, while mussels may be used sub-surface.

Both passive samplers and mussels should be deployed for a minimum of 2 weeks in the field before being brought back to the laboratory for analysis. See TG07 for further details (http://www.cefas.defra.gov.uk/premiam/publications). They should be deployed so as to be continually submersed during their exposure, so in tidal areas should be below the low water mark. Passive samplers (silicon rubber or SPMD would be the most appropriate for use in an oil related incident) are simply rinsed and frozen at -20 °C in a glass jar after retrieval. Mussels can be transported live over short time frames (up to 24 h) if kept cool and damp. Otherwise, they should preferably be dissected immediately and frozen for contaminant analysis at -20 °C.

4.8 HANDLING OF SAMPLES

4.8.1 Transport

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 offshore sampling programme) then appropriate storage facilities must be available on the vessel or vessel to shore shuttle transportation arranged and combined with overnight express couriers to ensure samples arrive for analysis in good time and condition. When using couriers, particularly from remote locations where transportation may take some time and involve multiple modes of transport, it is important to ensure that samples remain in a state that is suitable for later processing.

4.8.2 Storage

Samples for chemical analysis can be stored successfully for months/years at -20 °C although samples for biological effects analysis may need to be stored at lower temperatures (-80 °C or -196 °C for particular assays) in order that meaningful data can be generated. Samples for sensory testing can be stored frozen for 2 weeks (in the case of mussels) or up to 3 months for fish (see Marine Scotland Science guidelines "Sensory Assessment of Fish and Shellfish Following an Oil Spill"). Samples for taxonomic identification are normally preserved in formalin and stored at room temperature. Generally, samples from which data are needed for control purposes (e.g. to inform the response or fishery closure restrictions) would be prioritised and those which relate to the longer-term impact assessment may be stored for analysis at a later date, once the analytical load has eased.

4.8.3 Chain of Custody

In order to ensure that appropriate data are generated to support a robust environmental impact assessment, it is essential that suitable quality control procedures are applied during all stages of the monitoring programme. Samples need to be taken in a reproducible manner, and using practices which prevent contamination or loss of analytes. Standard operating procedures are needed at all stages of the sampling and analytical processes, and a chain of custody for samples must be maintained. Organisations which have a regulatory function may have specific requirements for sampling so that they can be used for evidential purposes, but general monitoring does not need to follow these necessarily. The main requirements are that:

- You know where the samples were taken from, when and by whom.
- Who is responsible for the storage and care of the samples at each stage of the process (and recording transfers of responsibility as they occur), and where the samples are at any given time (barcoding can help, as this can define locations to an individual storage location/area/shelf in quite a simple fashion – see Law et al., 2011; page 151).
- Which stage of the process they are currently undergoing and their current location.
- When the resultant data are transferred to a storage database, and you know which one, and who is then responsible for custody of the data and how the data are preserved.

5 Analytical Methods

5.1 CHEMICAL ANALYSIS

Discrete water samples for chemical analysis should be extracted and analysed using at least a screening technique, preferably UV fluorescence spectrometry, aboard the sampling vessel. Synchronous scanning UV fluorescence techniques can be used at this stage to profile the oil and confirm that it is at least similar in composition to that being released (Kelly et al., 2000). Water, sediment and biota samples can also be analysed in the laboratory. GC-MS analysis of PAH and full-scale, detailed, fingerprinting can be used to confirm the source of the oil and the degree of weathering and degradation of the oil which has occurred to the time of sampling. Extracts can be analysed immediately or, if there is insufficient analytical capacity at the time, be stored frozen in pre-cleaned glass containers with Teflon lid liners for later clean-up and GC-MS analysis. This procedure is described in detail in TG08 (http://www.cefas.defra.gov.uk/premiam/publications). PAH analysis using high performance liquid chromatography (HPLC) with fluorescence detection is not recommended for use in oil spill studies, as only parent PAH are determined though alkylated PAH will dominate in the samples.

5.2 ECOTOXICOLOGICAL ANALYSIS

FIGURE 15
Ecotoxicological analysis

In addition to PAH analysis in sediment or biota samples, determination of EROD (ethoxyresorufin-O-deethylase) in fish also provides a measure of exposure (Galgani and Payne, 1991; Kirby et al., 1999).

Other ecotoxicological analyses can also be performed on a range of matrices such as passive sampler extracts or mussels. If passive sampling and mussel deployments are not possible, water samples collected using a rosette sampler should be taken and returned to the laboratory for toxicity testing. Samples should be extracted and then dosed into standard seawater (or freshwater for the fish test). Samples should be subjected to a standard suite of tests as shown in table 2 below.

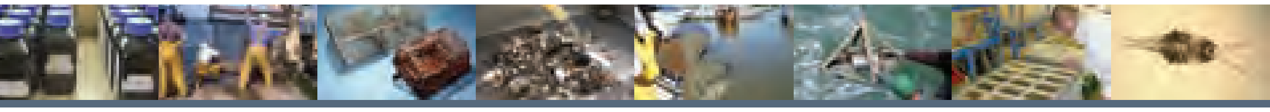


FIGURE 16 Copepod *(Tisbe battagliai)*

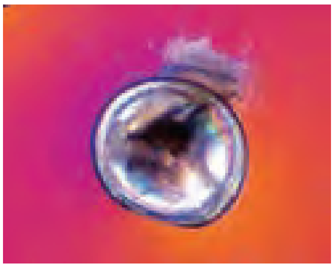


FIGURE 17 Oyster embryo *(Crassostrea gigas)*

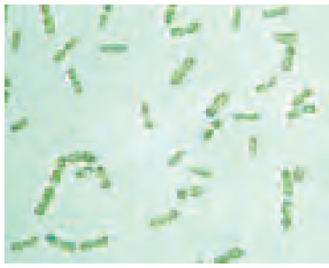


FIGURE 18 Algae *(Skeletonema costatum)*

Table 2. Recommended methods for biological effects analysis of water samples.

METHOD	REFERENCE
Copepod acute toxicity (Tisbe battagliai 48 hr LC50)	ISO, 1999.
Oyster embryo development (Crassostrea gigas 24 hr EC50)	Thain, 1991.
Algal growth inhibition test (Skeletonema costatum 72 hr EC50)	ISO, 2006.
Fish embryo acute toxicity test (24 hr LC50)	OECD, 2013

Sediments can also be assessed for toxicity, particularly if there is a potential threat to benthic species. Sediments obtained using grab samplers or corers can be brought back to the laboratory and used for whole sediment toxicity testing. Relatively large volumes of sediment are required for this procedure (up to 1 kg) and should be kept cooled while being transported back to the laboratory. Sediments should be subjected to one of the standard sediment tests shown in the table below.

Table 3. Recommended methods for biological effects analysis of sediment samples.

METHOD	REFERENCE
Amphipod whole sediment bioassay (*Corophium volutator* 10 d LC_{50})	Thain and Roddie, 2001.
Polychaete whole sediment bioassay (*Arenicola marina* 10 d LC/EC_{50})	Thain and Bifield, 2001.

