POLLUTION RESPONSE IN EMERGENCIES:

Marine Impact Assessment and Monitoring
Post-Incident Monitoring Guidelines

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Executive Summary

Spillages of oil and chemicals at sea can be high-profile events with significant environmental consequences. Effective response is essential to minimise risks to the public and the marine environment and to enable timely clean-up and recovery. While international conventions and national contingency plans set out many core response activities (for example, counter-pollution measures and situational awareness), environmental monitoring and impact assessment are often not addressed in sufficient detail.

These guidelines have been developed to support best scientific practice and effective management of post-spill monitoring. Prompt, robust monitoring is an essential part of an integrated spill response because it enables impacts and risks to the human food chain, marine ecosystems and commercial marine resources to be identified, and provides evidence on the effectiveness of response operations and subsequent mitigation or recovery actions. In the United Kingdom, the cross-government and industry initiative Premiam (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) promotes effective post-spill monitoring, and these guidelines, referenced in the UK National Contingency Plan, are a key deliverable.

These guidelines set out the principles of an environmental monitoring programme by clarifying the key aims and answering the practical questions of **why**, **where**, **when**, **what** and **how** monitoring should be undertaken. It then provides detailed guidance on design, sampling, sample management and monitoring techniques and strategies across a range of ecological habitats and marine resources, and highlights the importance of data management, communication and reporting. Although developed from a UK perspective, this latest edition is more inclusive of globally relevant marine habitats (for example, corals, mangroves and polar environments). The aims, principles and approaches are intended to support marine monitoring plans for spills wherever they occur and should be used both during an incident and as a reference for pre-planning, preparedness and resilience.

The Premiam guidelines have been produced in consultation with many major government and industry stakeholders across the United Kingdom, including:

1. Introduction

Spillages of oil and chemicals into the marine environment can be high-profile events with significant short and long-term environmental impacts. Although there is strong evidence that the number of oil spills has decreased in recent decades (Schmidt Etkin, 2024; ITOPF, 2026) due to improved practices and prevention, occasional large incidents, such as the *Deepwater Horizon* in 2010, still occur. Additionally, smaller spills and near-miss potential spills occur more frequently and are of significant concern, particularly near sensitive environments. In this context, relevant authorities require the development and maintenance of effective spill response and clean-up capabilities, including the ability to initiate and conduct scientifically robust post-incident environmental monitoring and impact assessments.

Spills of Hazardous and Noxious Substances (HNS) are an increasing concern in the marine environment, reflecting the continued growth in global transport of bulk chemicals and other potentially harmful cargoes. The fuels used to power ships are also evolving as the sector transitions to decarbonisation, with a range of products coming to market as replacements for oil. These fuels can also have environmental consequences if released. HNS incidents can involve a wide range of substances with differing physical and chemical properties, presenting complex challenges for response, monitoring and impact assessment. Although the behaviour, fate and potential effects of HNS may differ significantly from those of oil, the overarching principles of post-spill monitoring and impact assessment remain broadly the same.

In addition to oil and chemical releases, spills of plastic pellets (commonly known as nurdles), plastic flakes and plastic powder are an increasing concern in the marine environment. Plastic pellet spills can occur during shipping incidents or cargo loss, as highlighted by the *X-Press Pearl* disaster (2021) and the MSC *ELSA 3* (2025), and may result in the widespread distribution of primary microplastics across shorelines, surface waters, sediments and biota. Due to their small size, buoyancy and persistence, pellets can disperse over large distances, accumulate in high-tide zones and subtidal sediments, and be ingested by marine organisms (Hahladakis, 2024; Savoca *et al.*, 2025; Zhu *et al.*, 2025). Effective post-spill monitoring therefore requires harmonised sampling and analytical approaches across environmental compartments (shorelines, water column, sediments and biota), including robust particle identification and standardised reporting to enable assessment of environmental impacts and long-term trends.

An effective post-incident environmental monitoring programme, guided by clear principles, such as those presented in these guidelines, can ensure that:

- Key stakeholders, including government and the public, receive early and accurate evidence of the potential hazards and risks posed by the incident;
- There is an appropriate and effective means of investigating both short-term and longer-term impacts;
- Efficient coordination results in more effective use of resources and the ability to conduct integrated assessments;
- Information is gathered on the effectiveness of spill response and clean-up activities, including the use of oil spill treatment products (such as dispersants), providing direct input into evolving response strategies;
- Robust and defensible scientific evidence is generated to support impact assessment, liability, claims processes, and financial compensation.

For example, under the UK National Contingency Plan (NCP) (HM Government, 2024)[1], if a marine pollution incident is expected to have a significant environmental impact, it is recognised that arrangements should be made to monitor and assess both the short and long-term environmental impacts through a specialist and coordinated approach. Industry bodies have also produced a variety of useful guides (e.g. Ipieca, 2015; 2020) on monitoring, sampling, and ecological impact. However, the Pollution Response in Emergencies: Marine Impact Assessment and Monitoring (Premiam) post-spill monitoring guidelines provide a fully comprehensive overview of the techniques and principles, with a focus on a scientifically robust, yet practical, approach to implementing an environmental monitoring and impact assessment programme.

National authorities with responsibility for managing environmental quality and natural resources for the marine and coastal environments where spill incidents occur (e.g. the Department for Environment, Food and Rural Affairs – Defra – in the UK) will generally lead the coordination and commissioning of such work, ensuring it is linked with existing marine monitoring and assessment activities. However, depending on the incident scale, position, resources at risk, and source of pollution, many bodies may ultimately be involved in the conduct of post-spill monitoring, including government agencies, industry-appointed experts and consultants. Experience has shown that although response documents, such as national or local spill contingency plans, often advocate the requirement for monitoring and impact assessment, their focus tends to be on safety, response, and clean-up approaches, and there has been a lack of scientifically robust guidance on how to approach and conduct these programmes of work. It was against this background that the Premiam initiative (https://www.cefas.co.uk/premiam) emerged and developed the necessary guidance and processes to facilitate the conduct of effective post-spill monitoring, including the publication of guidelines. This third edition of the guidelines has been revised and expanded to make the principles and information it contains more widely applicable in a global context.

“Spills of hazardous and noxious substances (HNS) are an increasing concern in the marine environment, reflecting the continued growth in the global transport of bulk chemicals and other potentially harmful cargoes.”

1 National Contingency Plan: https://assets.publishing.service.gov.uk/media/668d41974a94d44125d9cf9c/National_Contingency_Plan_-_June_2024.pdf

As such, these guidelines aim to provide important preparedness and capability information for establishing and conducting effective post-incident monitoring programmes. They set out expert, best-practice principles for planning and conducting post-incident monitoring and impact assessment and are designed to be relevant in both the public and private sectors, as well as a source of guidance to be referred to in relevant documents such as contingency and response plans.

These guidelines are an important output from the UK Government-funded Premiam initiative, which has established mechanisms for overseeing the practical aspects of any programme, such as survey design, sampling, analysis, and interpretation.

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

- Speed – providing a faster response to gain early impact information and baseline data for areas under threat;
- Cost-effectiveness;
- Identification of the expertise needed for an effective monitoring programme;
- Use of best practices and the ability to learn from studies of earlier incidents;
- Improved coordination and integration;
- Improved preparedness and resilience.

“Spillages of oil and chemicals into the marine environment can be high-profile events with significant short and long-term environmental impacts.”

This guidance acknowledges the challenge of obtaining absolute statistical proof of spill impacts due to factors such as environmental variability, the accidental nature of spills, and the lack of baseline data.

Effective impact assessments rely on recent, quality baseline data for comparison. Relevant baseline data will often not be available and programmes may need to be developed in its absence. Nevertheless, assessments should aim to adhere to sound scientific principles and be designed to gather evidence using methodologies tailored to the incident characteristics and local limitations.

> **"These guidelines aim to provide important preparedness and capability information for establishing and conducting effective post-incident monitoring programmes."**

Designing a monitoring programme is not a one-off event. Circumstances will change as an incident proceeds, particularly if it is protracted, and the monitoring programme should evolve to meet changing aims. Logistics are also an important consideration:

- **Expertise, equipment, and capacity** – Many technical studies require specialist expertise and equipment and laboratory analysis of samples; large studies may stretch the availability of those resources;
- **Resource priorities** – Environmental monitoring may wish to draw on the same transportation, surveillance or other logistical resources as pollution-combating responders – this emphasises the need for coordination and integration with the overall incident management team;
- **Environmental conditions** – Survey timing should account for both predictable (e.g. tides and currents) and less predictable (e.g. weather) environmental conditions;
- **Access to sites** – Survey and sampling sites may be in difficult to access areas, restricted safety exclusion zones, or require permission;
- **Licence** – Some species are protected by law, and activities may require a licence from the relevant agency for handling or collection.

Finally, while these guidelines set out the core principles of designing and conducting an effective post-spill monitoring and impact assessment programme, including the description of key techniques and approaches, the ability to plan and undertake effective monitoring relies on factors such as the availability of appropriate expertise and equipment, access to funding, and integrated aims across stakeholder organisations. These guidelines help set out what needs to be done and how it can be achieved, including the importance of quality assurance, data management, and effective communications. These guidelines provide a broad overview and an important reference for those implementing programmes, but authorities with responsibility for ensuring capability and capacity for the prompt and effective implementation of such studies should also consider their level of preparedness, as described by Kirby *et al.* (2014) (see Appendix 1).

'Spill(s)' are referred to through the Premiam guidelines and means the spill of any form of contaminant, unless specified otherwise. They are largely analogous to oil pollution incidents[2] and a pollution incident by hazardous and noxious substances[3] as defined in International Maritime Organization Conventions.

2 See Article 2 of the International Convention on Oil Pollution Preparedness, Response and Co-operation, 1990

3 See Article 2 of the Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances, 2000

Part 2

The principles of a monitoring plan

2. The principles of a monitoring plan

2.1 When to monitor

Monitoring is necessary when any spill incident is anticipated to pose a potential for significant environmental and/or public health impact (see Appendix 2). Factors influencing this include the type of oil and/or chemical spilled, or potentially spilled, the quantity, the location, environmental and physical conditions, and the local resources at risk and their sensitivities (Hook *et al.*, 2016).

Assessing the potential significance of the impact from an incident generally requires scientific inputs from modellers, chemists, and ecotoxicologists, along with ecological and fisheries resource information from relevant conservation and fisheries management agencies. As this expertise likely resides in various government departments/agencies or external consultants, it is essential to collate and maintain necessary contact information so that prompt decision-making and action are possible. The process for initiating effective monitoring is also facilitated if agreed emergency response responsibilities are established in advance (Kirby *et al.*, 2014). The decision should consider the physicochemical properties of the spilled substance (density, solubility, volatility, ability to bind to particles, persistence, and reactivity), its hazard to wildlife (including inherent toxicity, bioaccumulation potential and physical smothering) and the public, and the likely movement of the material, whether as a coherent slick, plume, mass or in solution, in relation to the threatened resources.

Initially, detailed information on the scale of the incident may not be available. While incidents rarely result in a total loss of cargo and bunker fuel, using a worst-case scenario model can be a useful starting point until more accurate information is available. This process helps clarify the aims and extent of the monitoring programme based on expected impacts or implications. Monitoring should therefore be considered in the following scenarios:

- When species/habitats of nature conservation importance are likely to be impacted;
- When commercial fish and shellfish stocks are likely to be impacted;
- When other important natural resources are at risk;
- When contamination of the human food chain is likely;
- When an incident may have other human health implications (see Appendix 2).

2.2 Why monitor

Possible drivers for monitoring may include:

- Assessing the impact on species and habitats of nature conservation importance (e.g. in relation to the UK Habitats and species Regulations, OSPAR Convention);
- Evaluating the impact on commercial stocks of fish and shellfish (including aquaculture);
- Determining the impact on the wider ecosystem and its functionality;
- Ascertaining the effect on the human food chain;
- Informing decisions regarding fishery closure or re-opening;
- Evaluating the efficacy of response and clean-up operations;
- Assessing any impact on the local human population;
- Providing evidence to support financial compensation or insurance claims;
- Informing the public on impact and risk.

Even with clear monitoring programme aims and plans, several overlapping aspects should be considered. Clouds of volatile chemicals near population centres with onshore winds may affect the local human population and also impact species of conservation importance (e.g. fish and birds). Major incidents will attract significant media and public interest, necessitating information dissemination in an appropriate manner. Questions such as 'Can I still eat fish?' or 'Is it safe to go to the beach?' are legitimate and need to be answered clearly, and the responses are stronger when supported by sound monitoring data.

Moreover, in many countries and regions, environmental monitoring is a legal requirement as well as a scientific investigation. International agreements and national legislation commonly require authorities to assess, monitor, and report the impacts of pollution incidents and other environmental pressures. Such obligations often include determining the extent of impacts on ecosystems, biodiversity, human health, and socio-economic interests, while informing remedial actions and environmental management objectives. Consequently, effective monitoring is a fundamental component of environmental governance worldwide, supporting evidence-based decision-making, evaluating response measures, and fulfilling both statutory and public-interest responsibilities.

"Monitoring efforts may need to be prioritised, with decisions made by an expert (or expert cell/unit) to ensure optimal use of available resources. The nature of the incident will ultimately determine the specific requirements, which should be assessed on a case-by-case basis."

2.3 What to monitor

The specific elements included within a monitoring programme may need to be limited, particularly in the initial hours of an incident or where resources and funding are restricted or uncertain. Consequently, monitoring efforts may need to be prioritised, with decisions made by an expert (or expert cell/unit) to ensure optimal use of available resources. The nature of the incident will ultimately determine the specific requirements, which should be assessed on a case-by-case basis. However, typical considerations for planning the monitoring programme may include:

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

The primary focus of the monitoring effort will depend upon the concerns identified above and on prevailing priorities.

2.4 Where to monitor

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

- Impacted areas;
- Unimpacted areas that may later be affected;
- Unimpacted reference sites likely to remain unaffected.

All impacted areas should be considered for monitoring, with the geographic scale of the incident guiding the spatial extent of the monitoring programme. Fate and transport modelling can help predict pollutant behaviour and identify the areas at risk for inclusion in the monitoring plan. The maximum size of the impacted area is determined by the extent to which the pollutant might spread. Reference areas outside the impacted zone, with similar characteristics (in relation to sediment characteristics, species of fish and shellfish present, etc.), are vital for comparison, especially where baseline data within the impacted region are lacking. Comparisons between impacted sites and reference sites or background information allow the impacts of an incident to be determined and characterised. Habitat-sensitivity mapping can also provide information useful in the selection of sites to be monitored.

During oil spill incidents (and, potentially, chemical or plastics spills), Shoreline Clean-up Assessment Techniques (SCAT) can be deployed to survey and document affected coastlines, providing timely data for clean-up operations. The SCAT approach has been widely adopted and can also help to direct new or additional monitoring activities. SCAT guidelines, technical papers and manuals are widely available (e.g. Maritime and Coastguard Agency (2007); Shoreline Assessment Manual[4]; OSRL SCAT Field Guide[5]).

4 https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/shoreline-assessment-manual.html
5 https://www.osrl.com/knowledge-hub/resource-library/response/scat-field-guide/

2.5 Monitoring frequency

Several factors influence the frequency of monitoring, and it should be conducted:

- Frequently enough to track changes in status;
- At an appropriate scale – taking account of resource and funding constraints;
- Often enough to ensure that conservation status and objectives are maintained for designated species and habitats of conservation importance in Marine Protected Areas (MPAs);
- For a long enough duration to generate sufficient time-series measurements at multiple sites. This is important for assessing the development of impacts following an incident and the subsequent rates of recovery resulting from applied mitigation measures.

Contamination and the degree of impact can increase rapidly during the initial stages of an incident, as the spilled pollutant is generally present in the environment at its highest concentrations. These concentrations will reduce over time through processes such as dilution, dispersion, evaporation, dissolution, beaching, biodegradation and others. Typically, levels of contamination, such as polycyclic aromatic hydrocarbons (PAHs) from oils, rise rapidly, peak, and then decline over an extended period, with bioaccumulated chemicals expected to follow a similar pattern. Consequently, the frequency of monitoring is likely to be more intensive initially and then scaled back over time to ensure cost-effectiveness. In all post-incident monitoring, a balance should be achieved between the frequency of monitoring and the level of available funding and resources.

> **The frequency of monitoring is likely to be more intensive initially and then scaled back over time to ensure cost-effectiveness.**

2.6 When to stop monitoring

Unlike many traditional monitoring programmes, such as the UK Clean Seas Environment Monitoring Programme (CSEMP), post-incident monitoring programmes are generally not open-ended. However, in some instances, long-term impacts and rates of recovery may warrant continued study over an extended, multi-year timescale. Typically, these programmes are designed to operate for a finite period, ideally informed by an agreed acceptable endpoint, concluding with an impact assessment.

Where practicable, monitoring endpoints should be defined at the outset and revisited as evidence develops. An endpoint is the agreed, evidence-based point at which incident-specific monitoring can reasonably cease because the monitoring objectives have been met and further sampling is unlikely to materially change the assessment or management of the incident. Endpoints should be appropriate to the contaminant, receptor and monitoring objective. They may include return to an agreed baseline or background range, stabilisation of trends, recovery to an agreed reference condition, or demonstration that residual impacts are no longer distinguishable from natural variability or pre-existing pressures. Importantly, an endpoint does not necessarily require complete removal of contamination or restoration to a pristine condition; decisions should consider scientific evidence, environmental benefit, proportionality and the value of continued monitoring.

Additionally, it is important to note that various elements of the programme may commence and conclude at different times due to varying environmental recovery rates across habitats, species, impacted sites, and other variables. Ideally, the end point for each element should be established at the outset to ensure clarity as to when it has been reached and monitoring activities can cease.

For example, in the case of PAH concentrations in commercial shellfish following an oil spill, a logical end point would be when concentrations return to background levels. There is often an assumption that spilled oil or chemicals enter a previously uncontaminated environment and that concentrations should diminish to zero. In the UK and many other regions, this is rarely the case, especially for commonly transported chemicals or widespread contaminants near industrial and urban areas. As noted in this document, natural cycles related to spawning can also influence seasonal variations in lipophilic contaminants in shellfish tissues. Therefore, it is important to establish pre-existing contamination levels before the incident, ideally using baseline monitoring data if they are available; otherwise, this can be estimated by:

- Collecting and analysing samples taken from areas likely to be impacted prior to the arrival of the spilled pollutant;
- Collecting and analysing samples from outside the likely impacted areas but in regions believed to have similar contaminant levels prior to the incident.

The situation is similar for biological effects techniques relevant to oil and/or chemical spill exposure. Background levels of biomarker response may already be elevated due to pre-existing exposure to detectable compounds or other environmental or physiological processes (Lyons *et al.*, 2010; Martínez-Gómez *et al.*, 2010). The International Council for the Exploration of the Sea (ICES) (2011) study group has identified response ranges used as assessment criteria, representing a background response range, an elevated response range, and a high-level response range indicating concern. Monitoring should cease when values derived from relevant biological effects techniques fall within the background response range or the elevated response range typical of the affected area before the incident. Understanding the existing or background levels of contamination and biological markers is important when assessing the additional impact of the incident and can help determine when to cease incident-specific activity.

The aim of ecological monitoring is to track the progress of biological recovery from the spill's effects, particularly for sensitive species and habitats or those of local conservation and food importance. Ipieca defines recovery as 'the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and functioning normally.' Once achieved, this would indicate the point at which monitoring should cease. However, Ipieca notes two important caveats:

- The re-established healthy community may not have the same composition or age structure as that present before the spill;
- It is impossible to determine whether an ecosystem that has recovered from a spill is identical to or different from the one that would have persisted without the spill.

These points stem from the reality that ecosystems are naturally in constant flux, even without the influence of spilled oil or chemicals.

2.7 Coordination and integration

Significant spillages of pollutants into the marine environment can result in adverse environmental and/or public health impacts. Any significant response will likely require a multi-agency/stakeholder approach incorporating various expert providers. Therefore, response plans should include clear guidance on how the related environmental monitoring activities are to be coordinated and managed, both immediately after a spill, and during the longer-term recovery phase of an incident, and how pertinent results will be shared with stakeholders.

Many countries and companies use the Incident Management System (IMS)[6], which is incorporated into international standards via ISO 22320[7]. There are various Sections and Units within an IMS organisation where an environmental monitoring programme can be coordinated and integrated.

6 See the International Maritime Organization (IMO) Guidance Document on the Implementation of an Incident Management System (IMS), available at: https://imo-epublications.org/content/books/9789280115536

7 See https://www.iso.org/standard/67851.html

An efficient monitoring programme will be characterised by effective integration and coordination of relevant activities from various sources. In many cases, the core effort will primarily be delivered by government departments/agencies, but larger, more complex incidents may involve several organisations and include inputs from the responsible party. This is especially the case where responsibilities for different ‘at risk’ resources and zones are not managed by one body. For example, monitoring may be required to assess impacts associated with fisheries, environmental/conservation issues, or human health (from food and/or leisure exposure) in both coastal and/or offshore environments (see Appendix 2).

The range of methods and species considered during post-spill monitoring can be wide, providing options and flexibility within any programme. However, it is important that the approach adopted, species selected for monitoring, and any biological and/or chemical assays are relevant and contribute to a fully integrated post-incident assessment. For example, guidance on integrated biological effects and chemical monitoring has been produced by ICES (Davies and Vethaak, 2012) and incorporated into international programmes (OSPAR; CEMP 2025). While aimed at non-spill-related chemical monitoring programmes, the general principles and approaches can be applied to post-spill assessment strategies.

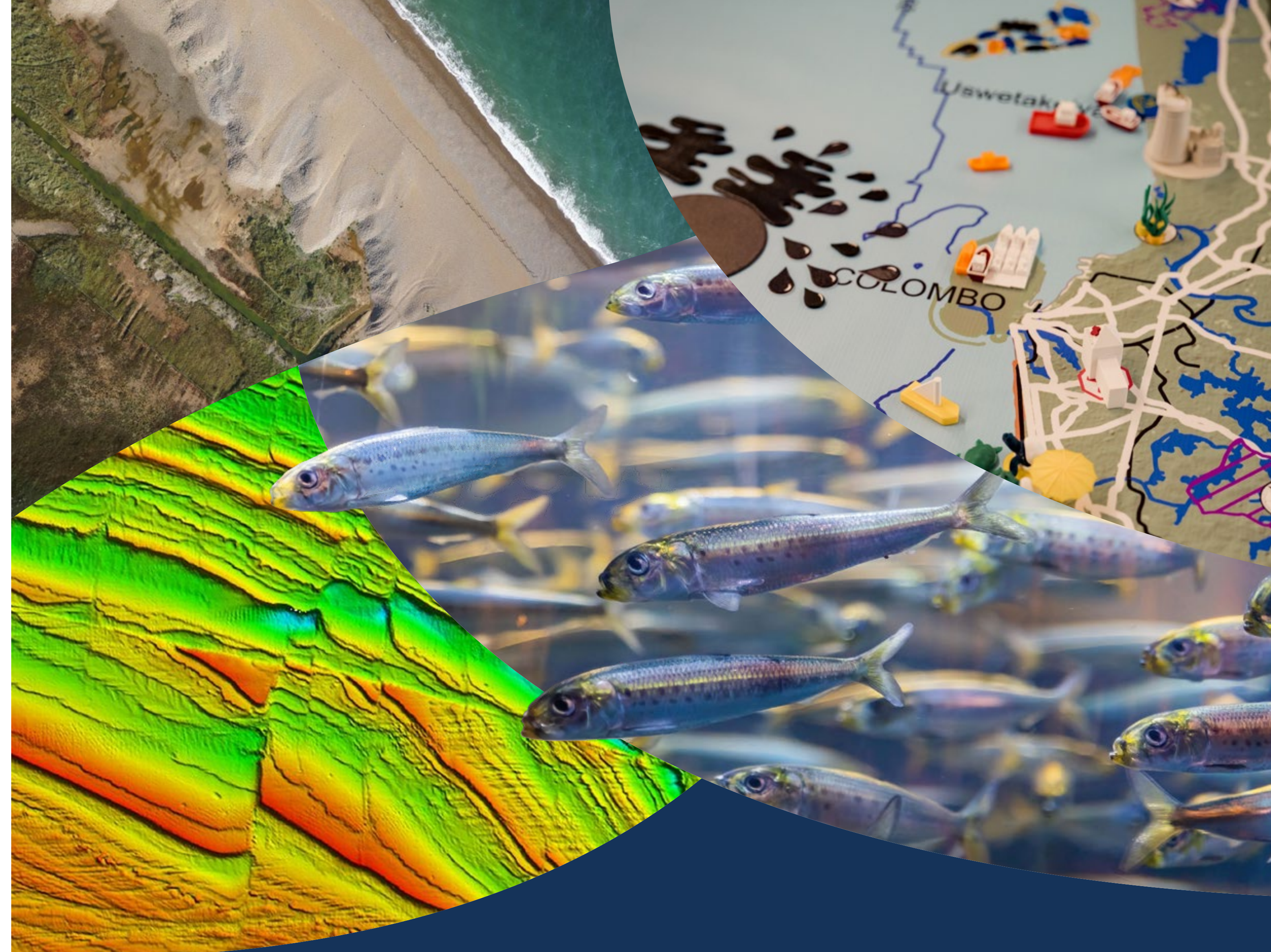
Results from biological methods are more valuable if they can be interpreted alongside chemical analyses taken at the same time and location. Additionally, the selection of methods should consider the ecology of the impacted region to ensure useful interpretation regarding the particular ecosystem. The importance of accurate recording and documentation across all aspects of the monitoring and emergency operations cannot be overemphasised.

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

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

- Routine sampling as part of national or regional environmental quality monitoring (these can be an important source of baseline information);
- Academic studies; universities may use real incidents as opportunities to deploy developmental techniques if funding is available;
- Industry or commercial; if the responsible party (‘polluter’) is identified, they may initiate their own monitoring activities or wish to integrate with and support government-led efforts;
- Voluntary/public activities; local and national groups such as wildlife and conservation associations can provide local knowledge and may initiate their own monitoring activities;
- Efforts should be made to integrate these alternative sources of monitoring information into the overall programme. An example of how the monitoring process is coordinated in England and Wales via the Premiam Monitoring Coordination Cell (PMCC) is outlined in Appendix 3.

“An effective monitoring programme is adaptive, its objectives, scope and intensity evolve with the incident, providing the evidence needed to guide response and demonstrate recovery.”



Part 3

Survey design, planning and implementation

3. Survey design, planning and implementation

3.1 Design

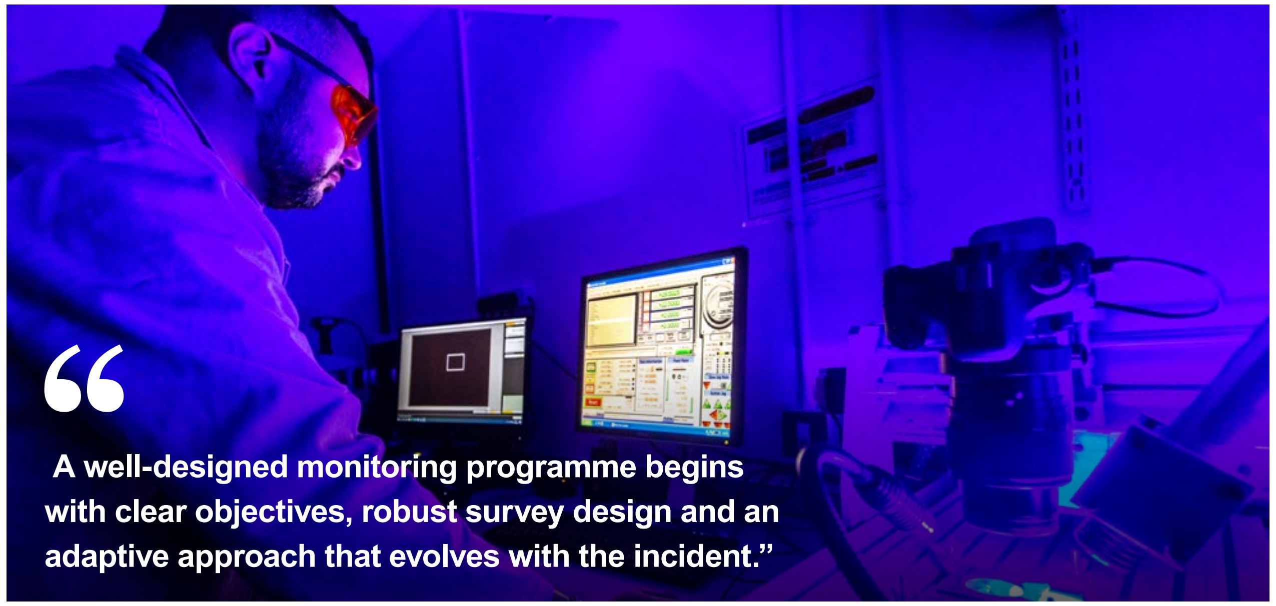
Designing an impact assessment study in the marine environment should be undertaken with considerable attention to detail and is often implemented at very short notice, likely within a few hours of response.

Each incident is unique and many decisions need to be taken which will affect the value of the study and its ability to provide useful conclusions. Therefore, clear objectives should be agreed and set at the start, which are measurable and achievable, but also capable of adaptation to an ever-changing scenario. Survey design and planning will typically include appropriate and effective sampling methods to quantify impacts and support impact assessments. Where an IMS is in use, environmental monitoring objectives should, where appropriate, be considered alongside the wider operational response. This can help ensure that monitoring activities are aligned with overall response priorities and that resource requirements, logistical support, and operational constraints are considered as part of the wider incident management process.

The following sections aim to provide guidance on how to design and plan appropriate studies, but more technical guidance on specific methods requires reference to other literature. Various methodological manuals are available, providing standard methods and procedures that have been used in previous oil spill studies (e.g. Robertson, 2001; Moreira *et al*., 2007; Hook *et al*., 2016).

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

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



It is not usually necessary to investigate all of an ecosystem's components to build up a picture of the impact caused by the incident. Sometimes, indicator species can be selected that will give an indication of the scale and extent of the impact. In general, amphipods (a diverse group of small shrimp-like crustaceans widespread in the marine environment) are sensitive to hydrocarbons in water and are often used as indicators in biological effects studies or sediment bioassays (Gómez Gesteira and Dauvin, 2000; Podlesiska and Dbrowska, 2019). On rocky shores, limpets are another indicator species that may act as a surrogate for the whole rocky shore community (Coleman *et al.*, 2006). Where appropriate, monitoring should focus on the biological elements most sensitive to the pressure caused by the incident, alongside commercially important species that could pose a risk to human health if consumed. The selection of biomarker species should take into account their distribution and abundance. This is particularly important where a fishery ban has been implemented. Effective monitoring supports timely decision-making on when a ban can be safely lifted, helping to avoid unnecessary restrictions and enabling activities to resume with minimal impact on fishers' income and livelihoods. Consideration needs to be given to the distribution and abundance of candidate species when choosing a biomarker species to avoid detrimental impacts to communities from the sampling.

The survey design should aim to establish a link of causation between the impacts and the incident, and this will be a strict requirement if compensation is to be sought under the international oil pollution compensation conventions, such as those administered by the International Oil Pollution Compensation Funds (IOPC Funds)[8]. Appendix 4 provides a useful summary of UK regulations relating to compensation for oil spill impacts from ships.

Survey design is an iterative process, particularly during long-running incidents, as priorities will change as the incident evolves.

There are three main strategies for impact assessment studies following pollution incidents:

- Comparison of post-incident data with pre-incident data;
- Comparison of data from impacted sites with data from reference sites;
- Analysing post-incident data monitored over a period of time to identify a recovery process.

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

3.1.1 Comparison of pre- and post-incident data

Pre-incident data are very valuable to impact assessment studies, so this is the preferred strategy where appropriate data are available (Figure 1). However, even if pre-incident data exist, the quality of those data will greatly affect the conclusions that can be derived from them. There will be a level of uncertainty if the pre-incident data are historic (i.e. data were collected at a time that can no longer be considered representative of the environment), are from a site that was not adversely impacted by the spill, do not include some important parameters (such as PAHs, background hydrocarbon levels, etc., in the case of an oil spill), or are from a location that cannot be identified accurately and/or precisely enough for reliable direct comparison with the impacted area. This is a common issue, as routine environmental monitoring is often designed for different risk purposes, for example, assessing bathing water quality using microbial indicators relevant to human health, rather than capturing parameters needed for spill impact assessment.

8 IOPC FUND: https://iopcfunds.org/

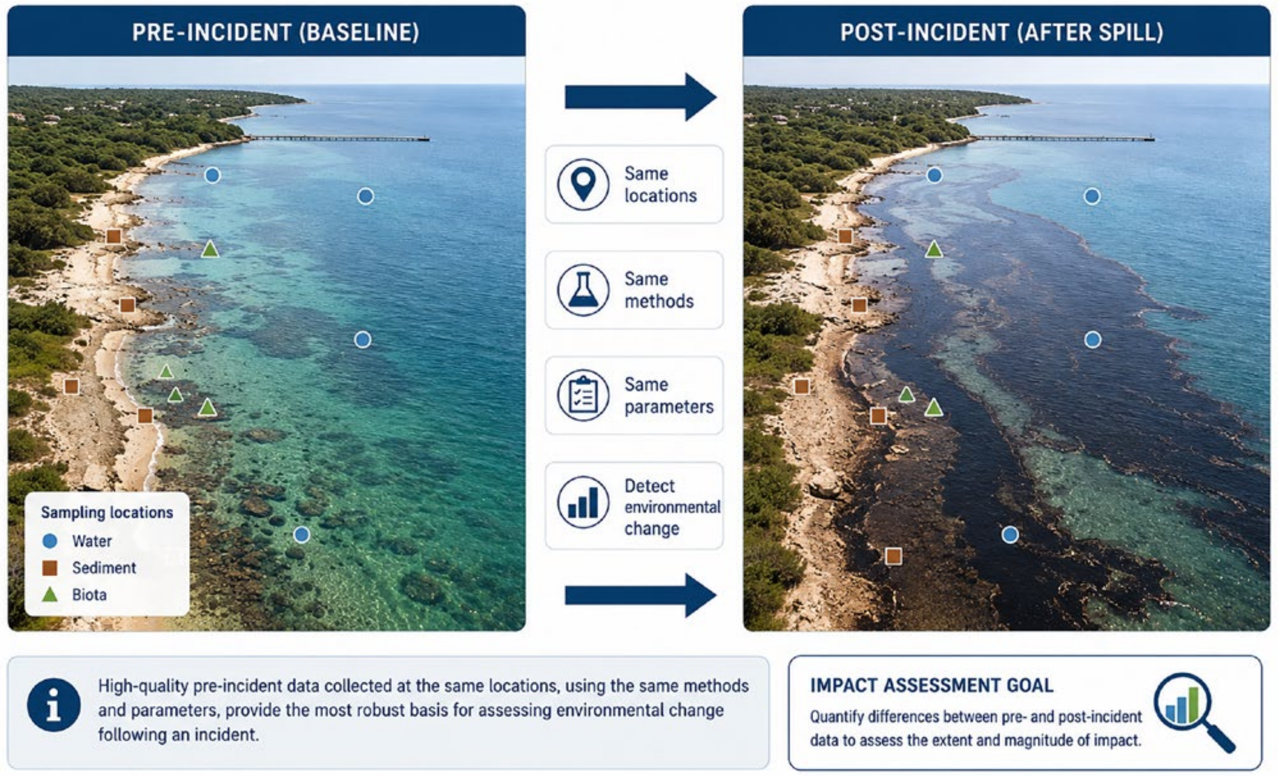


Figure 1: Conceptual illustration of a pre- and post-incident monitoring approach.

3.1.2 Data comparison from impacted and reference sites

This is the most common strategy for assessing post-incident impact and has many advantages for practical planning purposes (e.g. in the event of an oil or chemical spill, sites can be carefully chosen to be representative of the various levels of impact, and the most appropriate parameters can be selected for measurement). However, reference sites are not control sites in a strict scientific sense, and it will never be possible to select reference sites that had identical environmental conditions to the impacted sites prior to the incident. It is, therefore, rarely possible to demonstrate with certainty that differences in the parameters measured between reference sites and impacted sites are attributable solely to the primary or secondary effects of the incident and the pollutant involved. While absolute proof is not possible, very careful selection of reference sites, combined with the collection of good-quality data (i.e. data that are statistically robust) from as many sites as reasonably feasible, can provide a weight of evidence that goes beyond reasonable doubt.

For surveys of biological communities and populations, which are typically spatially patchy, a statistically balanced design would include samples from several impacted locations and an equivalent number of reference locations. In practice, researchers often reduce the number of reference sites; a typical scenario might include ten impacted sites and five reference sites, although the appropriate level of sampling will depend on the circumstances of each incident. Following statistical analysis, even this level of sampling may prove insufficient to detect an impact; however, it typically represents a practical compromise that takes account of available time, financial resources, and statistical rigour. Surveys of chemical contaminants may require fewer samples, due to their more consistent spatial distribution and the relatively low background concentrations that are naturally present in the environment.

3.1.3 Longer-term data analysis for trend and recovery

Where pre-incident data are not available and the impacted resource is discrete (e.g. where it is not possible to collect data from multiple sites and no suitable reference sites exist), it may still be possible to develop a weight of evidence from monitoring at a limited number of locations within and around the affected area. The primary objective of this approach is to identify and describe any recovery process following the incident. If a recovery trajectory can be clearly demonstrated and distinguished from natural temporal trends, this provides evidence that impact must have occurred.

Distinguishing recovery from natural trends will generally require concurrent monitoring of nearby unimpacted sites. Although these sites may not be directly comparable as reference sites, they can provide valuable information on background variability and natural change. Where feasible, this strategy can be strengthened by initiating data collection as soon as possible after the incident, allowing early-stage impacts to be documented and providing a clearer basis for interpreting subsequent recovery.

In some circumstances, it may be possible to collect data before impacts have fully manifested, or while sufficient evidence remains to enable a reasonable description of pre-incident conditions. For example, in certain intertidal and shallow subtidal habitats, monitoring sites may be established and densities of sessile organisms recorded before mortality occurs or organisms are displaced. This approach may also be applicable to some commercial and recreational resources, such as aquaculture, where assessments of stock condition and interviews with staff may be undertaken before losses occur.

Logistical and practical constraints (e.g. oil or chemical contamination obscuring features of interest, safety considerations in impacted areas, or site closures to support spill response operations) may limit the feasibility of this strategy. Nevertheless, it should be considered where circumstances allow, as it can provide valuable evidence to support post-incident impact assessment.

3.2 Establishment of baseline information

Information on the pre-existing baseline environmental data should be gathered in advance wherever possible. National monitoring programmes (e.g. CSEMP in the UK), undertaken by the relevant environmental regulators, may also yield useful information.

Relevant surveys and studies may also have been undertaken by local nature conservation agencies, universities, and research institutes, and these data need to be accessible during an incident. As best practice, a range of data repositories is publicly available and can provide an excellent source of pre-existing data, or direct users to monitoring organisations that hold relevant information. Examples are provided in Table 1.

Table 1: Key marine environmental data sources and repositories used to support spatial analysis, species assessments, and environmental baseline characterisation.

Name	Description	Source
MAGIC	Interactive mapping of the natural environment from across government	https://magic.defra.gov.uk/
MERMAN	Holds UK data collected to fulfil the UK's mandatory monitoring requirements under OSPAR JAMP; these data are used in support of EC directives and national assessments, such as *Charting Progress 2*, and are also supplied to EMODnet	https://texuna.com/DEFRA-Merman
United Kingdom Directory of Marine Observing Systems (UKDMOS)	An internet-based searchable database of marine monitoring conducted by UK organisations	https://ukdmos.org/
Cefas Data Portal	An online portal accessible to the public and UK businesses to explore, download, and reuse Cefas data for research	https://data.cefas.co.uk/
MEDIN Data Archive Centres (DACs) e.g. DASSH	The UK Data Archive Centre for marine biodiversity data for both species and habitats	https://medin.org.uk/
Data.gov.uk	Data published by government departments and agencies, public bodies, and local authorities	https://www.data.gov.uk/
EMODnet	Provides monitoring data that includes biological and chemical sampling, ecological surveys, and environmental monitoring Bathymetry, Biology, Chemistry, Geology, Physics, Seabed Habitats, Human Activities	https://emodnet.ec.europa.eu/en
SeaDataNet	Provides access to a wide range of oceanographic and marine data. The data includes biological, chemical, physical, geological, and geophysical parameters	https://www.seadatanet.org/
ICES Data Portal	Data Portal provides marine biological data, marine environment data, oceanographic data, underwater noise, and cetacean data	https://www.ices.dk/Pages/default.aspx; ICES: https://www.ices.dk/data/data-portals/Pages/Cetaceans.aspx
The NOAA Geoplatform	Offers access to reliable geospatial data, services, and applications. It provides a collaborative space to share authoritative data in various formats towards informed decision-making	https://noaa.maps.arcgis.com/home/index.html
Copernicus	A range of free and open marine data, including satellite and earth observation data	https://www.copernicus.eu/en/access-data
The Marine Protected Area Mapper Site Information Centres	An interactive Geographical Information System (GIS) dataset showing the location, boundaries, and protected features of UK Marine Protected Areas, used for marine conservation and planning	https://jncc.gov.uk/our-work/marine-protected-area-mapper/ https://jncc.gov.uk/our-work/offshore-mpas/
Welsh Atlas Update 2023	A spatial dataset of modelled distributions and abundance of cetaceans and seabirds in Welsh and surrounding waters, used to support marine conservation, planning, and impact assessment	https://datamap.gov.wales/maps/new?layergroup=geonode:nrw_marine_atlas_2023#/
OSPAR QSR23	A regional dataset and assessment of cetacean abundance, distribution, and population trends across the North-East Atlantic, used to monitor marine ecosystem health and inform conservation and management decisions	https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/

> **Information on pre-existing baseline environmental data should be gathered in advance wherever possible."**

The availability of pre-incident monitoring data, and how such data can be accessed, is one of the key topics that any Environment Group/Unit or monitoring coordination cell will aim to address. In the absence of pre-existing baseline information, samples (preferably sediments and biota) may be collected from selected locations and stored frozen for potential future analysis.