FIGURE 19 Amphipod whole sediment bioassay *(Corophium volutator)*

FIGURE 20 Polychaete whole sediment bioassay *(Arenicola marina)*

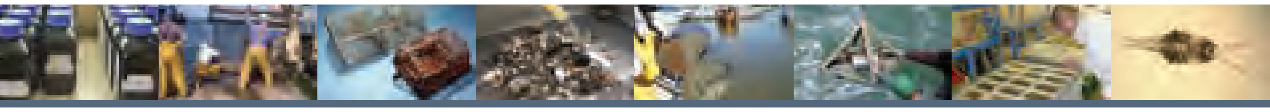
5.3 BENTHIC ASSESSMENT

Benthic habitats and species may be among the first affected during a subsea oil release, and so impacts on benthic communities will need to be investigated in the event of a subsea release occurring. Although unlikely to be extensive in the Deepwater Horizon-type scenario (evolution of a surface slick and a subsurface plume or plumes stabilised at depth) this should include study of the benthos in the direction of the oil's predicted and observed travel. Predictive modelling should be used in order to identify inshore areas where impacts may also occur. If there is only sparse information on the benthic communities present in these areas prior to the incident, then a baseline study should be implemented as soon as possible and ahead of the oil's arrival. This will aid the impact assessment. Epifauna on the seabed can be surveyed using drop cameras and camera sledges which are towed along the bottom on pre-determined transects. Sampling is undertaken using grab sampling techniques using grabs of suitable design for the seabed sediment present at the sampling locations. See TG02 for more detail (http://www.cefas.defra.gov.uk/premiam/publications). The process of identification is a time consuming one, and rapid results cannot be expected.

5.4 MICROBIAL ANALYSIS

During the Deepwater Horizon monitoring programme, microbial community analysis was conducted using a ribosomal 16S RNA targeted oligonucleotide microarray (a PhyloChip) (Hazen et al., 2010). By using PhyloChips for the analysis of bacteria in water samples, the reliability of the identification of bacterial species was enhanced, as all microorganisms of interest could be detected in a single assay. Another system which carries promise is the Environmental Sample Processor developed at the Monterey Bay Aquarium Research Institute (MBARI) (http://www.mbari.org/ESP/) which allows automated detection of micro-organisms and their gene products in water by applying molecular probes directly to the samples. A deep water version which can be operated down to 4,000 m depth has been developed, so this technique could be used to investigate bacterial communities in the dispersed oil plumes when deployed from a vessel.

A review of hydrocarbon-induced impacts on microbial communities can be found within the Premiam guidelines (Law et al., 2011; pages 156-157).



6 Impact Assessment

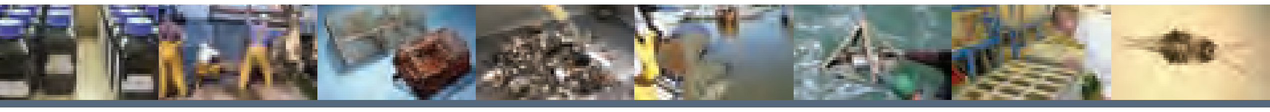
The initial focus of the assessment will be that relating to dispersant application aspect of the response operation. Whether the process was successful in terms of dispersing the released oil (thereby generating a subsurface plume) and so preventing a proportion of the oil reaching the sea surface and generating a surface oil slick. The impact of the subsurface plume on biological resources (e.g. benthic communities, fisheries etc.) will need to be assessed for deeper 'at sea' areas along its path of travel and at its arrival points in shallower, inshore and coastal waters.

Modelling will allow the locations and extent of potentially impacted areas to be predicted and sampling can take place ahead of time in order to generate additional data to feed into the assessment. The overall impact assessment must take account of all impacts of the oil spill, wherever they occur. This will include the immediate area of release, the adjoining coastlines and all areas and resources in-between these areas. In-depth study of the data produced will allow the overall damage to be assessed, and identify areas in which these impacts can be ameliorated or reversed. Environmental impact assessment will be a complex process, and the scope and scale of this cannot be predicted in advance of an incident occurring. Experience suggests that operation of an effective environmental monitoring programme and the subsequent impact assessment may take two years or longer. This is because it takes time for the effects to decline following a major oil release and to reach levels either observed prior to the incident or similar to those within defined reference areas. Guidance on when to stop post-spill monitoring is given in the Premiam guidelines (Law et al., 2011; pages 110-111).

Potential impacts which should be considered for study include:

- Levels of hydrocarbon and PAH contamination in the water column, sediments and biota
- Impacts on fish and shellfish stocks and populations of species of conservation importance
- Impacts on seabirds and marine mammals
- Impacts on benthic community structure
- Impacts on inshore aquaculture operations
- Socio-economic impacts (on e.g. fishing activities and tourism)

Guidance on relevant impact assessment methods is given in the Premiam guidelines (Law et al., 2011) for both habitats (terrestrial marine habitats, saltmarshes, seagrass beds, intertidal sediments, lagoons, subtidal sediments and subtidal rock) and species (plankton, fish, seabirds, inshore waterbirds, wetland birds, seals, otters and cetaceans). In addition, the vulnerability and sensitivity of each is described. While there are many scenarios of spill volume, depth, location and species at risk, and therefore many types of assessment which may be relevant in each case, environmental compartments particularly at risk in the event of a subsea release are subsea (deepwater) benthic species.



An example of the assessment strategy as applied for subtidal sediments deriving from the Premiam guidelines (Law et al., 2011; page 62) is given below. The strategy should include:

Recording dead wildlife – counts of washed-up dead or moribund bivalves, urchins etc will provide evidence of impact in coastal areas (or adjacent offshore areas) potentially impacted by the release.

Reconnaissance – in situ reconnaissance of subtidal sediments is not usually undertaken, but survey sites should not be established without reference to available data on distribution of seabed sediment characteristics. If these are not available, some initial sediment mapping may be needed. If biological samples are taken alongside sediment samples, it is recommended that they not be analysed until the sediment data are available. This allows prioritisation of samples and can greatly reduce effort and cost.

Biological survey attributes – some of the more likely potential indicators are: sediment mega-fauna abundance (particularly bivalves), sediment macro-fauna diversity and abundance (particularly amphipods and opportunistic polychaete worms). The polychaete to amphipod ratio has been suggested as an oil spill “bioindicator” previously. Investigation of sediment meiofauna has also been recommended as indicators of anthropogenic effects (e.g. abundance and diversity of nematode worms and copepods), but reliable techniques for oil spill impact assessment using these animal have not yet been developed.

This section was developed under the current legislative requirements in June 2014 and will be reviewed following the forthcoming Environmental Impact Assessment Directive recast and any implications of the implementation of the Offshore Safety Directive and the Environmental Liability Directive from the EU.

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8 Annex 1 List of Technical Guideline Documents

Table 4. List of Technical guideline documents.

DOCUMENT NO.	TITLE
TG01	Collection of water samples
TG02	Collection of benthic grab samples
TG03	Collection of finfish and shellfish of commercial and by-catch species
TG04	Collection of plankton samples
TG05	Use of fluorimetry to determine hydrocarbons
TG06	Deployment of current meter moorings
TG07	Deployment of biological and chemical passive samplers
TG08	Analytical determination of hydrocarbon content

9 Annex 2 Handling of Data and Communications

9.1 CO-ORDINATE COMPONENTS OF MONITORING PROGRAMME CONDUCTED BY DIFFERENT ORGANISATIONS SO AS TO MAXIMISE THE UTILITY OF THE DATA GATHERED AND PREVENT DUPLICATION OF EFFORT

One of the tasks of the Premiam Monitoring Coordination Chair is to oversee the overall monitoring effort, with a view both to ensure that all essential components making up the programme are covered and that a single organisation is responsible for directing each strand of the work. Other organisations can be involved, but the lead in each case should be clearly identified. Cefas took this role in the case of the *MSC Napoli* monitoring programme, deploying funding from Defra where necessary to ensure that all components were covered (Law, 2008). In a similar manner, an organisation and a named individual within that organisation need to be identified to undertake this crucial role in the event of a subsea release and the consequent response.

9.2 INSTITUTE A SECURE DATABASE TO HOLD ALL THE DATA GENERATED

The majority of sections in this document refer to the collection of samples and/or data or the use of data in some form. This section describes the guiding principles for the management and use of those samples and data. The key requirements of any data management and use system for this type of event are:

- The ability to establish data services rapidly and flexibly
- Processes to guide acceptance of quality assured data and associated metadata
- Controlled access to data
- Visualisation and mapping of data
- Discovery, view and download services for the data

The ability to establish data services rapidly and flexibly provides a challenge for established operational IT services, where timescales and specification levels are long and high respectively. In the events under consideration, set up timescales are short and the degree of specification is low, i.e. all sorts of data will be thrown at the system with expectations for rapid ingestion, storage and subsequent use. Combinations of dedicated IT specialists, data scientists and modern database and internet technologies can provide the necessary speed and flexibility.

Processes to guide the acceptance of quality assured data and associated metadata are required to ensure that all data collected are suitably documented. The metadata (sensor, machine and human generated) describes what the data are, where it is from, when it was collected, who collected it, how it was collected and what has been done to it in the form of quality assurance. The combination of data and metadata facilitates the appropriate use of the data, as well as providing discovery and management functions. The metadata database will, for example, allow the listing (display) of all physical samples (and their locations) and/or aerial images (and their location). The file formats and accepted date/time and co-ordinate systems all need to be defined early on in the incident in order to facilitate efficient data upload and availability to the response managers.

Controlled access to data is required as direct access to the event data holdings is vital for the associated specialists and members of the relevant Environment Group(s), the MCA and DECC and, in this case, specifically Marine Scotland – Science. Direct access by survey, analytical and modelling contractors for data upload purposes speeds ingestion but relies on the provision of high quality metadata. Direct access by data users provides read only access to ingested data but also requires the ability for those users to upload derived/processed datasets, with associated metadata.

Visualisation and mapping of data is covered, to some extent, below. Core requirements for mapping of data are covered in the metadata, e.g. spheroid. Standard file formats to be used for the event require early specification to facilitate ingestion, assimilation, integration, analysis and presentation. Standard map Legends, units and other associated information, including version, require early specification. This applies to observation data and to processed data, be they tables, animations or maps. All datasets and data products must have associated metadata for quality assurance, discovery and data management purposes.

Discovery, view and download services for the data emerge from all of the above; specifically discovery from metadata (lists, text and displayed on maps), view from metadata and mapping services and download from controlled access; all underpinned by the flexible database system, managed ingestion, controlled access and the inclusion of all data products and their associated metadata.

9.3 USE OF A MAPPING/PRESENTATION SYSTEM TO GENERATE PLOTS AND REPORTS FOR DISSEMINATION

The establishment of a secure database to store all of the requisite information, as detailed above, supports the use of Geographical Information System (GIS) functionality to integrate, interrogate, analyse and report on the stored data. This functionality can be used to improve contingency planning as hazards and risks can be pre-determined and mitigation strategies developed.

GIS provides a platform for management of geographic data and additional disparate data and documents (plans, photographs, video) allowing a means to access that information based on the geographic location to which it relates. In order to be prepared for a spill incident, readily available data should include: an inventory of coastal and marine resources; infrastructure, hydrographic and administrative boundary information; Ordnance Survey coastal topographic maps; Hydrographic Office nautical charts; panchromatic aerial imagery; shoreline environmental sensitivity information and details of any sensitive coastal sites, with details of their contingency plans, if applicable. Map templates should be available at a range of scales which can then be easily populated by data for the incident location to support a variety of response functions e.g. operations, logistical and tactical maps at appropriate geographical scales; incident prediction maps; forecast visualisations.

The GIS provides the capability to map, and visualise, the extent of the incident in combination with these data on e.g. critical infrastructure, population centres, environmentally sensitive areas. Calculation of distances, areas of overlap, movement rates etc. assist in the identification of vulnerabilities and the prioritisation for mitigation. Site selection processes can be employed to identify suitable areas for deployment of equipment, or for logistical support. Outputs from plume models can be visualised in 2 or 3-dimensions and animated to take into account changes over time. A combination of modelling, satellite imagery and aerial observations can be used to quantify more accurately volumes spilled and size of area affected. Models and scripts to carry out routine tasks could be prepared in advance and be ready to be executed in a timely manner in response to a spill incident.

If resource assets, responding to the incident, are inventoried and supplied with appropriate tracking systems (GPS) those assets can be tracked in real-time and relevant, and timely, information supplied to them as required. The combination of existing data assets and dynamic data (camera feeds, weather information, vessel/vehicle locations, sensor feeds) provide situational awareness for decision support. Mapping and outputs can be readily supplied using the suite of pre-defined map templates. Data being received from the field can be used to update the current picture e.g. resources at risk, wildlife stranding locations, extent of shoreline oiling, as well as providing useful information to support a post-incident damage assessment.

Appropriate configuration of the database, coupled with the use of online mapping tools, facilitate rapid development of web portals to provide continuously updated maps, data, and applications. Links to other incident-related Web sites can also be included. Interactive map applications can allow users to add volunteered geographic information (VGI) e.g. as photos, Web sites, or YouTube videos and increase awareness of activities related to the event.

9.4 INSTIGATE REGULAR REPORTING OF FINDINGS TO RESPONDERS AND REGULATORS, PARTICULARLY ON THE EFFECTIVENESS OF THE DISPERSANT APPLICATION IN DISPERSING OIL

Regulator reporting of data to all relevant stakeholders will be critical in order to ensure that everyone knows what the current situation is. Information concerning the effectiveness of the dispersant application should be reported as soon as it becomes available, in order to inform the continuing response operation and inform decisions relating to the continuation/cessation of the operation. During the *Sea Empress* incident, data from the monitoring programme (PAH concentrations in fish and shellfish) were reported on a weekly basis (each Friday) 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.

9.5 CONTRIBUTE TO WIDER REPORTING OF FINDINGS AND EFFECTIVENESS OF THE RESPONSE, E.G. TO THE GENERAL PUBLIC

To aid lead statutory bodies, the technical monitoring team should consider the likely types of information necessary to make stories about monitoring the situation as accessible as possible.

Potential questions and brief responses should 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 explain any acronyms or complex science.

A monitoring report template regularly updated could also be helpful – the ideal frequency and detail to be agreed by the key parties. It could cover key elements such as location, samples, impacts on edible species, other impacts, etc. In addition, a "key facts" box containing brief facts and figures might prove instantly helpful for news outlets and those needing a snapshot of the scale or progress associated with the incident.