Based on spill modelling, baseline samples may be collected from locations along the predicted spill trajectory that can be accessed and sampled prior to oiling. This proactive approach is particularly valuable in the case of chemicals or HNS, for which there is generally a low likelihood that relevant baseline data have been collected previously.

Ideally, sampling locations should be selected to represent both reference sites (unlikely to be impacted during the incident) and sites that are likely to be impacted. Wherever possible, the characteristics of samples collected from both sets of locations will be comparable (e.g. muddy sediments; mussels or fish/invertebrates of the same species). When selecting species, consideration should also be given to local commercial fisheries, ensuring inclusion of species that contribute significantly to landings in terms of quantity or value. Similarly, species and/or habitats of significant nature conservation importance should be considered for inclusion.

3.3 Design process

The following points describe a logical process for designing a survey of a natural resource. Not all steps are carried out in isolation, and several components may be interlinked (see Table 2).

Table 2: Five phases in the development of a natural resource survey.

Phase	Process	Description
1: Identify	Reconnaissance survey	Identify the natural resource of concern; the use of spill models can be valuable in identifying areas most likely to be impacted. Carry out reconnaissance surveys, as necessary, to assess the spatial extent and level of exposure to oil or chemicals.
2: Setting monitoring objectives	Aims and objectives of study	Define the aims and objectives of the study by first clearly understanding the question(s) to be answered. Examples of typical questions and their associated limitations are provided in Table 3.
	Define scope and scale	Define the geographic scope, scale and time limits of the study. A balance is required between the desire to understand the full spatial and temporal extent of effects and constraints relating to budget, accessibility, resources, deadlines and the need to provide timely data and results to support effective real-time decision-making in relation to preventative measures and response actions. A focus on the worst affected areas and typical timescales of effects, with a less intensive strategy for the wider area, may be appropriate.
3: Survey design	Decide methodology and evaluate pre-incident data	Examine existing information from studies of the resources in the affected area or elsewhere (see Section 3.2) to determine whether previously used methodologies are suitable for impact assessment of the oil or chemical(s) involved, whether modified methodologies may be appropriate, or whether new methodologies need to be devised. Evaluate pre-incident data from the affected area to assess their usefulness as a baseline.
	Select parameters	Select suitable parameters and/or attributes for measurement, ensuring that they are capable of detecting relevant change, are technically and logistically feasible within the study timescale, and will produce reliable and reproducible results.
	Ensure quality, consistency & statistical robustness	Select or design appropriate methods to obtain the required data, including preparation of detailed protocols to ensure quality, consistency and statistical robustness. This is important when multiple agencies are responsible for sample collection (e.g. where consistency in sampling and analytical approaches is key to ensuring that the data generated are comparable).
	Understand natural variability	Analyse existing pre-incident data from the site or from similar resources elsewhere (see Section 3.2) to understand the potential levels of natural variability (temporal fluctuations and spatial patchiness) or the influence of other non-spill-related pressures.
	Decide on the required level of accuracy	Decide on the level of accuracy required. Specialists in the resource, potentially supported by a statistician, can interpret information on natural variability and advise on the consequences of under- or over-sampling. This is particularly important where results may be used to support compensation claims or be subject to legal or scientific scrutiny.
	Impact assessment strategy	Decide on the basic impact assessment strategy, e.g. comparison of post-incident and pre-incident data, comparison of impacted and reference sites, monitoring recovery at impacted sites, or a combination of two or more approaches (see Sections 3.1.1 and 3.1.3).
	Data analysis requirement	Consider likely data analysis requirements. It is often advisable to seek guidance on appropriate statistical methods and software packages prior to data collection (see Section 3.8).

Table 2 continued:

Phase	Process	Description
4: Survey planning	Plan survey	Decide how many impacted and reference sites are required, the number of replicate samples or records at each site, and the frequency of survey or sampling, taking account of the objectives and statistical design with appropriate methods.
	Duration of the study	It may be difficult to define or accurately predict the duration of the monitoring campaign. Monitoring may continue until parameters return to a predefined baseline, although this could take considerably more or less time than initially anticipated. As such, decisions regarding the continuation or cessation of monitoring should be informed by the ongoing, real-time review and interpretation of data and results generated from previous sampling occasions.
	Sample and data curation	Define procedures for sample and data storage, tracking and chain-of-custody requirements (see Sections 4.4 and 4.5).
	Health and safety risk assessment, including licences around protected areas and species	Prepare health and safety risk assessments, organise logistics and plan work schedules. Generic assessments and procedures may already exist within relevant agencies. Appropriate authorisations may be required for sampling, particularly in protected areas or involving protected species.
	Forms and databases	Prepare fit-for-purpose recording forms, standard operating procedures, databases and reporting formats, and establish approaches for the timely sharing of results with relevant stakeholders.
	Site selection	Select sites representing different levels of impact, taking account of confounding factors and logistical constraints (see Sections 3.5).
	Methodology, test and review	Test and thoroughly review the methodology.
5: Implementation	Initiate survey	Initiate the survey, taking account of exposure to hazardous substances, weather conditions and the need for appropriate personal protective equipment (PPE). Conduct toolbox talks, implement measures to prevent cross-contamination between samples (Section 4), and ensure adaptive plans are in place should conditions change.

Biological and chemical sampling and ecological surveys are typically undertaken by different personnel, using different protocols and often by different organisations, reflecting the distinct academic disciplines involved. This separation can result in a lack of coordination between the collection of biological and chemical data, creating difficulties for subsequent comparison and correlation, as well as competing for the same logistical resources. It is therefore advisable that liaison between relevant personnel is established at an early stage of planning, to ensure that the two datasets can be assessed later in an integrated manner. This issue of coordination is considered in more detail in Section 2.7.

3.4 Survey evidence requirements and considerations

Questions will need to be addressed clearly, including how the information will be used to support the decision-making process. Table 3 presents the typical questions that a post-spill environmental monitoring survey needs to address and therefore those that may be asked at the start of an ecological impact assessment process following a spill.

Table 3: List of questions to help define the purpose of a survey and highlight associated limitations.

Component	Question	Evidence requirements and considerations
Impact/ exposure	Has the spill impacted the ecological resource?	What characteristics of the resource are of interest? Consider distribution, extent, abundance, productivity, biodiversity, protected status, reproductive capacity, etc.
	How long is the pollutant likely to cause persistent harm to the ecological resource?	Determine the sensitivities of the ecological resource and its potential exposure.
Population	How many individuals were killed by the spill?	Likely to require extrapolation from the data available and will need to be put in the context of information on the regional resources.
	Has the population decreased since the spill?	At what spatial scale?
	Has the population decreased at selected study sites?	Are selected study sites representative of the region? Could decrease be due to natural decline?
	Has the regional population decreased since the spill?	Requires a thorough census and comparable pre-incident data. Valuable for providing regional context. However, if acute impacts are relatively small or localised, they are likely to be masked by natural variability in total population data.
	Can patterns of population changes within the region be correlated with pollutant distribution?	Recognises that there will be natural fluctuations. Requires detailed surveys at numerous impacted and unimpacted sites.
Quality	Has the extent of the habitat decreased?	Similar issues and options as described above.
	Has quality of habitat or community decreased?	Numerous quality attributes to consider.
	Has the productivity or biomass decreased?	Relates well to ecosystem function, but pre-incident data may not be available for many resources.
	Has abundance of important and characterising species decreased?	Good chance that the pre-incident data and well-developed survey methods are available.
	Has species richness or diversity decreased?	Relates well to ecosystem function, but results are often strongly influenced by small differences in methodology and associated protocols.
	Has community composition changed?	Whole community studies are more likely to identify the subtler effects but require more time and effort in sampling and analysis.
	Are juveniles more sensitive than adults?	Juvenile stages are often more sensitive to pollutants, but study methods are often not designed to sample nor distinguish them from adults.
	Has the spill had sub-lethal impacts on the health of wildlife?	Large range of options for study, including growth rates, reproductive capacity and incidence of disease.

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Table 3 continued:

Component	Question	Evidence requirements and considerations
Cause	What is relationship between level of exposure and scale of impact?	Different levels of contamination should be built into the impact studies for most resources.
	Did fresh pollutants have more impact than weathered contaminants?	Toxicity and viscosity of the pollutants are likely to change dramatically during the course of the spill.
	What effects did acute impacts have on ecological processes associated with the resource? I.e. what were the knock-on effects?	Requires wide-ranging study of numerous biological and physical components, particularly where a proportionate response must be determined, as monitoring becomes increasingly challenging further from the immediate impact due to difficulties in establishing causality.
	Did other human activities influence the effects of the spill on the resource?	Understanding the influence of confounding factors will be very valuable to the overall assessment of the spill. However, there may be a lot of such factors. Understanding the influence of confounding factors will be critical to the overall assessment of the spill; however, the number and complexity of these factors may present a significant challenge.
	What physiological or chemical processes caused the impacts?	Likely to be laboratory-based studies. Need to maintain strong link to the reality of natural conditions.
Recovery	How long until resource has recovered?	Return to pre-incident conditions or same conditions as unimpacted reference areas? For most resources, it is likely that risk-based logistical and budgetary constraints will limit monitoring to selected sites.
	How long until resource has returned to pre-incident conditions?	Because natural environments constantly change, resources may not return to exact pre-incident conditions. Recovery should therefore be assessed against the natural variability of nearby comparable habitats.
	How long until resource has same conditions as unoiled reference areas?	Are there unoiled reference areas that are directly comparable? Critics will highlight any differences. Need multiple oiled and unoiled sites to provide statistical power.
	What were natural removal rates of remaining oil?	Natural removal can be surprisingly rapid, although opportunities to study these rates may be limited, as it is unlikely that sites would be left uncleaned solely to achieve a statistically robust survey design where intervention would aid recovery.
	How does recovery progress between start and end points?	A continuous linear progression in recovery is unlikely.
	Do patterns of post-spill changes correlate with level of initial impact?	Understanding thresholds in oiling and recovery rates will be very valuable but will require a lot of time and effort.

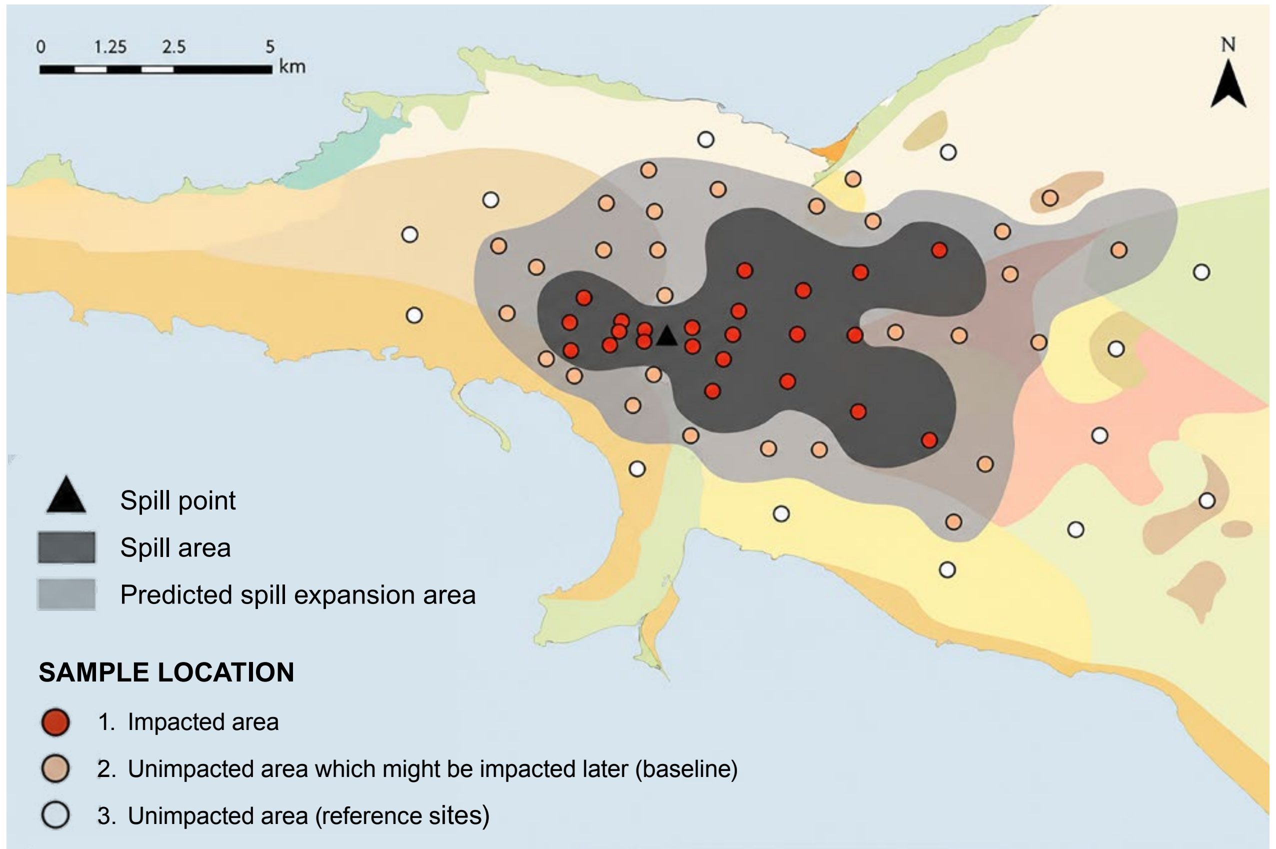
Table 3 continued:

Component	Question	Evidence requirements and considerations
Response	Did the spill response activity have beneficial or detrimental effect on resource?	Often not straightforward. Could involve assessment of short-, medium, and long-term physical impacts; toxicity associated with acute and chronic oiling; impacts of non-oil pollution (e.g. nurdles and other debris/objects); impacts of knock-on effects associated with wildlife; and behavioural (e.g. disturbance) effects. This is particularly relevant to pellet spill clean-ups, where the equipment and methods used for pellet removal may themselves have impacts on biota.
	Did clean up activity of pollutant speed up recovery of habitat/community?	Could be studied at broad scale, assessing recovery on basis of broad parameters like extent; or at site-specific level with more detailed community sampling.
	What effect did dispersants (if used) have on resources?	Will require considerable temporal data on the distribution and concentrations of oil in the water and sediment, and on the ecological resource.
	What was the behavioural response to the clean-up?	Behavioural responses are difficult to study but can provide valuable information to aid the understanding of ecological effects.
	Did habitat restoration measures work?	Assessing the success of restoration activity (e.g. replanting a saltmarsh or stabilising damaged dunes) should be related to the initial objectives of the work.

“Questions will need to be addressed clearly, including how the information will be used to support the decision-making process.”

3.5 Site selection

Site selection is an integral part of survey planning, and station points will need to be selected to ensure that the key questions outlined in Table 3 can be addressed effectively. The selection of sites and station points should take account of key geographical areas, as outlined in Section 2.4, and also consider the frequency, distribution, and occurrence of the resource selected for sampling or recording. Habitat maps can further support site selection (Figure 2) and are available for many intertidal and subtidal areas at a range of spatial scales from statutory conservation agencies, including online resources such as EMODnet (or higher-resolution datasets where available). The distribution (and proportion) of sampling between subtidal, intertidal and shoreline habitats will depend on the properties of the spilled pollutant. For example, after an oil spill, most contamination occurs in shoreline and intertidal habitats because the oil floats and is washed ashore. Therefore, a greater proportion of sampling would be focused on beaches and the intertidal zone, with less sampling in subtidal habitats. In contrast, a water-soluble chemical spill would require more sampling in subtidal waters where the pollutant is dispersed throughout the water column.



MCZ BROADSCALE HABITAT (EUNIS LEVEL 3)

- Intertidal mixed sediments (A2.4)
- Coastal saltmarshes and saline reedbeds (A2.5)
- Intertidal sediments dominated by aquatic angiosperms (A2.6)
- Subtidal coarse sediment (A5.1)
- Subtidal sand (A5.2)
- Subtidal mud (A5.3)
- Subtidal mixed sediments (A5.4)

Figure 2: Hypothetical example of a survey sampling plan, illustrating impacted areas, non-impacted areas which may subsequently become impacted (baseline), and unimpacted areas (reference sites) overlaid on habitat map.

3. Survey design, planning and implementation

Site selection will also need to consider the following guidelines:

- **Level of oiling, chemical impact, or other contamination sources** – Sites and stations should, where possible, represent a range of impact conditions. Shoreline oiling or chemical contamination is often highly patchy; therefore, robust evidence is required to demonstrate the degree of exposure at each site and station, both at the whole-shore scale and at the finer scale of individual stations. Coordination with any SCAT programme that may have been instigated to support clean-up operations is important. In practice, ecological impact is unlikely to be detected from very light oiling (e.g. sheens or small patches of oil) or low-level chemical contamination unless the resource is extremely sensitive and high-quality pre-incident data are available. Reference sites should be comparable with impacted areas (see Section 2.4).
- **Influences from other environmental factors** – Habitat and population quality may be affected by factors such as hydrodynamics, shore height, substratum type, and rock features. As far as possible, stations should be selected to ensure that environmental conditions are comparable across sites.
- **Influences from other human activities or pollution sources** – Locations influenced by recreational use, discharges, heavy fishing activity, or other anthropogenic pressures should be avoided unless these pressures are similarly present at all sites (particularly reference sites) and can be distinguished from spill-related effects, or where suitable baseline data are available.
- **Accessibility** – Sites should be safely accessible without compromising sample collection or transport and should ideally allow repeated access under a range of weather conditions, while not being so accessible that disturbance by the public is likely. Less accessible areas, such as those with difficult terrain or frequent adverse weather conditions, will require additional planning. Monitoring sites that can only be accessed during extreme low tides will generally need to be avoided. Permissions and licences required to undertake monitoring activities should be identified and incorporated into planning at an early stage. A SCAT programme should address accessibility for their ground teams, again emphasising the importance of coordination with potential clean-up operations.
- **Fixed stations** – Fixed sampling stations should be established wherever possible to ensure comparability and repeatability throughout the monitoring programme.
- **Ease of relocation** – Monitoring sites should not be marked using conspicuous indicators (e.g. paint or poles), which may attract attention and lead to disturbance or vandalism. Instead, sites should be identifiable using Global Positioning System (GPS) coordinates, digital photographs, and clear written descriptions.

“The selection of monitoring sites is one of the most important decisions in survey design, underpinning the reliability and defensibility of the evidence collected.”

3.6 Station selection

Station points should ideally be selected along gradients defined by transects radiating from the point source of pollution. The dominant pathways of pollutant transport and dispersal will be informed by hydrodynamic modelling, supported where appropriate by observational or anecdotal evidence of prevailing currents. Transects aligned both parallel and perpendicular to the most likely direction of pollutant transport should be included to maximise the likelihood of detecting contamination and to provide information on reference conditions. The spacing of station points should reflect local hydrodynamic conditions and site characteristics; more closely spaced stations may be required in relatively static environments than in highly dynamic systems.

Once monitoring sites have been selected, it is important to establish them carefully and consistently, as this will directly influence the reliability, accuracy, and comparability of the data collected over time. The following actions are recommended:

- **Coordinate biological and chemical sampling** – Interpretation is significantly improved when biological effects and chemical concentrations are measured at the same locations and within the same timeframes.
- **Record patchiness of oil or chemical contamination** – Pollution from accidental releases is typically unevenly distributed, and distribution and levels of contamination will be highly variable (particularly along the shoreline where the effects of tides can change distribution on a daily basis). Detailed records of contaminant presence and distribution will support later interpretation. Where feasible, similar records can also be made for chemical spills.
- **Record clean-up activity** – Clean-up operations are often patchy, and detailed records of where and how remediation was applied are valuable for subsequent assessment.

- **Identify reference sites** – Reference sites will need to be located in habitats that closely match impacted sites, particularly in terms of substratum, tidal height, natural energy/exposure of the site, and water movement. Considerable effort should be invested in their selection.
- **Accurately record station locations** – Precise recording of sampling station positions is essential to confirm that samples are collected from predetermined locations and to enable repeat sampling for trend analysis. GPS units and digital photography facilitate accurate relocation; however, a consistent and systematic methodology should be adopted to ensure reproducibility across survey teams and over time.

Where photographs of prominent site features are taken, recording the camera position using GPS is also recommended. For maximum reliability, site location sheets should be prepared and include: a location map with access routes; latitude and longitude coordinates (including chart datum); annotated photographs; sketches or diagrams illustrating sampling positions or transects; and brief notes on access, safety considerations, and key habitat features.

3.7 Health and safety

Health and safety considerations are fundamental when designing and implementing a post-spill monitoring programme, as field teams often operate in hazardous and rapidly changing environments. A comprehensive risk assessment should be undertaken at the planning stage and reviewed regularly as conditions evolve. This assessment must consider site accessibility, weather conditions, duration of fieldwork, exposure to hazardous substances, and the specific risks associated with working at sea and/or in intertidal environments. If a SCAT programme has been instigated to support clean-up operations, health and safety issues should have been considered for their ground teams. Integration of the environmental monitoring programme within the overall response will encourage information sharing and avoid duplication.

Accessibility is a primary concern. Monitoring sites should be selected with careful consideration of safe access routes, terrain stability, tidal constraints, and emergency evacuation options. Remote or difficult-to-access locations, such as rocky shores, mudflats, cliffs, or areas only exposed during extreme low tides, require additional planning, appropriate equipment, and possibly specialist personnel. Permissions and licences should be secured in advance, particularly for protected areas. Access must be carried out in a way that preserves sample integrity and does not require personnel to enter hazardous areas, such as zones with high contamination or structural instability.

Weather conditions can significantly affect safety and data quality. High winds, heavy rainfall, extreme temperatures, and rough seas increase risks of slips, trips, falls, hypothermia, heat stress, and vessel instability. Tidal cycles and rapidly changing sea states must be factored into daily planning, with conservative go/no-go criteria established. Continuous weather monitoring and clear communication protocols are essential, and contingency plans should be in place to suspend operations if conditions deteriorate.

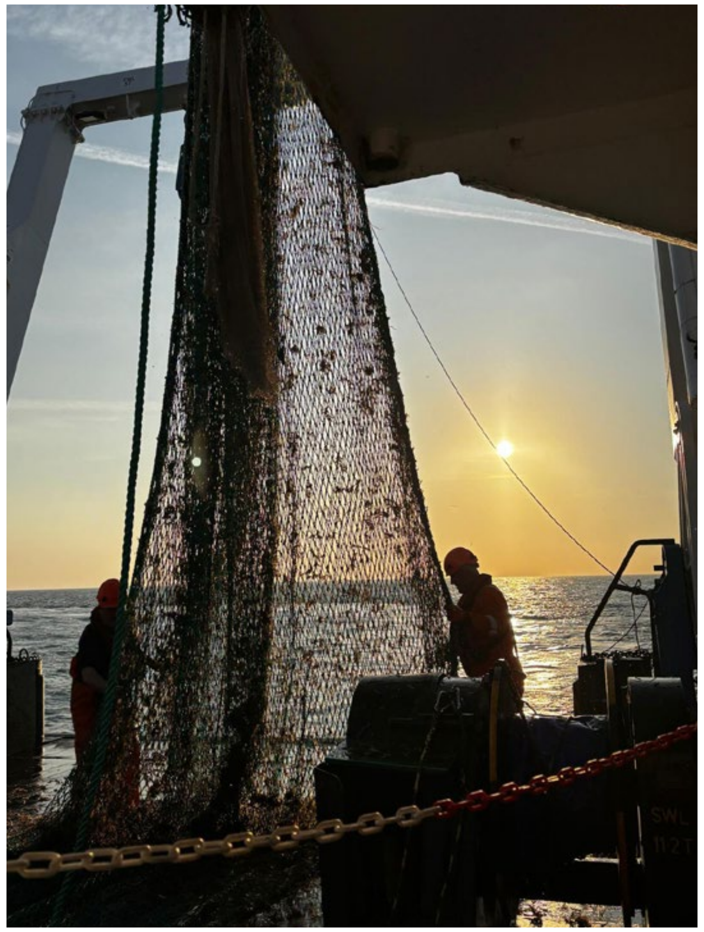
Post-spill surveys often require long working days under physically and mentally demanding conditions. Fatigue management is therefore critical. Work schedules should incorporate adequate rest periods, rotation of tasks where possible, and limits on consecutive long shifts. Supervisors should monitor team wellbeing, recognising that fatigue increases the likelihood of accidents and errors in sampling or recording.

Exposure to oil, chemicals, or HNS, and even non-hazardous materials that have been contaminated presents additional risks. Personnel must be informed of the nature of the contaminant and its potential acute and chronic health effects. Appropriate PPE, such as gloves, chemical-resistant clothing, eye protection, respiratory protection where necessary, and lifejackets, must be provided and properly fitted. Decontamination procedures should be established to prevent cross-contamination between sites and to protect staff, including safe handling, storage, and transport of contaminated samples. Training in hazardous substance awareness and emergency response procedures (e.g. spill exposure, inhalation incidents) is essential.

Working at sea introduces further hazards, including vessel movement, man-overboard risks, and heavy equipment handling. All personnel should receive marine safety briefings and participate in toolbox talks before deployment. In best practice, vessels should comply with maritime safety regulations, carry appropriate safety equipment, and be operated by qualified crew. (For at-sea sampling, personnel are typically required to hold relevant safety certification, such as personal survival techniques and valid seafarer medical certification in accordance with the relevant maritime safety regulations.) Clear communication between scientific staff and vessel operators is vital to ensure safe station positioning and sampling operations.

Health and safety planning should be integrated into every stage of survey design and implementation. Adaptive management, clear communication, and a strong safety culture are essential to protect personnel while ensuring the collection of robust and defensible monitoring data.

It should be noted that this guidance does not represent an exhaustive list of health and safety requirements but instead highlights some of the key fundamental considerations that should be addressed when designing and implementing post-spill monitoring activities.



3.8 Statistical power

The monitoring study will need to be designed to address the key questions identified at the planning stage and to deliver tangible, decision-relevant outcomes. In general, the principal design decisions relate to the number of locations to be monitored and the spatial and temporal frequency of monitoring at each location. Typical considerations include the following aims:

- **1. Pollutant Levels** – Determine whether mean levels of pollutants (or other measured parameters) at the contaminated site are statistically different to those at a reference site. If statistical significance is achieved, it is important to note whether the actual difference is practically significant.
- **2. Pollutant level trends** – Determine whether levels of pollutants (or other measured parameters) at the contaminated site are decreasing or increasing over time; that is, whether there is a downward or upward trend in the magnitude of measured parameters. Such trends may be assessed relative to any corresponding trends observed at reference sites.
- **3. Resource recovery** – Determine whether biological communities at impacted sites are recovering or deteriorating relative to reference site(s).

“If the monitoring programme is not adequately designed to answer the questions posed, the monitoring effort may ultimately represent an inefficient use of time and resources.”

For all of these aims, the concept of statistical power is important. The study design should ensure that sufficient sampling stations and an adequate temporal sampling frequency are able to detect effects with a high probability. For the detection of mean differences (Aim 1), a balance should be achieved between sample size and the magnitude of difference to be detected (call this D), such that the probability of detecting a statistical difference is sufficiently high (for example, 80 %), while ensuring that the chosen value of D is meaningful and protective (though we recognise that it may be difficult to determine D for some substances). If D is small, many observations will be required; if D is large, fewer observations will be adequate. These decisions also have resource implications. However, if the monitoring programme is not adequately designed to answer the questions posed, the monitoring effort may ultimately represent an inefficient use of time and resources.

Similarly, for the detection of trends (Aims 2 and 3), the statistical design of the monitoring programme should provide sufficient power to detect scientifically meaningful changes with a high probability.

The statistical power of a monitoring design is influenced not only by sample size but also by the degree of variability in the data. As variability decreases, the power of the design increases, meaning that fewer measurements will be required for a given power. Thus, if improved field and analytical techniques can be made that minimise the variability of factors within the monitor's control, this will therefore enhance the statistical power of the monitoring programme.

While the discussion above focuses on statistical power in the context of hypothesis testing, it is often equally important to estimate pollutant levels at contaminated sites with a defined level of precision. Sample size and data variability influence precision in a similar manner to statistical power: higher sample sizes and lower variability result in greater precision. Monitoring designs can therefore be selected to achieve an agreed and appropriate level of precision in the results.

Another useful approach when comparing pollutant levels at a contaminated site with a reference level is the application of statistical tests that assess whether pollutant concentrations are below a defined threshold. In this context, the null hypothesis is that the mean pollutant concentration at the contaminated site is greater than or equal to the threshold value, while the alternative hypothesis is that the mean concentration is below the threshold. A contaminated site may be considered 'healthy' only if the null hypothesis is rejected.

In general, these principles of statistical power and precision in monitoring design represent best practice for all types of measured parameters, not solely for contaminant measurements. There are many software packages that can be used to calculate designs for desired power and precision. For example, the R package emon (Barry *et al*., 2017) has functions specifically designed for marine monitoring surveys.

Part 4

Sample collection and management

4. Sample collection and management

4.1 Introduction

Sampling should include both impacted (or potentially impacted) sites and reference (unimpacted) sites, which should, wherever possible, have similar characteristics, as outlined in Section 3.5.

The range of sample types collected will depend on the nature of the incident and may include water, subtidal and intertidal sediments, subtidal and intertidal biota, commercial fish and shellfish, and samples of the spilled oil or chemical(s) from the sea surface, seabed or shoreline. The methods used to collect samples can significantly influence subsequent analysis. For any major spill event, monitoring activities are likely to involve multiple organisations. It is therefore essential that standard procedures are agreed in advance and consistently applied to ensure data quality, minimise the risk of contamination or cross-contamination, and reduce the likelihood of sample loss.

“Maintaining sample integrity from collection to analysis is fundamental to generating accurate, reproducible and defensible monitoring data.”

4.2 Sampling

4.2.1 Equipment and containers

The accuracy of results can be compromised by the containers and equipment used to collect samples, particularly in analytical chemistry and ecotoxicological studies. As dissolved contaminant concentrations are typically very low, even during marine incidents, careful selection of sampling devices is essential, together with rigorous cleaning and decontamination prior to use to prevent contamination or cross-contamination. Organisations undertaking routine analyses will normally have established protocols for sample container selection, handling and cleaning, which should be followed.

Plastics are generally unsuitable for samples intended for the analysis of organic compounds. Many plastics are not resistant to cleaning solvents, and plasticisers such as phthalate esters may leach into samples, causing analytical interference. In addition, organic compounds can adsorb to plastic surfaces, reducing measured concentrations. Glass containers are therefore typically used for organic analyses, although metal containers may be appropriate for sediments, and other inert materials, such as polytetrafluoroethylene (PTFE), may be used for specific applications, including deep-water sampling. Under best practice, all sample containers should be rigorously cleaned with appropriate solvents prior to use.

Some analytical determinands, such as PAHs, are sensitive to degradation by ultraviolet (UV) light. Samples collected for such analyses should therefore be protected from light as far as possible, for example through the use of amber glass containers or by wrapping samples in aluminium foil. Where samples are to be stored at very low temperatures (e.g. −80 °C or −196 °C), containers capable of withstanding these conditions should be used.

4. Sample collection and management

4.2.2 Water sampling

Water samples are typically collected to assess concentrations of dissolved oil or chemicals in the water column but may also be required to assess bacterial communities (e.g. to identify elevated abundances of hydrocarbon-degrading species) or for toxicity testing. Samples of the actual sheen/surface film can also be collected to determine the chemical structure of a pollutant or origin (chemical fingerprinting – see Section 5.3.3). Samples may be required from a range of depths; however, for surface spills, sampling will usually focus on relatively shallow depths. Samples should be collected in appropriate containers (typically glass or Teflon-coated Niskin or Non-metallic free-flushing sampling bottles) and taken below any surface films. Where specialist oceanographic sampling equipment is not available, particularly during the early stages of an incident or where resources are limited, water samples may also be collected using simpler methods, such as a glass Winchester bottle deployed on a hydrowire, provided the approach is appropriate for the monitoring objectives and suitable quality assurance procedures are followed.

A sub-surface water sample is collected using a Teflon-coated Niskin or Non-metallic free-flushing sampling bottle or a glass Winchester bottle deployed on a calibrated wire. The bottle is cocked so that both end caps are held open and then securely attached to the wire. The target sampling depth is determined prior to deployment, often using Conductivity, Temperature and Depth (CTD) data or site measurements. The bottle is lowered slowly through the water column to the desired depth, allowing it to pass beyond surface influence and stabilise.

Once the correct depth is reached, a messenger weight is sent down the wire to strike the release mechanism, causing both end caps to snap shut simultaneously and trap water from that specific depth. The bottle is then retrieved carefully to avoid agitation or contamination. On deck, the air vent is opened before the sampling tap to allow smooth dispensing, and the collected water is transferred into glass bottles following appropriate rinsing and preservation procedures. All relevant sampling details, including depth, time, and location, are recorded to ensure accurate documentation and quality control.

A water sampler is commonly coupled with an instrumented data logger frame to enable the collection of discrete water samples alongside high-resolution *in situ* measurements (Figure 3). In this configuration, the Niskin or Non-metallic free-flushing sampling bottle(s) is mounted directly to the Multi-Sensor Logging Platform frame, typically positioned approximately 50 cm above the Multi-Sensor Logging Platform data logger to minimise hydrodynamic interference from the sensors while ensuring both systems sample the same water mass. The Multi-Sensor Logging Platform package consists of the data logger, a suite of sensors (light, depth, conductivity and temperature, roll and pitch, oxygen, turbidity and fluorescence), and a data streaming pod providing a real-time data feed.

Figure 3: Multi-Sensor Logging Platform data logger with pressure, temperature, and conductivity sensors, in addition to a PAH sensor and a turbidity sensor.

Figure 4: Rosette Water Sampler with a set of Niskin bottles.

At depths greater than 50 m, water sampling for oil and chemicals is typically undertaken using hydrographic sampling bottles, preferably fitted with PTFE internal linings. These are most commonly deployed using a rosette sampler on a hydro-wire, allowing bottles to be closed at predetermined depths either by messenger or by electronic signal from the vessel (Figure 4). This approach also enables the collection of samples from multiple depths at a single GPS-referenced location. Under calm conditions and over a flat seabed, rosette samplers can collect samples to within approximately 1 m of the seabed; in rough seas or over uneven or rocky substrates, a greater clearance (typically 2–5 m) is required. Examples of the application of these methods during the *Deepwater Horizon* incident are provided by Camilli *et al*, (2010) and Hazen *et al*. (2010).

Water samples may also be collected using remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs), particularly where sampling directly above a plume presents elevated safety risks. While the number of samples obtained using these platforms is typically lower than with rosette systems, the same principles apply. Sampling containers should be clean, solvent-rinsed, prevented from opening near the surface to avoid sampling the sea-surface microlayer, and triggered only at depths appropriate to the survey design.

In addition to discrete sampling, oil concentrations may be monitored semi-continuously using fluorometric sensors. The use of sensors and remote sampling technologies is discussed further in Section 5.1.

4.2.3 Sediment sampling

Sediment sampling following an oil or chemical spill serves two primary purposes: to determine whether oil or chemicals have entered sediments, and to assess changes in benthic communities in order to evaluate the extent and severity of seabed impacts from a spill event.

Sediment samples may be collected using a range of techniques depending on the survey objectives, sediment type, water depth, and the level of sample disturbance that can be tolerated. Common methods include grabs, corers, and ROVs deployed from surface vessels. Grab samplers, such as Day grabs, Van Veen grabs, or Hamon grabs, are typically used to collect surface sediments for chemical analysis and benthic ecology studies, providing relatively large sample volumes over a defined seabed area. Corers, including box corers, gravity corers, and vibrocorers, are used where preservation of sediment structure and stratification is important, allowing assessment of contaminant penetration with depth and historical deposition layers.

In shallow coastal or shoreline environments, sediments may also be collected manually using solvent-rinsed stainless steel spoons or scoops and transferred into pre-cleaned glass jars with foil-lined lids to minimise contamination and preserve sample integrity for laboratory analysis. ROV-based sampling systems may be employed where seabed access is difficult, water depths are significant, or precise visual positioning is required, enabling targeted sample collection in sensitive or heterogeneous habitats. In subtidal areas, sampling generally requires a vessel, with sediments collected using grab samplers or coring devices, such as a Van Veen Grab. Smaller versions may be operated by hand from small boats, jetties, or quaysides. This section focuses on grab and corer sampling methodologies; information on ROV-based sampling is provided in Section 5.1.

Further offshore, a range of grab samplers may be deployed from larger vessels, with the choice of sampler largely determined by sediment type. Corers are typically used where information on contaminant accumulation over time is required, as they allow the collection of vertical sediment profiles. In stable sedimentary environments, increasing depth within a core represents progressively older deposited material.

Sediment cores may be dated using radionuclides such as ^210Pb, typically providing age information for sediments deposited over the past ~150 years. However, in post-spill investigations, recent deposition is usually of greatest interest. Consequently, grab samplers, which collect the upper few centimetres of sediment, are most commonly used.

A 0.1 m modified Day grab (Figure 5) is suitable for general-purpose sampling in fine to moderately coarse sediments. In sediments containing stones, the bottom-closing jaws may be held open, resulting in sample loss during retrieval; in such cases, a Shipek grab, which closes laterally using a single jaw (Figure 6), would be more successful in sampling. In coarse or gravel-dominated sediments, a Hamon grab is generally more effective. Where sediment characteristics are uncertain, use of a Hamon grab is recommended, as it is more likely to provide successful samples across a wide range of sediment types (Figure 7). However, samples returned with a Hamon grab are homogenised. If possible, sampling with a Shipek would still be preferable in order to retain an intact sediment surface to ensure targeted sampling where contamination is likely to be highest.

4. Sample collection and management

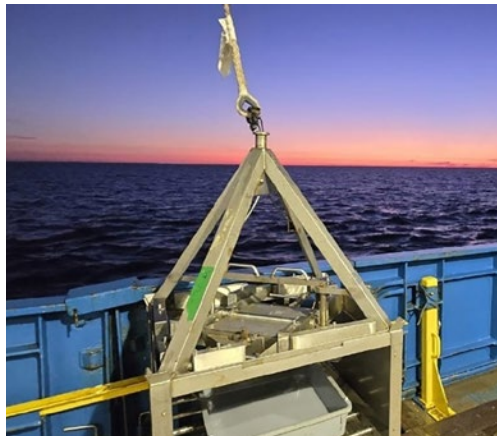


Figure 5: Day grab (0.1 m^2).

Figure 6: Shipek grab.

The choice of sampling gear has important implications for sample integrity and subsequent analysis. The Hamon grab causes substantial sediment mixing during collection and recovery, precluding examination or sub-sampling of an undisturbed surface. Sub-samples therefore represent an integrated sample across the full depth collected, and particle size analysis (PSA) may under-represent coarse sediment fractions.

By contrast, the Day grab allows access to an undisturbed sediment surface, enabling targeted sub-sampling of surface layers. PSA samples obtained using a Day grab are generally considered adequate, provided the device is used only in areas of soft sediments such as sand and mud.

Where undisturbed sediment profiles are required, benthic corers may be used. An example is the NIOZ corer (Figure 8). Recovery of intact sediment cores permits investigation of *in situ* biogeochemical processes and detailed examination of sediment stratigraphy, including the depth of the redox discontinuity layer. An overview of commonly used sediment sampling devices is provided in Table 4.