A simple, visual representation of information will instantly focus minds on the essential take-home messages and will aid understanding by non-specialists. A traffic light (green, amber, red) or arrows (up, down, ongoing) system showing progress or impact degree could help to make trends more easily seen. An example of this approach is the MCCIP (Marine Climate Change Impacts Partnership) report card, see http://www.mccip.org.uk/media/18758/mccip-arc2013.pdf)

Making such a report accessible by digital means could help hard-pressed incident teams/call centres. In addition, interactive links to supporting maps, photos ("before" and "after" shots) and infographics could help to connect directly and quickly with audiences that increasingly expect such an approach.

Other channels of communication shouldn't be overlooked, however. Events, meetings, and specialist articles all have a role to play. But the information presented in a Monitoring Report template could still form the basis for those interactions and would ensure that a consistent and constantly updated story about any monitoring activity could be told with minimal extra effort, save communicating the lessons learnt in the long run.

10 Annex 3 Design Process

The flowchart below describes a logical process for designing a survey of a natural resource.

This flowchart is reproduced from the Premiam guidelines (Law et al., 2011).

1. Select the natural resource for which there is concern and carry out reconnaissance surveys to assess the spatial extent and level of exposure to oil or chemicals.

2. Define aims and objectives of the study – first understand clearly what question(s) you want answered.

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

4. Examine information from studies of the resource in the affected area or elsewhere 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.

5. With the above in mind, select suitable parameters/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.

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

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

8. 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.

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

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

11. Decide how many impacted sites and reference sites (with similar physical and biological characteristics) to survey/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 8 above).

12. Decide or estimate the duration of the study – you may wish to monitor until levels return to a pre-defined baseline but this may take a much longer or shorter time than you predict.

13. Define procedures for tracking samples/data and other chain-of-custody requirements.

14. Prepare relevant health and safety risk assessments, organise logistics and plan work schedule.

15. Prepare recording forms and database.

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

17. Test and thoroughly review the methodology.

18. Initiate survey.

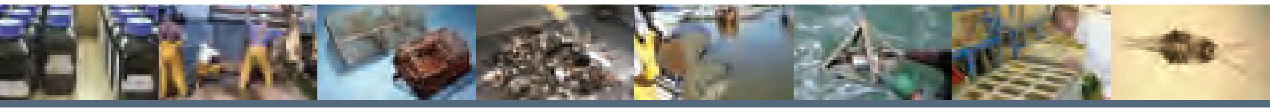
11 Annex 4 Vessel Specification and Personnel Requirements

11.1 VESSEL REQUIREMENTS

The type and size of a vessel required will depend on the depth of water to be sampled, distance from a safe haven (and the safety equipment and facilities required to support this), and the details of the survey plan in terms of frequency of sampling, number of vessels available, types of samples to be taken. In order to obtain the samples described in section 4, vessels will need to have the equipment and capability described in Table 4. In most emergency situations, samples need to be analysed very quickly in order that ongoing decisions can be made. For this reason, it would be necessary to have samples that cannot be analysed onboard coming ashore almost immediately. In the scenario below, we assume that the main working vessel would stay on station for weeks at a time. In this case, additional vessels or helicopters would be required to deliver samples to the shore for analysis during this period.

Table 5. Single vessel requirements for water depths >300 m

SPECIFICATION	REQUIREMENT DELIVERED
Powered winches with coring wire	Box corers and grab samplers
Slipring winch with fibre optics	HD camera, camera sledge, CTD rosette
‘Clean’ power (240 V AC)	All sensors and electronic equipment
A frame	Box corers, multi-corers, grab samplers, CTD rosette
Dynamic Positioning	Grab sampling
Internet access/computers	Data processing
Gear Handling system	Deployment of buoy or small boat
Winches for beam trawl	Beam trawls
Seawater supply (controllable) on deck	Sieving
Freshwater supply	Cameras, sample preparation
Deployable small boat	Surface film sampler
Blast freezer or freezer	Storage of samples
USBL (ultra short base line)	Cameras, ROV
Dry area	Analysis of video images, data processing
Laboratory/clean area	Sample preparation, swathe operation
LARS	ROV
ROV shack	ROV
Engineer shack	ROV
Deck space	Storage of samples, stowage of buoys and equipment when not deployed, container lab



Vessels will need to be certified to work at the necessary distance from shore and to comply with Lloyds/MCA regulations more information of this can be found at http://www.dft.gov.uk/mca.

Vessels will be required to have accommodation for all personnel, satellite or very short aperture terminal (VSAT) communications, endurance for at least three weeks at sea and experienced crew for 24 h operations. It is likely that given the number of crew and scientists required for a single vessel operation (see section 10.3 for personnel requirements), that a vessel in excess of 90 m would be required to conduct a full monitoring survey.

11.2 SUMMARY OF EQUIPMENT REQUIRED TO UNDERTAKE SURVEYS

Rosette CTD water sampler with internally PTFE-coated sampling bottles the primary use of this device is to generate CTD (conductivity (an analogue for salinity), temperature and depth profiles down the water column to show its structure). They generally are also fitted with water samplers which can be triggered to take samples at preset depths and return them to the surface. Given the depths and likely weather to be encountered, other samplers are not likely to be suitable, other than for near surface samples.

Large box corer – Reineck, Nioz or similar coring device deployed via a winch of suitable capacity for the equipment to be deployed and the prevailing weather. Given the water depths in which sampling may need to be done and the exposure to Atlantic weather (particularly in the FSC area) substitution of a large, heavy corer with a smaller alternative is not likely to be possible.

Grab samplers used to collect surface sediment samples for chemical analysis and sediment characterisation, or for benthic community studies. Numerous different types are available, but their differing configurations make each most suitable for a sediment type in terms of granularity (e.g mud, sand or gravel – rock cannot be sampled and will probably damage the grab). The choice will therefore be influenced strongly by the sediment type.

Surface film sampler (handheld) used to sample surface oil films and best deployed from a small boat away from the main vessel and its sources of contamination. Most likely to be used to collect samples for chemical fingerprinting of suspect oil slicks which may/may not derive from the main spill.

Demersal trawl and/or Pelagic trawl both deployed from fishing winches aboard a vessel. There are a number of types of both which could be used, and the choice would depend on what was available, the species targetted and, for demersal trawls, the nature of the ground and depth to be fished.

Crab/lobster pots deployed using a fairly small winch. Only likely to be used in water depths less than 150 m as crabs and lobsters of commercial significance are not likely to be found at greater depth.

Drop camera/camera sledge deployed via winch with slipring. Requires a power source.

Remotely-operated vehicles possibly with a sample collection capability. Deployed via launch and recovery system (LARS) in deep water or via a moon pool or by means of an A-frame in shallower water.

Gliders/autonomous underwater vehicles deployable by hand or requiring LARS to deploy, depending on type and size of equipment.

Acoustic Doppler Current Profiler (seabed or buoy-mounted) gear deployment system required. Exact requirements depend on type of system used.

Echosounders installed on vessels or deployed over the side.

Swathe-bathymetry may be installed onboard a vessel or occasionally towed, depending on the system used.

Container laboratories for use on ships of opportunity which do not have dedicated laboratory or clean space. Need to have bench space, stable power supplies (240 v AC) and a fume hood as a minimum requirement.

Storage containers for samples. Pre-cleaned glass jars for contaminant analysis. Plastic tubs for benthic and PSA samples.

11.3 PERSONNEL REQUIREMENTS

Bridge crew need to be able to operate DP system effectively in different conditions, to be able to run along survey lines and to be good at keeping station. Deck crew need to be familiar with the deployment of different types of gear and the various pieces of scientific equipment.

Specifying the scientific personnel needed in order for a monitoring programme to be conducted successfully when the monitoring programme has not been defined (i.e. before the location and detail of the spill incident are known) is difficult. However, certain generic considerations can be made. The measurements which will need to be made fall into three categories: physical, chemical and biological, and some information can be given in regard to each of these.

11.3.1 Physical measurements

These relate to the structure of the water column in the study area, in relation to both the hydrographic characteristics and the development of surface slicks and plumes resulting from an oil release at the seabed. Detailed knowledge of the water column structure and currents, eddies, etc, is essential if the fate and behaviour of the oil is to be successfully modelled and predicted. Water column structure can be established by conducting a series of CTD casts and establishing salinity and temperature profiles from the sea surface to close to the seabed. In order to determine the current regime and the presence/absence of eddies or other features it would be necessary to emplace ADCPs on the seabed (upward looking) and below the sea surface (downward looking, buoy-mounted).

A minimum of two scientists would be needed to conduct each of these tasks, and the requisite skills for both may not reside in single individuals. It is suggested that 2/4 scientists be used per shift. Interpretation of data from satellites and surveillance aircraft can take place in a shore laboratory, as can data telemetered back from the ADCPs, so this task need not impinge on the vessel capacity.

11.3.2 Chemical measurements

Collection of water and sediment samples for chemical analysis would require a minimum of two trained personnel to operate the sampling gear. If on-board analysis of water samples for oil and/or dispersants is necessary, then in order to be effective two additional chemists would be needed, and suitable laboratory space would need either to be available (as on a research vessel) or provided, probably in a containerised form. It is suggested that 2/4 scientists be used per shift.

11.3.3 Biological measurements

Two types of biological sampling and analysis are envisaged, targeting fish and shellfish and benthic biological communities. Grabs and/or corers used to collect benthic samples could be operated by the same staff collecting sediments for chemical analysis, but a minimum of 3 scientists per shift would be needed to process the benthic samples to a point at which they could be stored for return to a shore laboratory for study. Fish and shellfish would be collected for chemical analysis in order to establish levels of contamination and the risk that this poses to human consumers, but may also be collected for study of impacts on their populations. In the former case only limited biological information (such as size) may need to be collected, but in the latter case much more detail may be needed. It is suggested that 2/4 scientists may be required assuming that fishing is conducted during daylight.

It is quite likely that a single vessel would not be used to undertake all of these tasks on a single integrated monitoring cruise and that specific tasks (e.g. fishing) may be conducted from a specialist vessel such as a commercial fishing boat, with scientists added to that crew roster. Using the figures suggested above, between 9 and 15 scientists per 12-hour shift might need to be accommodated: 18 to 30 in total. All of these would need to be appropriately trained in their tasks, and the need for them to be available at short notice would likely preclude the training of staff who do not have the skills and experience already in place. Information regarding skilled scientists and trained equipment operatives within the UK marine community, and possibly beyond, will need to be compiled and accessible at the cruise planning stage.

12 Annex 5 Modelling Parameters

In order to produce potential trajectories of sub-surface and surface oil plumes an integrated modelling system is required to produce accurate and timely forecasts for use by responders and regulators. An example of such a suite of numerical models is shown diagrammatically below.

The first stage of parameterising the model is to establish the hydrographic conditions at the release site using existing models from oceanic modelling systems, such as those available from NOAA and MyOcean. These models' systems should incorporate the key physical processes at the release site, such as eddies, internal tides, storm mixing and different water masses – additional development of models may be needed. Outputs of 3D flow fields and density profiles from these models can then be used as inputs into spill models with appropriate parameterisation of the oil type, release rates, temperature and gas to oil ratios, etc. Key processes within the oil spill models should include vertical rising velocities, formation of gas hydrates, dynamics of gas bubbles and oil droplet sub-surface plumes and surface plumes. Subsequent outputs from oil spill models such as trajectories, volumes and composition are suitable for analysis and interpretation by expert oceanographers/ecotoxicologists and the development of appropriate advice to responders and regulators as well as feeding into the PMCC so that the monitoring plan can be suitably adapted.

Any modelling system should be capable of receiving flow fields from a variety of primary sources (in industry standard NetCDF format) to enable an "ensemble modelling approach" using the strengths and weaknesses of each model in space and time, as well as moving towards a probabilistic approach to forecasting the potential fate of subsea oil plumes.

One scenario for a UK deep water release in UK waters is that both a surface and sub surface (say at 100m at the base of the seasonal pycnocline) plume transits from deep waters on the shelf. Therefore, inclusion of shelf break processes such as eddies/meanders, deep water incursions and internal tides are important factors in effective prediction the fate of oil. This is the subject of ongoing research and is currently not fully incorporated into existing models.

Diagram 1. Schematic modelling system for deep water releases.

Ocean /Shelf Circulation Models	Spill Models	Interpretation
Outputs		
3D flow and TS Fields	Trajectories Volumes Composition	Advice to responders
Examples:		
MyOcean Hycom NEMO ROMS	OSCAR OILMAP OSIS (not for subsea)	Regulators Responders Consultancies

13 Annex 6 Experience during the Deepwater Horizon Monitoring Programme

During the extensive monitoring programme which followed the Deepwater Horizon incident, there were a number of relevant applications of techniques and findings which may be relevant in the event of a similar incident occurring on the UKCS. These are summarised in this annex.

13.1 COLLECTION OF WATER SAMPLES

Samples of the fluids exiting the Macondo well were sampled using isobaric gas-tight samplers deployed using an ROV (Reddy et al., 2012). Water samples in the same study were collected using a standard rosette sampler. In another study, an in situ mass spectrometer deployed on an AUV was used to determine hydrocarbon concentrations in water without the need for water sample collection and analysis (Camilli et al., 2010).

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., Maloney, J.V., 2010. Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon. Science 330, 201-204.

Reddy, C.M., Arey, J.S., Seewald, J.S., Sylva, S.P., Lemkau, K.L., Nelson, R.K., Carmichael, C.A., McIntyre, C.P., Fenwick, J., Ventura, G.T., Van Mooy, B.A.S., Camilli, R., 2012. Composition and fate of gas and oil released to the water column during the *Deepwater Horizon* oil spill. Proceedings of the National Academy of Sciences of the United States of America 109, 20235-20239.

13.2 COLLECTION OF SEDIMENT SAMPLES

Samples of sediment for chemical and physical analysis were collected using an OSIL multicorer (Montagna et al., 2013). This collects 12 simultaneous cores per cast, of 10 cm diameter and 60 cm in length if the substrate is suitable.

For details of the multi-corer device see

http://www.osil.co.uk/Products/MarineInstruments/tabid/56/agentType/View/PropertyID/63/Default.aspx accessed 7 January 2014.