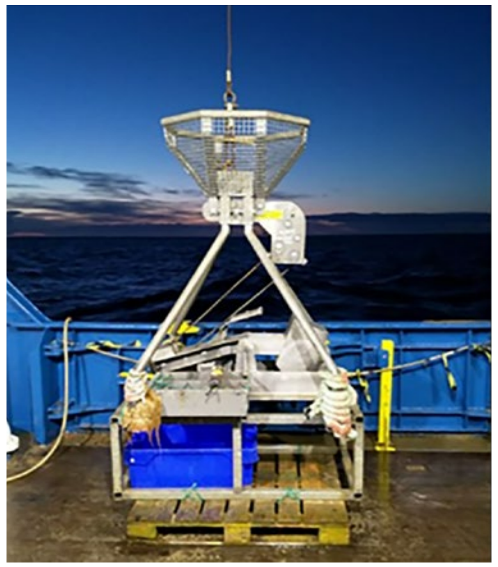


Figure 7: Hamon grab.

Figure 8: NIOZ corer.

Table 4: Overview of sediment sampler types.
PSA = *Particle Size Analysis.*

	NIOZ corer	Day grab/Van Veen	Shipek grab	Hamon grab
Soft sediments	✓	✓	✓	✓
Stony ground			✓	✓
Unknown substrate			✓	✓
Advantages	Preserves stratigraphy; retains undisturbed surface; redox layer identifiable	Retains undisturbed surface; suitable for PSA	Effective in coarser substrates; retains undisturbed surface	Low sampling failure rate
Limitations	Limited applicability during spill incidents; requires vessels with adequate lifting capacity	Requires vessels with adequate lifting capacity; ineffective on stony substrates	Sediment mixing; small volume of sample returned	Sediment mixing; PSA may be unrepresentative; requires vessels with adequate lifting capacity

Surface sediment samples for chemical analysis should be collected from the upper 2 cm of an undisturbed sample and transferred to aluminium or glass containers. Containers should be filled to no more than 80 % capacity to allow for expansion during frozen storage at -20 °C prior to laboratory analysis. Core samples should be extruded and sectioned at 2 cm intervals, with each section stored under the same conditions. Samples for PSA should be collected using a plastic scoop or syringe and stored in tubs or bags at -20 °C. Samples for infaunal analysis should be sieved on board and preserved in formalin. If on-board sieving is not possible, samples can be preserved whole (bulk sediment) or a representative sub-sample can be retained, depending on the size of sediment sample collected. Preserved sediment can then be sieved at the point of faunal analysis.

Mudroch and MacKnight (1994) provide comprehensive guidance on sampling procedures for bottom sediments, suspended particulate material, and sediment pore water. International standards are also available, including ISO 5667-1:2023 *Water quality ® Sampling ® Part 1: Guidance on the design of sampling programmes and sampling techniques*, which provides overarching guidance on sampling design, and ISO 5667-19:2004 Water quality — Sampling — Part 19: Guidance on sampling of marine sediments, which provides specific guidance on marine sediment sampling and was reviewed and confirmed in 2023.

4.2.4 Biota sampling

The collection of macrobiota (primarily fish and shellfish) following an emergency may be undertaken to assess immediate contaminant uptake. Sampling approaches depend on the species and habitats involved. Pelagic fish integrate contamination within the water column, whereas demersal species, particularly flatfish, are more closely associated with contaminated sediments. Shellfish, especially bivalve molluscs, but also crustaceans, occur in both coastal and offshore environments and, due to their relatively sessile nature, readily accumulate hydrocarbons; they should therefore be prioritised for sampling. In areas where aquaculture is significant, farmed fish and shellfish should also be prioritised.

Obtaining fish/shellfish from retail outlets (e.g. fish markets) is not recommended, as point-of-origin information is often unreliable. When assessing potential human health risks, local consumption habits should be considered. For example, following the *Sea Empress* oil spill in 1996, three species of seaweed were included in the monitoring programme because they were consumed locally (Law and Kelly, 2004).

Pelagic and demersal fish are best collected using commercial fishing gear at pre-selected locations from fishing or survey vessels. While survey vessels may offer greater technical capability, the local knowledge of commercial fishers regarding safe and productive fishing grounds is often invaluable. Shellfish and other intertidal organisms may be hand-collected at suitable tidal states or sampled using nets, dredges, or other equipment routinely used by commercial vessels.

Biota should be transported whole to the laboratory on ice or with cool packs where feasible (see Section 4.3; Figure 9). Individual fish should be wrapped in solvent-rinsed foil to prevent contamination, degradation, and dehydration before being placed in plastic bags. As contaminant concentrations may vary substantially between individuals, sufficient numbers of organisms should be collected and analysed, either individually or as pooled samples, to reduce uncertainty. Table 5 provides an example of recommended minimum sample size: a minimum of 100 g is required for metals and PAH analysis, and 500 g is required if performing additional contaminants analysis. Sample sizes should be determined based on expected contaminant variability, following guidance such as the OSPAR Joint Assessment and Monitoring Programme (JAMP) Guidelines (OSPAR, 2012) and Coordinated Environmental Monitoring Programme (CEMP) Guidelines (1999).

Fish and shellfish collected must only comprise animals that are within commercial size range. Immature, juvenile, old or excessively large animals may provide results that are unrepresentative of mature stock that will be harvested for commercial sale/human consumption and should therefore be avoided. In circumstances where less mature stock is being commercially harvested for human consumption, then samples of these smaller animals may be collected for analysis.

In some cases, fish may require dissection ahead of storage if being analysed for certain biomarkers such as 7-ethoxyresorufin-O-deethylase (EROD) activity, 1-hydroxypyrene equivalent (1-OH bile metabolites) or acetylcholinesterase activity (AChE) (Davies and Vethak, 2012; Askem *et al*., 2018; and Dalessandri *et al*., 2023). Dissection should be carried out in accordance with standard protocols and samples stored in liquid nitrogen at -190° C (usually in a dry cryogenic shipper).

Strict avoidance of contamination during collection and transport is essential. Potential on-board sources include sampling gear, fuels, lubricants, greases, engine exhaust, overboard discharges, and contaminated decks or work surfaces.

Table 5: Recommended minimum sample number for shellfish analysis.
Source: Adapted from Food Standards Scotland (2022), Shellfish Sampling Protocol Version 4, September 2022.

Shellfish species	Chemical contamination for 100 g flesh	Chemical contamination for 500 g flesh
King scallops *(Pecten maximus)*	12 - 15	50 - 70
Queen scallops *(Aequipecten opercularis)*	20	80 - 100
Oysters *(Crassostrea gigas or Ostrea edulis)*	20	80 - 100
Otter clams *(Lutraria lutraria)*	12 - 15	50 - 70
Manila clams *(Tapes philippinarum)*	16 - 25	80 - 125
Cockles *(Cerastoderma edule)*	100	500
Shore mussels *(Mytilus spp.)*	80	400

Deck and fish-handling areas should be cleaned regularly, and nets, buckets, and sampling equipment thoroughly washed. Gloves used for sample handling should not be used for general deck duties, and smoking must be prohibited in sample-handling areas due to the presence of PAHs in smoke. All surfaces and equipment should be inspected for contamination (e.g. oil sheen) and cleaned as necessary. Seawater used for washing equipment must be uncontaminated and collected well away from the spill site.

4.3 Sample preparation

It is essential to prevent contamination of samples, cross-contamination, and loss of analytes during storage, preparation, and analysis. Appropriate control measures depend on the analytical requirements and physicochemical properties of the target compounds, and all potential sources of contamination or analyte loss should be identified and controlled.

Some compounds are sensitive to degradation by UV light; where this is the case, UV filters should be fitted to laboratory lighting. Amber glassware should be used at any stage where samples are stored for more than 24h. Where amber glassware is unavailable, transparent containers should be wrapped in aluminium foil to exclude light.

Biota tissue samples are particularly vulnerable due to the time required for dissection. Tissue preparation should therefore be conducted in a dust-free environment, preferably within a laboratory operating under positive pressure with filtered air to minimise particulate contamination. For this reason, sample preparation should be undertaken in a laboratory rather than in the field wherever possible. In some circumstances, however, field preparation may be unavoidable, for example where rapid dissection is required to preserve analytes, or where transporting whole organisms is impractical due to sample numbers or logistical constraints.

The following best-practise steps for shellfish should be followed; more details are outlined in Shellfish Sampling Protocol Version 4.

- Collect the number of individuals outlined in Table 5;
- Rinse or scrub off mud using potable fresh water or local seawater and allow shellfish to drain;
- Prepare separate samples for each required analysis;
- Place shellfish in a strong food-grade plastic bag (double-bag if needed);
- Label each bag clearly with the site name using a permanent marker;
- Complete, sign, and date the sample logsheet (Table 6);
- Securely attach the form to the correct sample (place in a sealed plastic bag to keep dry if needed);
- If necessary, temporarily store samples (up to 4 hours) in a portable container with cool packs;
- Keep samples cool but prevent direct contact with cool packs (use insulation like newspaper);
- As soon as possible, transfer samples to the laboratory cool box;
- Ensure temperature does not exceed 10 °C;
- Do not allow samples to freeze;
- Seal the cool box securely with adhesive tape.

Ideal suggested packaging for samples is shown in Figure 9. Care should be taken to make sure that samples do not come into contact with the ice blocks and become frozen. Frozen samples may not always be accepted for analysis.

> **"It is essential to prevent contamination of samples, cross-contamination, and loss of analytes during storage, preparation, and analysis."**

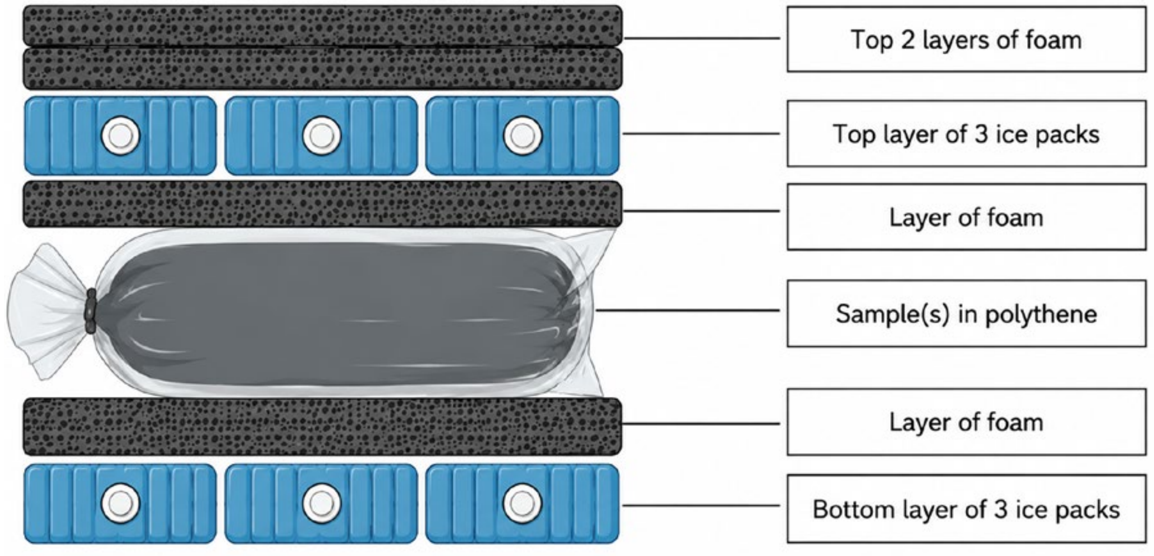


Figure 9: Recommended packaging arrangement for shellfish sample transport, adapted from the Food Standards Agency shellfish sampling and transport protocol (Food Standards Agency, 2022).

4.4 Sample labelling and tracking

Appropriate labelling and tracking of samples are essential to ensure robust and defensible data. A clear chain of custody is required to guarantee the identity and integrity of each sample from collection through to reporting of analytical results and should be applied in all post-spill monitoring studies. While most scientific organisations have established procedures, a common approach should be agreed at the outset of an incident.

Chain of custody is the documented process used to record the chronological history of a sample. Documentation should include a unique sample identifier, the name of the person collecting the sample, details of each individual or organisation subsequently responsible for the sample, its location, the dates of collection and transfer, and a brief description of the sample. A secure chain of custody, combined with validated and quality-controlled analytical methods, ensures the production of reliable and legally defensible data. An example chain of custody form is provided by Yender *et al.* (2002).

The information to be recorded as metadata for each sample is summarised in Table 6, which provides an example log sheet and chain of custody form.

Table 6: Example of a sample chain of custody form.

Sample label information	
Station number:	
Sample number:	
Sample type:	
Sampling date:	
Sampling time:	
Destination laboratory:	
For the attention of:	
Logsheet information	
Station number:	
Sample number:	
Sampling Date:	
Sampling platform (ship) code (if relevant):	
Sampling time (GMT/UTC):	
Site code:	
Location (name, and lat/long or National Grid Reference):	
Position fixing method/code:	
Sample type:	
Sampling method:	
Destination laboratory:	
For the attention of:	
Storage temperature:	
Analysis (or analyses) to be undertaken:	
Additional information:	
Additional information for biota	
Species common name:	
Species scientific name:	
Benthos sample: Y/N	
Additional information for seawater:	
Sampling bottle code:	
Sampling depth (m):	
Filtration method (if used):	
Additional information for sediments:	
Sediment type (visual characterisation):	
Additional information for birds:	
Ring attached?: Y/N	
Ring description and number:	

4.4.1 Sample tracking using barcodes and barcode readers

Managing large numbers of samples requires effective systems for labelling and organisation. A simple and effective approach is the use of barcode labels applied at the time of collection and linked to a database containing full sample information, accessible via a portable digital device. Barcode-based tracking is an important component of quality assurance, ensuring that information on sample location, processing status, and current custody is readily available.

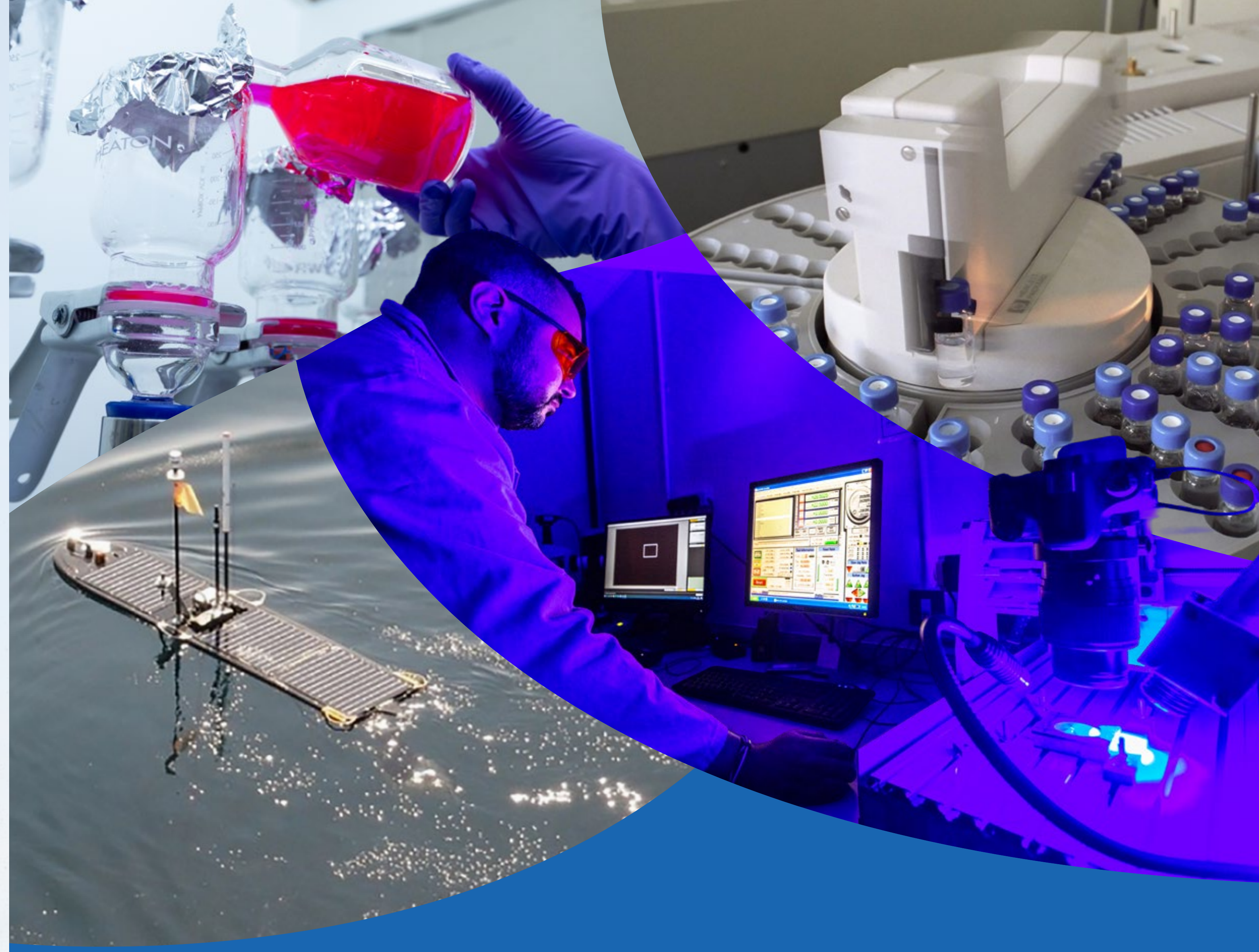
Storage locations (e.g. cupboards, freezers, and shelves) may also be barcoded, allowing sample movements to be recorded by scanning and the database updated automatically. User authentication (e.g. usernames and passwords) is required to transfer responsibility for a sample, thereby providing a secure and auditable chain of custody.

4.5 Transport and storage

All samples should be transferred to the analytical laboratory for storage as soon as possible after collection. Where sampling personnel are not returning directly to the laboratory (e.g. during extended sampling programmes), samples should be transported by priority delivery. Couriers need to be capable of maintaining appropriate sample conditions during transit, including keeping samples frozen where required and preventing contact with potential sources of contamination.

During major or prolonged incidents, laboratories involved in sample storage and analysis may need to procure additional freezer capacity to accommodate the volume of samples generated. Where immediate analysis of all samples is not feasible, priority should be given to those directly informing time-critical management decisions, such as fisheries closures. Samples collected for broader impact assessment purposes may be retained in frozen storage until analytical capacity becomes available, for example, as fisheries are progressively re-opened.

Surface water samples for Volatile Organic Compounds, like hydrocarbons, can be preserved with concentrated hydrochloric acid or they may be unpreserved. Preserved samples have a two-week holding time, whereas unpreserved samples have only a seven-day holding time (USEPA, 2013).



Part 5

Monitoring tools and analytical methods

5. Monitoring tools and analytical methods

5.1 Aerial surveillance and remote sensing

The integration of aerial surveillance and satellite remote sensing has significantly enhanced post incident marine pollution monitoring. Satellite imagery and aerial data offer wide coverage and high-frequency observations, delivering critical information to decision-makers during marine environmental emergencies (Brown & Pearce, 2026).

These technologies provide rapid, largescale assessments of spills and other incidents, enabling more effective response and long-term impact evaluation (Brekke and Solberg, 2005; Garcia-Pineda *et al.*, 2019). National and regional Earth Observation (EO) centres can play an important role in supporting environmental monitoring by integrating data from satellites, aerial platforms, and *in situ* sensors to inform data-driven decision-making and operational response. For example, the Defra Earth Observation Centre of Excellence (EOCoE)[9] champions the use of EO across the UK government, providing access to EO data, analytical tools, and operational frameworks that can strengthen post-incident monitoring and environmental assessment.

5.1.1 Remote sensing and emerging monitoring technologies

Satellite observations offer a comprehensive overview of marine pollution incidents, especially in remote or hazardous areas where *in situ* monitoring is challenging. Key satellite-based techniques include:

Synthetic Aperture Radar (SAR)

SAR is a primary tool for detecting oil slicks and chemical spills on the ocean surface because of its all-weather, day-and-night capability (Brekke and Solberg, 2005; Jafarzadeh *et al.*, 2021). For example, NOAA's Satellite Analysis Branch operates a 24/7 programme analysing SAR and multispectral imagery to identify oil slicks, providing timely spill maps to responders. SAR works by transmitting microwave pulses towards the Earth's surface and measuring the amount of energy reflected back to the sensor. Oil on the sea surface dampens small waves, making the water smoother than the surrounding sea. As a result, less radar energy is returned to the sensor, causing the oil slick to appear as a dark patch on the SAR image (see Figure 10).

One of the drawbacks of SAR is the difficulty in distinguishing mineral oil slicks from other natural phenomena, including (but not limited to) biogenic films/slicks, grease ice, and wind effects that dampen the short surface waves and create dark patches on the surface (Brekke and Solberg, 2005). Biogenic material produced by different types of organisms in the water column can rise to the surface and accumulate as films under low wind conditions (<5 m/s). They are more common in coastal areas during plankton blooms, in upwelling areas and over coral reefs (Alpers *et al.*, 2017). Conventional methods to discriminate between different types of surface features are based on shape, reduction in radar backscatter and image texture.

Additional information, such as the presence of a ship nearby or coastal topography that can cause a wind wake, has also been successfully incorporated (Paolo *et al.*, 2024). SAR images have granular imaging artefacts due to the use of coherent radiation. This type of multiplicative noise poses particular problems to oil spill detection. The effective resolution is generally lower than the image resolution, which means that the minimum slick size detectable can be one order of magnitude larger than pixel size.

9 Defra Earth Observation Centre of Excellence: https://www.gov.uk/government/groups/defra-earth-observation-centre-of-excellence

Multispectral and hyperspectral imaging

Optical sensors, such as Sentinel-2's MSI, can map oil slicks across visible and infrared bands and monitor water quality parameters like chlorophyll concentration and turbidity, which indicate ecosystem health (ESA, 2022). Unlike with SAR, the images are affected by the presence of clouds and by the sun angle, which strongly reduces the coverage but can detect more subtle leaks (such as from historic shipwrecks) as limited noise is present compared to SAR imagery.

Furthermore, depending on the orbits of the satellites, MSI may only be available, which can be used to improve the SAR coverage; it can also assist in the separation from natural slicks. The spectral response or even just the colour can provide information on the nature of the feature (Kolokoussis and Karathnassi, 2018). Additionally, specific oil spill indexes (OSI) have been designed to detect and quantify oil spills using satellite imagery. It leverages the unique spectral properties of oil, which differ from those of water and other substances.

Global coverage satellites, with either SAR or optical sensors, have polar orbits. This results in more frequent coverage near the poles than over the equator, where the orbits are further apart. It should also be noted that some satellites that have global coverage do not routinely capture images over open ocean, which can limit the use in marine settings.

> **"This rapid data access is essential for fast decision-making during large-scale environmental incidents."**

Thermal infrared sensors

Thermal imaging from satellites highlights temperature anomalies associated with pollution. This technique has been used to gauge oil thickness because oil absorbs and re-emits thermal radiation differently from water. A study showed how adding thermal infrared data to hyperspectral imagery can improve the discrimination of oil slick types and even estimate oil film thickness under varying conditions (Yang *et al.*, 2023). Whilst thin oil and sheens are not detected by infrared images (Fingas and Brown, 2014), sheens can be detected using UV sensors due to the high reflectance of sunlight in the UV range; however, this technique is not used extensively due to the fact that thicknesses are not relevant to the oil spill countermeasures (Fingas and Brown, 2014).

Ocean colour and productivity sensors

Satellites such as Sentinel-3, MODIS, and VIIRS monitor ocean colour to evaluate chlorophyll levels and turbidity. Changes in these parameters after an incident can signal ecological stress. By integrating these data, users can track broad-scale environmental health in affected areas (ESA, 2022).

Next-generation satellites and sensors

Future satellite missions and nanosatellite constellations promise higher imaging frequency and improved resolution.Innovations such as NASA–ISRO's NISAR mission and the deployment of CubeSat swarms will further enrich the data available for monitoring marine incidents.

5.1.1.1 Additional observations

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

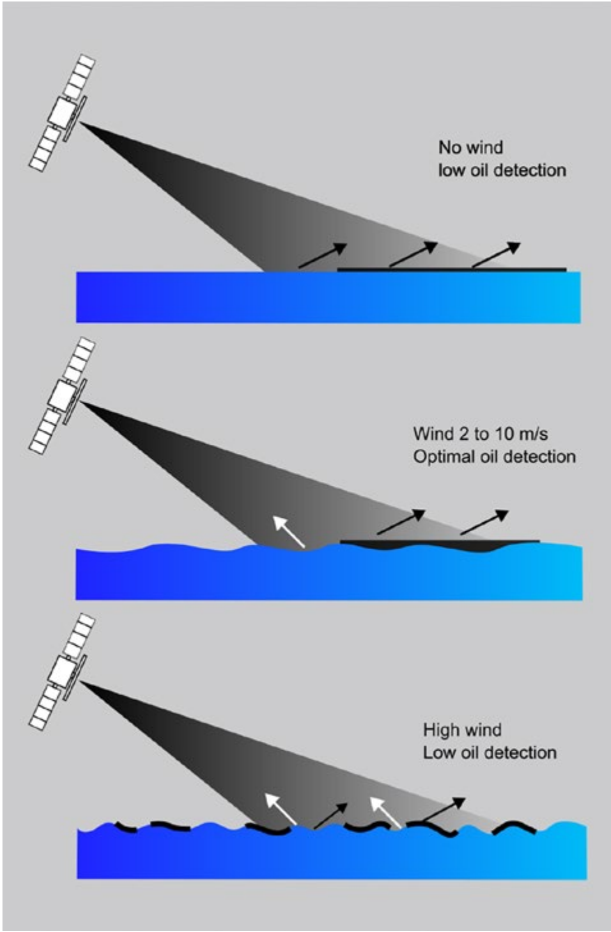


Figure 10: Detection of oil slicks by imaging radar relies on the ability of oil in flattening the surface of the ocean and reducing energy reflected back to the sensor.

5.1.1.2 International Charter

The International Charter "Space and Major Disasters" was initiated by the European and French space agencies (ESA and CNES) and aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters (e.g. tropical cyclones and oil spills, respectively) through authorised users. This means that, in addition to a country's own satellites, through invoking the Charter they are able to access data from all other Charter members, with situations arising where other members' satellites may be switched on specifically to collect data when transiting over the area of interest (Figure 11).

Key points include:

- **Rapid satellite data access** – When a disaster occurs, the Charter can be activated to mobilise satellite imagery from a wide range of international partners, enabling near-real-time monitoring. This rapid data access is essential for fast decision-making during large-scale environmental incidents.
- **Diverse sensor technologies and case studies** – The Charter details how various sensor types (e.g. SAR, optical, multispectral) are used in concert to monitor recent disasters. Detailed case studies on the website demonstrate successful applications in mapping oil spills, floods, and wildfires, highlighting how multi-sensor approaches yield comprehensive situational awareness.
- **International collaboration** – The Charter represents a collaborative framework among governments, space agencies, and commercial satellite operators. It provides a coordinated mechanism for data sharing, ensuring that responders worldwide have access to the best available imagery during disasters. This model has been instrumental in recent events, where rapid data dissemination facilitated timely and effective response efforts.

In major incidents, the International Disaster Charter (https://disasterscharter.org/) can be instigated by the appropriate authorities (the Cabinet office in the UK), which give access to a wide range of optical and radar satellites. In parallel, the Copernicus Emergency Service (https://emergency.copernicus.eu) can provide on-demand mapping and early warning and monitoring services.

By integrating the operational methods and current practices detailed on the Disasters Charter website, members of the EOCoE can benefit from a globally and locally coordinated approach. This collaboration not only enhances data availability during a crisis, but also ensures that post-incident monitoring is informed by the latest technologies and methodologies (Copernicus Emergency; NOAA, 2022; Disasters Charter, 2024).

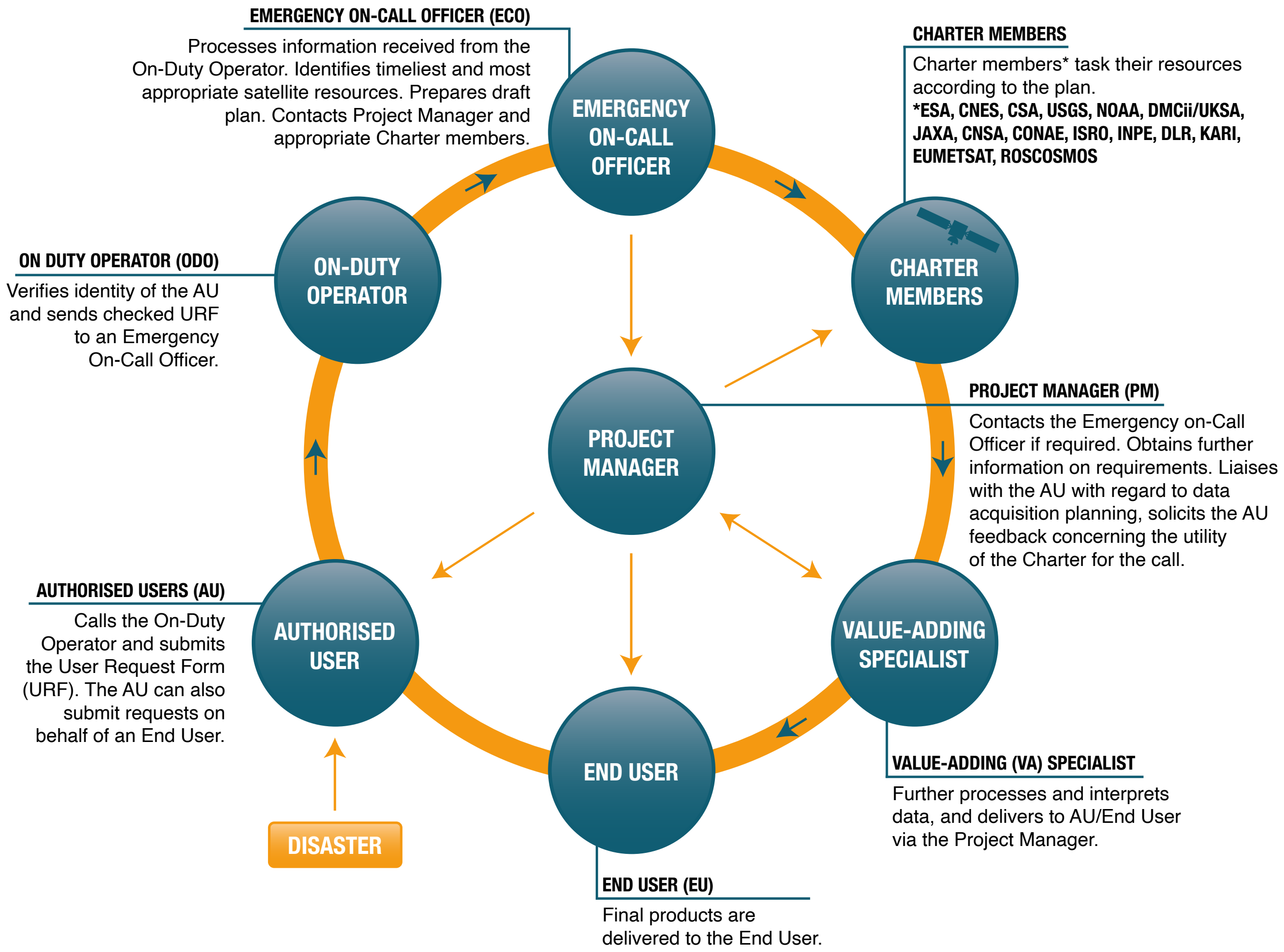


Figure 11: Charter Operational Loop (Source: www.disasterscharter.org).

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

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

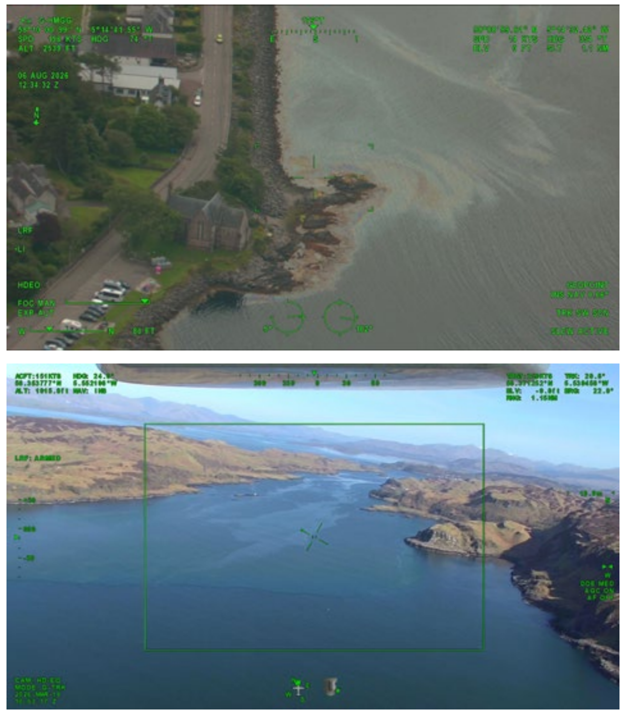


Figure 12: Examples of aerial surveillance imagery used to identify, quantify and monitor marine pollution, including oil contamination in coastal and nearshore environments © Maritime and Coastguard Agency (MCA).

The UNEP/OCHA Joint Environment Unit (JEU), works with partners in the UN, NGO and donor communities to provide environmental data and support to UN Member States during emergencies, including maritime pollution incidents. This support extends to satellite images through the International Charter and incorporates the UNOSAT[10] service.

5.1.1.3 Copernicus Emergency Management Service

The Copernicus Emergency Management Service (CEMS)[11] is part of the Copernicus Programme, the European Union's Earth Observation initiative. It is designed to support emergency response and disaster risk management worldwide using satellite data and geospatial information. CEMS is operational 24/7 and delivers free data and products that help authorities and humanitarian actors understand and respond to emergencies. CEMS can be instigated in major incidents, for example, *MT Terra Nova* in Manila Bay on 25 July 2024. Products tend to be map-orientated rather than imagery.

10 See https://unosat.org/services
11 See https://emergency.copernicus.eu

5.1.2 Aerial surveillance

Aerial surveillance provides a valuable means of detecting and monitoring marine pollution and assessing affected coastal and nearshore environments (Figure 12).

5.1.2.1 Detection

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

5.1.2.2 Impact and recovery

Aerial imagery offers the ability to undertake coastline and intertidal environmental monitoring in a cost- and time-efficient way, and in areas where oil spills have already impacted, manage human exposure risks. The use of aerial imagery also removes the requirement for direct access to the site, which in many intertidal and coastal areas may be limited and/or dangerous. Many aspects of a response to a maritime emergency are likely to benefit from aerial surveillance. This creates pressure on available aerial platforms, particularly in the early stages of a response. The integration of environmental monitoring needs into the overall incident management system allows for coordination and gives the best opportunity for the platforms to be prioritised and utilised efficiently.

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

Utilising both the RGB and IR data allows assessments to be made on the quality of the macrophytes and to identify areas which have been directly or indirectly impacted by a spill. However, to ensure such environmental monitoring is conducted in a consistent manner, a robust post-spill monitoring methodology is required.

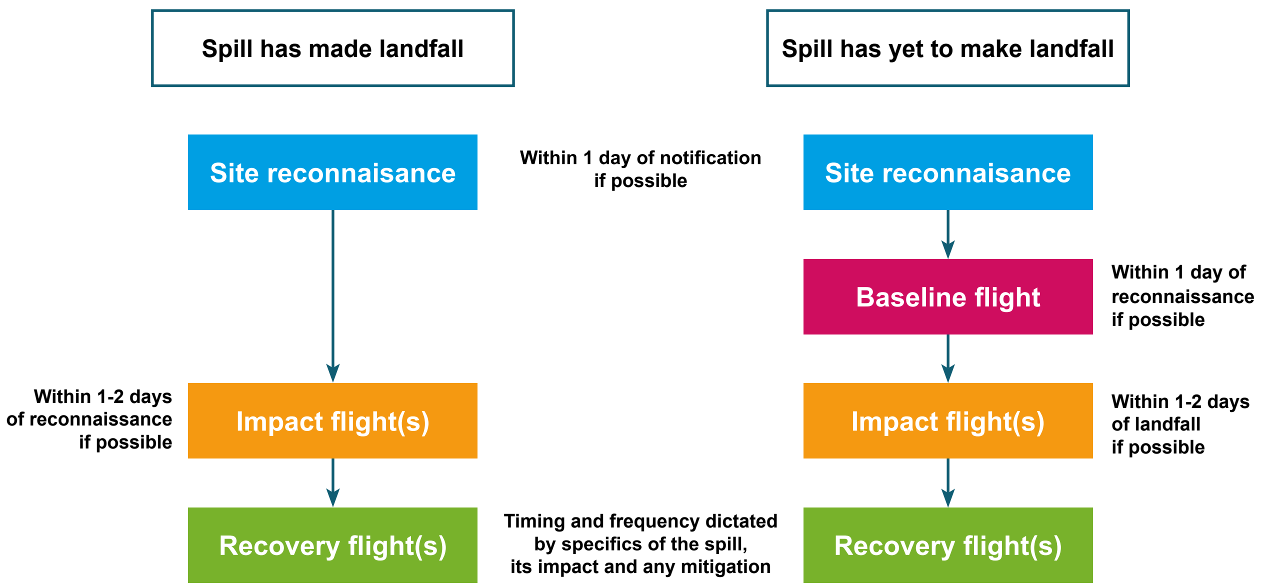


Figure 13: Schematic of the emergency response deployment strategy. Response times are given for each type of survey flight; all timings will be influenced by site and spill characteristics and health and safety considerations. (Source: Bremner *et al.*, 2016).

Associated with the development of technology and legislation around unmanned aerial vehicles, it is anticipated that such monitoring can be most efficiently delivered using remotely piloted aircraft (RPA), with the above schematic (Figure 13) representing a draft methodology for the use of RPAs for such monitoring.

In contrast to manned aerial systems, RPA offer greater flexibility through their ease of mobilisation, enabling surveys to be undertaken at short notice. Their lower operating altitudes also allow surveys to be conducted beneath cloud cover, and their high level of repeatability makes them particularly well suited to monitoring coastal habitat recovery over short temporal scales. This repeatability supports consistent data acquisition, facilitating robust change detection and time-series analysis. However, payload capacity and endurance requirements are critical factors in determining an RPA's suitability for monitoring, particularly where high-resolution sensors, LiDAR, or multispectral equipment are required over large areas.

It is also important to note that RPA operations are subject to aviation regulations. Operators are required to obtain the appropriate licences and operational authorisations from the relevant national aviation authority (e.g. Civil Aviation Authority in the UK or equivalent body in other jurisdictions). This typically involves completing accredited theoretical and practical training, undertaking a flight assessment, developing an operations manual, and obtaining operational authorisation for specific categories of flight. In addition, pilots must complete certified training to demonstrate competency in areas such as airspace regulations, safety procedures, flight planning, risk assessment, and emergency response. Ongoing currency requirements and insurance cover are also generally mandatory to maintain legal compliance.

High-Altitude Pseudo Satellites (HAPS) represent an emerging form of aerial surveillance. HAPS are unmanned, solar-powered aircraft that operate in the stratosphere, offering satellite-like coverage with the flexibility of aerial platforms. Their long endurance and continuous monitoring capabilities may help bridge the gap between traditional satellite passes and on-demand drone missions (Gonzalo *et al.*, 2018).

5. Monitoring tools and analytical methods

5.1.3 Static and autonomous monitoring platforms

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

Systems such as USVs and robotic sailing drones offer the potential for continuous, real-time monitoring. These platforms can complement aerial and satellite data by providing persistent, on-the-ground measurements.

5.1.3.1 Platforms

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

- Fixed infrastructure (e.g. oil and gas platforms);
- Drifters;
- Buoys;
- Instrument moorings;
- Seabed frames;
- Vessel-deployed sensors (e.g. CTD/ROV);
- Autonomous vehicles.

Benefits of such systems is that they allow the ability to detect change over time, with the majority of surface-deployed platforms offering the ability to telemeter data in real-time and facilitate effective management. Subsurface platforms can either return to the surface periodically, in the case of gliders, or can be paired with a surface system for communications. Which platform is most appropriate depends on location, depth, expected duration and the power and size requirements of the sensor payload. Most *in situ* platforms will require vessel support in deployment and recovery.

Autonomous vehicles include:

- Unmanned Surface Vehicles (USVs);
- Undulating buoyancy gliders;
- AUVs.

These mobile systems can be targeted at specific areas of interest (latitude, longitude and depth), which may change over the post-spill monitoring period. Additionally, due to their mobile nature, they can act as sentries around sensitive marine and coastal habitats, providing alerts and informing management of the associated risk. They can, however, be limited by speed, and in regions with strong currents, may struggle to maintain position or follow a spill.

Autonomous vehicles vary in size and capability, from USVs as large as crewed workboats to smaller than a kayak. ROVS and AUVs are routinely used for leak detection in pipelines by oil and gas operators.