Additionally, six sediment samples were collected using a robotic arm deployed from a research submarine (Wang et al., 2011). The sediments were soft, fine (muddy) sediments overlain by bacterial *Beggiatoa* mats.

Montagna, P.A., Baguley, J.G., Cooksey, C., Hartwell, I., Hyde, L.J., Hyland, J.L., Kalke, R.D., Kracker, L.M., Reuscher, M., Rhodes, A.C.E., 2013. Deep-sea benthic footprint of the Deepwater Horizon blowout. PLoS ONE 8, e70540.

Wang, C., Sun, H., Chang, Y., Song, Z., Qin, X., 2011. PAHs distribution in sediments associated with gas hydrate and oil seepage from the Gulf of Mexico. Marine Pollution Bulletin 62, 2714-2723.

13.3 PROCESSING AND ANALYSIS OF SEDIMENTS FOR THE ASSESSMENT OF BENTHIC INFAUNA AND EPIFAUNA

During the Deepwater Horizon incident, remotely operated vehicles were used to fly at 1 – 2 m above the seabed, acquiring video data that was examined in order to quantify megafauna (Valentine and Benfield, 2013). In addition, samples of macrofauna and meiofauna were collected using an OSIL multicorer which collected 12 samples simultaneously (Montagna et al., 2013) which identified a benthic footprint of seabed impact extending to 3 km from the wellhead in all directions, covering an area of 24 km^2.

Montagna, P.A., Baguley, J.G., Cooksey, C., Hartwell, I., Hyde, L.J., Hyland, J.L., Kalke, R.D., Kracker, L.M., Reuscher, M., Rhodes, A.C.E., 2013. Deep-sea benthic footprint of the Deepwater Horizon blowout. PLoS ONE 8, e70540.

Valentine, M.M., Benfield, M.C., 2013. Characterization of epibenthic and demersal megafauna at Mississippi Canyon 252 shortly after the Deepwater Horizon oil spill. Marine Pollution Bulletin 77, 196-209.

13.4 PROCESSING AND ANALYSIS OF ENVIRONMENTAL SAMPLES FOR THE DETERMINATION OF HYDROCARBON CONTAMINATION

A major programme addressing levels of PAH contamination in seafood samples from the closed fishery area of the Gulf of Mexico in the wake of the Deepwater Horizon spill from a human health perspective was undertaken by Xia et al. (2012). No PAH concentrations above the levels of concern established following the incident were reported in this paper or a review by Gohlke et al. (2011), but a subsequent reassessment of the data by Rotkin-Ellman et al (2012) suggested that up to 53% of Gulf shrimp samples were above levels of concern for pregnant women who were also high-end seafood consumers.

In the UK, the levels of concern used in order to assess safety from a human health viewpoint would be those set for PAHs by the European Food Safety Authority. In bivalve molluscs, these regulatory limits are 5 µg kg^{-1} wet weight for benzo[*a*]pyrene and 30 µg kg^{-1} wet weight for the sum of 4 PAHs (benzo[*a*]pyrene, benz[*a*]anthracene, chrysene and benzo[*b*]fluoranthene) (Duedahl-Olesen, 2013). Regulatory levels are no longer set for fish other than as smoked products, as fish have such a high metabolic capacity for PAHs.

Mulabagal et al. (2013) used hopane and sterane GC-MS fingerprinting techniques to positively identify emulsified mousse and tar balls from the Alabama coastline as deriving from Deepwater Horizon oil.

McKenna et al. (2013) demonstrated the use of Fourier transform – ion cyclotron resonance mass spectrometry for the identification of components of the Deepwater Horizon oil and a tar ball and demonstrated changes due to weathering processes.

Sammarco et al. (2013) determined TPH and PAHs in sediments, seawater, biota and seafood along the Gulf of Mexico coast and in inshore waters from Texas to Florida. No direct linkages with Deepwater Horizon oil were made.

Duedahl-Olesen, L., 2013. Polycyclic aromatic hydrocarbons (PAHs) in foods. In. *Persistent Organic Pollutants and Toxic Metals in Foods*. M. Rose and A. Fernandes (editors). Woodhead Publishing, Cambridge. ISBN 978-0-85709-245-8. Chapter 13, 308-333.pp.

Gohlke, J.M., Doke, D., Tipre, M., Leader, M., Fitzgerald, T., 2011. A review of seafood safety after the Deepwater Horizon blowout. Environmental Health perspectives 19, 1062-1069.

McKenna, A.M., Nelson, R.K., Reddy, C.M., Savory, J.J., Kaiser, N.K., Fitzsimmons, J.E., Marshall, A.G., Rodgers, R.P., 2013. Expansion of the analytical window for oil spill characterization by ultrahigh resolution mass spectrometry: beyond gas chromatography. Environmental Science and Technology 47, 7530-7539.

Mulabagal, V., Yin, F., John, G.F., Hayworth, J.S., Clement, T.P., 2013. Chemical fingerprinting of petroleum biomarkers in Deepwater Horizon oil spill samples collected from Alabama shoreline. Marine Pollution Bulletin 70, 147-154.

Rotkin-Ellman, M., Wong, K.K., Solomon, G.M., 2012. Seafood contamination after the BP Gulf oil spill and risks to vulnerable populations: a critique of the FDA risk assessment. Environmental Health Perspectives 120, 157-161.

Sammarco, P.W., Kolian, S.R., Warby, R.A.F., Bouldin, J.L., Subra, W.A., Porter, S.A., 2013. Distribution and concentrations of petroleum hydrocarbons associated with the BP/ Deepwater Horizon oil spill, Gulf of Mexico. Marine Pollution Bulletin 73, 129-143.

Xia, K., Hagood, G., Childers, C., Atkins, J., Rogers, B., Ware, L., Armbrust, K., Jewell, J., Diaz, D., Gatian, N., Folmer, H., 2012. Polycyclic aromatic hydrocarbons (PAHs) in Mississippi seafood from areas affected by the Deepwater Horizon oil spill. Environmental Science and Technology 46, 5310-5318.

13.5 THE USE OF FLUORIMETRIC AND OTHER TECHNIQUES FOR THE IN SITU DETERMINATION OF HYDROCARBONS IN THE WATER COLUMN

Both acoustic and analytical approaches can be adopted in order to detect and visualise subsea plumes of dispersed oil, although not all have been investigated to date and some experimental work is likely to be necessary in order to establish which are most effective. During the Deepwater Horizon incident, echo sounder/sonar surveys were used to track the plume's location (Fuller et al., 2013) and the same authors conducted a laboratory study using acoustic backscatter from an Acoustic Doppler Current Profiler (ADCP) to quantitatively detect oil droplet suspensions. 38 kHz echo sounders have been shown to be useful for tracking sub-surface oil releases. Similarly, 38kHz ADCPs could detect at the surface sub-surface oil plumes at depths of up to 800 – 1,000 m (Fuller et al., 2013).

Following the Deepwater Horizon spill, Camilli et al. (2010) conducted subsea hydrocarbon surveys using both an autonomous underwater vehicle and a ship-cabled rosette sampler. Both involved measurements made using an *in-situ* membrane inlet mass spectrometer and the rosette sampler also carried a fluorimeter. A continuous plume of oil 35 km in length was identified at approximately 1,100 m depth. Two further underwater membrane inlet mass spectrometers, one based on a quadrupole MS and the other based on an ion trap MS, have also been described (Short et al., 2001). The ion-trap instrument yielded the lowest detection limits, with a mass range up to 650 Daltons and MS/MS capability.