5.1.3.2 Key parameters for measurement

In situ UV fluorescence hydrocarbon sensors are tuned for a particular functional group of hydrocarbons, and knowledge of what has been spilt allows the correct filters to be used and the correct calibration coefficients to be applied. Otherwise, any measurements will be a relative measure. These sensors typically fall into two categories: those tuned for crude and those for refined oils (typically using Chrysene as the reference material). Sensitivity is usually in the region of 3 ppb of crude oil, but limits of detection are mostly controlled by interferences.

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

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

a. Surface wind (speed and direction);
b. Currents (speed and direction) – profiles preferable where available;
c. Water temperature – profiles preferable where available;
d. Wave height (significant and maximum) and direction (peak);
e. Salinity – profiles preferable where available;
f. Suspended sediment concentration (seabed and surface);
g. Seabed composition (particle size analysis);
h. Chlorophyll;
i. Water depth.

Additionally, acquisition of water samples for subsequent analysis in the laboratory can offer additional confidence in the sensor and aerial measurements. Automated water sampling systems can be used to collect these samples autonomously, for later validation and classification and *in situ* sensor data.

5.1.4 Artificial intelligence and machine learning

Artificial intelligence is increasingly used to analyse vast remote sensing datasets. Recent deep learning applications have improved the automatic detection of oil spills from Sentinel-1 data, reducing analysis time and increasing detection accuracy (Krestenitis *et al.* 2019).

The integration of advanced satellite and aerial surveillance technologies into post-incident monitoring has made response efforts more data-driven and effective. By exploiting the complementary strengths of satellites (for broad coverage) and aerial platforms (for detailed, on-demand inspection), responders can detect incidents sooner, track their evolution accurately, and deploy mitigation strategies more efficiently.

Ongoing innovations in AI analytics, cloud computing, and autonomous monitoring platforms further enhance these capabilities. As organisations continue to integrate these technologies with established guidelines, the result is a more proactive, informed, and coordinated response to marine environmental emergencies. This not only helps protect marine and coastal resources but also ensures greater transparency and accountability in the aftermath of pollution incidents.

5.1.4.1 The use of artificial intelligence/machine learning (AI/ML)

The accelerating integration of AI and ML into emergency response represents a fundamental shift in how incidents are detected, analysed, forecast, and managed. Although many applications remain in development or early operational deployment, clear technological trajectories are emerging that are poised to significantly enhance response capability, situational awareness, and post-spill monitoring over the coming decade. As computational power increases and data availability expand, AI-driven systems are expected to become central to both real-time operational decision-making and longer-term environmental impact assessment.

EO satellites operating in SAR and visible wavelengths are routinely used to delineate and characterise oil releases (Figure 14). Algorithms are already available to improve the image processing in order to detect oil spills, e.g. Krestenitis *et al.* (2019); Al Hashmi (2024) for SAR images and Cai *et al.* (2024) for optical Landsat images. This trend will only increase as computing power and AI algorithm development accelerates. The Cerulean portal[12] uses neural networks to detect oil spills around the world and uses ship locations from both Automatic Identification System (AIS) and image detection to link pollution events to specific vessels. In parallel, development with the image processing community relating to the unmanned aerial vehicles is rapidly increasing, e.g. De kerf (2024).

Numerical modelling approaches are increasingly incorporating AI techniques to enhance the forecasting of oceanographic conditions and, by extension, the prediction of spill trajectories and potential environmental receptors (e.g. Bisen *et al.*, 2024). AI-driven approaches can augment traditional physics-based models by improving

"Collectively, these developments indicate that AI is moving from a peripheral analytical tool to a core component of marine pollution response and impact assessment."

short-term forecasts, reducing computational demands, and refining spatial and temporal resolution. This is particularly valuable in situations where conventional models operate on coarse grid scales or are updated infrequently (for example, on a daily cycle), limiting their responsiveness to rapidly evolving conditions. By bridging these gaps, AI-enhanced models can provide more timely, granular, and adaptive predictions to support operational decision-making during spill events.

Finally, the broader emergency response framework is particularly well suited to further AI development, given its need to integrate multiple, complex streams of information in real time. By bringing together environmental sensitivity maps, trajectory and oceanographic model outputs,

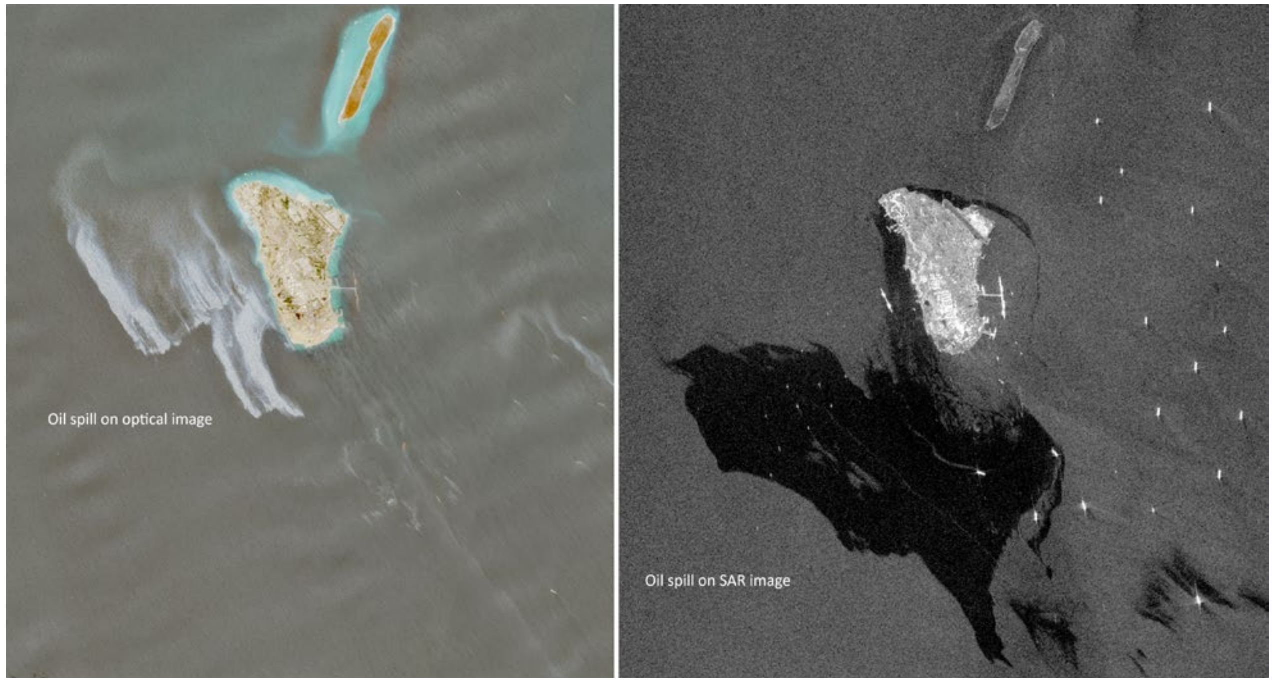


Figure 14. Oil spill around Kharg Island, Persian Gulf, shown in optical imagery (left) and Synthetic Aperture Radar (SAR) imagery (right).

12 https://cerulean.skytruth.org

meteorological forecasts, and available response options within advanced expert systems and decision-support platforms, AI can help synthesise disparate datasets into coherent, actionable intelligence. Such systems could improve the prediction of potential spill pathways, identify high-risk receptors, and evaluate alternative response strategies, thereby supporting faster, more transparent, and evidence-based decision-making. In doing so, AI-driven tools have the potential to significantly reduce environmental impacts both offshore and at landfall. AI systems could also be used to assess the significance of any impacts.

Collectively, these developments indicate that AI is moving from a peripheral analytical tool to a core component of marine pollution response and impact assessment. By integrating satellite and UAV observations, enhancing predictive oceanographic modelling, and embedding decision-support intelligence, AI systems have the potential to significantly improve speed, accuracy, and transparency in both response and post-spill evaluation. As these technologies mature and become more interoperable, they will not only strengthen immediate incident management but also support more robust environmental accountability, adaptive management, and long-term resilience in marine and coastal systems.

AI systems could also play an important role in assessing the significance of environmental and socioeconomic impacts following a spill event; AI-driven analytical tools could support more rapid and consistent evaluation of impact severity. Machine learning models trained on historical incident data may help identify likely short- and long-term ecological consequences, estimate recovery trajectories, and quantify relative levels of risk across affected receptors.

5.2 Modelling

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

5.2.1 Existing spill model types, data requirements and capabilities

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

Various commercially available models are presently available, including OSCAR, OilMap, webGNOME, OPENDrift and OSIS for oil spills, and Chemmap and DREAM for chemical incidents.

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

Table 7: Operational considerations for selection of models.

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

Data required to run the model includes geographical information such as coastlines, seabed depths and (optionally) seabed sediment types. Usually these are pre-prepared, covering the region of potential use, so the necessary inputs to the model can be generated automatically when an incident occurs. For surface slicks, the wind plays a dominant role, and these are generally obtained from meteorological model forecasts provided by national weather forecasting organisations. Also required are water currents, which may also be obtained from publicly or commercially available 3D model forecasts (for example the EU Copernicus site), although such data may not be available in all regions or at sufficient resolution. In some areas, the operational use of HR radars can be used to improve model forecasts (Abascal *et al.*, 2017). An alternative is a database of pre-prepared tidal information that can allow higher resolution near the shore but will not include non-tidal currents such as those driven by wind or density differences. How far into the future oil or chemical spills can be predicted will clearly be limited by the length of the wind or current forecast used.

Similar particle-tracking approaches can also be applied to marine plastic pollution. Models such as OpenDrift[13] have been adapted to simulate the transport, dispersion and accumulation of floating plastic debris and microplastics. These models use many of the same environmental inputs, including winds, currents and coastline data, but may also incorporate processes specific to plastics, such as biofouling, fragmentation, beaching and resuspension. Such modelling can support the identification of areas where plastic debris may accumulate and inform monitoring and clean-up activities.

A summary of the key data requirements for setting up a model simulation are:

- Bathymetry – pre-prepared database;
- Coastline – pre-prepared database;
- Winds – Automatic access to forecasts required;
- Characterisation of the material spilt – either oil or HNS;
- Information on the depth of release and the rate of release;
- Currents – Access to ocean/coastal model outputs and/or database of tidal information;
- Other/Optional – e.g. Seabed sediments, biological species;
- Regular feedback from responders to enable validation of the models, e.g. from airborne monitoring or from SCAT surveys.

13 https://opendrift.github.io/#

The most basic output from spill models typically consists of oil or chemical trajectories on the water. However, most models now provide a wide range of more sophisticated output such as estimates of oil or chemical concentrations in a variety of phases, e.g. suspended or dissolved in the water, or (where information on suspended sediment concentration is available) adsorbed onto particles (Figure 15). Models also generally estimate the quantity attached to the seabed and shoreline, as well as the amount that has evaporated, and some models also allow the calculation of the airborne trajectory of evaporated chemical components. Some models allow testing of the impacts of dispersant on the potential trajectory, for instance, the use of airborne or shipborne spraying. At the most sophisticated level, estimates of concentrations in biota may be calculated. Model stranding locations are often in Geographical Information System (GIS) format, enabling rapid transfer into decision support systems.

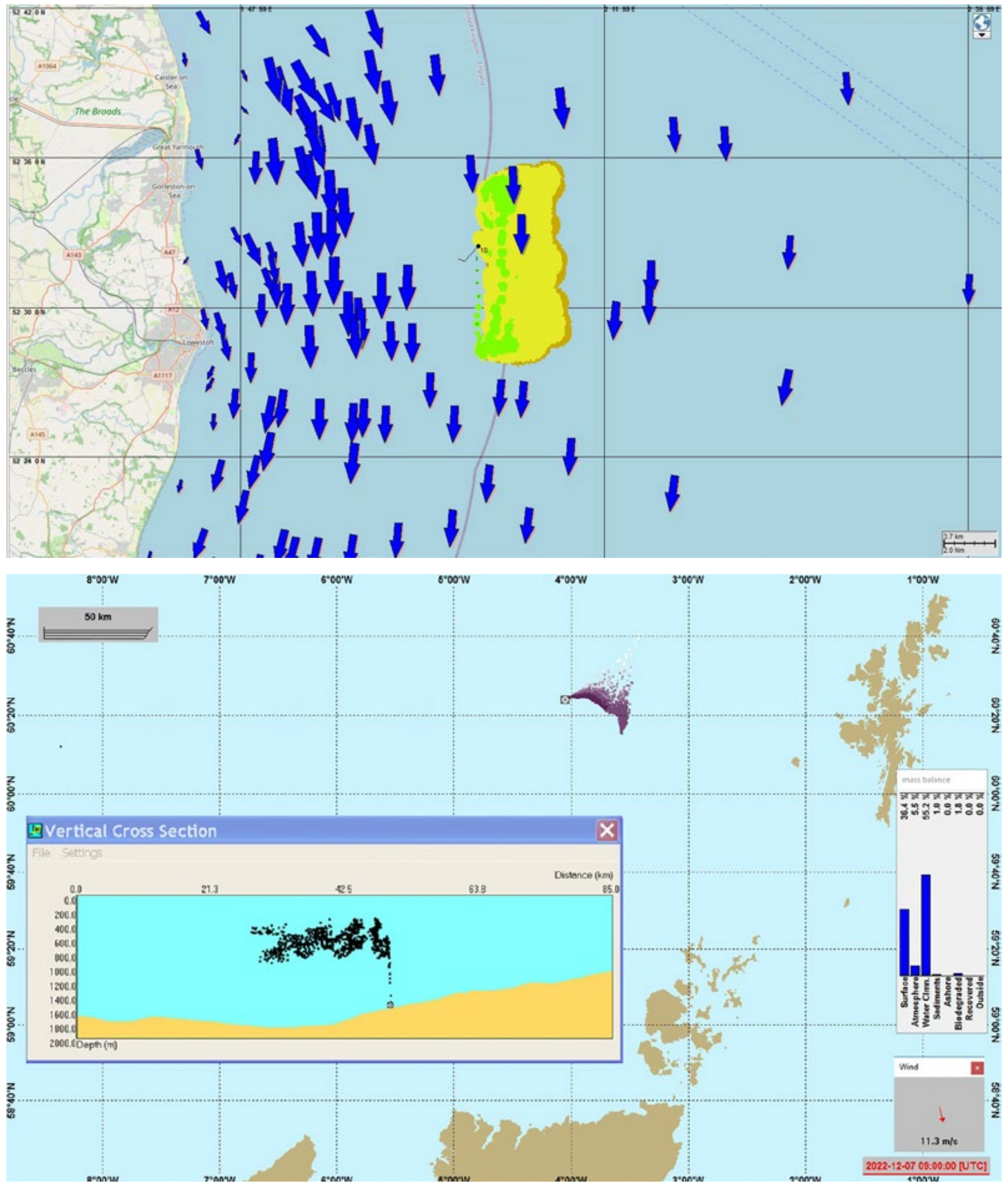


Figure 15: Outputs from chemical and oil spill modelling. The upper panel shows the predicted dispersion of ammonium nitrate, while the lower panel shows a deep-water (>1,000 m) wellhead oil release, illustrating the development and horizontal transport of a subsurface plume within the mid-water column.

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

Standard spill modelling aimed at predicting the path of contaminants during an incident will also suggest areas unlikely to be impacted, giving an early indication of potential unimpacted reference sites for post-spill monitoring. The same modelling could, in principle, also identify sites likely to be impacted within the next 48 hours (for example), allowing the chance to take samples immediately prior to impact. This, however, places some faith in the accuracy of predictions that may not be achievable for a given incident.

More broadly, modelling at this stage of an incident can give an indication of the relative partitioning of contaminants between atmosphere, water column, sediments and shoreline, providing an early indication of where monitoring resources need to be focused. For example, model indications of the quantity of material attaching to seabed sediments would help guide decisions on seabed sampling. Similarly, some models can provide estimates of contaminant concentrations in biota (e.g. fish), and this will inform decisions on whether to monitor these organisms. In practice, however, this relatively sophisticated modelling is more likely to be done in a post-spill context. In all these applications, it is highly desirable that model results can be readily incorporated into a GIS, enabling them to be combined with other information such as locations of environmentally or commercially sensitive areas.

5.2.3 Post-spill monitoring: use of models post-incident

Post-spill, the chance to run a greater range of scenarios and include additional data collected during the incident allows more refined modelling and increased confidence in results. It is at this point that modelling is most likely to be used to help in the identification of priority and reference sites for survey planning purposes, including whether there is a need to monitor seabed sediments. Predictions of biota concentrations might be attempted, although in practice the uncertainties involved and adoption of a precautionary approach might dictate this, irrespective of modelling results.

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

Table 8: Model selection considerations.

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

5.3 Chemical analysis

Chemical analysis is undertaken to characterise contamination, define its spatial and temporal extent, and support source identification and toxicity assessment.

For oil spills, the choice of analytical determinands is largely predefined. Oils are complex mixtures of hydrocarbons, including aliphatics, mono-aromatic compounds (BTEX: benzene, toluene, ethylbenzene and xylenes), and PAHs comprising two to six fused aromatic rings.

An initial assessment of hydrocarbon contamination is typically obtained using *total hydrocarbon* measurements. These may be undertaken *in situ* using fluorimeters mounted on vessels or autonomous platforms (see Section 5.1.3), or in the laboratory following solvent extraction. Extracts, usually prepared using pentane, are analysed by UV fluorescence spectroscopy (Kelly *et al.*, 2000). These approaches provide rapid, indicative information to identify potentially impacted areas.

Where greater analytical resolution is required, for example for source identification or toxicity assessment, more detailed techniques are applied. Combustion-derived PAHs are dominated by parent (non-alkylated) compounds, whereas oils contain more complex mixtures in which alkylated PAHs predominate. While high-performance liquid chromatography (HPLC) is suitable for the relatively limited range of combustion PAHs, its resolving power is insufficient for oil-derived PAHs; gas chromatography–mass spectrometry (GC-MS) is therefore the preferred technique.

A summary of analytical techniques for hydrocarbon analysis and the different possible matrices is given in Table 9.

Table 9: Summary of analytical techniques for hydrocarbon analysis and their use in possible matrices.

Analytical technique	Matrix	*In situ*/ Laboratory	Hydrocarbon compounds
GC-MS Most used common approach, more than adequate for most needs Fully quantitative (e.g. PAHs). Also used for Total Petroleum Hydrocarbons (TPH) methodologies (semi quantitative), oil spill identification and fingerprinting/ forensic analyses GC (may be coupled with Flame Ionisation Detection (FID) instead of MS but less powerful for detailed analyses)	Water, sediment, biota, oil	Laboratory	Relevant oil compounds (including important alkylated PAHs dominant in oil, and biomarkers for fingerprinting) Can be used when food safety is of concern to quantitively measure levels of PAHs to assess against regulatory thresholds
HPLC Insufficient for oil analysis	Water, sediment, biota, oil	Laboratory	Parent PAHs only (not suitable for oil analysis)
UV Fluorescence Spectroscopy Good screening technique for indicative levels of oil contamination Semi quantitative (calibrated against relevant standard oil) – can be used when GC-MS/FID are not available	Water, sediment, biota, oil	Laboratory (some field devices available)	Total Hydrocarbon Content (THC) – all compounds that fluoresce at the relevant wavelength
Fluorimetry – good screening technique for the field Uses sensors, needs calibrating against known oil Semi quantitative – can used from survey boats to generate water column profiles	Water column	*In situ*	Compounds that fluoresce, including relevant PAHs in oil
GC x GC – MS Two-dimensional separation of oil – better resolution than 'standard' GC-MS and more peaks Particularly powerful when combined with high resolution mass spectrometry (HRMS) Advanced technology, requires training and expertise Quantitative and qualitative	Water, sediment, biota, oil	Laboratory	Forensic level detail

Electron impact ionisation produces abundant parent ions for PAHs, and ion-trap mass spectrometers are advantageous as they can operate in full-scan mode without loss of sensitivity. This enables concurrent analysis of aliphatic hydrocarbons and biomarker compounds (e.g. *n*-alkanes, pristane, phytane, steranes and triterpane) within the same samples.

The development of PAH methodologies is described by de Boer and Law (2003), with more recent reviews provided by Law *et al.* (2011), Soursou *et al.* (2023) and Mogashane *et al.* (2024). Techniques applied during the *Deepwater Horizon* incident are summarised by White *et al.* (2016), including two-dimensional gas chromatography (GCGC-MS), which offers improved resolution compared with conventional GC. Although historically less accessible, GCGC is increasingly applied, including for the analysis of novel fuels such as low sulphur fuel oils (LSFOs), for example following the MV *Wakashio* spill (Scarlett *et al.*, 2021).

A range of extraction and clean-up procedures is available, with methods described by Kelly *et al.* (2000) widely applied in oil spill and monitoring studies. In practice, a combination of rapid screening techniques (e.g. fluorimetry) and more time-intensive, high-resolution analyses is typically required. Forensic characterisation and source identification may be undertaken using established standards such as EN 15522-2:2023+A1:2025 (see Section 5.3.3).

5.3.1 Hazardous and noxious substances

Analytical assessment of HNS spills is often more complex due to the wide range of substances transported in bulk or packaged form. Metals, including mercury, can be determined using inductively coupled plasma–mass spectrometry (ICP-MS) (Wilbur and Jones, 2015; Helaluddin *et al.*, 2016). Alternative techniques include graphite furnace atomic absorption spectroscopy (GF-AAS), inductively coupled plasma–optical emission spectrometry (ICP-OES), X-ray fluorescence, cold vapour atomic absorption spectrophotometry, atomic fluorescence spectrometry, and anodic stripping voltammetry.

For organic chemicals, combined liquid chromatography–mass spectrometry (LC-MS) and GC-MS techniques provide broad analytical capability across a wide range of physicochemical properties. Fully validated, compound-specific methods may not exist for many spilled substances, as they are not routinely monitored; however, validated methods should be used wherever possible, or quality assurance procedures clearly documented.

Non-target screening (NTS) approaches using high-resolution mass spectrometry (HRMS) are increasingly applied to detect and semi-quantify unknown or unexpected compounds. These methods are already used in some coastal monitoring programmes (e.g. Environment Agency, England) and are becoming part of the HNS spill response toolbox (Yang *et al.*, 2024). They may be valuable for identifying substances that warrant further targeted analysis. Sample collection typically involves a combination of GC-MS and LC-MS techniques.

Although modern analytical instruments are capable of detecting trace concentrations of many chemicals, the analytical methods employed must be selected according to the substances released. Given the wide range of HNS, multiple analytical techniques are often required to identify and quantify the contaminants of concern. Consequently, the parameters selected for analysis will vary depending on the chemical(s) involved. As many HNS releases are localised and relatively short-lived, timely sampling is essential to accurately characterise the extent and severity of contamination.

5.3.2 Passive samplers

Passive samplers are of limited value during the initial response phase due to the long deployment periods (typically weeks) required to obtain representative data. However, they are well suited to post-incident monitoring, including assessment of recovery and return to background conditions. Their application across Europe has been widely investigated (Miège *et al.*, 2015; Booij *et al.*, 2016; Pintado-Herrera *et al.*, 2020), and they form part of the QUASIMEME framework supporting quality assurance for potential inclusion in the OSPAR CEMP. Passive samplers are also being explored as part of future monitoring strategies to complement, or potentially replace, traditional biota-based sampling approaches (Allan *et al.*, 2025).

5.3.3 Chemical fingerprinting

Environmental forensics can be used to improve understanding of the source of contamination following a spill. It has been defined as the systematic and scientific evaluation of physical, chemical, and historical information to develop defensible scientific conclusions relevant to liability for environmental contamination (Murphy and Morrison, 2015). Chemical fingerprinting forms a key component of this approach and employs a range of analytical methods and target biomarker compounds.

Chemical fingerprinting has been widely applied to oil spills of both known and unknown origin, including the *Prestige* oil spill (Salas *et al.*, 2006; Bartolomé *et al.*, 2007), investigations of unidentified spills in Brazil and Canada (Wang *et al.*, 2009; Lobão *et al.*, 2010), and studies of oil weathering and longer-term spill legacy effects (Scarlett *et al.*, 2024). These approaches are comprehensively described by Wang and Stout (2007) and, more recently, in a volume of forensic oil spill case studies (Stout and Wang, 2018). A summary of relevant methods is provided below and the process is illustrated in Figure 16.

Oil enters the marine environment from both anthropogenic and natural sources, including natural oil seeps. The objective of chemical fingerprinting is to generate and compare diagnostic chemical features among oil samples, including environmental samples and suspected source oils (Stout and Wang, 2007). It also aims to distinguish contamination associated with a specific spill from chronic background inputs and to account for compositional changes resulting from weathering over time. Applications of source allocation techniques following the *Exxon Valdez* spill are described by Short *et al.* (1999), Boehm *et al.* (2001), and Burns *et al.* (2006), with an overview provided by Bence *et al.* (2007). Reviews of oil spill fingerprinting methods are given by Christensen and Tomasi (2007) and more recently by Oliveira *et al.* (2021).

High-resolution gas chromatography–mass spectrometry (GC–MS) is the most commonly applied technique for chemical fingerprinting (Stout and Wang, 2007). Advances in comprehensive two-dimensional gas chromatography (GCxGC) have further enhanced forensic investigations by substantially increasing chromatographic resolving power, allowing the separation of many more compounds in complex mixtures than is possible with conventional one-dimensional GC. This has been demonstrated following its application to the *Deepwater Horizon* spill (White *et al.*, 2016) and, more recently, during the world's first major spill of low sulphur fuel oil (LSFO) in the MV *Wakashio* incident (Scarlett *et al.*, 2021).

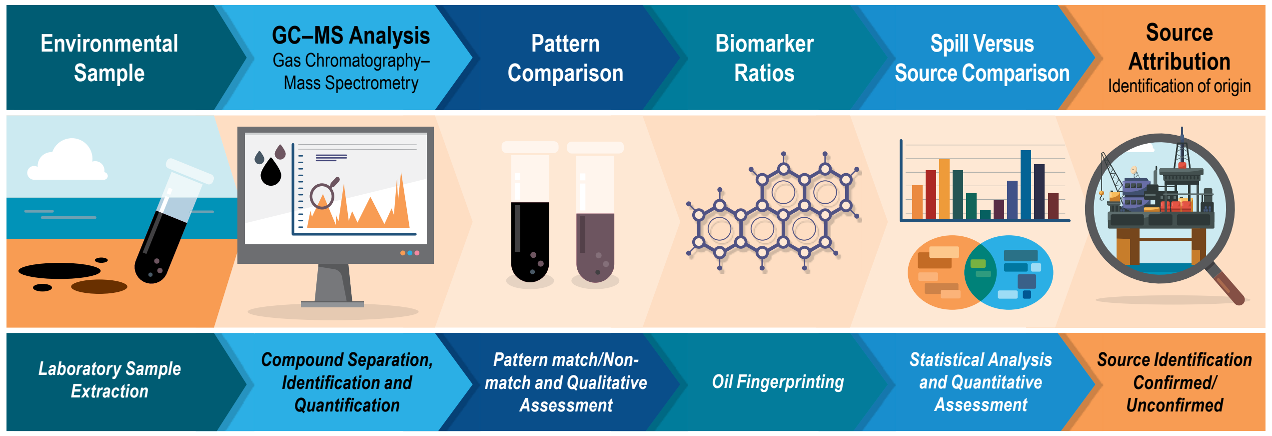


Figure 16: Chemical fingerprinting process.

In GCxGC, increased resolution is achieved by coupling two columns of differing selectivity using a modulator, which periodically traps a portion of the effluent from the first column and injects it into the second column for further separation (Gaines *et al.*, 2007). Owing to the rapid elution of peaks, GCxGC is preferably coupled to a time-of-flight mass spectrometer (ToF-MS), forming a GCxGC–ToF-MS system. Eiserbeck *et al.* (2012) demonstrated that GCxGC–ToF-MS is particularly effective for separating compounds with identical molecular masses and similar fragmentation patterns. This technique was used extensively following the *Deepwater Horizon* spill to investigate weathering processes (Hall *et al.*, 2013; Gros *et al.*, 2014) and more recently in the MV *Wakashio* case.

In GC-MS analyses, both low-resolution (quadrupole or ion-trap) and high-resolution mass spectrometers can be used satisfactorily. When accurate-mass high-resolution mass spectrometry is coupled with two-dimensional GC (GCxGC–ToF-HRMS), compound separation and identification are further enhanced. Suitable instrumental conditions for chemical fingerprinting using GC-MS are described in US EPA Method 8270D (US EPA, 1998) and the European Standard EN 15522-2:2023+A1:2025.

Combustion-derived PAHs consist primarily of parent (non-alkylated) compounds, whereas oils contain predominantly alkylated PAHs. Consequently, post-spill studies typically determine suites of PAHs including C1–C4 alkylated homologues (a representative list is provided by Stout and Wang, 2007). These compounds exhibit numerous isomers, and differences in their relative distributions allow PAH isomer profiles to be used for comparative analysis and source matching between spill samples and potential or known source oils.

Biomarkers (biological markers) are complex hydrocarbon molecules derived from formerly living organisms and occur in crude oils at low concentrations, typically <100 ppm (Wang *et al.*, 2007). Their environmental application has been extensively reviewed elsewhere (Peters *et al.*, 2005a, b; Wang *et al.*, 2006; Wang *et al.*, 2016) and is summarised below. All oil biomarker compounds are derived from isoprene subunits (isoprene: 2-methyl-1,3-butadiene; $CH_2{=}C(CH_3){-}CH{=}CH$) (Peters and Moldowan, 1993). Compounds composed of isoprene subunits are referred to as terpenoids or isoprenoids.

The most commonly determined acyclic isoprenoids are pristane and phytane (2,6,10,14-tetramethylpentadecane and 2,6,10,14-tetramethylhexadecane). On low-polarity GC columns, these compounds elute immediately after *n*-heptadecane and *n*-octadecane, respectively. Both occur in oils; however, pristane is also produced by biogenic sources (e.g. algae). The pristane/phytane ratio can therefore indicate whether hydrocarbons are derived solely from a spill or include natural inputs. These branched-chain hydrocarbons are more resistant to biodegradation than straight-chain alkanes, and changes in the C17/pristane and C18/phytane ratios can be used to track oil biodegradation in the environment (Law, 1980).

The most commonly used cyclic terpenoids in forensic oil spill investigations are steranes and terpanes (see Wang *et al.*, 2007 for a comprehensive list). These compounds are typically identified using extracted ion chromatograms at *m/z* 191 (terpanes) and *m/z* 217 (steranes). Wang *et al.* (2007) also provide extensive reference chromatograms identifying commonly used biomarker peaks, together with illustrative examples demonstrating oil-to-oil variability and the application of pattern matching for source discrimination.

5.4 Ecotoxicology in post-incident monitoring

One of the most important potential impacts of accidental spills into the marine environment is the ability of released substances to cause toxic effects within the receiving ecosystem, so ecotoxicological methods are needed as a complement to chemical analyses. Where contaminants are known and well understood, such effects may be somewhat predicted in advance by evaluating the bioavailability, bioactivity and mode of action associated with specific oils or chemicals. Where a release has already resulted in environmental contamination, *in situ* toxicity can be assessed through ecotoxicological evaluation of affected water, sediment, and effects in biota.

The use of ecotoxicological techniques to assess both potential and actual biological effects during an incident, and throughout the post-incident recovery phase, is central to determining overall environmental impact. These approaches can be incorporated into a planned monitoring strategy (Kirby and Law, 2010; Martínez-Gómez *et al.*, 2010; Radovi *et al.*, 2012). This section provides general guidance on appropriate assessment approaches. While certain core methods are recommended, a broader range of non-standard techniques may be required for specific incidents, for example where substances exhibit particular modes of toxic action or where impacts affect ecologically important or sensitive species.

“The use of ecotoxicological techniques to assess both potential and actual biological effects during an incident, and throughout the post-incident recovery phase, is central to determining overall environmental impact.”

5.4.1 Pertinent questions

When considering whether ecotoxicological techniques should be deployed as part of post-incident monitoring, a number of general questions should be addressed. Although each incident will be unique, consideration of the questions below will help determine the most appropriate ecotoxicological approach.

- What substance has been released, and is it known or suspected to be toxic?
- Where has the spill occurred, and how is it likely to disperse?
- Which key ecological and/or commercially important species may be affected?
- Does the timing of the spill coincide with sensitive biological periods, such as spawning, key developmental or growth stages, or migration?
- What is the likely physical behaviour of the substance in seawater (e.g. evaporation, flotation, sinking, or dissolution)?
- Is the substance persistent and/or likely to bioaccumulate?
- Is there concern regarding short-term acute effects, longer-term chronic effects, or both?
- Has an impact already occurred, and is monitoring of recovery required?

5.4.2 Recommended scenarios for ecotoxicological monitoring

Ecotoxicological methods can be used as powerful tools in post-incident monitoring and the assessment of actual or potential impact. Fundamentally, the decisions about the need for and type of ecotoxicological monitoring will depend on the matrix most likely to be impacted, and will broadly fall into four categories: water, sediment, biota and chemicals.

5.4.2.1 Water

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

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

Water samples to be used in ecotoxicological studies should be taken according to Section 4.2.2. Recommended standard water exposure tests are listed in Table 10.

5.4.2.2 Sediment

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

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

Sediment samples to be used in ecotoxicological studies should be taken according to Section 4.2.3. Recommended standard sediment exposure tests are listed in Table 10.

5.4.2.3 Biota

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

- Where there is a concern that *in situ* biota could have been affected by the contamination (the water/sediment may be still contaminated, or the biota could have been exposed to a transient concentration);
- Where the impacted area contains dominant biota types that can act as good sentinel indicators for the area (e.g. molluscs in shellfish beds, macrophytes in sea grass beds, sentinel fish species if the impacted area is in the vicinity or comparable to marine areas covered by regular monitoring programmes);
- Where there is commercially exploitable biota (e.g. fish or shellfish) in or near the impacted area that rely on healthy populations for sustainable harvesting;
- Where there are concerns for long-term contamination and biological impacts.

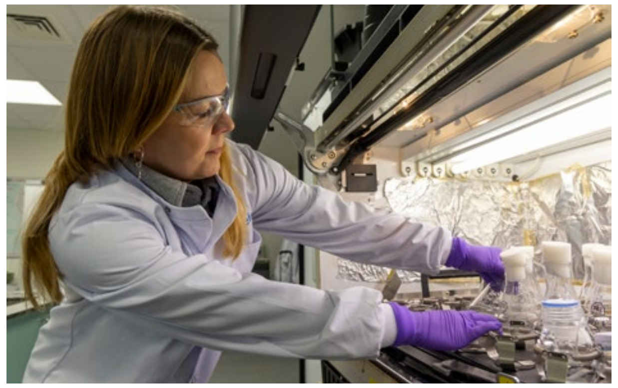
The use of transplanted or caged biota (such as mussels) may be considered where any of the above concerns exist but where naturally occurring specimens are difficult to obtain. Biomarker and specific biota tests are listed in Table 11.

5.4.2.4 Chemicals

Efforts should be made to source relevant toxicological hazard information from the literature or from relevant chemical hazard databases (e.g. GESAMP, 2015, ECHA CHEM[14], US EPA ECOTOX Home[15]) before resorting to novel data generation. Alternatively, modelling approaches such as QSARs (Quantitative structure-activity relationship) (e.g. EPA EPISUITE, US NIH's OPERA or OECD QSAR toolbox) can be used to predict ecotoxicological properties of chemicals of known structure. However, on occasion there may be the need to conduct direct ecotoxicological testing of a specific chemical. These would more often be when a vessel has foundered or is in danger of breaking up and the cargo is still wholly or partially in place:

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

Table 10 and Table 11 describe techniques which can be used to test specific chemicals.



14 https://chem.echa.europa.eu/
15 https://cfpub.epa.gov/ecotox/

5.4.3 Recommended baseline approach

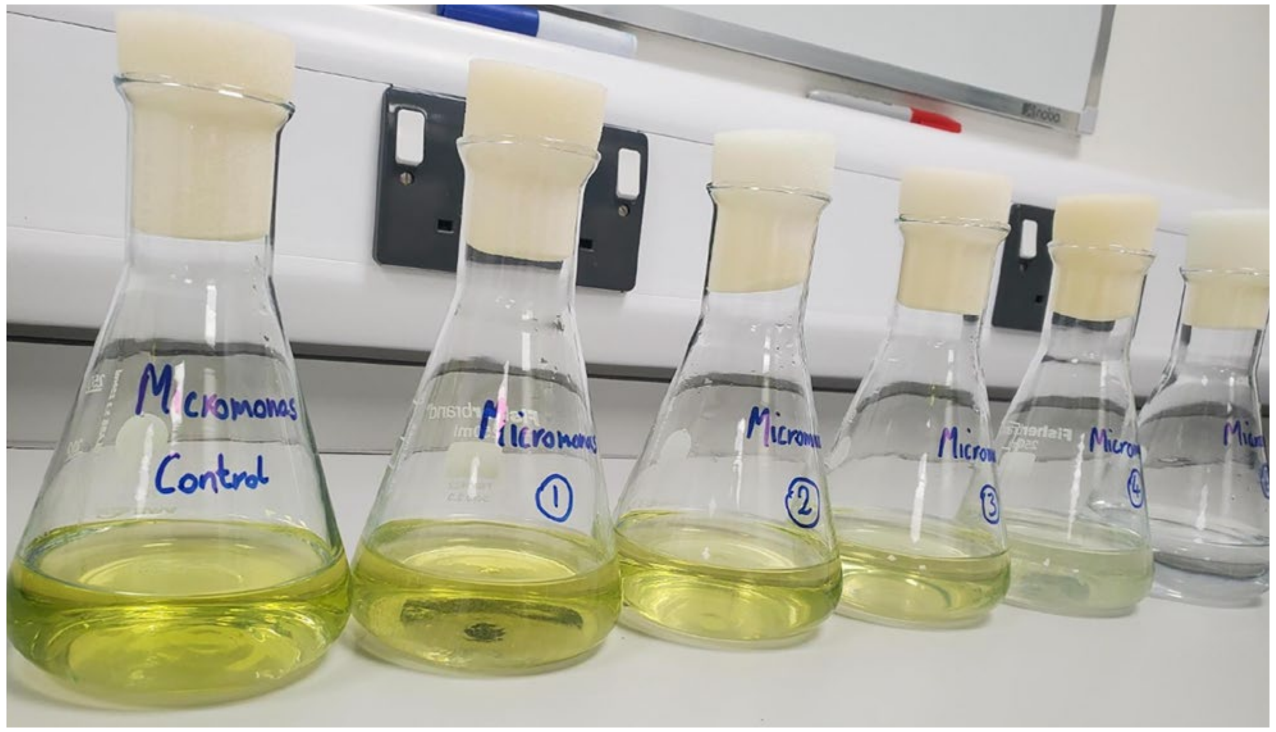
The defined use of specific ecotoxicological methods within an integrated post-incident monitoring programme can be problematic. There are some fundamental differences between monitoring programmes designed to assess long-term temporal trends, such as national marine monitoring programmes, and those required to assess post-incident impacts and recovery (Kirby and Law 2010). However, it is highly recommended that a baseline standard approach is available, including standardised techniques, to facilitate the prompt deployment of testing following a spill incident. Furthermore, where possible, the design and technical content of the baseline programme should follow internationally accepted protocols such as those set out in the OSPAR CEMP (OSPAR, 1997; OSPAR, 2008).

Tables 10 and 11 overleaf outline a suggested baseline approach.

5.4.3.1 Bioassays

Table 10: Recommended baseline battery of bioassays for use in post-incident monitoring.

Water (also relevant for sediment pore waters and elutriates)	
Copepod acute toxicity (*Tisbe battagliai* 48 hr LC50) **Oyster embryo development (*Crassostrea gigas* 24 hr EC50)** **Algal growth inhibition test (*Skeletonema costatum* 72 hr EC50)** ***Aliivibrio fischeri* luminescent bacteria test**	ISO, 1999. ISO 14669:1999(E) Water quality – Determination of acute lethal toxicity to marine copepods (Copepoda, Crustacea). Leverett, D. and Thain, J. 2013. Oyster embryo-larval bioassay (Revised). ICES Techniques in Marine Environmental Sciences No. 54. 34 pp. ISO, 2006. ISO 14442:2006(E) Water quality – Guidelines for algal growth inhibition tests with poorly soluble materials, volatile compounds, metals and wastewater.
Sediment	
Amphipod whole sediment bioassay (*Corophium volutator* 10 d LC50) **and/or,** **Polychaete whole sediment bioassay (*Arenicola marina* 10 d LC/EC50)** ***Aliivibrio fischeri* luminescent bacteria solid phase test**	Thain, J. and Roddie, B., 2001. Biological effects of contaminants: *Corophium* sp. sediment bioassay and toxicity test. ICES Techniques in Marine Environmental Sciences no. 28. 21 pp. Thain, J. and Bifield, S., 2001. Biological effects of contaminants: Sediment bioassay using the polychaete Arenicola marina. ICES Techniques in Marine Environmental Sciences no. 29. 16 pp. Env Canada 2002. Biological Test Method. Reference method for determining the toxicity of sediment using luminescent bacteria in a solid-phase test. ISBN 0-660-18911-9. Cat En49-24/1/54E.
Chemical	
Where direct chemical toxicity is required, any of the above recommended tests can be deployed using serial dilution or sediment spiking methods.	ISO, 2006. ISO 14442:2006(E) Water quality – Guidelines for algal growth inhibition tests with poorly soluble materials, volatile compounds, metals and wastewater. ISO 2007. ISO 11348-3:2007. Water quality – Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test) – Part 3: Method using freeze-dried bacteria.