Both measurements of dissolved oxygen and fluorimetry were used in the detection of subsurface oil plumes (Smith et al., in press). Four in situ fluorimeters (Chelsea Technologies Aquatracka, Turner Designs Cyclops, Satlantic SUNA and WET Labs Inc. ECO) were tested in tank experiments using simulated dispersed oil plumes (Conmy et al., 2014). All sensors estimated oil concentrations down to 300 ppb oil, and so would be suitable for investigating subsea dispersed oil plumes.

Numerous models have been run to either predict or hindcast the subsurface plumes of oil generated during the incident. Suggestions that subsurface oil reached the West Florida continental shelf and the bottom of the Mississippi Canyon have recently been published (Weisberg et al., in press; Lindo-Atichati et al., in press).

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., Maloney, J.V., 2010. Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon. Science 330, 201-204.

Conmy, R.N., Coble, P.G., Farr, J., Wood, M., Lee, K., Pegau, W.S., Walsh, I., Koch, C., Abercrombie, M., Miles, S., Lewis, M., Ryan, S., Robinson, B., King, T.A., kelble, C.R., Lacoste, J., 2014. Submersible optical sensors exposed to chemically-dispersed crude oil: wave tank simulations for improved oil spill monitoring. Environmental Science and Technology 48, 1803-1810.

Fuller, C.B., Bonner, J.S., Islam, M.S., Page, C., Ojo, T., Kirkey, W., 2013. Estimating sub-surface dispersed oil concentrations using acoustic backscatter response. Marine Pollution Bulletin 70, 140-146.

Lindo-Atichati, D., Paris, C.B., Le Hénaff, M., Schedler, M., Valladares Juárez, A.G., Müller, R., in press. Simulating the effects of droplet size, high-pressure biodegradation, and variable flow rate on the subsea evolution of deep plumes from the Macondo blowout. Deep-sea Research II.

Short, R.T., Fries, D.P., Kerr, M.L., Lembke, C.E., Toler, S.K., Wenner, P.G., Byrne, R.H., 2001. Underwater mass spectrometers for in situ chemical analysis of the hydrosphere. Journal of the American Society for Mass Spectrometry 12, 676-682.

Smith, R.H., Johns, E.M., Goni, G.J., Trinanes, J., Lumpkin, R., Wood, A.M., Kelble, C.R., Cummings, S.R., Lamkin, J.T., Privoznik, S., in press. Oceanographic conditions in the Gulf of Mexico in July 2010, during the Deepwater Horizon oil spill. Continental Shelf Research

Weisberg, R.H., Zheng, L., Liu, Y., Murawski, S., Hu, C., Paul, J., in press. Did Deepwater Horizon hydrocarbons transit to the West Florida continental shelf ? Deep-sea Research II.

13.6 THE PROCESSING OF WATER SAMPLES TO DETERMINE MICROBIAL CHARACTERISATION

Impacts resulting from the Deepwater Horizon oil spill on microbial communities along the Gulf of Mexico coast were studied by Looper et al. (2013) using a variety of functional and phylogenetic markers. Seventeen bacteria genera known for their capacity to degrade hydrocarbons were identified in a contaminated sediment sample. When exposed to the spilled oil, the distinct wetland microbial communities responded with decreased diversity and increased abundance of selective degradative species. Also, Baelum et al. (2012) reported that indigenous hydrocarbon-degrading bacteria from the Gulf could rapidly degrade oil in cold, deep marine habitats. Using a 16S rRNA microarray, 951 subfamilies of bacteria were detected in the subsea plume, with three families in the class *Oceanospirillales* dominating (Hazen et al., 2010). The sea temperature at depth was 2 – 5°C.

Baelum, J., Borglin, S., Chakraborty, R., Fortney, J.L., Lamendalla, R., Mason, O.U., Auer, M., Zemla, M., Bill, M., Conrad, M.E., Malfatti, S.A., Tringe, S.G., Holman, H.-Y., Hazen, T.C., Jansson, J.K., 2012. Deep-sea bacteria enriched by oil and dispersant from the Deepwater Horizon spill. Environmental Microbiology 14, 2405-2416.

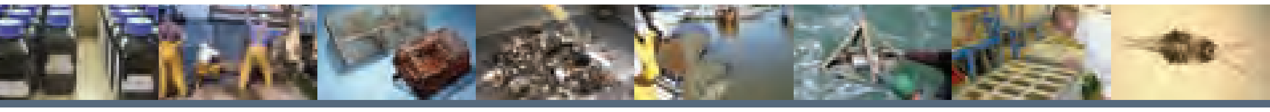
Hazen, T.C., Dubinsky, E.A., DeSantis, T.Z., Andersen, G.L., Piceno, Y.M., Singh, N., Jansson, J.K., Probst, A., Borglin, S.E., Fortney, J.L., Stringfellow, W.T., Bill, M., Conrad, M.E., Tom, L.M., Chavarria, K.L., Alusi, T.R., Lamendella, R., Joyner, D.C., Spier, C., Baelum, J., Auer, M., Zemla, M.L., Chakraborty, R., Sonnenthal, E.L., D'Haeseleer, P., Holman, H.Y.N., Osman, S., Lu, Z.M., Van Nostrand, J., Deng, Y., Zhou, J.Z., Mason, O.U., 2010. Deep-sea oil plume enriches indigenous oil-degrading bacteria. Science 330, 204-208.

Looper, J.K., Cotto, A., Kim, B.-Y., Lee, M.-K., Liles, M.R., Ní Chadhain S.M., Son, A., 2013. Microbial community analysis of Deepwater Horizon oil-spill impacted sites along the Gulf coast using functional and phylogenetic markers. Environmental Science Processes & Impacts 15, 2068-2079.

13.7 ESTABLISHING PHYSICAL AND HYDROGRAPHIC CONDITIONS IN THE SURVEY AREA

Smith et al. (in press) reported studies of oceanographic conditions in the Gulf of Mexico, particularly in relation to the Loop Current and associated eddies. These involved airborne ocean surveys deploying expendable ocean profilers, satellite-tracked drifters, satellite altimetry, shipboard surveys, CTD casts from vessels including both visible range fluorimeters for determining chlorophyll and coloured dissolved organic matter (CDOM), Acoustic Doppler current profilers were used both hull-mounted and attached to the CTD frame. Continuous underway measurements of sea surface temperature, salinity, chlorophyll and CDOM using a flow-through system were also made along cruise tracks.

Smith, R.H., Johns, E.M., Goni, G.J., Trinanes, J., Lumpkin, R., Wood, A.<., Kelble, C.R., Cummings, S.R., Lamkin, J.T., Privoznik, S., in press. Oceanographic conditions in the Gulf of Mexico in July 2010, during the Deepwater Horizon oil spill. Continental Shelf Research



13.8 DEPLOYMENT OF IN SITU SAMPLING EQUIPMENT (PASSIVES, MUSSELS)

During the Deepwater Horizon incident, Carmichael et al. (2012) assessed the contribution of oil materials to the diet of oysters (*Crassostrea virginica*) by comparing carbon and nitrogen stable isotope ratios in oyster shell to those in suspended particulate material and in fresh and weathered oil. Shells were collected from oysters transplanted to various sites along the Mississippi-Alabama coasts, and the growth portion added during the transplant period prepared and analysed using continuous flow-isotope ratio mass spectrometry.