5.4.3.2 Biomarkers (short-term)

Table 11: Recommended baseline battery of biomarkers for use in post-incident monitoring.

Test matrix	Recommended method	Reference
Vertebrates – fish Dab (*Limanda limanda*) Flounder (*Platichthys flesus*) Plaice (*Pleuronectes platessa*) Cod (*Gadus morhua*)	EROD activity	Stagg, R., McIntosh, A., and Gubbins, M. J. 2016. Determination of CYP1A-dependent mono-oxygenase activity in dab by fluorometric measurement of EROD activity in S9 or microsomal liver fractions. ICES Techniques in Marine Environmental Sciences No. 57. 21 pp.
	PAH metabolites in bile	Ariese, F., Beyer, J., Jonsson, G., Visa, C.P. and Krahn, M.M., 2005 Review of analytical methods for determining metabolites of polycyclic aromatic compounds (PACs) in fish bile. ICES Techniques in Marine Environmental Sciences no. 39. 41 pp.
	AChE (Acetylcholinesterase activity	Bocquené, G. and Galgani, F., 1998. Biological effects of contaminants: Cholinesterase inhibition by organophosphate and carbamate compounds. ICES Techniques in Marine Environmental Sciences no. 22. 12 pp.
	Comet assay and micronucleus frequency (genotoxic damage)	Bean, T. P. and Akcha, F. 2016. Biological effects of contaminants: Assessing DNA damage in marine species through single-cell alkaline gel electrophoresis (comet) assay. ICES Techniques in Marine Environmental Sciences no. 58. 17 pp. Stankeviit, M., Gomes, T., Campillo González, J. A. 2022. Nuclear abnormalities in mussel haemocytes and fish erythrocytes. ICES Techniques in Marine Environmental Sciences Vol. 66. 13 pp.
Invertebrates – Molluscs Mussel (*Mytilus edulis*)	Lysosomal stability	Martínez-Gómez, C., Bignell, J. and Lowe, D. 2015. Lysosomal membrane stability in mussels. ICES Techniques in Marine Environmental Sciences No. 56. 41 pp.
	Scope for growth	Widdows, J. and Staff, F., 2006. Biological effects of contaminants: Measurement of scope for growth in mussels. ICES Techniques in Marine Environmental Sciences no 40. 30 pp.
	Cellular Energy Allocation	Coen, W. M. D., and Janssen, C. R. (1997). The use of biomarkers in Daphnia magna toxicity testing. IV. Cellular Energy Allocation: A new methodology to assess the energy budget of toxicant-stressed Daphnia populations. 43–55.
	Comet assay (genotoxic damage)	Bean, T. P. and Akcha, F. 2016. Biological effects of contaminants: Assessing DNA damage in marine species through single-cell alkaline gel electrophoresis (comet) assay. ICES Techniques in Marine Environmental Sciences no. 58. 17 pp.
	Stress on stress	Thain, J., Fernández, B., and Martínez–Gómez, C. 2019. Biological effects of contaminants: Stress on stress (SoS) response in mussels ICES Techniques in Marine Environmental Sciences no 59. 11 pp.

5.4.4 Other assays/approaches

While a recommended base set of bioassays and biomarkers offers an important standardised initial approach, it is fully recognised that a range of other ecotoxicological techniques could be deployed to meet specific needs. In fact, because marine incidents can involve a wide range of habitats or involve an extensive list of oils or chemicals, it is recommended that other methods are promptly considered and deployed if they offer value in monitoring and impact assessment for a specific incident. Such approaches have been discussed by Martínez-Gómez *et al.* (2010) and Radovi *et al.* (2012). Current work to improve chemical impact assessment uses adverse outcome pathways (AOP) to establish new approach methods (NAMs), some of which are likely to become useful environmental monitoring techniques. Some examples where other current techniques should be considered are outlined below.

5.4.4.1 Chemical specific

Where there is good information about the exact nature of the spilled material, one should consider whether there are any biomarkers available that have a specific Mode of Action (MOA) response to a particular chemical. Examples of this are EROD activity, which responds to PAHs and certain planar polychlorinated biphenyls (PCBs) (Stagg and McIntosh, 1998), and PAH bile metabolites (Ariese *et al.*, 2005), which become elevated due to exposure to certain PAH, an important component of many oils. Other examples of chemical-specific biomarkers include metallothionein (for Cu, Zn, Cd and inorganic Hg) (Viarengo *et al.*, 1997), delta-aminolevulinic acid dehydratase (ALAD) (for Pb) (Johansson-Sjobeck and Larsson, 1979) and acetylcholinesterase inhibition (Bocquené and Galgani, 1998) for a range of neurotoxic chemicals (e.g. organophosphate and carbamate pesticides). So, for incidents in which chemicals are spilled, consideration should be given to the MOA of the chemical, which will guide the deployment or extended use (either spatially or in other species) of biomarkers that are known to respond specifically to that chemical, if they exist.

5.4.4.2 Mixtures

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

5.4.4.3 Habitat specific

Specific ecotoxicological techniques can also be extremely valuable in assessing the impact, or potential impact, of spills in certain habitats. Where a habitat is at threat or already impacted, it would be beneficial in the assessment of impact and recovery to be able to use sentinel species that are representative of that environment. Published ecotoxicological methodologies using habitat-representative species are manifold and examples might include the use of periwinkles (*Littorina littorea*) or limpets (*Patella vulgata*) (Dicks, 1970) for rocky shore environments or various macrophytes (e.g. Zostera, Fucus or Ceramium species) (Chesworth *et al.*, 2004; Brooks *et al.*, 2008; ISO, 2010) for a range of intertidal and coastal environments. Use of vertebrates and decapods in some countries for monitoring purposes should always be assessed, reflecting on ethical issues versus the need for monitoring information. Where the sampling of fish is justified following a spill, research in Europe was undertaken to consider what the most suitable species might be. Following a pilot study on the coast of Portugal within the EU-funded EROCIPS project, Moreira *et al.* (2007), Lima *et al.* (2008) and Santos *et al.* (2010) have recommended the use of the shanny *(Lipophrys pholis*) in oil spill monitoring studies. This species was also successfully used as a sentinel species following the *Sea Empress* oil spill (Lyons *et al.*, 1997; Harvey, 1999). Common on all shores and abundant on rocky shores, it can be found in rock pools and under stones on all UK coasts (Wheeler, 1969). It is not sessile, but has a restricted home range, and so is representative of its immediate environment. Adults feed mainly on barnacles and mussels, which bioaccumulate a wide range of contaminants, so the shanny may also be of use in chemical spill monitoring programmes. The same study also identified the common goby (*Pomatoschistus microps*) as a suitable sentinel organism. The goby is widely distributed around the UK, and is abundant in intertidal pools, estuaries and salting pools on sandy or muddy shores. Its food consists mainly of small crustaceans. The lifestyle and habits information used to select this species are a useful starting point for identifying suitable species in other areas of the world.

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

5.4.4.4 Activity screening

A range of biologically-based assays are also available to measure specific types of activity or modes of action that can be attributed to released contaminants, (e.g. the summary of approaches outlined in Hylland *et al.,* 2017). Again, this can be useful when dealing with mixtures, unknown quantities or as a simple biological screen of potential short- or long-term effects. Other screening methods available include:

- Those for genotoxic or mutatoxic compounds (e.g. the Umu or Ames tests, Oda et al., 1985; Maron and Ames, 1983);
- In-vitro screens for the assessment of binding to aryl hydrocarbon (e.g. DR CALUX, Murk *et al.*, 1996);
- Oestrogen (e.g. ER-CALUX, YES assays, Legler *et al.*, 1999; Routledge and Sumpter, 1996);
- Androgen (e.g. YAS assay, Sohoni and Sumpter, 1998) receptors.

These types of tests can provide important indicators as to the mode of action of the primary contaminants and the type of biological effects that might be manifest in exposed animals. Some of these screening assays, such as those using luminescence in *Aliivibrio fischeri* (Zwart and Sloof, 1983) are now highly portable, with a few manufacturers offering field-based kits that can generate ecotoxicological data without the need for sophisticated laboratory facilities (e.g. Smith *et al.*, 2021).

5.4.4.5 Longer-term effects

It is understandable that the initial focus of any post-incident monitoring programme will be to quickly understand the potential for and/or breadth of short-term acute impacts. Therefore, the recommended baseline battery of bioassays and biomarkers (Table 10 and Table 11) have been selected to enable that short-term assessment to be made. However, spills in the marine environment also have the potential to elicit their detrimental effects over longer time periods (Kingston, 2002; Barron *et al.*, 2020) and, for example, oil residues have been shown to persist in sediments for several decades under certain conditions (Kirby and Law, 2010; Venosa *et al.*, 2010).

Ecotoxicological methods also offer a wide range of options and specific endpoints that are appropriate to be used to monitor long-term impacts. These approaches are likely to include assessments of reproductive competence, methods of which exist for many species and can range from measures of reproductive performance, fecundity and inter-generational offspring viability to measures of sperm motility and fertilisation success. Longer-term effects might also result from cellular damage, and assays of DNA damage (e.g., DNA adducts, micronuclei and comet assay) can act as indicators for the potential of ongoing damage. Ultimately, long-term effects might be evident in the prevalence of tissue damage and neoplastic disease which can be assessed in a range of species through histopathological techniques (Feist *et al.*, 2004; Martínez-Gómez *et al.*, 2010).

“Ecotoxicological methods also offer a wide range of options and specific endpoints that are appropriate to be used to monitor long-term impacts.”

5.4.4.6 Temporal and spatial considerations

Any ecotoxicological assessments not only need to fit within an integrated assessment programme but also need to incorporate appropriate spatial and temporal coverage in their deployment. Because spills cannot be predicted with precision in terms of timing or location, reliable baseline (pre-incident) data for the affected area are often unavailable. Good communications, predictive modelling and pre-planning for the deployment of the recommended baseline battery of methods may mean that samples can be promptly taken in an area before it is impacted, and any spatial sampling plans should take account of predictive modelling. However, it will often be the case that pre-incident data will not be available, and any assessment of impact will be reliant on sufficient spatial coverage and replication, with consideration given to representative control sites. The temporal aspect of the monitoring/ sampling programme will vary depending on the extent of any impact and the potential for persistence and mobilisation of contaminants in the receiving environment. Ultimately, the spatial and temporal aspects of any sampling programme will depend on the incident in question; however, it is recommended that, wherever possible, the principles of sampling for biological effects monitoring as set out in the OSPAR CEMP (OSPAR, 2016) should be adhered to.

5.4.4.7 Confounding factors

It is important, when using biological effects biomarkers and assays, to appreciate the range of confounding factors that can influence the data and their interpretation (Martínez-Gómez *et al.*, 2010; Dalessandri *et al.*, 2023). For example, certain biomarkers (e.g. EROD) can be affected by the temperature that the species has been acclimated to and this and other physical parameters can affect sentinel organism sensitivity and contaminant availability (Kirby *et al.*, 1999). Therefore, in parallel with any water/sediment sampling or the collection of field biota samples, a record of physical parameters (e.g. temperature, salinity, pH, etc.) should be taken to aid later interpretation of results.

Other factors such as size, gender and reproductive status can also have a substantial impact on biomarker response, so parameters such as length, weight, sex and gonad weight need to be recorded for all specimens of biota.

Wherever possible, standardised sex and size classes should be sampled at all sites and sampling occasions to minimise the effect of variability on the results. For certain biomarkers (e.g. EROD), the status of sexual maturation can have a particularly large effect on biomarker levels (Kirby *et al.*, 1999) and certain times of the year are not recommended for annual monitoring. However, for post-incident monitoring one cannot choose the time of year and so collecting these data is therefore even more important. Again, wherever possible, the principles of sampling as set out in the OSPAR JAMP (OSPAR 1997; 2008) should be followed. Additional guidance on the supporting parameters that should be considered when undertaking biological effects monitoring in fish and shellfish has been published by ICES (Balk *et al.*, 2012; Davies and Vethaak, 2012).

5. Monitoring tools and analytical methods

5.5 Physical and chemical characterisation of plastic pellets

Although methods for monitoring and evaluating environmental impacts after oil spills are well developed, the scientific foundation for post-spill monitoring of plastic pellet releases is comparatively underdeveloped. Furthermore, the ecotoxicological risk associated with plastic pellets is not fully understood. That said, research and practical experience are steadily expanding the evidence base around effective monitoring strategies and analytical techniques for incidents involving emerging contaminants such as plastics (IMO, 2024; Ipieca and OSRL, 2026; Cedre, 2025; ITOPF, 2025). The transport and fate of plastic pellets following container loss at sea is governed by a combination of physical oceanography, meteorological conditions, polymer properties (e.g. polymer density) and environmental processes. The fate of the container loss at sea and its position will also impact on how plastic pellets enter the environment, as well as their distribution and partitioning between compartments (Figure 17; ITOPF 2025). Understanding this type of transport and association behaviour in the marine environment is an important factor dictating which compartment to monitor (Figure 18).

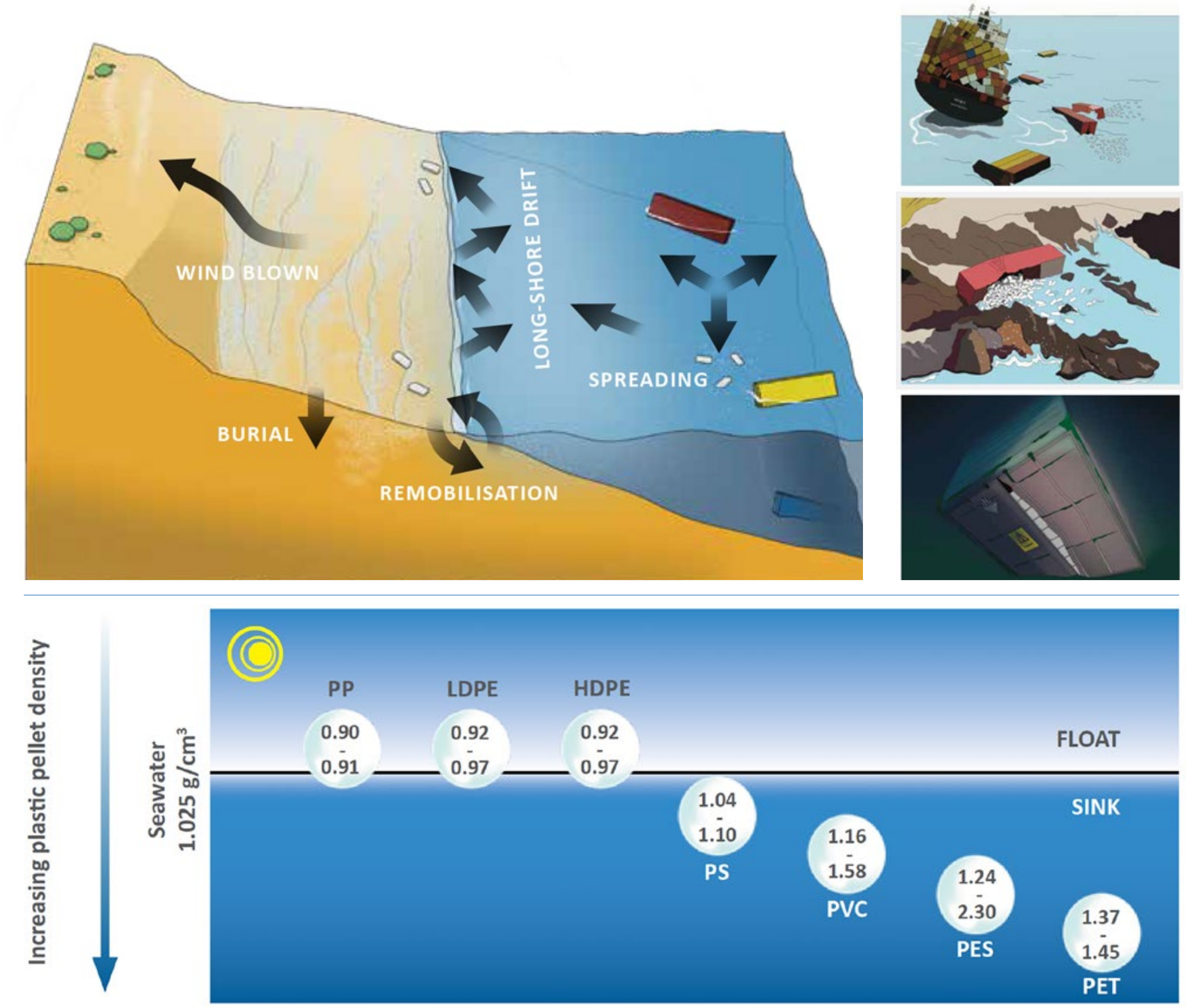


Figure 17: Pathways of plastic pellets release following container loss and subsequent distribution in the marine environment (from ITOPF Technical Information Paper 19: Response to plastic pellet incidents, 2025).[16]

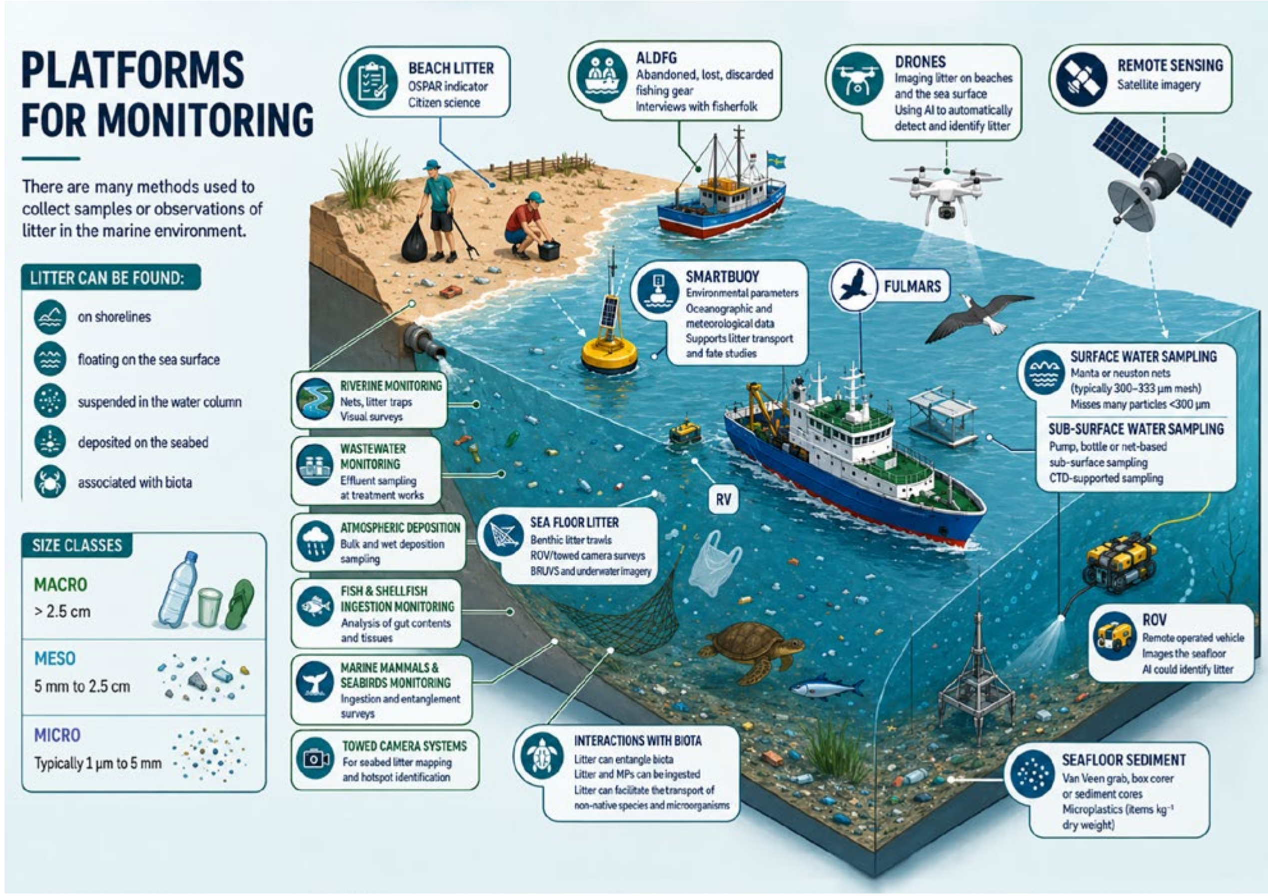


Figure 18: Platforms for the monitoring of marine litter, including plastic pellets, in the marine environment (Cefas, 2025).

Monitoring plastic pellets after a spill requires a multi-compartment approach due to mobility and remobilisation potential from coastal processes (Figure 17). The development of temporal monitoring strategies is critical across all compartments with immediate, short- to long-term actions:

- Immediate (days – weeks): surface waters and nearby shorelines;
- Short-term (weeks – months): beaches and estuaries;
- Long-term (months – years): sediments, seabed and inland traps.

A rapid response is initially required to reduce spread in acute spills, and short- to long-term monitoring strategies are needed to address pellets persistence and redistribution over time due to environmental processes. A robust monitoring design should include source → transport → accumulation → long-term sinks → remobilisation. Evidence from field studies and spill assessments consistently shows they redistribute across surface waters, shorelines, sediments, and inland pathways with some interactions with biota with potential impacts at the individual and population level.

16 TIP 19: Response to plastic pellet incidents: https://www.itopf.org/knowledge-resources/documents-guides/tip-19-response-to-plastic-pellet-incidents/

5.5.1 Shorelines and beaches

Beaches are both accumulation zones and long-term reservoirs. An effective sampling campaign should be able to capture surface deposition, burial and remobilisation over time. Protocols have been developed at the EU and OSPAR level for the monitoring of mesoplastics (5 mm – 2.5 cm) and plastic pellets (Galgani *et al.*, 2023).

5.5.2 Surface waters and water column

Plastic pellets are usually being collected from the sea surface, however the water column can also be considered to investigate plastic profiling down the water column and associated exposure to pelagic and demersal organisms. Plastic items are generally being collected using trawl netting, either horizontally for surface water or vertically for the water column.

Monitoring biota for marine litter (GESAMP, 2019) is important because it provides useful information on:

- Impact on biota;
- Impact on human health and wellbeing;
- Impact on ecosystem;
- Overall indicator of ecosystem contamination.

Biota can be sampled from the aquatic environment by different methods, including trawl nets, traps or hand collection from sediments/shorelines. When organisms are collected for stomach content analysis, precautions must be taken to account for stomach eversion prior to preservation. Therefore, the time between collection and storage should be as short as possible and individuals should be frozen, ideally at -20 °C, as soon as possible after collection to avoid gut clearance (Lusher *et al.*, 2017). Additionally, animals should be frozen whole where possible to limit contamination through dissection onboard a vessel/in the field. Samples should remain frozen at -20 °C until further analysis in the laboratory. To represent the population, a suitable sample size of at least 50 similarly sized specimens per research unit (species, food web, feeding type, etc.) is recommended, following the guidelines of the EU MSFD (EU, 2008). However, based on availability of organisms, statistical power analysis and monitoring constraints, sample sizes can be smaller when justified accordingly (Bessa *et al.*, 2019).

5.5.3 Seafloor and benthic habitats

Seafloor sediment collection should focus on depositional and low-energy environments, where pellets are more likely to accumulate. Sediment samples are more commonly collected using Grab samplers (Van Veen or Day Grab) for the top 1-5 cm.

Following pellet collection, a range of analytical approaches can be applied depending on the goals of the response programme. Drawing on recent incidents, three key categories of post-spill pellet analysis are commonly regarded as important:

- Physical and chemical characterisation of the polymer;
- Identification of the polymer's source;
- Environmental impact evaluation and toxicity assessment.

There is no single, universally accepted methodology for the sampling, extraction, and analysis of microplastics across environmental compartments. The absence of standardised protocols hampers direct comparisons between datasets and limits the production of robust, reproducible scientific evidence on which guidelines and policy measures can reliably be based. Addressing these methodological inconsistencies is currently a priority for international expert groups (e.g. OSPAR, ICES, EU-TGML) and standardisation bodies such as the International Organization for Standardisation (ISO).

Fourier Transform Infrared (FT-IR) spectroscopy and Raman spectroscopy are the most widely applied techniques for the identification of microplastic polymers. Both methods are powerful analytical tools that enable reliable chemical characterisation of microplastics in environmental samples. Prior to spectroscopic analysis, density separation followed by filtration is commonly employed to extract microplastics from complex environmental matrices. An overview of microplastics particle identification techniques is shown in Table 12.

5. Monitoring tools and analytical methods

Table 12: Microplastics particle identification technical overview.

Analytical method	Minimum particle size (mm)	Filter requirement	Degree of automation	Acquisition speed	Advantages	Disadvantages	Relative cost	Analytical method
ATR-FTIR spectroscopy	> 500	N/A	Very low	Fast	Ease of use Minimum sample preparation	Contact analysis (ATR)	£	ATR-FTIR spectroscopy
FT-IR microscopy	> 10	IR transparent	High	Fast	Ease of use Minimum sample preparation		££	FT-IR microscopy
ATR-FTIR microscopy	> 5	Any filter Any substrate	High	Medium	Ease of use Minimum sample preparation	Contact analysis (ATR)	£££	ATR-FTIR microscopy
FT-IR imaging	> 5	IR transparent	Very high	Very fast	Ease of use Minimum sample preparation		£££	FT-IR imaging
ATR FT-IR imaging	> 2	Any filter Any substrate	High	Medium	Ease of use Minimum sample preparation	Contact analysis (ATR)	£££	ATR FT-IR imaging
LDIR imaging	> 10	Flat, reflective surface (e.g. kevley slide or IR reflective filter)	High	Very fast		New technique, not applied for environmental samples	£££	LDIR imaging
Raman imaging	> 0.5	Non-fluorescent	Very high	Fast	Resolving particles down to 1 micron and less	Less commonly used as FTIR, limited reference spectra	£££	Raman imaging
Pyr-GC-MS		N/A			Suitable for nanoplastics identification Analysis of polymer type and additive chemicals	Destructive analysis Reporting unit (mass vs number) Complex data	£££	Thermal analysis

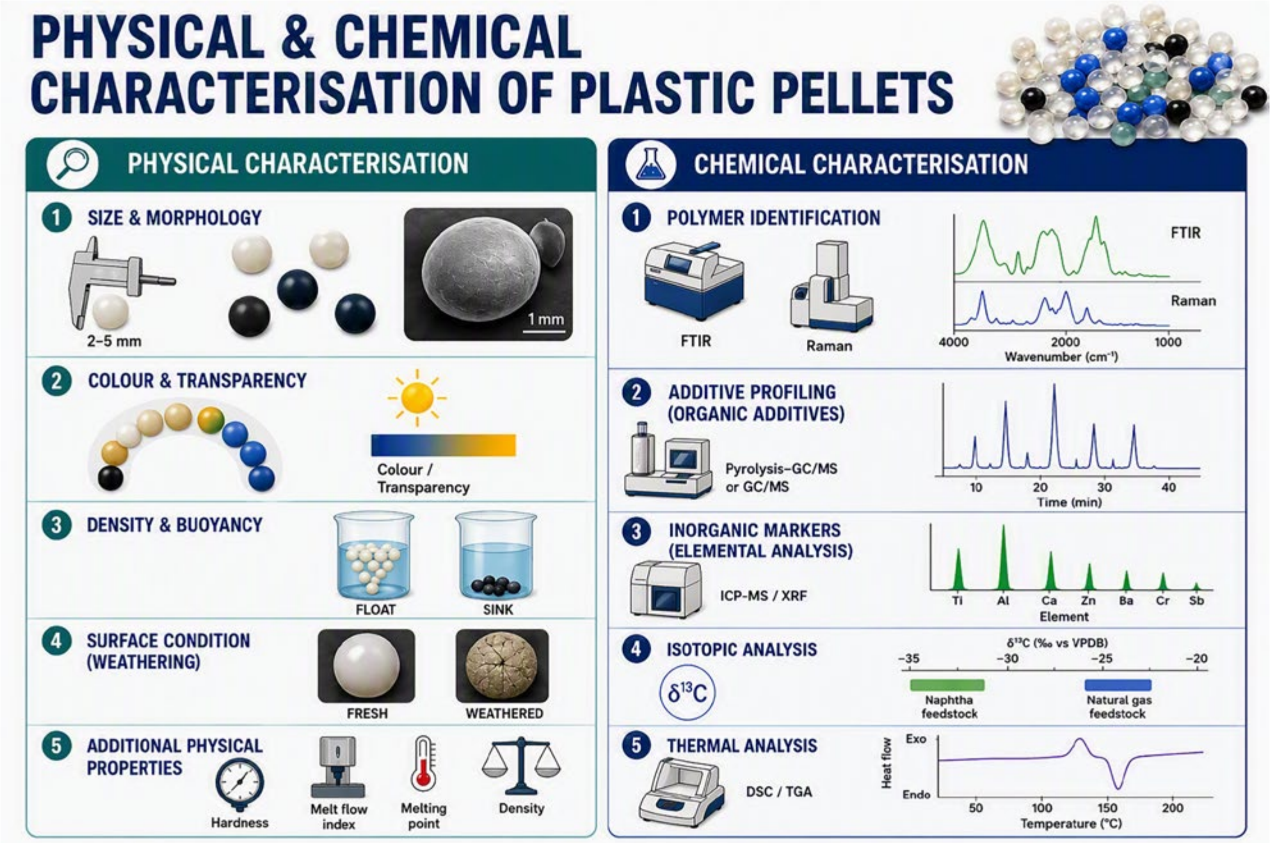


Figure 19: Example of techniques applied for the physical and chemical characterisation of plastic pellets.

Polymer identification of plastic pellets is typically carried out using benchtop ATR-FTIRs (attenuated total reflectance – Fourier transform infrared) (Figure 19 and Figure 20). The resulting spectra are compared to published spectra databases of known plastics to assist with the identification of plastic type. Reporting parameters should include a list of any commercial or open access FTIR spectra databases used, including the name of specific libraries. Minimum acceptable % match against the database should also be specified.

Generally, library matches of ≥ 80 % are deemed acceptable. In some cases, matches ≥ 60 % are acceptable and further validation can be achieved by confirmation of characteristic IR-peaks for different polymers. Any spectral post-processing applications should also be documented for transparency and repeatability purposes.

Because pellet formulations are often commercially confidential and not publicly disclosed, tracing them to their source after a spill can be difficult. As a result, detailed analytical techniques, similar to oil spill fingerprinting, may be needed to identify their source.

Plastic fingerprinting is typically carried out using thermal analytical techniques. These may include GC-MS, pyrolysis – gas chromatography – mass spectrometry (pyr-GC-MS), differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA) and potentially isotopic analysis (White *et al.*, 2004; Akoueson *et al.*, 2021; Morales-Caselles, 2026). Such methods examine how a polymer behaves under controlled heating conditions and can identify distinctive characteristics linked to a specific manufacturer or production batch. For instance, analysts may detect particular additive packages, unique thermal degradation products, or characteristic melting temperature profiles that help differentiate one source from another.

Surface characteristics can also aid source identification, as trace metals, organic compounds, or biofilms on pellets may provide useful indicators. However, this method is more uncertain, since weathering, environmental exposure, and the adsorption of other particles can alter surface contaminants over time, complicating definitive source attribution.

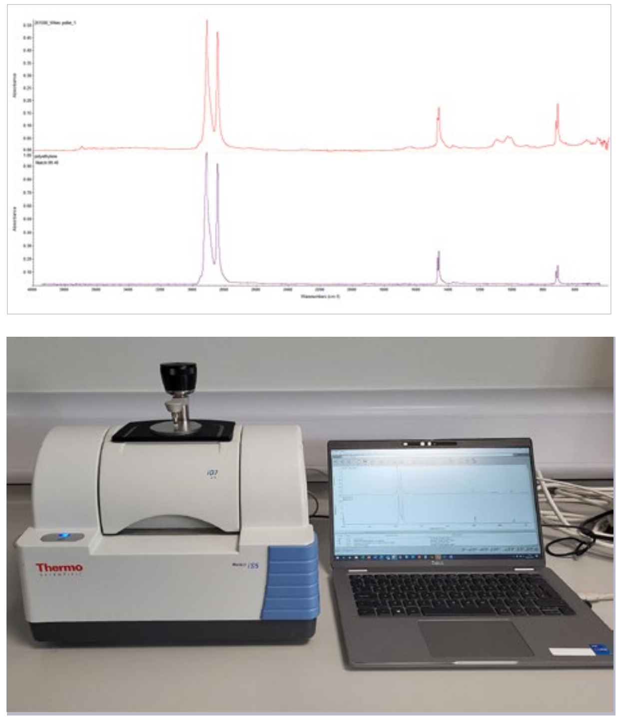


Figure 20. FTIR analysis for polymer characterisation, showing example spectra (above) and an FTIR spectrometer used for sample analysis (below).

5.6 Molecular approaches to ecological monitoring

The use of environmental DNA (eDNA) in post-spill monitoring has emerged as a valuable tool for assessing biodiversity, detecting the presence of species, and monitoring the recovery of marine ecosystems (Capurso *et al.*, 2023). eDNA can be collected from environmental samples such as water or sediment, providing a rapid, non-invasive method to detect genetic material shed by organisms (Fonseca *et al.*, 2023). The application of eDNA allows the monitoring of a wide range of taxa and can provide complementary information in post-spill assessments, particularly where rapid information and non-invasive screening is required or where conventional surveys are constrained (Bohmann *et al.*, 2014). Compared to traditional physical sampling, the non-invasive nature of eDNA offers the advantage of being applicable in remote or hazardous areas where conventional monitoring techniques may be challenging or unsafe, particularly where baseline eDNA data exist or where such approaches are already used within routine monitoring (Fonseca *et al.*, 2023).

By collecting and analysing eDNA, it is possible to identify the absence and presence as well as the diversity of key species, including those sensitive to pollution, and track changes in biodiversity with high spatial and temporal resolution. Notably, eDNA can support the detection of pollution-sensitive taxa where relevant reference sequences are available and appropriate genetic markers and primers exist, as certain species or microbial groups are known to respond predictably to specific pollutants, making them effective bioindicators. For example, the presence or absence of pollution-tolerant bacteria such as Desulfovibrio in hydrocarbon-contaminated sediments can indicate the severity of oil spills (Muyzer and Stams, 2008). Changes in the detection and relative signal of such microbial taxa, as revealed through eDNA analysis, can provide supporting qualitative insight into the type of contamination present and indicate early shifts in microbial community composition following a spill. This microbial signal complements traditional chemical analyses and enhances our understanding of ecosystem disturbance and resilience.

eDNA's recognised efficiency for detecting genetic material from rare or elusive species can support the identification of taxa that are ecologically meaningful or functionally important, particularly where such organisms are difficult to observe through conventional monitoring techniques (Ruppert *et al.*, 2019). When interpreted alongside knowledge of species' ecological roles and supporting environmental data, these detections can contribute to the assessment of potential ecosystem-level responses to pollution. Additionally, eDNA can provide early warning signs of ecological disturbance, such as changes in species composition or the decline of pollution-sensitive taxa, allowing for more timely and informed decision-making (Fonseca, *et al.*, 2023). Its cost-effectiveness and scalability make it a valuable tool for large-scale assessments, particularly when resources are limited or when continuous monitoring is required over extended periods (Ruppert *et al.*, 2019; Fonseca *et al.*, 2023) (Figure 21). As such, eDNA is poised to become an indispensable part of marine pollution monitoring, complementing and enhancing traditional methods, and ensuring more comprehensive, real-time assessments of post-spill impacts and recovery.

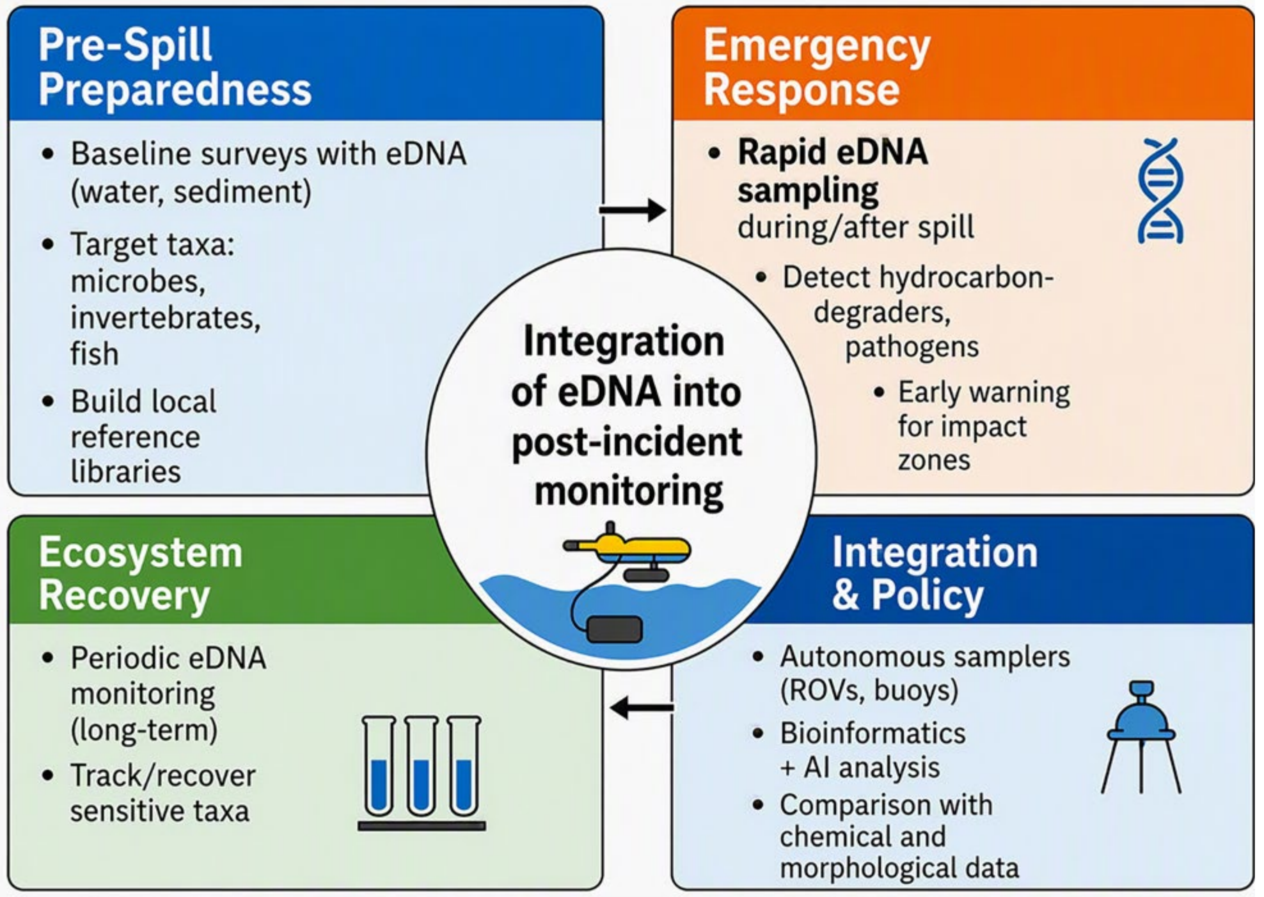
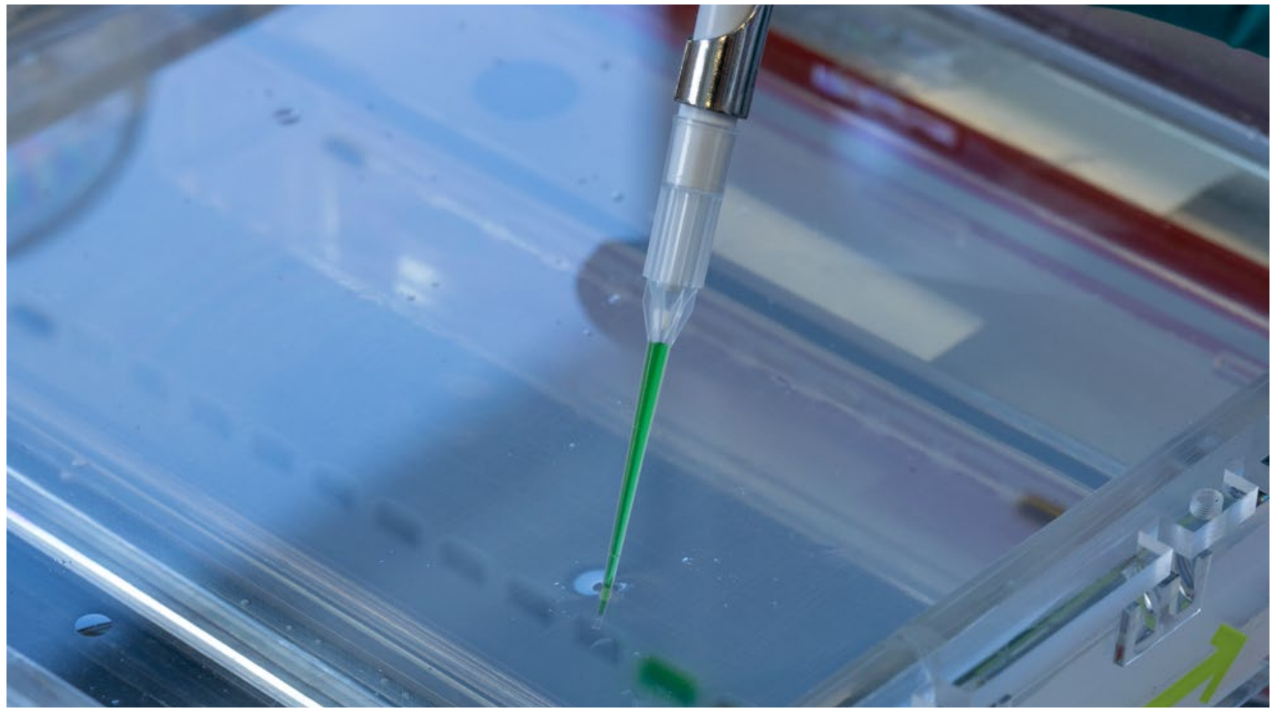


Figure 21: Integration of eDNA in oil spill monitoring across four phases (1) pre-spill preparedness, (2) emergency response, (3) ecosystem recovery and (4) integration and policy actions.



5.6.1 Integrating eDNA and recommended approaches

At this stage, eDNA should complement, not replace, traditional monitoring methods such as visual surveys, sediment core sampling, and chemical analyses. Integration with these methods will provide a comprehensive understanding of the incident's biological and chemical impacts. Its application in pollution response and monitoring offers several key advantages:

- **Rapid biodiversity assessments** – eDNA allows for comprehensive assessments of marine biodiversity, including microbial, meiofaunal, and macrobenthic communities, which are often difficult to sample using traditional methods. This is particularly valuable in post-incident scenarios where quick assessments of impacted areas are needed to inform response strategies.
- **Detection of pollution-sensitive indicators** – Certain species or microbial taxa are sensitive to specific pollutants, making them useful bioindicators. For example, the presence or absence of pollution-tolerant bacteria, such as Desulfovibrio in hydrocarbon-contaminated sediments, can indicate the severity of oil spills (Muyzer and Stams, 2008). In principle, eDNA approaches may also support investigation of species presence or community shifts associated with the use of dispersants, where organisms or functional groups are known to respond to dispersant exposure and where appropriate reference data, markers, and contextual baseline information are available. At present, such applications remain case-specific and exploratory, and interpretation should be undertaken cautiously and in combination with chemical and ecological monitoring data.
- **Temporal and spatial monitoring** – eDNA can track changes in community composition over time and across different spatial scales, offering a dynamic perspective on ecosystem recovery. This is crucial for monitoring the long-term impacts of pollution events, such as changes in biodiversity and shifts in community structure.
- **Integration with chemical monitoring** – eDNA data can be integrated with chemical analyses of pollutants to establish links between contamination levels and biological impacts. This holistic approach enhances the understanding of ecosystem responses to pollution.

5.6.2 Immediate post-incident monitoring

eDNA may contribute to early post-incident monitoring where samples, if collected promptly, can support early assessment. While field deployable sequencing technologies (e.g. portable nanopore platforms) have the potential to reduce turnaround times in some contexts, eDNA analysis is not yet routinely real time due to practical constraints related to sample handling, analytical capacity, and the availability of suitable baseline data. This is particularly important in the aftermath of a spill, where timely information is required to assess potential impacts, identify risks to sensitive species, and inform mitigation efforts (Xie *et al.*, 2018).

Following a pollution event, eDNA sampling can be carried out in parallel with sediment collection in impacted and reference areas to support assessment of initial conditions. Sampling should target:

- **Microbial communities** – Changes in microbial diversity, such as an increase in hydrocarbon-degrading bacteria, can indicate pollutant presence and early-stage ecosystem responses (Xu *et al.*, 2018).
- **Benthic and pelagic species** – The detection of stress-sensitive taxa, such as certain fish or invertebrates, can help identify areas of high impact (Costas *et al.*, 2018).
- **Sediment and water columns** – eDNA analysis of sediments and water can reveal the vertical distribution of pollutants and their biological impacts (Barrenechea *et al.*, 2023).

“eDNA may contribute to early post-incident monitoring where samples, if collected promptly, can support early assessment.”

5.6.3 Long-term recovery monitoring

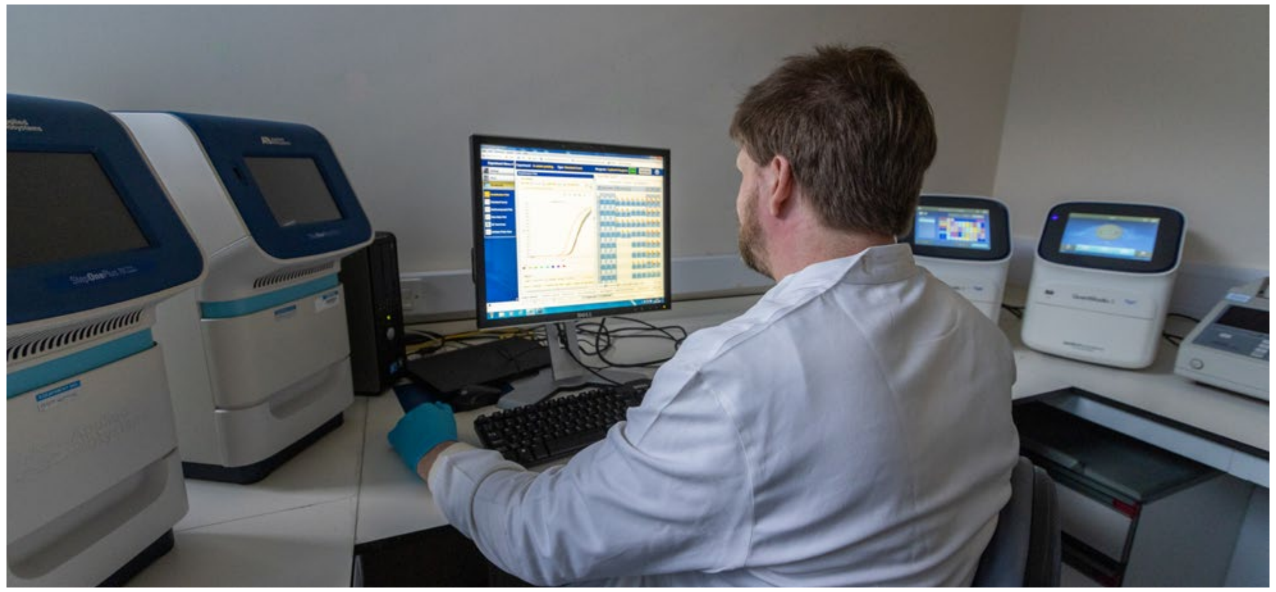
Long-term monitoring is essential to assess ecosystem recovery after a spill. This includes tracking the re-establishment of biodiversity and the return of pollution-sensitive taxa. eDNA can also detect persistent impacts, such as shifts in microbial communities associated with chronic contamination (Barrenechea *et al.*, 2023).

5.6.4 Sampling and analysis protocols

The effectiveness of eDNA monitoring depends on the development and implementation of standardised sampling and analysis protocols (Ruppert *et al.*, 2019). These protocols are essential for ensuring the reliability, reproducibility, and comparability of results across different locations and spill events (Deiner *et al.*, 2017; Bruce *et al.*, 2021). In post-spill contexts, where environmental conditions may be highly variable or chemically altered, protocols must be adapted to ensure robust detection of biodiversity signals.

Key questions addressed by eDNA sampling protocols include:

- What species or microbial taxa are present or absent in impacted versus control sites?
- How does community composition shift over time following a pollution event?
- Can we detect pollution-sensitive or oil-degrading indicator taxa?
- What is the spatial extent and severity of contamination?



Techniques and parameters used:

The following provides a non-exhaustive overview of key technical considerations relevant to the application of eDNA in post-incident monitoring, building on the principles outlined above:

- **Sample collection** – Sterile techniques are used to collect water, sediment, and tissue samples from both impacted and reference sites. Spatial and temporal replication is critical to account for variability in eDNA transport and decay.
- **Preservation and storage** – Filtration, freezing, or chemical preservation (e.g. ethanol, sodium hypochlorite) are applied immediately post-collection to prevent DNA degradation.
- **DNA extraction and inhibition control** – Extraction methods are optimised for yield and purity, with controls for PCR inhibitors common in polluted environments. Multiple marker genes may be used to capture a broader taxonomic range.
- **Data analysis** – Bioinformatics pipelines identify taxa and detect shifts in community composition. Quality control measures are implemented to detect contamination and ensure data integrity.
- **Reference databases** – Taxonomic assignment relies on curated databases, ideally supplemented with local baseline datasets to improve resolution and accuracy.
- **Longitudinal monitoring** – Time-series sampling tracks biodiversity recovery and eDNA degradation dynamics post-spill.
- **Comparative baseline data** – Pre-spill eDNA profiles serve as a benchmark to assess biodiversity loss and recovery trajectories.
- **eDNA transport modelling** – Hydrodynamic models help interpret eDNA dispersal and distinguish local from upstream contamination sources.
- **Integration with traditional methods** – eDNA results are complemented by morphological surveys, chemical analyses, and biomarker-based assessments for a holistic understanding of ecosystem health.

Expected outcomes:

- Detection of rare, elusive, or pollution-sensitive taxa that may be missed by conventional methods.
- Early warning signals of ecological disturbance, enabling timely management responses.
- Qualitative or semi-quantitative insights into changes in biodiversity and community composition over time, where interpretation is supported by appropriate baselines and complementary data.
- Enhanced spatial and temporal resolution of monitoring data, especially in remote or hazardous areas.

5.6.5 Key parameters for measurement in eDNA-based pollution response and monitoring

Effective use of eDNA in pollution response requires tracking a range of biological, chemical, physical, and analytical parameters. The table below summarises the core metrics and their relevance, providing a practical reference for designing and interpreting eDNA monitoring programmes (Table 13).

Understanding and accurately measuring these parameters is crucial for successful eDNA monitoring. Proper handling of these factors will ensure that eDNA is used effectively to assess the ecological impacts of pollution and guide future mitigation and restoration efforts (Table 13).

Table 13: Key parameters for measurement in eDNA-based pollution response and monitoring. Metrics should be interpreted within a weight-of-evidence framework and in line with emerging international standards (e.g. ISO 17805), noting that standardisation of eDNA methods is still evolving.

Parameter category	Key metrics/Indicators	Purpose/Use
Biological	Biodiversity (species richness, diversity indices); detection of pollution-tolerant and sensitive taxa	Assess ecological stress and community shifts
Biological	Community composition (e.g. microbial, planktonic, invertebrate, vertebrate shifts)	Evaluate ecological impacts and pollutant responses
Biological	Functional diversity (e.g. pollutant degradation genes, pathogenic taxa)	Identify functional responses to pollution
Biological	Bioindicators (e.g. hydrocarbon degraders, invasive species)	Track ecological indicators of pollution
Biological	Pathogen and harmful microbe detection	Identify pollution-related health risks
Biological	Trophic interactions and food web disruptions	Assess ecosystem-level impacts
Chemical	Pollutant concentrations (e.g. hydrocarbons, heavy metals); oxygen levels; organic matter	Understand pollutant effects on eDNA and species survival
Physical	Water temperature, pH, salinity, turbidity	Control for environmental variables affecting eDNA
eDNA-Specific	eDNA concentration; target species markers; degradation rates; contamination controls	Ensure data quality and interpretability
Temporal and Spatial	Sampling frequency; spatial gradients; vertical profiles	Capture recovery dynamics and pollutant distribution
Statistical and Computational	Diversity metrics (alpha, beta); similarity indices; network analyses	Analyse biodiversity patterns and functional interactions

5.6.6 eDNA advantages, challenges and mitigation strategies

Advantages

- ***Rapid biodiversity assessments*** – eDNA enables efficient detection of microbial, meiofaunal, and macrobenthic communities, supporting timely evaluation of impacted areas.
- ***Detection of pollution-sensitive indicators*** – eDNA can identify taxa that respond to specific pollutants, aiding in early detection of ecological stress.
- ***Temporal and spatial monitoring*** – Repeated sampling across gradients allows monitoring of ecosystem recovery and pollutant spread.
- ***Integration with chemical monitoring*** – Combining eDNA with contaminant analysis strengthens interpretation of biological impacts.

Challenges and mitigation strategies

Despite its advantages, the implementation of eDNA in post-spill monitoring guidelines must address certain challenges and mitigation strategies (Table 14).

Table 14: Key challenges and mitigation strategies in marine eDNA monitoring.

Challenge	Mitigation strategy
DNA degradation due to environmental conditions	Use robust extraction methods and target resilient markers
Contamination risks during sampling and processing	Apply strict field and lab controls (e.g. blanks, replicates)
Inability to distinguish live vs. dead organisms	Combine with Ribonucleic acid (RNA)-based or meta transcriptomic approaches
Lack of standardisation across sites and studies	Develop and apply consistent protocols tailored to marine pollution
Interpreting ecological relevance of eDNA signals	Use baseline data where available and integrate it with traditional monitoring approaches, acknowledging the widespread absence of comparable pre-incident baseline data globally
Primer bias and incomplete taxonomic coverage	Use multiple markers where appropriate; validate primers against relevant taxa and environments
Gaps or inaccuracies in reference databases	Improve curation of reference libraries and supplement with local or regional baseline datasets
Uncertainty in eDNA dispersal and degradation	Interpret results alongside hydrodynamic and environmental data; use replicated spatial and temporal sampling
Limited validation and standardisation	Apply emerging international standards (e.g. ISO 17805) and validated protocols where available

Part 6

Ecological assesment

6. Ecological assessment

6.1 Ecological assessment – general guidance

6.1.1 General recording of conspicuous impacts

Once an initial survey of the extent of impact has been carried out, and the risk to human life is minimised, the next phase is to understand the immediate and ongoing impact on the ecology, habitats and species that have been potentially impacted by the event. Reliable records of impacts to habitats or species provide the most persuasive evidence of ecological impact.

It can be difficult to determine whether the observed impacts were caused by the pollution event, as this requires a clear understanding of ecological conditions prior to the event. Understanding this baseline will help to prioritise immediate activities and to develop medium to long-term monitoring strategies to establish scale and extent of impact.

Whilst injured or dead wildlife may not be visible immediately after the event, it is important to have procedures in place to record and collate data as quickly as possible once the the event has occurred. For example, bird surveys along a shoreline can be resource-intensive, requiring significant time and logistical effort. Volunteers may need to conduct daily surveys immediately after an event, with monitoring continuing for weeks or even months at a reduced frequency. If a SCAT programme has been instigated to support clean-up operations, it may be useful to ensure ground teams are given guidance and briefings on recording environmental impacts. Reasonable steps and appropriate analysis should also be undertaken to determine whether observed death, injury, or oiling was caused by the spill, recognising that correlation does not necessarily imply causation.

Such observations should not be limited to birds or other visible wildlife. Marine fish and invertebrates (including bivalves, crabs, sea urchins and starfish) that live in shallow coastal waters have also sometimes been washed up dead or moribund on the shore after an oil spill (e.g. following the *Sea Empress* oil spill in Wales in 1996; see Law and Kelly, 2004). Records (ad hoc or from systematic surveys) of the numbers and species present should be collated, with photographs and, where possible, some specimens taken for later analysis.

Some specimens may need to be frozen for potential chemical analysis; this may be required to clarify if the animals were impacted by the spill or by a natural event. Other conspicuous signs of impact of the spill may also appear over time, including the development of green algal 'blooms' (resulting from the reduced feeding of grazing animals) and bleaching of algae. Records of such changes should also be made and collated. The degree of natural variability in algal cover can be seen in the NOAA Mearns Rock time series initiated following the *Exxon Valdez* oil spill in Alaska in 1989 (NOAA, 2023).

The confidence in attributing observed ecological responses directly to the spill will be greater when multiple scientifically validated lines of evidence are applied and presented, rather than relying on a single factor that may under- or over-estimate the true extent of impact (Camphuysen and Heubeck, 2001).

6.1.2 Selecting and prioritising subjects for study

Reviews of historical oil spill impact assessment programmes have highlighted that many studies detected no impacts and provided little value to the spill assessment, except to prove that an ecological resource (e.g. species, population, habitat) was still present and apparently functioning and that this result was predictable before the study was initiated (Moore, 2005). While it may be useful to demonstrate that a natural resource was not damaged, this can waste a limited monitoring budget and may not fully encapsulate the many ways that an ecosystem can be damaged in the long term. To do this properly, a prioritisation of assessment studies is therefore appropriate. Lessons learned from previous spill incidents have generated a substantial body of knowledge and experience, providing valuable guidance on the key factors that should be considered when planning and undertaking a post-spill assessment (Table 15).

Table 15: Factors to consider when selecting and prioritising subjects for post-incident assessment.

Study subject	Factors to consider
Contamination and vulnerability	■ Degree or likelihood of oil/chemical(s) reaching the resource
	■ Observed degree of oiling or chemical contamination
	■ Vulnerability of the resource to oil/chemical(s)
Importance of resource	■ Nature conservation importance
	■ Rarity and distribution
	■ Ecological or functional importance
	■ Profile of the resource, including public and scientific expectations
Impact detection	■ Likelihood of being able to detect and demonstrate an impact
	■ Known or likely sensitivity to the oil or chemical spill, including recovery potential
	■ Quality of existing baseline information
	■ Potential confounding factors, including other pollutants or human pressures
	■ Scale of natural spatial and temporal fluctuations
	■ Availability of established methodological protocols or indicators capable of producing meaningful results
Feasibility	■ Logistical considerations, including access, expertise and licensing requirements
	■ Available budget and cost-effectiveness
	■ Data-collection costs should be reasonable, proportionate and relevant, with sufficient budget available to meet justifiable costs

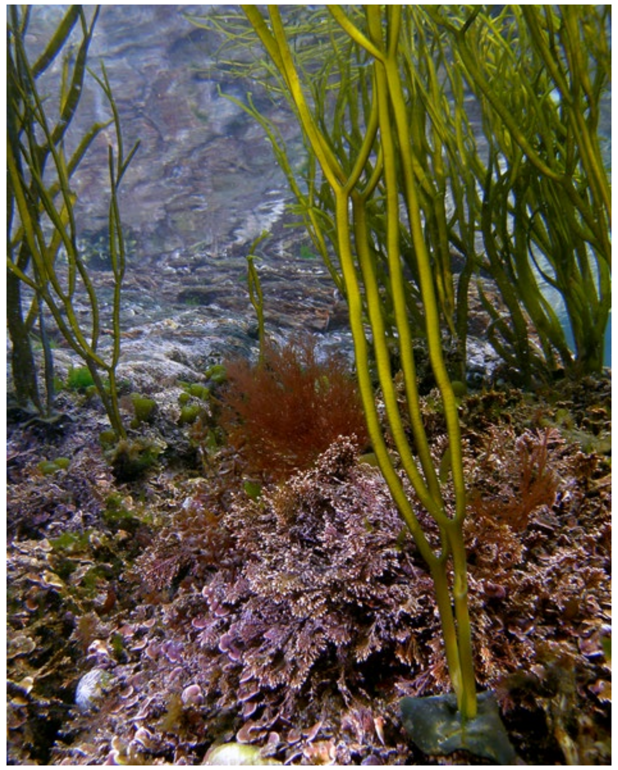
While the factors listed in Table 15 will need to be considered in relation to the specific characteristics of the spill event, experience from previous spills provides considerable information on the sensitivity and vulnerability of different resources and their potential for natural recovery. These considerations are relatively general and should not be interpreted as fixed categories of impact or vulnerability. Each event or spill will require a bespoke approach depending on the scale and intensity of impact, the species or habitats affected, and the ability to respond quickly.

The likelihood of adverse effects is an important consideration when selecting species or biological communities to study, but there are also a number of additional factors which should be considered. For example, it is important to understand the natural variability, both spatial and temporal, of many of the species or biological communities that may be studied. In addition to the spill itself, other human activities or pollutants may also affect the resource as confounding factors, and it may therefore be difficult to distinguish the impact of the spill.

"Reliable records of impacts to habitats or species, provide the most persuasive evidence of ecological impact."

The following general observations may assist in prioritising resources for assessment:

- The majority of serious long-term impacts occur from oil on the surface of the water and on shorelines; subtidal impacts are less common and can be shorter in duration, although their absence and brevity should not be assumed. When high concentrations of toxic hydrocarbons are dispersed into the water column, either naturally or by the application of chemical dispersants, the resulting impact reduces rapidly as depth increases. It is therefore normally appropriate to put less emphasis on studies of subtidal resources, particularly in deep water, unless there is evidence that oil or chemicals have been carried into, or have arisen directly in, deeper waters, or there is particular concern for a very important population or community. Subtidal impacts can be difficult to address through effective clean-up options.
- Wave-sheltered habitats are usually much more sensitive to oil spills than wave-exposed habitats, due to the persistence of the oil or chemical(s). Similarly, habitats that are not well flushed by tidal movements will also tend to retain the pollutant and have longer-lasting impacts.



- Some intertidal habitats where oil or chemical(s) may become trapped are more vulnerable to effects and may suffer longer-term impacts. Many of these habitats are also important for their species richness. These include rock pools, areas under boulders, and rock fissures and crevices.
- Birds that spend time on the surface of the water are most at risk from spills of oil or floating chemicals. In contrast, seabirds that spend most of their lives in the air or at roosting or nesting sites, and relatively little time in contact with the water, are generally less vulnerable, although shoreline nesting areas may still be affected.
- Some groups of invertebrate animals are known to be particularly sensitive to oil and chemicals. These species are primarily mobile forms, particularly small crustaceans such as amphipods, isopods and shrimps; some types of intertidal snails, including limpets and other gastropods; burrowing clams in lower-shore and very shallow subtidal sediments; and starfish and sea urchins on the lower shore and in very shallow subtidal waters. Sensitivity to spilled chemicals is likely to vary considerably among species and life stages, and the sensitivity of many marine species to many chemicals remains poorly understood.
- Oil and other spilled chemicals tend not to penetrate muddy sediments unless the surficial sediments are heavily burrowed by sediment-dwelling invertebrates or the spill occurs during severe weather. However, muddy sediments tend to be anaerobic just below the surface and therefore oil trapped in such sediments may persist for extended periods. The behaviour of spilled chemicals will depend on their intrinsic properties.
- Oil and other spilled substances may behave differently on wet lower-shore habitats depending on their physical and chemical properties. Bulk oil tends not to remain on wet lower-shore habitats but concentrates along upper-shore strandlines. If the oil is very weathered before it arrives at the shore, it is then unlikely to have a substantial toxic effect on lower- and middle-shore habitats. The behaviour and potential effects of spilled chemicals will be very dependent on their intrinsic properties.

- Wading birds may be affected by oil and chemical spills throughout direct exposure, reduced access to feeding grounds or reductions in prey availability. The magnitude of these effects depends on the availability of alternative feeding opportunities and the birds' ability to compensate. Effects are likely to be greatest where food resources or suitable feeding habitat are already limiting.
- Contaminants reaching the marine environment in high concentrations as a result of spills or leakage during transport can directly affect microbial populations. A summary of the current state of knowledge in this area is provided in Section 6.3.1, although microbial populations are not considered a high priority for study for most incidents. The extent and behaviour of these contaminants may also vary depending on whether the source originates at sea or from land-based inputs, as terrestrial releases can allow greater interaction with sediments and interstitial waters before reaching the marine environment.
- Planktonic communities have generally been observed to show no more than transient impacts from oil or chemical spills and are therefore rarely included in impact assessments. One notable exception was the 2010 *Deepwater Horizon* oil well blow-out in the Gulf of Mexico during which the US NOAA investigated potential effects of the spill on productivity, nutrient cycling and species composition in near and offshore habitats, which included plankton sampling.
- Most species of fish will avoid contaminated waters where possible. However, the potential for fish mortality will depend on the nature and concentration of the spilled substance, the extent and duration of exposure, and local environmental conditions.
- In shallow water, where oil or chemicals have sunk or accumulated on the seabed, mobile marine species are generally less at risk of contamination than sessile species or slow-moving species that spend all or part of their life cycle close to the sea floor.
- Most marine macroalgae, including intertidal species, can survive considerable oiling, probably due in part to the protection provided by their mucous coating. The effects of chemical spills will vary according to the properties of the chemical and the nature and duration of exposure.

6.1.3 Planning for ecological monitoring surveys

6.1.3.1 Reconnaissance

Early reconnaissance is appropriate for priority habitats, particularly intertidal habitats such as saltmarsh, seagrass beds and other features and sites of interest that have received significant oiling or chemical contamination.

A reconnaissance survey should be conducted by a suitably qualified ecologist with relevant expertise at the earliest opportunity following cessation of oil or chemical movement and once any immediate risk to human health has been eliminated. The survey may be undertaken alongside detailed SCAT-style assessments (see Section 2.4 and MCA, 2007). In addition to documenting the distribution of oil or chemicals, the survey should include:

- Contaminant distribution mapping, including not only presence/absence but also the level of contamination (e.g. low–high) and the characteristics of contamination on the shoreline (e.g. across a swath of beach, confined to the high tide mark, buried, pooled, continuous, patchy or fragmented). Where possible, classifications should follow recognised field guidance methodologies (OSRL, 2015; ITOPF, 2024);
- A preliminary habitat classification using an appropriate national or regional classification system (e.g. the UK National Vegetation Classification (NVC), EUNIS, or an equivalent standard), together with mapping of contaminated areas. Mapping contaminated land is a primary objective of the reconnaissance survey; however, the level of detail need only be sufficient to identify potential study areas for subsequent investigation;
- Numerous photographs (view shots with adequate geo-referencing, habitat shots (with appropriate scaling and geo-referencing) and close-ups (mark location on map or geo-reference with handheld GPS));

- Ecological observations of condition of impacted plants and animals (any signs of decay or stress, growth status and evidence of new growth, reproductive status, which parts of the plants are oiled or show signs of chemical contamination);
- Brief assessment of the condition of any known populations of protected species (conspicuous species only, e.g. plants);
- Collection of a representative sample of impacted flora and fauna (stored as pressed specimens);
- Other relevant observations (e.g. dead animals, green algal cover, evidence of any clean-up);
- Brief assessment of potential for follow-up surveys (including practical and logistical constraints).

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

6.1.3.2 Biological features and parameters

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

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

> **“For each biological feature, there are also many possible attributes to choose from; and for each attribute there will also be a variety of optional study techniques and detailed protocols”**

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

Individual (sub-lethal) effects – studies that describe changes in individuals of particular species or groups of species, including physical (external pathology), internal (histopathology), reproductive, biochemical and genetic condition and animal behaviour. Conspicuous effects that can be studied in the field or on whole organisms (e.g. growth rates of plants and sessile invertebrates, egg-laying success by birds and abnormal growths on fish) are useful for some species, but in recent years there have been developments in various techniques to identify sub-lethal effects of pollutants in the tissues of individual animals, sometimes referred to as biomarkers[17]. However, even if sub-lethal effects are found and are linked to the spilled oil or chemicals, their relevance and importance to the condition of animal populations and the ecosystems they live in may not be apparent.

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

6.1.3.3 Selecting and developing methods and protocols

All biological features are influenced by a range of environmental factors that may confound the effects of an oil or chemical spill and complicate interpretation of study results. When collecting biological samples and data for communities, populations, and species, it is therefore important to also record the environmental factors that characterise their habitat.

Relevant international and national standards and best practices should be followed during sample collection and analysis to minimise the risk of later queries or challenges. Although standard methodological protocols are available for some habitats and species, these may require modification to ensure they are appropriate for the specific characteristics of the affected environmental resource and spill conditions. Section 6.2 provides references to standard methodological texts for surveying and monitoring biological resources.

Methodologies should clearly define sampling approaches, survey techniques, laboratory procedures, equipment requirements, and protocols for data recording, sample collection, preservation, storage, laboratory processing, and data analysis. They should also include measures to minimise sampling error where practicable, prevent cross-contamination, and ensure robust quality assurance and quality control procedures. Survey and laboratory personnel should possess appropriate qualifications and experience.

The amount of data required will depend on factors such as the natural variability of the resource, the extent and intensity of the impact, and the type of system affected, all of which influence statistical requirements. These considerations should inform the selection of impacted and reference sites, the number of replicate samples collected at each site, and the frequency of survey and sampling activities. A fixed-station sampling design is advocated to support consistency and comparability over time, with stations established at impacted and reference locations. Site selection should therefore aim to ensure representative spatial coverage while maintaining statistical robustness and operational practicality. Site selection guidance is provided in Section 3.5.

Given the inherent variability of natural environments, obtaining absolute statistical proof of impact can be challenging. Sampling programmes should therefore be designed to achieve the highest practicable level of statistical robustness (see Section 3.8).

6.2 Coastal and marine habitats

This section provides guidance to support ecological assessment of specific resources (habitats and wildlife) that may be affected by a spill. It is intended to help practitioners understand the key ecological features that influence exposure, sensitivity and recovery, and to support proportionate selection of survey and monitoring activities. For consistency, each habitat or species entry is presented using a common structure:

1. *Characteristics of habitat/species* (a brief description of the resource and relevant ecological attributes);
2. *Known vulnerabilities and sensitivities* (how and why the resource may be affected by the contaminant, and factors influencing recovery); and
3. *Impact assessment method and strategy* (practical considerations for survey design, indicators and approaches for assessing impact and recovery).

The guidance provided in the following sections is primarily derived from experience gained from studies carried out during oil spills. Similar studies have not generally been undertaken on chemical spills in the marine environment. However, similar considerations will generally apply, although the broader range of physicochemical properties and behaviours of chemicals will affect the applicability of the guidance depending on the chemical(s) spilled.

For the purposes of this assessment, habitat and species sensitivity is defined as the likelihood of change when a pressure is applied, based on a combination of resistance (tolerance to disturbance) and resilience (capacity for recovery). Vulnerability is used here to describe the exposure of habitats or species to a spill event in combination with their sensitivity. Where available, nationally or regionally recognised habitat sensitivity assessment frameworks should be used. The guidance presented in this section draws on published habitat sensitivity frameworks, including the UK Marine Life Information Network (MarLIN)[18] and its MarESA sensitivity assessments, which have been developed for offshore and coastal habitats within and outside MPAs, consistent with Joint Nature Conservation Committee (JNCC) conservation advice[19]. Equivalent national or regional frameworks should be used where available.

[Note: several habitats and species groups described in the following sections may include populations of protected species of conservation importance. Surveys affecting protected species may require permits or licences from the relevant national or regional authority. In the UK, this would normally involve an emergency wildlife licence issued by the Marine Management Organisation (MMO)].

18 https://www.marlin.ac.uk/
19 https://www.jncc.gov.uk/our-work/conserving-marine-protected-areas/

6.2.1 Terrestrial maritime habitats

Characteristics of habitat

Terrestrial maritime habitats occur above the normal limit of high tides but remain strongly influenced by the sea through salt spray, storm overtopping, sea mists, wind exposure and coastal sediment dynamics. They include coastal dunes (embryo, mobile and fixed dunes), shingle structures, cliffs and cliff-top grasslands/heath, coastal grassland and scrub, and associated transitional communities at the land–sea interface. These habitats often show strong zonation and patchiness driven by exposure, substrate mobility, freshwater availability and disturbance. Vegetation is typically salt-tolerant and stress-adapted, with plant communities shaped by nutrient limitation, desiccation, abrasion by windblown sand or shingle, and episodic storm events.

Known impacts and sensitivities

While impacts are generally less severe than those associated with marine environments, terrestrial environments may nevertheless be affected, including through physical smothering, contamination of substrates, and ingestion by wildlife.

The *Braer* oil spill was one of the few incidents to result in significant terrestrial contamination, due to incredibly strong winds and the large volumes of light oil that were released next to the coast and moving into the terrestrial environment. However, nearly all other studies of marine oil spills, including the *Sea Empress*, have shown no discernible effects on terrestrial vegetation that was not heavily oiled. It is currently concluded that terrestrial vegetation is not normally vulnerable to marine oil spills and that impacts are unlikely to be detected unless visibly coated with oil. However, to date, such studies have not been undertaken following chemical spills.

However, coastal habitats, above the level of spring high tides, may be impacted by intensive clean-up activity if they are used as an access route to the shore or as a laydown area for equipment. Those that will be particularly vulnerable include sand dune and vegetated shingle ridge communities.

Impact assessment method and strategy

Assessing the impacts of spills on terrestrial coastal habitats is generally more straightforward than on intertidal areas, largely due to the absence of water and the ability to remove surface contamination and affected vegetation. While initial signs of damage, such as scorching and dieback, may be evident soon after the incident, these effects can fade as new growth emerges during the following spring or summer. After a spill, there is usually a window of several weeks to document the extent of contamination, analyse soil samples for pollutants, carry out preliminary surveys, and establish a robust scientific methodology for impact assessment. Such a methodology should incorporate the following key elements:

1. Reconnaissance: Record visible signs of scorching and dieback in vegetation.
2. Biological survey attributes: Monitor indicators such as vegetation condition, specifically noting evidence of scorching and dieback. Observe recovery through the appearance of new growth in spill-impacted perennial species.

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

- If good quality pre-incident data exist from the impacted area, then establish previous survey sites and use the same methodology to survey impacted vegetation;
- If no (or inadequate) pre-incident data are available from the impacted area, but oiling or chemical contamination is very severe and significant impacts are expected, establish discontinuous belt transects or random quadrats across selected impacted communities (preferably stratified by level of oiling or contamination) and in reference areas outside;
- Use standard botanical survey methods to survey plant communities; monitor changes at seasonal intervals. Comparisons between impacted and reference sites will be strongly influenced by other environmental factors;
- Bioassay studies on soil from the contaminated areas and reference sites include counts of germinating seeds of local grasses;
- Effects of clean-up: methods to study effects of physical impact from access and clean-up would depend on the affected habitat; but measurements and monitoring of percentage cover are likely to be appropriate; and
- QA/QC – measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. Repeat recording and data checks by other surveyors will also be appropriate.

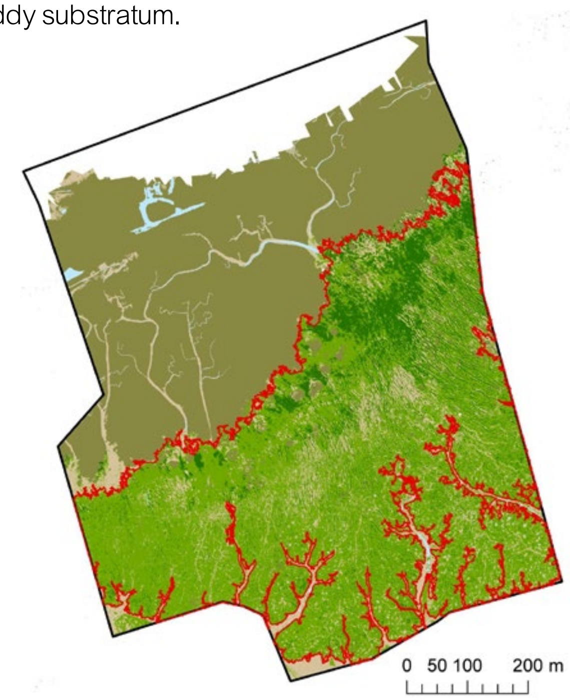
6.2.2 Saltmarshes

Characteristics of habitat

Intertidal habitats occurring in sheltered coastal environments, typically in estuaries and embayments. Saltmarshes are characterised by fine, soft, muddy or silty sediments, frequent tidal inundation, and the presence of salt-tolerant vegetation. They are generally close to shore, often lowlying and gently sloping, and may be dissected by tidal creeks and pools. Saltmarshes are highly productive ecosystems, providing important nursery for fish, sediment stabilisation, and natural coastal protection.

Known vulnerability and sensitivity

Saltmarshes are generally considered to be very vulnerable to oil and chemical spills as they form in the upper part of sheltered muddy shores where contaminants may accumulate. Oil, in particular, can become concentrated in these areas, while the behaviour and persistence of spilled chemicals will depend on their intrinsic properties. Once pollutants enter a marsh, they may become trapped by the vegetation and sediments, potentially resulting in long-term contamination. Impact to the saltmarsh vegetation affects the whole marsh ecosystem and is also likely to affect neighbouring ecosystems that rely on services from the marsh. Saltmarshes are one of the more difficult habitats to clean, due to the soft and muddy substratum.



Impact assessment method and strategy

Attempts to clean up these areas are not recommended without specialist advice. Access can be difficult due to soft substrata, waterlogged conditions, and limited land access points.

Effects can also be expected from exposure to spilled chemicals, but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical. There is a considerable body of literature on impacts of oil spills and on spill clean-up on saltmarshes. Ipieca (2015) summarised information on their sensitivity and recovery potential. AURIS (1994), Sell *et al.*, (1995), Baker *et al.*, (1996), and Michel and Rutherford (2014) have reviewed the literature on impacts and recovery of saltmarshes following several oil spills and experimental studies. A summary of likely effects is summarised in Baker *et al.*, (1996):

- Light to moderate oiling, oil mainly on perennial vegetation with little penetration of sediment. Some or all plant shoots may be killed, but recovery can usually take place from the underground systems. Good recovery commonly occurs within one to two years;
- Light to moderate oiling, oil mainly on annual vegetation with little penetration of sediment. It is possible that areas of vegetation may die completely. If large areas are affected, recovery may be delayed due to a lack of local seed supply or an inability to germinate because it has been oiled;
- Oiling of perennial vegetation such that species composition is altered. Following oiling, it is sometimes found that species composition is altered for some time because relatively resistant species take over from more susceptible species. If good vegetative cover (of whatever species composition) can be established quickly, there will be minimal risk of soil erosion;
- Oiling of shoots combined with substantial penetration of oil into sediments. This is more likely to happen with relatively fresh light crude oils or light products such as No. 2 fuel oil (diesel), because these are less viscous. Impact to the underground systems results from the effects of sub-surface oil, and recovery is prolonged. Areas of vegetation may die completely. Sediment erosion may occur if re-colonisation does not start within a year; and
- Thick deposits of viscous oil or mousse on the marsh surface. Vegetation is likely to be killed by smothering, and recovery delayed because persistent deposits inhibit re-colonisation.

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

- **Group 1**: Filamentous algae (e.g. *Ulothrix, Enteromorpha, Vaucheria*). Filaments may be killed quickly by some oils, but populations can recover rapidly by growth and vegetative reproduction of any unharmed fragments, or by spores.
- **Group 2**: Shallow rooting, usually annual plants with no underground storage organs (e.g. some species of *Suaeda* and *Salicornia*). The plants can be quickly killed by a single spillage, and recovery depends upon the successful germination of seeds. Seedlings of perennial plants are also easily killed.
- **Group 3**: Shrubby perennials with exposed branch ends (e.g. *Halimione, Iva, Baccharis*) which may be badly impacted by oil. If some parts of the plant remain undamaged, recovery can take place through new shoot formation.
- **Group 4**: Perennial grasses and some other grass-like plants which usually recover well from light or moderate oiling (e.g. *Festuca, Puccinellia*). New growth can take place from the basal areas, which are typically protected from oil by overlying vegetation or old leaf sheaths. Some grasses, notably *Spartina*, have extensive underground systems with food reserves; these are an advantage when new shoots are produced after a spill. Other grasses (e.g. *Agrostis stolonifera*) may have a competitive advantage in vegetation recovering from oil because of their fast rate of growth and mat-forming habitat.
- **Group 5**: Perennials with robust underground storage organs (e.g. tap roots), including *Armeria, Limonium* and *Plantago*. These plants tend to be the most resistant to oiling, with new growth occurring from the rosette centres.

Baker *et al.* (1996) highlight that the effectiveness of recovery in saltmarshes following an oil spill is strongly influenced by the time of year the incident occurs. Recovery rates can vary depending on whether plants are in a period of natural dormancy, the timing of seed production, and how much energy is stored in underground tubers. Repeated evidence shows that physical or chemical clean-up methods in oiled saltmarshes often result in substantial long-term damage. As a result, most professional oil spill responders now agree that allowing the marsh to recover naturally is usually the preferred approach for most contaminated areas (Michel and Rutherford, 2014; Zengel *et al.*, 2015). Nonetheless, errors in clean-up do still occur, sometimes leading to harm such as damaged root systems, deep ruts that persist in the marsh, oil being forced deep into muddy sediments, and even significant erosion along marsh edges. For situations where a response is essential, guidance on suitable clean-up options are documented in NOAA (2013) and Michel and Rutherford (2014).