Allan et al. (2012) conducted a study in the coastal waters of the Gulf of Mexico (locations in Louisiana, Mississippi, Alabama and Florida) using lipid-free passive sampling devices. Significant increases in bioavailable PAHs were seen following the oil spill, however, pre-oiling levels were observed at all sites by March 2011, approximately 1 year after the blow-out.

Allan, S.E., Smith, B.W., Anderson, K.A., 2012. Impact of the Deepwater Horizon oil spill on bioavailable polycyclic aromatic hydrocarbons in Gulf of Mexico coastal waters. Environmental Science and Technology 46, 2033-2039.

Carmichael, R.H., Jones, A.L., Patterson, H.K., Walton, W.C., Pérez-Huerta, A., Overton, E.B., Dailey, M., Willett, K.L., 2012. Assimilation of oil-derived elements by oysters due to the Deepwater Horizon oil spill. Environmental Science and Technology 46, 12787-12795.

13.9 TOXICOLOGY

Paul et al. (2013) used a number of bioassays to assess toxicity and mutagenicity of seawater and sediment porewater samples from the Gulf of Mexico following the Deepwater Horizon oil spill. These assessed microbial and phytoplankton toxicity and DNA damage, and demonstrated seabed impacts due to the oil.

Following the arrival of oil from the Deepwater Horizon spill in Barataria Bay, Louisiana, Lin and Mendelssohn studied its impacts on two dominant coastal saltmarsh plants. Moderate oiling impacted *Spartina alterniflora* less severely than *Juncus roemerianus* and, relative to reference marshes, had no significant effect on *Spartina* whilst significantly lowering live above ground biomass and stem density of *Juncus*. Khanna et al. (2013) used Advanced Visible Infrared Imaging Spectrometer (AVIRIS) data flown over Barataria Bay in September 2010 and August 2011 to investigate saltmarsh vegetation stress and recovery. Vegetation stress was restricted to the tidal zone extending 14 m inland from the shoreline in 2010. Comparison of data between 2010 and 2011 indicated that areas denuded after the oil impact showed varying degrees of revegetation by 2011, the poorest regrowth being close to the shoreline. Natter et al. (2012) studied ten selected Gulf saltmarsh sites in Louisiana, Mississippi and Alabama months after the Deepwater Horizon spill. This study indicated (1) that lighter compounds of oil are quickly degraded by microbes while the heavier fractions remain, and (2) higher inputs of organic matter from the oil spill enhanced the key microbial processes associated with sulphate-reducing bacteria.

Muhling et al. (2012) studied the potential impact of Deepwater Horizon oil on eggs and larvae of bluefin tuna in the northern Gulf of Mexico, using a combination of satellite-derived estimates of oil coverage and spawning habitat models. Although eggs and larvae were likely impacted in the eastern Gulf, high abundances of larvae were found elsewhere, particularly in the western Gulf. Overall, less than 10% of bluefin tuna spawning habitat was predicted to have been covered by surface oil, and less than 12% of larvae were predicted to have been located within contaminated waters in the northern Gulf.

The toxicity of dispersant Corexit 9500A and Macondo oil and mixtures of the two to a marine rotifer was studied by Rico-Martínez et al. (2013). They found that individually they were of similar toxicity, but when mixed toxicity increased up to 50-fold. Similarly, Corexit 9500A increased impacts of the oil on growth, reproduction and gene expression on the marine worm *Caenorhabditis elegans* (Zhang et al., 2013).

Carmichael et al. (2012) indicate that the impact of the Deepwater Horizon oil spill contributing to stress in bottlenose dolphins which, along with the effects of two additional stressors (sustained cold weather in 2010 and large volumes of freshwater entering the Gulf following an unusually large snowmelt) caused an unusual number of near term and neonatal mortalities.

Carmichael, R.H., Graham, W.M., Aven, A., Worthy, G., Howden, S., 2012. Were multiple stressors a "perfect storm" for northern Gulf of Mexico bottlenose dolphins (*Tursiops truncatus*) in 2011 ? PLoS ONE 7, e41155.

Khanna, S., Santos, M.J., Ustin, S.L., Koltunov, A., Kokaly, R.F., Roberts, D.A., 2013. Detection of salt marsh vegetation stress and recovery after the Deepwater Horizon oil spill in Barataria Bay, Gulf of Mexico using AVIRIS data. PLoS ONE 8, e78989.

Lin, Q., Mendelssohn, I.A., 2012. Impacts and recovery of the *Deepwater Horizon* oil spill on vegetation structure and function of coastal salt marshes in the northern Gulf of Mexico. Environmental Science and Technology 46, 3737-3743.

Muhling, B.A., Roffer, M.A., Lamkin, J.T., Ingram Jr., G.W., Upton, M.A., Gawlikowski, G., Muller-Karger, F., Habtes, S., Richards, W.J., 2012. Overlap between Atlantic bluefin tuna spawning grounds and observed Deepwater Horizon surface oil in the northern Gulf of Mexico. Marine Pollution Bulletin 64, 679-687.

Natter, J., Keevan, J., Wang, Y., Keimowitz, A.R., Okeke, B.C., Son, A., Lee, M.-K., 2012. Level and degradation of Deepwater Horizon spilled oil in coastal marsh sediments and pore-water. Environmental Science and Technology 46, 5744-5755.

Paul, J.H., Hollander, D., Coble, P., Daly, K.L., Murasko, S., English, D., Basso, J., Delaney, J., McDaniel, L., 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.

Rico-Martínez, R., Snell, T.W., Shearer, T.L., 2013. Synergistic toxicity of Macondo crude oil and dispersant Corexit 9500A® to the *Brachionus plicatilis* species complex (Rotifera). Environmental Pollution 173, 5-10.

Zhang, Y., Chen, D., Ennis, A.C., Polli, J.R., Xiao, P., Zhang, B., Stellwag, E.J., Overton, A., Pan, X., 2013. Chemical dispersant potentiates crude oil impacts on growth, reproduction and gene expression in *Caenorhabditis elegans.* Archives of Toxicology 87, 371-382.

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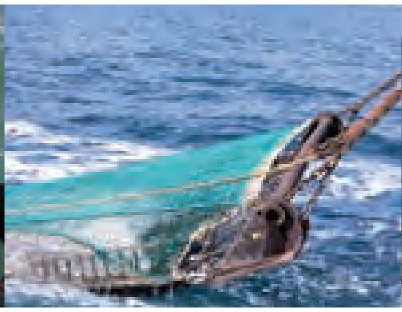
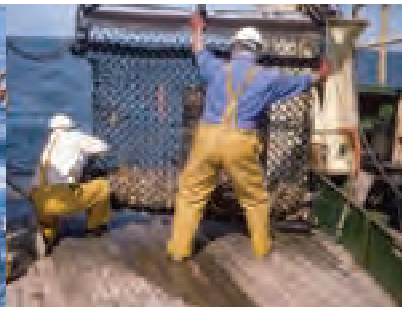


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