Although spatial patchiness and temporal variability in saltmarshes are not as pronounced as in many other habitats, it is important to recognise that seasonal and inter-annual changes can still be significant. These fluctuations must be considered when conducting impact assessments, as they may influence the interpretation of observed effects and recovery processes. Understanding the natural variability in saltmarshes is essential for accurately distinguishing between changes caused by external impacts and those resulting from normal ecological cycles. This means that while baseline data will be very valuable, impact to saltmarsh communities may be best assessed by methodically monitoring their condition over the following weeks, months and possibly years; and using the same methods in uncontaminated reference sites. It is recommended that aerial photographs (or multispectral scans) are acquired as soon as possible of the contaminated marsh and surrounding areas.

If the oil or chemical causes plants to die or lose their leaves, the aerial photographs/images will provide a baseline for assessing and monitoring the extent of impact, although this will need to take account of natural seasonal dieback. Initial focus of the assessment should consider the following elements:

1. It is useful to record dead wildlife as counts of recently dead crabs and snails will provide useful evidence of impact;
2. Reconnaissance should include taking note of the condition of contaminated plants (signs of decay in leaves, shoots, and roots; evidence of new growth; reproductive status); which parts of the plants are contaminated; any evidence of long-term natural trends (signs of natural dieback; is the marsh young and spreading or old and degenerating?). Reconnaissance should make use of appropriate aerial photographs or imagery, which can help define the area of impact and inform the selection of survey and sampling locations; and
3. Biological survey attributes: some of the more likely potential indicators include vegetation condition (decay and death of leaves, stems and roots), opportunistic algal cover and sediment macrofauna abundance (particularly snails and opportunistic polychaetes). Recovery will be indicated by new growth from damaged perennials, the lodging and rooting of vegetative fragments on mud surfaces, invasion of damaged areas by vegetative runners from undamaged areas, germination of seeds and seedling growth. Aerial photo-monitoring of vegetation cover may show extent and recovery from severe impacts.

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

- Some assessment should be carried out in all marsh zones that were significantly coated with oil (i.e. more than sheens or a few small patches) or chemical(s);
- Resurvey and compare with pre-incident data if available, bearing in mind that natural fluctuations will be high for annual plant species and mobile invertebrates. Where possible, post-incident surveys should be undertaken at a consistent time of year, ideally corresponding with the timing of pre-incident surveys, to help distinguish recovery from natural seasonal variability;
- Comparison between stations with different degrees of contamination may be possible within spatially extensive marshes;
- Comparison between stations on different marshes will be strongly influenced by other environmental factors;
- An alternative option may be to monitor changes in some of the above attributes at temporal intervals from early stages of spill for at least one year at selected sites;
- Effects of clean-up – methods to study effects of physical impact will depend on the affected features and extent of impact, but are likely to include basic ecological observation, vegetation mapping and, in worst cases, measures of the rate of erosion at marsh edges;
- QA/QC – measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording;
- Identification of epibiota (e.g. saltmarsh snails and algae) will require specialist training. Repeat recording and data checks by other surveyors will also be appropriate.

6.2.3 Mangroves

Characteristics of habitat

Mangrove forests occupy sheltered, low-energy tropical and subtropical coastlines, including estuaries, lagoons, deltas, and bays. They consist of salt-tolerant tree and shrub species growing in waterlogged, anoxic, fine sediments. Mangrove systems provide structurally complex root networks (e.g. prop roots, pneumatophores) that trap sediments, support rich invertebrate and juvenile fish communities, and stabilise shorelines. Their tidal inundation cycles, organic rich substrates, and limited water exchange mean that contaminants, including oils and solid pollutants such as plastic pellets, can become trapped and slow to degrade.

Known vulnerability and sensitivity

Mangroves are highly vulnerable to oil spills, particularly heavy or weathered oils that adhere to roots and sediments. Oil smothering blocks gas exchange through lenticels and pneumatophores, causing root anoxia, leaf yellowing, defoliation, reduced productivity, and in severe cases, tree mortality. Because mangrove root systems are vital to tree survival, even thin oiling can result in delayed die-off months after exposure. Oil can also accumulate in mangrove sediments for prolonged periods due to low oxygen conditions, limited flushing rates, prolonging toxicity and inhibiting recovery.

Mangroves are also notably susceptible to contamination by plastic pellets (nurdles), which commonly accumulate within their complex root systems. These pellets are physically trapped amongst roots and sediments, proving challenging to remove and persisting for considerable periods. This persistence results in extended exposure and potential secondary contamination. Research has demonstrated that plastic pellets can smother sediments, be ingested by invertebrates and juvenile fish, and interact with chemical additives or adsorbed pollutants, thereby posing ecological risks to mangrove habitats (Sewwandi *et al.*, 2022). Evidence from the MV *X-Press Pearl* disaster further demonstrated that spilled nurdles can persist for months to years in coastal environments, undergo physical weathering and chemical alteration, and adsorb contaminants including combustion-derived PAHs, increasing their potential ecological hazard and complicating clean-up efforts (Sewwandi *et al.*, 2022; James *et al.*, 2023).

In summary, the persistent nature of oil and other contaminants within mangrove sediments, compounded by the structural complexity and limited flushing of these habitats, makes mangroves exceptionally vulnerable to environmental pollution. The difficulties associated with effective clean-up, alongside the risk of causing further damage through intervention, highlight the need for careful, specialised management. Ultimately, such impacts extend beyond immediate mangrove health, resulting in significant mortality among crabs, molluscs, and juvenile fish that depend on mangroves for nursery grounds, as well as diminishing detrital production vital to sustaining adjacent coastal food webs.

Clean-up in mangroves must be approached with extreme caution, as physical disturbance often causes more damage than the oil itself. Mechanical removal, flushing with high-pressure water, or trampling by response teams can uproot seedlings, compact anaerobic soils, damage pneumatophores, and accelerate erosion. Best practice emphasises low-impact, carefully controlled interventions, such as removing floating oil before it strands, using sorbents to capture surface residues, and manually recovering small accumulations where accessible. In many cases, natural recovery, supported by preventing further contamination, is preferable, as aggressive clean-up can kill roots and prolong ecosystem degradation. Clean-up decisions must weigh the sensitivity of mangrove communities and the likelihood of causing long-term damage through intervention, with expert ecological input essential to avoid irreversible impacts.

Impact assessment method and strategy

Impact assessment in mangroves should include both immediate and delayed effects, as symptoms often manifest over weeks to months. Surveys should record visible oiling on roots, sediments, and litter; leaf chlorosis or necrosis; branch dieback; and tree mortality. Because oil persistence in sediments is a major concern, sediment sampling should assess hydrocarbon concentrations and penetration depth. Biological indicators may include crab abundance, mollusc mortality, root condition, seedling recruitment, and changes in macrofaunal communities. Aerial or drone imagery can document canopy dieback and the spatial extent of affected stands, while long-term monitoring tracks recovery trajectories or continued decline.

Assessments should also consider natural variability, confounding factors, and the feasibility of detecting true-spill related impacts versus other stressors, using unaffected reference sites wherever possible.

1. Conduct initial reconnaissance along the mangrove shoreline, noting the condition of vegetation, visible oiling, and presence of key species such as crabs and molluscs.
2. Undertake systematic surveys to record the following:
   - Visible oiling of roots, sediments, and leaf litter;
   - Leaf chlorosis, necrosis, and branch dieback;
   - Tree mortality and seedling recruitment;
   - Crab and mollusc abundance and mortality;
   - Macrofaunal diversity and changes in community structure.
3. Collect sediment samples to measure hydrocarbon concentrations and penetration depth, focusing on areas with limited flushing and organic-rich substrates.
4. Use aerial or drone imagery to map canopy dieback and quantify the spatial extent of impacted mangrove stands.
5. Monitor recovery trajectories or ongoing decline through repeated assessments at intervals, ideally for at least one year post-incident.
6. Compare impacted sites with unaffected reference sites to distinguish spill-related effects from natural variability and other environmental stressors.

Document confounding factors (e.g. tidal cycles, freshwater input, previous disturbances) to improve interpretation of impact data.

Where pre-incident data are available, resurvey and compare to detect changes attributable to contamination.

Assess the persistence and removal of contaminants such as oil and plastic pellets, noting their physical trapping within root systems and potential for secondary ecological impacts.

6.2.4 Intertidal sediments

Characteristics of habitats

Intertidal sediments comprise beaches and foreshores of sand, muddy sand and mud that are regularly inundated and exposed by the tide, including estuarine mudflats and sheltered bays as well as more exposed sandy shores. These habitats are often physically dynamic and strongly structured by sediment grain size, organic content, drainage, wave exposure and tidal currents, which influence oxygen penetration, redox conditions and the distribution of infauna. Intertidal sediments typically support diverse communities of burrowing and tube-building invertebrates (e.g. polychaetes, bivalves, crustaceans) that underpin coastal food webs and provide key feeding areas for fish and waterbirds. Sediment characteristics and biological communities can vary markedly over short spatial scales (e.g. across shore height, creek edges and patches of differing grain size) and seasonally, reflecting natural disturbance and recruitment cycles.

Known vulnerability and sensitivity

Sedimentary shores range from coarse shingle shores exposed to wave action to soft mudflats in sheltered bays. There are a number of physical and biological characteristics of sedimentary shores that can influence their vulnerability and sensitivity to oil or chemical spills, including wave exposure, shore topography, sediment composition, height of water table, presence of large burrows, abundance and diversity of infauna. The use of the shore by birds for feeding and roosting may also influence the ecological consequences of a spill. Wave-exposed, clean sandy shores are often considered to have a low vulnerability and sensitivity due to the natural cleaning of the waves and the relative sparsity of fauna present in the sediment. However, a sheltered muddy gravel shore with a high biodiversity, including numerous long-lived bivalves, would have a high vulnerability and sensitivity. Oil can persist and remain toxic in sheltered muddy sediments for many years (decades), particularly in unoxygenated sediments. AURIS (1985) reviewed the effects on intertidal sediments from many spills and experimental studies, while Ipieca (2016) summarised information on their sensitivity and recovery potential.

Potential impact pathways will vary depending on the physical and chemical properties of the spilled substance. For example, floating substances may remain at the surface and affect surface-dwelling biota or shoreline habitats; while sinking or neutrally buoyant substances may accumulate in sediments and affect benthic habitats. Solubility, persistence and tendency to adhere to particles or organic matter will further influence exposure pathways, uptake by organisms and the potential for both physical and toxic effects.

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

Some faunal communities associated with sedimentary habitats are more sensitive to oil than others. Small crustacea (particularly amphipods and small crabs), some bivalves (e.g. cockles) and surface-grazing snails (e.g. winkles) have been identified as the main casualties at several oil spills. Some other species of fauna which are associated with intertidal sediments may opportunistically increase following oil spill impacts. These include small polychaetes such as *Capitella* spp.

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

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

Impact assessment method and strategy

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

[Note: Surveys and monitoring of sediment communities have two important advantages over rocky shore communities: much reduced small-scale variability (patchiness) of confounding environmental factors and relatively well-defined sample units (specified sampling devices, mesh sizes, etc.). However, impacts are generally less conspicuous and temporal fluctuations are just as high as on rocky shores.]

“

Severe impacts to infaunal communities of intensive and extensive flushing operations … were found on beaches oiled by the 1989 *Exxon Valdez* spill; and effects were still evident more than two years later.”

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

1. Recording dead wildlife: counts of dead crabs, bivalves, etc., will provide useful evidence of impact.
2. Reconnaissance: taking note of drainage features; presence of seagrass, surface grazing snails, cockles and other large bivalves (particularly on the lower shore), lugworm casts, large burrows, areas that would be very difficult to core into (due to subsurface coarse material), presence and character of strandline debris.
3. Biological survey attributes: some of the more likely potential indicators include megafauna abundance (particularly bivalves); macrofauna diversity and abundance (particularly amphipods and opportunistic polychaetes); growth rates of long-lived bivalves. The polychaete/amphipod ratio has been suggested as an oil spill ‘bioindicator’ by Gesteira and Dauvin (2000). Meiofauna abundance and diversity may be useful for following short- to medium-term effects, but natural fluctuations and patchiness may hamper robust impact assessments beyond several months. The development of a method to assess sediment toxicity from natural copepod egg viability may become useful. The Infaunal Quality Index (IQI), developed under the Water Framework Directive (WFD), is designed to assess sediment community health in response to organic enrichment and contaminant effects (Phillips *et al.*, 2014) and should therefore identify notable impacts of the oil or chemical.

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

- Resurvey and compare with pre-incident data if available; but consider initially analysing only a selected few of the total samples to assess scale of impact before full re-analysis.
- Comparison between stations with different degrees of contamination may be possible on very extensive beaches/shores. Comparison between sites on different shores will be complicated by confounding environmental factors.
- Monitoring changes in some of the above attributes at intervals (bimonthly or seasonal) from the early stages of a spill and for at least one year at selected sites may show stages in impacts and recovery.
- Bioassay tests: whole-sediment bioassays (e.g. survival of laboratory reared amphipods in sampled sediment) could provide very useful tests of toxicity, particularly when natural variability of infaunal communities is very high and it is uncertain whether amphipods would naturally be present.
- Effects of clean-up: potential impacts are from physical disturbance and burial of oil (particularly from trenching), and contaminated water run-off (from intertidal flushing operations). Such operations are most likely on firm sand beaches. Impact assessment could be similar to the methods above, but it will be difficult to separate clean-up effects from other spill effects unless an experimental approach (incl. pre-clean-up sampling) is applied. Physical disturbance effects are more likely if these operations can occur on sheltered muddy sediments; and monitoring of the infaunal communities should be able to detect impacts and follow recovery; and
- QA/QC: Sediment sampling and analysis should follow recognised national or international quality assurance standards (e.g. NMBAQC in the UK).

6.2.5 Rocky shores (including splash zone lichens)

Characteristics of habitat

Rocky shores are often high-energy intertidal habitats characterised by hard substrata (bedrock, boulders, cobbles) and strong physical gradients in exposure, tidal height and wave action. Distinct biological zones occur from the splash/supralittoral (including salt-tolerant lichens) through upper, mid and lower shore communities dominated by barnacles, mussels, fucoid seaweeds and kelps, with crevices, pools and overhangs providing local refuges and microhabitats. Community composition can vary over very small distances due to aspect, shelter, substrate roughness and freshwater seepage.

Known vulnerability and sensitivity

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

There is a considerable body of literature on the impacts of oil spills and on spill clean-up on rocky shores. Ipieca (1995; 2016) summarised information on their sensitivity and recovery potential. AURIS (1994) and Baker *et al.* (1996) reviewed the literature on impacts and recovery of rocky shores following many oil spills and experimental studies.

Studies on the effects of the 1967 *Torrey Canyon* oil spill by Southward and Southward (1978) defined the classic impacts and long-term recovery processes that oil and detergents (not 'dispersants' as they are now defined) could have on limpet-dominated communities. However, the longevity of the effects they described (on a decadal scale) has not been recorded from any spill since; presumably because the chemical agents used on the oil had a much more devastating effect than the oil by itself. More recent studies on various oil spills have found that recovery is normally much quicker (less than three years), although chronic persistent oil (particularly residues of viscous black oils in sheltered locations) can have long-term localised impacts.

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

"Sheltered rocky shores are often more vulnerable and sensitive, particularly if they include large numbers of rockpools and crevices."

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

- Acute mortality of intertidal limpets is a good indicator of fresh oil contamination (by liquid oil or very high concentrations in water), but mortality is much reduced if the oil is weathered. Adult limpet abundances are relatively easily recorded and monitored by a variety of quantitative and semi-quantitative techniques. Juvenile limpets (<10 mm in length) may be more sensitive than adults, but abundances are less easily recorded, and the most recent recruits are certainly too well hidden to record during winter months. Size frequency monitoring can also provide useful information on impacts and recovery of the limpet populations;
- Acute mortality of other gastropods (e.g. winkles and topshells) is also likely if large amounts of fresh oil or high concentrations of oil in water are present; but their cryptic behaviour can make robust monitoring more difficult in some habitats;
- Diversity and abundance of small crustacea (e.g. in kelp holdfasts and algal turf habitats) are greatly affected by hydrocarbon concentrations in water (and presumably by liquid oil) and seem to have potential as indicators of oil contamination. More research is required on their sensitivity to different hydrocarbon concentrations and weathered oil, on recovery processes after impact, and on the development of appropriate survey/sampling/analysis techniques;
- Mortality of barnacles, primarily by smothering rather than chemical toxic effect, is likely where oil covers rocks; but full recovery is likely to occur by new recruitment in the following year unless residues of oil are persistent (e.g. from viscous oils in sheltered locations);
- Bleaching of coralline algae (crustose forms and *Corallina* spp.), and in very worst cases of other red algae, is likely to occur from toxic oil concentrations, but not from weathered oil. However, death of the plants is not inevitable unless oiling and toxicity is very severe, and surviving plants are likely to regain colour quickly;
- Other algal groups, particularly adult fucoids, have often been considered relatively insensitive to oil contamination. However, this view largely reflects a focus on adult growth responses, with early and juvenile life stages frequently overlooked. Evidence suggests that early developmental stages of fucoid algae can exhibit sub-lethal responses to hydrocarbon exposure, including growth retardation and cellular effects, indicating potential utility as sensitive indicators of spill impacts, although detection under field conditions may remain challenging (Holland, 2011).
- Studies on rock pool communities have suggested that acute and chronic oiling can have effects on diversity and abundance of species, but methodological difficulties so far limit the reliability of monitoring. Further research and development of the techniques are suggested;
- Splash zone lichens are vulnerable to oiling on very high tides, and some of these long-lived slow-growing species are sensitive to oil coating their thalli (particularly *Xanthoria parietina*);
- No other reliable indicators of oil spill impacts have been found. It is likely that various other rocky shore species and communities may be sensitive to oil spills (particularly small mobile species in other cryptic sub-habitats, e.g. crevices and under-boulder habitats), but reliable survey and monitoring techniques have not been developed.
- Effects can also be expected from exposure to spilled chemicals, but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Impact assessment methods and strategy

Detecting impacts on rocky shore communities, beyond the characteristic temporary 'green flush', can be very difficult, even with good pre-incident data. This is due to their typically high degree of spatial patchiness and temporal variability.

Early reconnaissance of contaminated rocky shores is recommended so that signs of initial impacts can be recorded. Subsequent assessment of population effects is likely to require considerable efforts to collect data from numerous contaminated sites and numerous comparable reference sites.

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

1. Recording dead wildlife: counts of dead/moribund limpets and other gastropods will provide useful evidence of impact.
2. Reconnaissance: taking particular note of fresh limpet scars on rock (estimate proportion of scars to live limpets); bleached coralline algae and other red algae; cover of ephemeral green algae; distribution and typical plant sizes of fucoid algae; presence of rock pools with algal turf; presence of mature kelp in sublittoral fringe.
3. Biological survey attributes: some of the more likely potential indicators are: limpet density and size/age structure of populations; amphipod diversity and abundance in kelp holdfasts (and maybe in algal turfs); proportional cover of bleached coralline algae crusts; abundance of ephemeral algae and percentage cover of the lichens *Xanthoria parietina* and *Ramalina siliquosa*. Reduced grazing pressure over a period of months may result in increased abundance of fucoids and other brown/red algae. Potential indices for measuring sub-lethal stress in some rocky shore species (e.g. mussels and limpets) have been developed in recent years, but it may be difficult to translate results from these tests into evidence of impact.

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

- Resurvey and compare with pre-incident data if available; bearing in mind that age and quality of pre-incident data will greatly affect impact detection;
- Comparisons of conspicuous species/community data from contaminated and uncontaminated sites, or trends along a gradient of increasing distance from source, are unlikely to detect more than the very gross effects that are obvious anyway, even if moderately large numbers of sites are established. This is due to the influence of many confounding factors that are almost impossible to effectively reduce;
- Comparisons of small crustacea (particularly amphipod) diversity and abundance in kelp holdfasts and other cryptic sub-habitats (e.g. algal turfs) from contaminated and uncontaminated sites, or along a gradient of increasing distance from source, may be very useful. Such studies should preferably start soon (within a few weeks) after the spill, and be repeated at intervals to allow recovery processes to be assessed;

- Monitoring changes in some of the above attributes at intervals from early stages of spill for at least one year (more for longer living species) at selected sites, may show development of effects and then the subsequent recovery process;
- Combination of resurvey of pre-incident data and continued monitoring of changes at badly affected sites will provide best description of effects and recovery process;
- Effects of clean-up: methods to study effects of impact from clean-up would depend on the affected habitat; but photographic monitoring and basic ecological observations are likely to be appropriate;
- QA/QC: *in situ* identification of epifauna and epiflora will require training. Measures of percentage cover can be subjective and require training and survey aids to ensure consistency of recording. Repeat recording and data checks by other surveyors will also be appropriate. Analysis of amphipods and other infauna from algal samples should recognise national or international quality assurance standards (e.g. NMBAQC in the UK).

6. Ecological assessment

6.2.6 Seagrass beds

Characteristics of habitat

Seagrass beds are submerged flowering plant communities found in shallow coastal and estuarine waters where light reaches the seabed. They typically occur on sandy or muddy sediments in sheltered to moderately exposed settings, including bays, lagoons and estuary mouths. Seagrasses form meadows of shoots and leaves above the sediment, supported by extensive below-ground rhizome and root systems that stabilise sediments and promote sediment accretion. These habitats can be highly productive and structurally complex, providing nursery and feeding areas for fish and invertebrates and supporting characteristic epiphytic and benthic communities. The distribution, density and health of seagrass beds are strongly influenced by water clarity (turbidity), nutrient status, salinity, temperature and physical disturbance, and they often show seasonal variation in biomass.

Known vulnerability and sensitivity

There have been relatively few studies examining oil spill impacts on temperate seagrass beds (e.g. AURIS, 1995; Fonseca *et al.*, 2017), but available evidence indicates that both intertidal and shallow subtidal beds may be sensitive to contamination (Zieman *et al.*, 1984). Most studies report limited direct effects on the seagrass plants themselves, aside from leaf blackening and temporary reductions in growth rates (e.g. Jacobs, 1980; Howard *et al.*, 1989; Dean *et al.*, 1998). However, oil and chemically dispersed oil can have more pronounced impacts on associated fauna inhabiting the sediments and leaf surfaces (e.g. Jewett *et al.*, 1999), potentially altering community structure and ecosystem functioning.

Subtidal seagrass beds are often important fish nursery areas, and juvenile fish may be sensitive to high concentrations of dispersed oil. Seagrass habitats also support a range of globally sensitive and protected species, including fish, invertebrates, marine mammals, and reptiles, some of which may rely on these habitats for feeding, breeding, or shelter. Specific consideration may therefore be required where there is potential for sensitive species to be present.

The vulnerability of subtidal seagrass communities to dispersed oil or chemicals will depend greatly on the flushing rate of seawater through the bed, the depth of water and the way in which the contaminants are distributed. Any impact to the plants affects the whole seagrass ecosystem and is also likely to affect neighbouring ecosystems that rely on services from the seagrass. Some seagrass species go through seasonal patterns of growth and dieback.

Impact assessment method and strategy

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

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

There are typically greater effects on populations of animals living in the seagrass bed, although these are subject to greater levels of spatially heterogeneity and temporal variability. Detecting impacts in populations of these sensitive species (e.g. snails and small crustaceans) is likely to require considerable efforts to collect data from numerous contaminated sites and numerous comparable reference sites.

While seagrass beds show natural spatial and seasonal variability, their levels of spatial irregularity and temporal change are generally lower compared to many other habitats. This means that it is often feasible to identify clear effects on seagrass health, provided monitoring starts promptly and incorporates unaffected reference locations. According to Unsworth *et al.* (2014), an effective assessment of seagrass beds, particularly within the UK context, should initially focus on several key aspects, including the recording of dead wildlife, careful reconnaissance to note the condition of seagrass and presence of molluscs, and the evaluation of biological survey attributes such as epifauna, blade condition, algal cover, sediment fauna, and juvenile fish abundance.

A. Intertidal seagrass beds

1. Recording dead wildlife: counts of dead biota (e.g. bivalves) will provide useful evidence of impact.
2. Reconnaissance: taking particular note of condition of seagrassand presence of molluscs (e.g. *Hydrobia, Littorina* and *Cerastoderma*). Aerial photographs (preferably geo-referenced, vertical shots) will help to define the area of impact and may be useful for site selection.
3. Biological survey attributes: some of the more likely potential indicators are: epifauna on blades of seagrass, blade condition (signs of blackening and defoliation), opportunistic algal cover, sediment macrofauna abundance (particularly bivalves), sediment macrofauna diversity and abundance (particularly tube-dwelling amphipods and opportunistic polychaetes) and juvenile fish abundance.

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

- Resurvey and compare with pre-incident data if available. Note, however, that it will be difficult to detect any changes beyond the natural variation unless pre-incident data on any of the above attributes are very good (and recent) and oiling by fresh toxic oil or chemical contamination was/is severe.
- Comparison between stations with different degrees of contamination may be possible on very extensive beds.
- An alternative option may be to monitor changes in some of the above attributes at temporal intervals (e.g. bimonthly) from early stages of spill for at least one year at selected sites.
- Effects of clean-up: the most likely impacts are from physical damage (trampling, vehicle traffic); impact assessment should be based on basic mapping of impacted features, ecological observation and seagrass coverage in relation to impacted features.

B. Subtidal seagrass beds (and extreme lower intertidal)

1. Recording dead wildlife: counts of washed-up bivalves, urchins etc. will provide useful evidence of impact.
2. Reconnaissance: by snorkelling, taking note of condition of seagrass plants, epifauna on blades (including amphipods in tubes and snails) and speed of retraction of bivalve siphons in sediment.
3. Biological survey attributes: some of the more likely potential indicators are: epifauna on blades of seagrass, blade condition (signs of blackening and defoliation), opportunistic algal cover, sediment megafauna abundance (particularly bivalves), sediment macrofauna diversity and abundance (particularly tube dwelling amphipods and opportunistic polychaetes) and juvenile fish abundance.

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

- Resurvey and compare with pre-incident data if available. Note, however, that it will be difficult to detect any changes beyond the natural variation unless pre-incident data on any of the above attributes are very good and contamination by toxic concentrations of oil or chemical were/are severe.
- Comparison with reference sites will be greatly hampered by influence of other environmental factors (some seagrass beds are often relatively small and well separated with distinct, site-specific characteristics).
- Best option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least one year at selected sites.
- Effects of clean-up: potential impacts are from physical damage (trampling of beds at extreme low water), contaminated water run-off (from intertidal flushing operations) and chemically dispersed oil. Impact assessment of the former should be based on basic mapping of damage features, ecological observation and seagrass coverage in relation to damage features. Impact assessment of contaminated water run-off and chemically dispersed oil could be similar to the methods above, but it will be difficult to separate clean-up effects from other spill effects unless an experimental approach (incl. pre-clean-up recording) is applied.

[Note: Where protected species are present, surveys may require permits or licences from the relevant national authority. Surveys involving protected species may require permits or licences from the relevant national or regional authority. In the UK, this would normally involve an emergency wildlife licence issued by the Marine Management Organisation (MMO)].[20]

- QA/QC: for both intertidaland subtidal seagrass beds, measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. *In situ* identification of epifauna and epifloral will require specialist training. Repeat recording and data checks by other surveyors will also be appropriate. Sediment sampling and analysis should follow recognised national or international quality assurance standards (e.g. NMBAQC in the UK (https://nmbaqcs.org/qa-standards/)).

20 https://www.gov.uk/guidance/understand-marine-wildlife-licences-and-report-an-incident

6.2.7 Lagoons

Characteristics of habitat

Coastal lagoons are shallow, semi-enclosed water bodies typically separated from the open sea by barrier beaches, sand spits or coral reefs, with restricted water exchange through inlets or channels. They occur across temperate and tropical regions and may receive inputs from both marine and freshwater sources. Lagoons are generally low-energy environments with fine, muddy or silty sediments and high organic content, often supporting seagrass beds, macroalgae, benthic invertebrates and nursery habitat for fish. Limited flushing, variable salinity and long water residence times increase the potential for contaminants to accumulate in lagoon waters and sediments. In addition to their ecological importance, lagoons often have high socioeconomic value. They commonly support small-scale and commercial fisheries, aquaculture activities such as shrimp or fish farming, and provide a vital source of protein and livelihoods for local communities. As a result, pollution impacts to lagoons can have significant environmental, economic and social consequences, particularly where communities rely heavily on lagoon resources for food security and income.

Known vulnerability and sensitivity

No documented cases of oil or chemical spills contaminating coastal lagoons in the UK or along the north-west Atlantic coastline were identified during this review. UK coastal lagoons are typically semi-enclosed systems with limited or intermittent connectivity to the open sea, which reduces their direct exposure to offshore spill pathways (JNCC, 2004). However, the absence of recorded incidents does not preclude the potential for impacts should contamination occur.

The vulnerability of lagoons to marine spills is highly dependent on the frequency, duration and route by which seawater exchanges with the coastal zone. Lagoons connected via narrow inlets or barrier systems may receive only limited volumes of contaminated seawater and, in some cases, may be relatively amenable to protection through rapid response measures such as temporary barrier closure or deployment of booms at entrances (ITOPF, 2014a).

Despite this generally low likelihood of exposure, lagoon habitats are considered highly sensitive to contamination. Evidence from major oil spill incidents in low-energy and semi-enclosed

coastal environments, particularly in North America, demonstrates that once oil enters such systems it can persist for prolonged periods due to limited flushing, fine sediments and reduced oxygen conditions (Peterson *et al*., 2003). This persistence has been shown to result in long-term impacts on benthic communities, vegetation and associated fauna, with delayed recovery and chronic ecological effects extending many years beyond the initial spill event (Peterson *et al*., 2003; ITOPF, 2014b).

Impact assessment method and strategy

A comprehensive approach to impact assessment for lagoon habitats should begin by thoroughly evaluating key ecological, physical, and socio-economic factors that may influence the extent and nature of potential impacts. In line with best practice, the initial phase of assessment ought to incorporate consideration of the following elements:

1. Reconnaissance: along shore and subtidally by snorkelling, taking particular note of condition of lagoon vegetation and conspicuous presence of species for which the lagoon is known to be important.
2. Biological survey attributes: some of the more likely potential indicators include abundance and diversity of gastropods on emergent vegetation, plant condition (signs of blackening and defoliation), opportunistic algal cover and sediment macrofauna diversity (particularly tube-dwelling amphipods and opportunistic polychaetes).

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

- If pre-incident data are available: resurvey and comparison of new data with pre-incident data. It will be difficult to detect any changes beyond the natural variation unless toxic concentrations of oil or chemicals are very high.
- Comparison with reference sites will be greatly hampered by influence of other environmental factors (lagoons are often relatively small and well separated with distinct site-specific characteristics).
- Best option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of incident for at least one year at selected sites.
- Effects of clean-up: methods to study effects from access and clean-up will depend on the affected features and extent of impact but are likely to include basic ecological observation and vegetation mapping. If a lagoon is protected from oil or chemical ingress by use of a dam (e.g. Pickleridge lagoon during the *Sea Empress* spill) or other prolonged blockage of normal water flow, then monitoring of water quality (e.g. bottom water oxygen concentration) and a related biological attribute may be appropriate.

[Note: Where protected species are present, surveys may require permits or licences from the relevant national authority. In the UK this is typically an emergency wildlife licence issued by the MMO. Surveys affecting protected species may require permits or licences from the relevant national or regional authority. In the UK, this would normally involve an emergency wildlife licence issued by the Marine Management Organisation (MMO)].[21]

- QA/QC: measures of plant condition can be subjective and require training and survey aids to ensure consistency of recording. Identification of epibiota (e.g. snails and algae) will require training. Repeat recording and data checks by other surveyors will also be appropriate. Sediment sampling and analysis should follow recognised national or international quality assurance standards (e.g. NE Atlantic Marine Biological Analytical Quality Control (NMBAQC) in the UK).

21 Understand and apply for marine wildlife licences and report an incident: https://www.gov.uk/guidance/understand-marine-wildlife-licences-and-report-an-incident

6.2.8 Subtidal sediments

Characteristics of habitats

Subtidal sediment habitats occur below the low-water mark and extend across continental shelf areas, estuaries and sheltered coastal waters. They include a range of sediment types, from fine muds and silts to sands, gravels and mixed sediments, with physical characteristics determined by depth, hydrodynamic energy and sediment supply. These habitats are often characterised by relatively stable conditions compared with intertidal areas, although they may be influenced by currents, wave action and seasonal changes in sediment mobility.

Subtidal sediments support diverse benthic communities, including infaunal and epifaunal invertebrates (e.g. polychaetes, bivalves, crustaceans and echinoderms), and provide important feeding grounds for demersal fish. Fine-grained sediments, in particular, tend to be organically rich and may exhibit low oxygen conditions below the sediment surface. Due to their depositional nature, subtidal sediments can act as sinks for contaminants, with limited natural disturbance leading to prolonged retention of pollutants once deposited.

Known vulnerability and sensitivity

Dispersed oil in water (in water-soluble form, as fine droplets, or adsorbed to water particulates) and oil bound to shoreline sediments can make its way down to the seabed and contaminate subtidal sediments. It is also likely that high concentrations of dispersed oil can affect sediment epifauna and filter feeders without necessarily becoming bound into the sediment. Impacts on the infaunal communities associated with the seabed sediments have been described after several oil spills, but normally only in shallow depths where oil in water concentrations were particularly high or close to sandy beaches. The extent to which sediment contamination occurs is also a function of the sediment character. For example, oil particles preferentially adsorb onto fine particles of silt and clay, so higher concentrations are normally found in muddy sediments.

While it is generally considered unusual for notable quantities of oil from surface oil spills to reach depths greater than 10m, there are known cases where this has happened. For example, dispersed oil from the *Braer* spill in the North Sea was apparently transported by strong downward currents and contaminated seabed sediments (petroleum hydrocarbon concentrations reaching 11,320 ppm) a considerable distance to the west and south of Shetland in depths of at least 100 m (Kingston *et al*., 1997). Sub-surface spills, caused by releases from offshore oil installations during exploration, have greater potential for contamination and impacts to seabed communities, as shown by the *Deepwater Horizon* spill (Beyer *et al*., 2016) (also considered in Section 5.2.5.9 on deep-water habitats).

Certain groups of subtidal sediment-dwelling fauna exhibit heightened sensitivity to oil contamination. Amphipods – especially the filter-feeding, tube-dwelling species such as *Ampelisca* spp. – filter-feeding bivalves (e.g. *Ensis* spp.), and burrowing urchins (e.g. *Echinocardium cordatum*) are particularly vulnerable to the impacts of oil spills. Following the *Amoco Cadiz* incident, populations of *Ampelisca* spp. plummeted dramatically across extensive seabed areas and took 15 years to recover to pre-spill levels (Dauvin, 1998). A similarly widespread effect was observed after the *Sea Empress* spill. Amphipods' well-documented sensitivity to oil and other pollutants has led to their routine use in toxicity testing (Nikitik & Robinson, 2003).

Large numbers of filter-feeding bivalves and burrowing urchins are often found washed up on beaches after oil spills. Sediment contamination is not always necessary, or even the main driver, for the adverse effects observed in filter feeders. Brief periods of high concentrations of dispersed oil in the water column can cause these species to leave the sediment in a torpid state, leaving them stranded and unable to re-burrow. After the 1996 *Sea Empress* spill, large numbers of lethargic bivalves washed ashore in Carmarthen Bay, Wales, yet hydrocarbon levels in seabed sediments remained at background concentrations (Lunel and Elliott, 1998). Nevertheless, where sediment contamination does occur, it can influence population recovery.

Conversely, certain infaunal species, particularly small polychaetes, may increase opportunistically in response to oil spill impacts. Exposure to spilled chemicals can also be expected to have detrimental effects, but direct empirical evidence is lacking. The extent and nature of any impact will depend on the inherent properties of the chemical involved. Macrofaunal communities found in shallow subtidal sediments are highly sensitive to oil spills; however, there are relatively few studies specifically examining their response. Notably, Jewett *et al.* (1999) investigated the impacts on shallow subtidal seagrass beds following the *Exxon Valdez* spill, providing one of the few detailed assessments. Research into the effects of oil spills on subtidal sediment meiofauna has yielded inconsistent results (Moore *et al.*, 1997), though reductions in abundance or diversity are generally anticipated.

Impact assessment method and strategy

A robust and effective impact assessment of subtidal sediment environments, especially following oil or chemical spills, should begin with a systematic evaluation of several essential components. This approach ensures that the assessment captures all relevant ecological, chemical, and biological factors that influence the health and recovery of these sensitive habitats.

1. Recording dead wildlife: counts of washed-up bivalves, urchins, and other marine animals will provide useful evidence of impact.
2. Reconnaissance: *in situ* reconnaissance of subtidal sediments is not normally appropriate, but survey sites should not be established without reference to available data on distribution of seabed sediment characteristics. If these data are not available, it would be beneficial to undertake some form of sediment mapping before biological survey sites are established. If biological samples are collected at the same time as the sediment characterisation, it is recommended that the biological samples are not analysed until the sediment data are available. This can greatly reduce unnecessary effort and cost.

“Due to their depositional nature, subtidal sediments can act as sinks for contaminants, with limited natural disturbance leading to prolonged retention of pollutants once deposited.”

3. Biological survey attributes: some of the more likely potential indicators include sediment megafauna abundance (particularly bivalves), sediment macrofauna diversity and abundance (particularly amphipods and opportunistic polychaetes). The polychaete/amphipod ratio has been suggested as an oil spill ‘bioindicator’ by Gesteira and Dauvin (2000). Various authors have highlighted the advantages of sediment meiofauna as useful indicators of anthropogenic effects (e.g. abundance and diversity of nematodes and copepods); and while reliable techniques for spill impact assessment have not yet been developed, they may be useful for following short- to medium-term effects. The IQI, developed under the WFD, is designed to assess sediment community health, and therefore may be an option to identify impacts of the oil or chemical.

[Note: Surveys and monitoring of sediment communities can have advantages over epibenthic rocky-shore communities, including reduced small-scale variability (patchiness) in some environmental factors and the ability to standardise sampling through defined sampling areas or volumes and consistent sample-processing protocols)].

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

- Initial emphasis should be placed on areas where near-seabed concentrations of oil or chemicals were likely (from empirical or modelling evidence) to be high.
- Resurvey and compare with pre-incident data if available; but consider carrying out a pilot survey at most vulnerable sites (or initially analysing only a selected few of the total samples) to assess scale of impact before full resurvey and analysis.
- Establishing comparative reference sites in unaffected areas, or analysing trends with distance from spill site, will be difficult if contaminant concentrations are widely distributed (the normal situation) because other confounding environmental factors (e.g. sediment character) are likely to reduce comparability.
- If sediments contaminated by oil or chemicals from the spill are identified, it may be easier to establish viable reference sites or a series of sites along transects. However, it is also likely that contaminated sediments will have a different character to the surrounding uncontaminated sediments (e.g. mud content).
- Monitoring changes in some of the above attributes at intervals may allow an assessment of recovery processes.
- If pre-incident data are unavailable, use evidence of stranded fauna to identify sites and consider small-scale macrofauna or meiofauna sampling programme with increasing distance from source, resurveyed at seasonal intervals for one or two years.
- Effects of clean-up: methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil in water concentrations), with some additional considerations for site selection. Methods to study physical impact from anchors (deployed during clean-up) would depend on the affected habitat, but would only be appropriate in very unusual circumstances.
- QA/QC: sediment sampling and analysis should follow recognised national or international quality assurance standards (e.g. NMBAQC in the UK).

6.2.9 Subtidal rock

Characteristics of habitat

Subtidal rock habitats occur below the low-water mark on bedrock, boulders and stable cobble substrates, across a range of depths from the shallow subtidal to the continental shelf. These habitats are typically found in areas with moderate to high water movement, including open coasts, tidal channels and around headlands, where currents, waves and tidal flows limit sediment accumulation and maintain exposed hard surfaces.

Subtidal rocky habitats support diverse and structurally complex biological communities, including macroalgae (such as kelp forests), encrusting algae, sponges, anemones, bryozoans and reef-associated invertebrates. They provide important feeding, shelter and nursery areas for fish and mobile invertebrates and play a key role in coastal productivity and biodiversity. Habitat structure varies with depth, light availability and hydrodynamic exposure, with transitions from macroalgal-dominated assemblages in shallow waters to invertebrate-dominated communities at greater depths.

Known vulnerability and sensitivity

Very few studies have examined the effects of oil or chemical spills on epibenthic communities associated with subtidal rocky habitats. In general, these habitats are relatively well-flushed and lack fine sediments that would promote long-term retention of contaminants. As a result, persistent contamination is considered unlikely, and impacts are most likely to arise from short-term, acute exposure to dispersed oil or chemicals in the water column, unless secondary contamination occurs through seepage or mobilisation from adjacent intertidal sources.

Despite this, the irregular and complex surfaces of subtidal rock can locally retain contaminants within crevices, depressions and beneath dense biological cover, particularly under macroalgal canopies. Retention in such microhabitats may prolong exposure for epibenthic organisms and influence recovery.

Recovery potential is also affected by natural disturbance regimes, with recolonisation dependent on species life-history traits, larval supply and the extent of physical damage.

As noted for subtidal sediments, it is generally considered uncommon for significant quantities of dispersed oil to reach depths greater than approximately 10 m; however, there are documented cases where this has occurred. Amphipod species, particularly infaunal taxa, are known to be highly sensitive to dispersed oil, and it is therefore expected that epibenthic amphipods associated with subtidal rock would also display high sensitivity. The available literature suggests that other crustacean groups may also be affected, although typically to a lesser extent. Evidence for acute sensitivity in other epibenthic taxa present in European waters is limited, which may in part reflect a lack of targeted studies in shallow subtidal environments.

Information on sub-lethal effects is particularly sparse. It is reasonable to infer that effects described for intertidal mussels, including bioaccumulation of hydrocarbons from the water column, may also be relevant to shallow subtidal mussel populations. Effects from exposure to spilled chemicals are also plausible, but empirical evidence is lacking and impacts are expected to depend strongly on the specific properties and behaviour of the substance involved.

There has similarly been little investigation of the effects of clean-up activities on subtidal rock habitats. Potential impacts include increased concentrations of dispersed oil in the water column following dispersant application or intertidal flushing operations, as well as physical damage from anchors, vessels or boom deployment. Such impacts are thought to have occurred in some locations following intensive shoreline clean-up operations after major spill events.

Impact assessment method and strategy

When undertaking an impact assessment for subtidal rock habitats, it is essential to follow recognised best practice by starting with a targeted evaluation of several core elements. This process not only ensures a thorough understanding of the ecosystem's condition but also lays the groundwork for effective monitoring and management strategies. The initial phase should therefore concentrate on identifying relevant biological indicators, considering available baseline data, and establishing reference points, all of which are key to accurately measuring and interpreting any ecological changes resulting from oil or chemical spills.

1. Reconnaissance: possibly useful in very shallow areas, possibly by snorkelling (after surface pollution has gone); taking particular note of presence of amphipods and snails and any unusual behaviour (suggesting narcotisation) of any mobile fauna.
2. Some of the more likely potential indicators include amphipod presence across a range of typical sub-habitats and relative abundance. While no *in situ* method is likely to provide a fully accurate measure of abundance, the development of a standardised approach for sampling algal turf may offer a practical and repeatable proxy, given that algal turf matrices are known to retain sediments and particulates and support associated epibenthic fauna (Tebbett *et al.*, 2022). Additional indicators include the presence and abundance of mobile epibenthic invertebrates, and the presence and abundance of inshore fish species such as scorpionfish, wrasse and gobies.

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

- Resurvey and compare with pre-incident data if available. Note, however, that it will be difficult to detect any changes beyond the natural variation unless pre-incident data on any of the above attributes is very good and concentrations of contaminant were/are high.
- Comparison with reference sites will be greatly hampered by influence of other environmental factors, but the characteristics of some sub-habitats (e.g. algal turfs – for amphipod sampling) may be less variable.
- Best option may be to monitor changes in some of the above attributes at intervals (e.g. bimonthly) from early stages of spill for at least one year at selected sites.
- Effects of clean-up: methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil in water concentrations), with some additional considerations for site selection. Methods to study physical damage from anchors (deployed during clean-up) would depend on the affected habitat but would only be appropriate in very unusual circumstances.
- QA/QC: *in situ* identification of epibenthic invertebrates and fish will require training. Repeat recording and data checks by other surveyors will also be appropriate. Analysis of amphipods and other infauna from algal samples should follow recognised national or international quality assurance standards (e.g. NMBAQC in the UK).

6.2.10 Coral reefs

Characteristics of habitat

Coral reefs occur in clear, shallow, well-lit tropical and subtropical waters. They are formed by colonies of living corals that build calcium carbonate frameworks supporting highly diverse assemblages of fish, invertebrates, algae, and microorganisms. Reef surfaces include branching, massive, plate, and encrusting corals, along with complex microhabitats that host symbiotic species. Their structural complexity makes them ecologically rich but physically fragile, with many species having slow growth rates and limited capacity for rapid recovery.

Known vulnerability and sensitivity

Coral reefs are highly sensitive to oil spills, particularly fresh, light oils that can disperse easily and coat coral tissues. Oil can smother coral surfaces, interfere with gas exchange, damage mucous layers, and cause the loss of symbiotic algae (zooxanthellae), leading to bleaching and reduced energy reserves. Exposure may impair coral reproduction, larval settlement, and juvenile survival, while polycyclic aromatic hydrocarbons (PAHs) can cause chronic toxicity to reef organisms. Reef-associated fauna, including fish, echinoderms, and crustaceans, may also accumulate hydrocarbons, altering trophic interactions. Reefs in sheltered lagoons or nearshore environments are especially vulnerable, as oil becomes trapped and persists in low-energy waters. Mechanical disturbance during response operations can cause additional breakage of delicate corals, making them one of the most challenging habitats to protect and restore.

Impact assessment methods and strategy

Assessment of oil spill impacts on coral reefs requires systematic, long-term monitoring because effects may appear gradually via bleaching, colony mortality, reduced recruitment, or shifts in species composition. Baseline data (where available) should be compared to post-spill surveys documenting:

- the proportion of coral cover affected, including signs of tissue necrosis, bleaching, or mucous production;
- changes in associated reef fauna (fish, crustaceans, echinoderms), including mortality events;
- presence of oil residues on coral, sediments, or reef flats;
- alterations in algal cover or increases in opportunistic, pollution-tolerant species;
- sub-surface oil accumulation in sediments of reef flats or lagoons, which can prolong toxicity.

Aerial imagery can help determine spatial extent of damage, while underwater photoquadrats or video transects allow detailed monitoring of coral condition and recovery. Resurveys should occur at regular intervals over months to years, as chronic PAH exposure may delay coral recruitment and impede ecosystem recovery. As with other sensitive habitats, specialist training and quality assurance are recommended to ensure consistency in identifying coral lesions, bleaching patterns, and structural damage.

Aggressive clean-up is generally not recommended on coral reefs due to the high risk of physical damage. Mechanical removal (e.g. dredging, raking, or high-pressure washing) can shatter colonies, erode reef framework, and resuspend sediments, causing further stress. Chemical dispersants may increase hydrocarbon bioavailability and are usually avoided unless absolutely necessary and approved under expert guidance. Best practice emphasises natural dispersion and degradation, combined with targeted, low-impact methods such as manual removal of floating oil, booms to prevent further contamination, and recovery of pooled oil in calm water. Any intervention should be guided by reef specialists who can evaluate the site's water flow, coral health, and species composition. As with most habitats, decisions must weigh the ecological harm of active clean-up against the benefits of allowing natural recovery processes to proceed.

6.2.11 Deep water habitats

Characteristics of habitat

Deep water habitats occur beyond the continental shelf, typically at depths greater than approximately 200 m, extending across the continental slope, rise and abyssal plain. These habitats encompass a wide range of physical environments, including soft sediments, rocky outcrops, canyons, seamounts and other seabed features. Environmental conditions are characterised by low temperatures, high hydrostatic pressure, limited water movement near the seabed and the absence of light, resulting in ecosystems that are largely decoupled from surface primary production.

Known vulnerability and sensitivity

Deep water habitats, i.e. beyond the continental shelf, between 200 and 1500 m depth, will not be vulnerable to surface oil spills, but may be vulnerable if a subsea oil leak occurs during oil exploration and production activities. Potentially vulnerable resources include benthic invertebrates, living on and in the seabed, and benthic and demersal species of fish, living on or close to the seabed. Our knowledge of the sensitivity of these invertebrates and fish to oil is very limited, primarily from studies following the 2010 *Deepwater Horizon* spill and some laboratory experiments. More recent studies have also improved understanding of oil transport, dispersant behaviour, and microbial processes in marine sediments, providing important context for assessing benthic exposure (e.g. Perez Calderon *et al.*, 2019). Dispersed oil from *Deepwater Horizon* contaminated a large area of seabed around the well, which resulted in notable impacts. Impacts on infaunal species diversity and community composition (Montagna *et al.*, 2013), diversity and abundance of epibenthic and demersal megafauna (Valentine and Benfield 2013) and health of deep-sea corals (Fisher *et al.*, 2016) have been described, and that work is continuing. It is known that many deep-sea species (including corals) are long-lived and slow-growing, suggesting that recovery from impacts may be slow (Beyer *et al.*, 2016).

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

Impact assessment method and strategy

Given the inevitable logistical challenges of mobilising surveys in deep water habitats, it is unlikely that surveys of biological resources can be initiated very rapidly, so they should wait for information on the distribution of near-seabed contaminant concentrations (from water sampling or modelling). Survey of populations and communities on hard substrata, particularly deep-water corals, will require video sampling techniques. Law *et al.* (2014) offer a comprehensive framework along with extensive guidance for conducting post-spill investigations. The section below outlines further recommendations regarding relevant attributes and approaches.

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

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

- It is likely that at least some pre-incident data on fish populations and benthic communities will be available from environmental assessment studies, so resurveys should be a priority.
- Establishing comparative reference sites or looking for trends with distance from spill site may also be appropriate, using designs that are commonly used for studying offshore oil well impacts (OSPAR, 2004). The relative homogeneity of deep water sediments across large areas will hopefully make it easier to distinguish natural trends from contaminant impacts.
- Monitoring changes in some of the above attributes at intervals may allow subsequent assessment of the recovery processes.
- Effects of clean-up: methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil in water concentrations), with some additional considerations for site selection.
- QA/QC: sediment sampling and analysis should follow best practice standards and guidelines.

6.2.12 Polar environments

Characteristics of habitat

Polar environments encompass marine and coastal habitats within the Arctic and Antarctic regions, including ice-covered and seasonally ice-influenced seas, polar shelves, deep basins and associated coastal systems. These habitats are characterised by extreme environmental conditions, including low temperatures, strong seasonality in light availability, and the presence of sea ice, ice shelves and icebergs, which exert a dominant influence on physical and biological processes.

Known vulnerability and sensitivity

The polar regions show great variability in the types of coastal habitat that may be subject to pollution, ranging from lagoons to rocky shorelines, estuaries and soft sediments, to coastal fast ice, as well as marine-terminating glaciers and ice shelves. The Antarctic coastline is roughly 42 % ice shelf, 46 % glacial ice and only 12 % rock, compared to over a third of Arctic coastline being ice-free for at least part of the year. In both polar regions, the presence of fjords and inlets may serve to limit the dispersal of spilled chemicals or increase their residence time in these biodiverse habitats.

Annually, sea ice varies hugely in extent over the Arctic (6 to 15.5 million km^2) and Southern Oceans (2.5 to 18.5 million km^2) between summer and winter. This solid floating surface provides habitat for a wide range of marine mammals, birds, fish and marine invertebrates (including juvenile krill in the Antarctic) and microbial primary producers. However, little is known about the vulnerability of many of these species to hydrocarbon spills. Sea ice may limit the movement of spilled chemicals and reduce wave action that, in other locations, can facilitate dispersal.

Slow metabolic and growth rates in polar fish and invertebrates found in near-shore marine and/or intertidal areas may increase their vulnerability to pollution. Polar waters are cold and have high oxygenation levels and, consequently, the physiological responses and tolerances of marine invertebrates may not be the same as equivalent species found in habitats elsewhere. Therefore, care is needed when extrapolating species physiological response data from other regions to the poles. Low intertidal biodiversity and biomass may limit monitoring opportunities and deployment of research equipment and scuba diving in cold remote environments can be a substantial safety and logistical challenge.

Some of the largest concentrations of wildlife globally are found in the polar regions, where they rely upon the seasonally productive terrestrial and/or marine environments for food. Large densities of wildlife at colonies may make the consequences of any spill severe (e.g. whale foraging areas, seals resting or giving birth on sea ice, coastal haul-out sites for seals and walrus, penguin colonies, flying bird breeding sites). For example, over one million penguins are found in a single colony on Zavodovski Island, South Sandwich Islands. Foraging zones for many of these species may extend from 10s to 100s of kilometres from their colony, leaving them vulnerable to spill pollution over wide areas. Scavenging of contaminated wildlife can transfer pollutants into species not directly subject to the spill event. Several seabird species (e.g. albatrosses) with spatially limited breeding sites are currently endangered due to other anthropogenic stresses (e.g. fishing by-catch, negative interactions with human-introduced terrestrial species), and an oil spill near a colony may have catastrophic implications for the future survival of such species.

"The entire area of Antarctic green vegetation is estimated to be only 44 km^2 (i.e., the continent's vegetation would fit within a square measuring 6.7 x 6.7 km) which emphasises the need for appropriate protection."

Coastal habitats are often very spatially limited on land (particularly in the Antarctic), with terrestrial species often taking decades or more to grow to substantial sizes, making them vulnerable to disturbance and pollution caused during intensive clean-up activities (trampling, clean-up kit deployment, off-road use of overland vehicles, etc.), meaning monitoring of terrestrial habitats needs to be an important component of any remediation activities. In Antarctica, terrestrial communities are at their most rich and extensive near the coast. The entire area of Antarctic green vegetation is estimated to be only 44 km^2 (i.e., the continent's vegetation would fit within a square measuring 6.7 x 6.7 km) which emphasises the need for appropriate protection. Furthermore, the polar regions have few invasive marine or terrestrial species compared to other regions of the Earth, and strict biosecurity measures must be applied to ensure any arriving spill response personnel and associated equipment are free of introduced non-native species.

Due to the phenomenon of 'polar amplification', the polar regions are already subject to some of the most extreme effects of climate change on the planet. Air temperatures have increased and oceans have warmed and freshened more rapidly than elsewhere, resulting in increased stresses for native marine species. In particular, sea ice thickness and extent have rapidly declined in the Arctic over the past 40 years, while Antarctic sea ice has declined markedly since 2016. Climate change may also lead to more extreme weather events, increased ice shelf instability, higher levels of iceberg formation (with associated risks to shipping) and changing coastlines due to glacier retreat and ice shelf collapse. In the Arctic, climate change impacts on permafrost may destabilise pipes transporting oil, potentially resulting in spills which could affect terrestrial, coastal and marine environments.

Impact assessment method and strategy

Some coastal polar areas include rocky shores and beaches, making techniques employed in other parts of the world applicable, particularly in the Arctic (e.g. chemical analyses of sediments and water, determination of invertebrate mortality rates, levels of bird and marine mammal oiling, eDNA estimates of sediment biodiversity, etc.). However, new, or modifications of existing methods may be required to monitor impacts at coastlines comprised of permanent ice.

Due to the remote nature of much of the polar regions and inherent dangers of sea ice, ice shelves and marine-terminating glaciers, remote sensing methods can be extremely useful for monitoring. Satellite imagery (e.g. available through Polar View[22]) can help monitor the extent of fast ice and sea ice following a spill. Satellite images may also be used to detect hydrocarbon spills or the location of wildlife (e.g. whales, walrus, seals, penguins, or large flying seabirds). This approach is already being used, meaning there may already be baseline population abundance and location data available. Remotely Piloted Aircraft Systems or aircraft may also be used to monitor the extent of spills over more limited spatial scales, potentially at much higher resolution. While more complex logistically, Autonomous Underwater Vehicles or tethered Remotely Operated Vehicles (ROV) may be useful in determining the sources or extents of spills on the seabed or under sea ice, including through the use of sonar and fluorescence sensors (acknowledging that further technological development may be required).

Assessing the dispersal of chemicals under sea ice presents a unique challenge. The movement of oil is particularly difficult to predict or monitor due to factors including ice thickness and extent, level of sea ice breakup and rate of movement by currents and wind. Modelling may improve understanding of spill distribution, which can also be affected by sea ice or local topography (e.g. fjords).

Those engaging in post-spill monitoring will need to fully consider safety issues, particularly due to the potentially long distances and transfer times required to anything other than rudimentary health care facilities should an accident occur in the polar regions. This is particularly the case due to the cold conditions, and the challenges associated with accessing contaminated coastal regions (e.g. poor sea ice quality, steep cliffs, slippery surfaces, unstable ice and snow, etc.). In some more remote regions of the Arctic and Antarctica, it may be a challenge to deliver basic search and rescue.

Practical experience: To date, clean-up of a major marine spill in Antarctica has not occurred, resulting in little experience of clean-up or monitoring within the Antarctic policy, environmental management and research communities and little contingency planning. In contrast, several major pollution events in the Arctic over recent decades mean greater post-spill monitoring experience exists for Arctic environments.

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Very long-term monitoring (decades) may be required to assess repair/ bioremediation due to the slow growth and reproductive rates of many polar species.

22 https://www.polarview.aq/

Challenging conditions: Depending upon the time of year, access to the spill or impacted site may be severely limited and seasonal extremes in temperature, day length, snow cover and sea ice extent may complicate any response to a chemical spill. In remote polar regions, post-spill monitoring for much of the year may simply be impossible.

Even minimal levels of personnel or infrastructure may not exist to support a land-based response, unless in the immediate vicinity of one of the larger of the 70 or so coastal stations in Antarctica or one of the widely dispersed settlements in the Arctic. In the Arctic, local knowledge of indigenous peoples may be of substantial value in designing spill response plans and monitoring activities. Lack of roads, airstrips, built infrastructure, appropriate levels of logistic support and remoteness from analytical facilities severely limit the monitoring that is achievable. In the Antarctic, laboratory facilities on many research stations are often basic. Oil-spill response practitioners may have prior experience of deploying to remote locations, but delivery of specialised clean-up kit and post-spill monitoring expertise may not be available for weeks to months after an incident, if at all, should the incident occur late in the summer season or during the winter. Consequently, in remote polar environments, long supply chains mean monitoring teams need to be self-sufficient and methods need to be straightforward.

As in many other remote areas, baseline data to inform monitoring are largely lacking for the great majority of the polar regions, and those that exist are unlikely to be current. On-going climate change is already altering permafrost depth, sea ice distribution, ice shelf stability and wildlife distribution, resulting in a constantly changing 'baseline', further complicating monitoring plans. Knowledge of the types and duration of chemical spill impacts is limited and patchy. However, low temperatures may increase oil viscosity and reduce evaporation rates compared to environments elsewhere, while rougher seas may increase dispersal rates. Very long-term monitoring (decades) may be required to assess repair/bioremediation due to the slow growth and reproductive rates of many polar species.

6.3 Marine biological communities

6.3.1 Microbial communities

Characteristics of microbial communities

Microbial communities are ubiquitous across marine and coastal environments and occur throughout the water column, within sediments, on hard substrates, and in association with plants, animals and detrital material. These communities include bacteria, archaea, microalgae, fungi and protists, and collectively play a fundamental role in ecosystem structure and functioning across all marine habitats, from intertidal zones to the deep sea.

Marine microbial communities are central to biogeochemical cycling, including the transformation and recycling of carbon, nitrogen, sulphur and other key elements. They underpin primary production in pelagic systems, contribute to organic matter decomposition, and mediate nutrient availability for higher trophic levels. In sediments and biofilms, microbial assemblages drive processes such as denitrification, sulphate reduction and methanogenesis, often under low-oxygen or anoxic conditions.

The composition, diversity and activity of microbial communities are strongly influenced by local environmental conditions, including temperature, salinity, oxygen availability, light, organic matter supply and substrate type. As a result, microbial communities can exhibit high spatial and temporal variability, responding rapidly to natural seasonal cycles, disturbance events and changes in environmental conditions.

"Given their foundational role, changes in microbial communities can have cascading effects on ecosystem processes and overall habitat functioning."

Known vulnerability and sensitivity

Unlike many faunal and floral components of marine habitats, microbial communities typically have short generation times and high dispersal potential, allowing for rapid turnover and adaptation. However, while microbial biomass may recover quickly following disturbance, functional recovery and community composition may be altered for longer periods, particularly where environmental conditions or substrate characteristics are changed. Given their foundational role, changes in microbial communities can have cascading effects on ecosystem processes and overall habitat functioning.

Oil spills dramatically alter the composition of marine microbial communities, generally resulting in a large decrease in species richness and diversity, and an increase in the abundance of hydrocarbon-degrading bacteria (Head *et al.*, 2006; McGenity *et al.*, 2012; Joye *et al.*, 2016). While microbial community analysis is still an emerging approach for post-spill monitoring, shifts in community composition, including the enrichment of specialist hydrocarbon-degrading bacteria following oil exposure, can provide evidence of ongoing biodegradation and natural attenuation (Head *et al.*, 2006; McGenity *et al.*, 2012; Joye *et al.*, 2016).

For example, in marine waters, the increased relative abundance of sentinel genera such as *Alcanivorax, Thalassolituus, Oleispira* and *Oleibacter* (primarily alkane-degrading) and *Cycloclasticus* (primarily PAH-degrading) indicates that these components of crude oil are being biodegraded and that the community has the capacity to naturally attenuate the oil (assuming that nutrients, such as N, P and Fe, do not become limiting).

However, the selection for particular sentinel species and their abundance are influenced by numerous factors including oil composition, degree of weathering (Head *et al.*, 2006), proximity to the oil phase (Chronopoulou *et al.*, 2015), temperature (Coulon *et al.*, 2007), nutrient availability and extent of dispersion (McKew *et al.*, 2007b).

Biodegradation is a successional process, meaning that microbial community composition changes over time following an oil spill. These changes are influenced by factors such as declining nutrient availability, shifts in hydrocarbon bioavailability, and the increasing dominance of hydrocarbons that are more resistant to degradation. While some microbial genera are known hydrocarbon degraders, others, such as *Marinobacter*, are more metabolically versatile, making their role less clear. Although this variability can complicate the interpretation and limit the value of microbial monitoring, it may also provide useful information on the stage and progression of biodegradation.

For example, it is well established that there is niche-partitioning between species in the utilisation of different hydrocarbon components (McKew *et al.*, 2007a), which could inform on the status of a spill, i.e. changes in oil composition over time as particular hydrocarbon substrates are removed (generally proceeding from low- to high-molecular weight hydrocarbons).

Impact assessment method and strategy

Microbial communities can be monitored and assessed using nucleic-acid-based and functional assays that characterise community composition, functional potential and biodegradation activity following oil contamination. These approaches are well suited to detecting both the response of hydrocarbon-degrading microorganisms and broader community-level changes.

A widely applied method is environmental nucleic acid extraction followed by high-throughput sequencing of phylogenetic or functional marker genes. Sequencing of the 16S rRNA gene is most commonly used to assess bacterial and archaeal diversity and relative taxonomic abundance, allowing shifts in overall community composition and the enrichment of known oil-associated taxa to be identified (Dumbrell *et al.*, 2016). Illumina next-generation sequencing platforms are currently the most widely used laboratory-based systems for this purpose. In parallel, sequencing of functional genes can be used to assess the hydrocarbon-degradation potential of microbial communities. For example, the alkane hydroxylase gene (*alkB*) can be used as a functional marker for aerobic alkane degradation, while separate functional markers can be applied to characterise anaerobic hydrocarbon-degrading microorganisms and pathways (Scoma *et al.*, 2017; von Netzer *et al.*, 2018).

For more targeted monitoring, quantitative PCR (qPCR) can be employed to track changes in the relative abundance of selected sentinel taxa or functional genes. This approach is particularly useful for monitoring well-characterised hydrocarbon-degrading genera, such as *Alcanivorax*, or specific catabolic genes associated with oil degradation (McKew and Smith, 2017). Careful selection of target genes and primers is essential to ensure ecological relevance and comparability across studies (Scoma *et al.*, 2016).

In addition to detecting taxa that increase in response to oil inputs, microbial monitoring can also focus on taxa that decline following exposure, potentially acting as indicators of inhibition or toxicity. For example, decreases in the abundance of ubiquitous groups such as SAR-11 have been observed following oil exposure (Chronopoulou *et al.*, 2015). However, interpretation of such responses requires caution, as declines may reflect direct toxicity, indirect effects of response measures, or competitive exclusion by specialist hydrocarbon-degrading bacteria (Paul *et al.*, 2013).

Monitoring may also be extended beyond bacteria to include microeukaryotic and archaeal communities. Sequencing of the 18S rRNA gene has been used to identify shifts in microphytoplankton, microzooplankton and fungal communities following oil exposure, including increased dominance of fungi in some oil-impacted sediments (Bik *et al.*, 2012; Brussaard *et al.*, 2016). To date, no consistent responses have been identified for archaeal community composition, although this may reflect limited empirical evidence (Sanni *et al.*, 2015).

Complementary culture-based and functional assays can provide additional information on biodegradation capacity. For example, microplate Most Probable Number (MPN) techniques have been used to estimate changes in the abundance of hydrocarbon-degrading bacteria (Johnsen, 2017). Metabolite profiling can further inform on degradation pathways and the extent of hydrocarbon transformation (Bonifay *et al.*, 2016).

At the community level, ecological indices based on microbial composition may provide integrated indicators of hydrocarbon exposure. Lozada *et al.* (2014) proposed an index using 16S rRNA gene data, classifying phylotypes according to their association with hydrocarbon-degrading taxa. Such indices could be refined by incorporating improved understanding of taxonomy-trait relationships and functional information obtained through advanced techniques such as single-cell genomics, DNA stable-isotope probing, epicPCR or metagenomics (Mason *et al.*, 2012; Gutierrez *et al.*, 2013; Röling and van Bodegom, 2014; Spencer *et al.*, 2016).

An important component of microbial assessment is the quantification of hydrocarbon bioavailability, as this determines both potential toxicity and biodegradability. Bacterial bioreporters provide quantitative assays for measuring the bioavailability of specific oil fractions, including n-alkanes, BTEX compounds and low-molecular-weight polycyclic aromatic hydrocarbons (van der Meer and Belkin, 2010). These tools have been successfully deployed during experimental spills and field studies, demonstrating their potential for rapid, *in situ* monitoring of dissolved hydrocarbons over time (Tecon *et al.*, 2010; Brussaard *et al.*, 2016).

To increase the practical applicability of microbial monitoring, there is substantial scope for the development of rapid and simplified tools for nucleic acid extraction, detection and analysis, as well as integration with mobile or fixed marine monitoring platforms. Advances in autonomous sampling, *in situ* sensors and miniaturised molecular technologies offer opportunities to deploy microbial indicators more routinely in oil-spill monitoring and assessment programmes (van der Meer, 2016; McQuillan and Robidart, 2017).

6.3.2 Plankton

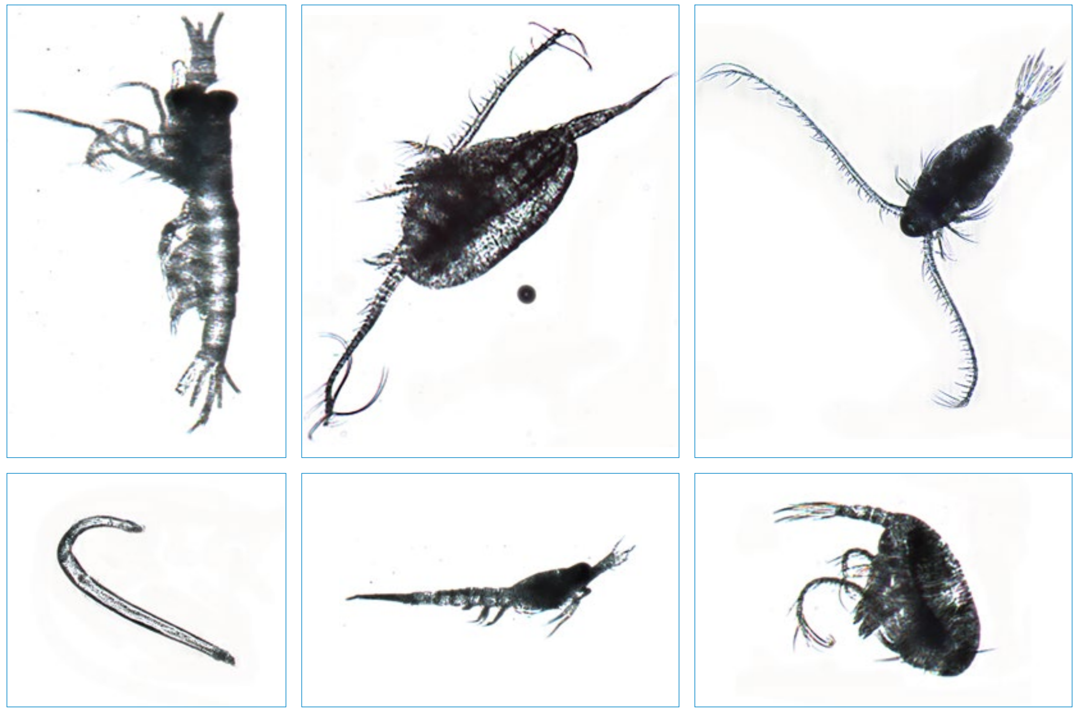
Characteristics of plankton communities

Planktonic communities comprise a diverse assemblage of organisms that drift within the water column and include phytoplankton (microscopic photosynthetic organisms) and zooplankton (heterotrophic organisms ranging from protozoans to larval stages of invertebrates and fish). Plankton are present in marine and coastal waters worldwide, from surface layers to deeper waters, although the highest biomass and productivity are typically found in the upper, sunlit (photic) zone.

Phytoplankton form the base of pelagic food webs and are responsible for the majority of marine primary production, driving carbon fixation and oxygen production. Their distribution and productivity are strongly influenced by light availability, nutrient concentrations, temperature, water column stratification and mixing processes. Zooplankton play a key role in transferring energy from primary producers to higher trophic levels and contribute to nutrient recycling through grazing, excretion and vertical migration.

Known vulnerability and sensitivity

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



Following the *Sea Empress* oil spill in Wales in 1996, no impacts on plankton abundance or species composition were observed in Continuous Plankton Recorder (CPR) records from the area (Batten *et al*., 1998; Law and Kelly, 2004). However, CPR data primarily represent larger, near-surface plankton taxa and do not fully capture smaller size classes, fragile organisms or deeper-water components of the planktonic community; therefore, impacts on poorly sampled or non-recorded plankton groups cannot be ruled out.

Tas *et al*. (2011) studied phytoplankton following the oil spill from the Volgoneft-248 in Turkey in 1999, and observed changes in the species composition, abundance and diversity. In the case of the chemical tanker Ece, which sank in the English Channel in 2006 with a cargo of phosphoric acid yielding phosphate in the surrounding waters as a nutrient, Kelly-Gerreyn *et al*. (2007) studied enhancement of phytoplankton communities rather than impairment. Ferrybox data were also used to assess elevations of the phosphate concentrations in the vicinity. In the Ferrybox system, ferries and other vessels are instrumented with a “box” of autonomous sensors which can provide data, which are logged continuously whilst the vessel is on passage. Effects can also be expected from exposure to spilled chemicals, but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

“Many species of phytoplankton and zooplankton are very sensitive to toxic components of oil (particularly the water-soluble fraction), but that recovery by recruitment from other areas is rapid.”

Impact assessment method and strategy

The initial focus of the impact assessment conducted for plankton should consider the following elements:

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

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

- In the unusual circumstances of an oil spill (or release of a chemical with the potential for toxicity or growth stimulation) affecting an area where ongoing or recent plankton studies have got pre-incident data, then resurvey and comparison with that data is appropriate.
- Compare post-spill plankton abundance, biomass, diversity and species composition with available pre-incident data.
- Measure supporting water quality parameters (e.g. temperature, salinity, nutrients, chlorophyll-a, hydrocarbons or spilled chemicals).
- Sample impacted and reference sites over time to distinguish spill effects from natural variability.
- Assess planktonic eggs and larvae where important spawning areas are present.
- Continue monitoring until plankton communities return to baseline or expected seasonal conditions.

6.3.3 Fish

Characteristics of species

Fish are a diverse group occupying pelagic and demersal habitats from estuaries to offshore waters. Species differ markedly in mobility, habitat use, diet, and life-history strategy, which influences both their exposure to pollutants and the likelihood that impacts will be detected. Fish may be exposed via direct contact with contaminated water (including dissolved and dispersed fractions), via ingestion of contaminated prey or particles, and via sediment-associated contaminants for bottom-dwelling species. Sensitivity and exposure also vary across life stages, with eggs and larvae often more vulnerable than adults. Fish species can also have high ecological and socio-economic importance, including as key predators or prey, and as targets of commercial and recreational fisheries and aquaculture.

Known vulnerability and sensitivity

Fish populations are at greatest risk from contamination by oil or chemical spills when the water depth is very shallow. Below 10 m, in open waters, the likelihood that contaminant concentrations will be high enough to affect fish populations is very small, even if chemical dispersants are used to disperse oil. In shallow or enclosed waters, however, high concentrations of freshly dispersed oil may kill some fish and have sub-lethal effects on others. Juvenile fish, larvae and eggs are most sensitive to the oil toxicity; fish nursery areas are particularly vulnerable (Samuelsen *et al.*, 2019), although field studies following the *Braer* oil spill reported no detectable effect on herring larval growth (Gallego *et al.*, 1995). Even if the elevated concentrations of oil do not kill the fish, they may taint the flesh with an oily taste and thereby make it unpalatable. Similar effects may occur with some chemicals, depending on their properties and behaviour. Finfish will usually move away from oil-contaminated water; but even if their tissues do become contaminated, through the gills or from contaminated food, detoxification enzyme systems are able to metabolise oil, so they do not retain contamination for long. Most fish species can produce high numbers of eggs, and this counteracts high levels of natural as well as oil-induced mortality. Even when many larvae or juveniles have been killed, this has not been subsequently observed to result in fluctuations of the adult populations. Ipieca (2015) summarises information on the sensitivity and recovery potential of fish and fisheries.

Impact assessment method and strategy

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

1. Reconnaissance: collect samples of selected fish species of nature conservation importance for analysis (including PAH analysis in the case of oil spills, to facilitate assessment of risks to human consumers of commercial species).
2. Biological survey attributes: Biomarkers including hepatic EROD activity, PAH metabolites in the bile and DNA damage in sampled fish are likely to be the best measure of oil exposure (Martínez-Gómez *et al.*, 2010; Radović *et al.*, 2012). Other biological effects techniques may be useful for specific chemicals. Abundance measures of intertidal (e.g. in rockpools) or nearshore shallow water fish (caught using standardised sampling techniques: traps or nets) may detect severe reductions from high concentrations of dispersed oil or chemicals but will normally require some pre-incident data. Recently developed techniques can be used to detect sub-lethal stress in fish tissues and may be useful for monitoring their recovery but may not provide a reliable measure of the health of the affected population.

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

- Comparison between pre- and post-incident data on EROD activity, followed by monitoring to show recovery, will provide the best evidence of sub-lethal effects on fish populations from spilled oil;
- Comparison between pre- and post-incident data on nearshore shallow water fish populations will provide the best evidence of impacts on fish populations from spilled oil or chemicals;
- Comparison of data between impacted and unimpacted reference areas is unlikely to detect impacts, unless they are substantial and sufficient reference sites are studied to determine levels of natural variability;
- Effects of clean-up: methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil in water concentrations), with some additional considerations for site selection. For chemicals, very little is known currently of the effects of different clean-up methodologies.

6.4 Birds

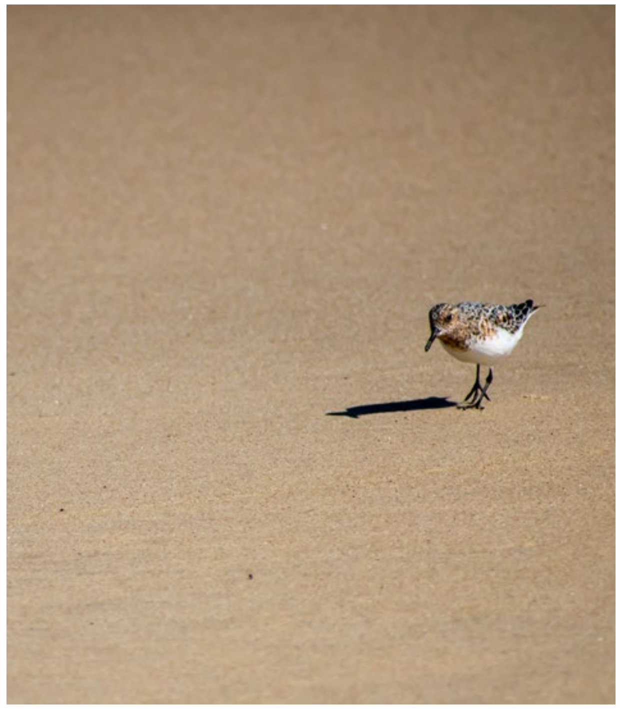
6.4.1 Seabirds

Characteristics of species

Seabirds are highly mobile marine birds that rely on the marine environment for foraging while depending on terrestrial habitats for breeding and roosting. Species differ in their foraging range, feeding ecology and degree of association with the sea surface, which strongly influences exposure to floating oil, surface slicks and contaminated prey. Many seabirds spend prolonged periods sitting on the water and are therefore vulnerable to external oiling; even small amounts of oil can compromise feather structure and waterproofing, leading to heat loss, loss of buoyancy and reduced flight capability. Seabirds may also be affected through ingestion of oil directly (during preening) or indirectly via contaminated prey, with potential for sub-lethal effects on condition, behaviour and breeding success. Sensitivity and detectability of impacts vary markedly with season, breeding status and local aggregation patterns.

Known vulnerability and sensitivity

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



Seabirds feeding or resting on the sea surface are vulnerable to water-borne pollution, and the periods when they will be most vulnerable are when large numbers of birds are aggregated on the water, including during the breeding season when they are aggregated inshore and, for species of auk, during the autumnal moult, when gatherings of flightless birds form rafts on the water. However, large numbers of birds have been killed by offshore oil spills that have affected very large areas of the sea (e.g. those from the *Erika* and *Prestige* oil tankers). Sensitivity to pollutants will also be affected by the condition of the birds, so winter food shortages could increase the sensitivity of many birds.

The sensitivity and vulnerability of seabirds to floating oil is species-specific and a variety of sensitivity indices have been developed. Webb *et al*. (2016) describe an index that has been developed for use on oil sensitivity maps of UK waters (see Table 17). The most sensitive species are those which spend a substantial period of their lives on the water surface, particularly divers, shag, guillemots, puffins and razorbills. Other factors that contribute to the calculation of the species-specific index are the proportion of tideline corpses oiled, habitat flexibility, the proportion of the biogeographical population present in the UK, the status on the list of Birds of Conservation Concern and in Annexes to the EC Birds Directive, the potential annual productivity and the adult survival rate.

Table 16: Species-specific seabird oil sensitivity index. From Webb *et al.* (2016).

Species		Winter	Summer
Great Northern Diver	*Gavia immer*	0.976	0.865
European Shag	*Phalacrocorax aristotelis*	0.851	0.823
Black-throated Diver	*Gavia arctica*	0.845	0.845
Common Guillemot	*Uria aalge*	0.843	0.902
Atlantic Puffin	*Fratercula arctica*	0.843	0.874
Red-throated Diver	*Gavia stellata*	0.808	0.808
Razorbill	*Alca torda*	0.799	0.865
Slavonian Grebe	*Podiceps auritus*	0.726	0.726
Black Guillemot	*Cepphus grylle*	0.721	0.721
Common Scoter	*Melanitta nigra*	0.712	0.667
Velvet Scoter	*Melanitta fusca*	0.657	0.657
Little Auk	*Alle alle*	0.655	0.655
Common Eider	*Somateria mollissima*	0.651	0.651
Common Goldeneye	*Bucephala clangula*	0.597	0.555
Red-necked Grebe	*Podiceps grisegena*	0.597	0.597
Great Cormorant	*Phalacrocorax carbo*	0.579	0.521
Long-tailed Duck	*Clangula hyemalis*	0.57	0.57
Greater Scaup	*Aythya marila*	0.561	0.529
Balearic Shearwater	*Puffinus mauretanicus*	0.534	0.534
Black-headed Gull	*Chroicocephalus ridibundu*	0.484	0.429
Great Skua	*Catharacta skua*	0.472	0.523
Manx Shearwater	*Puffinus puffinus*	0.472	0.547
Common Gull	*Larus canus*	0.467	0.429
Great Crested Grebe	*Podiceps cristatus*	0.463	0.463
Great Black-backed Gull	*Larus marinus*	0.459	0.459
Black-legged Kittiwake	*Rissa tridactyla*	0.436	0.471
Goosander	*Mergus merganser*	0.427	0.427
Red-breasted Merganser	*Mergus serrator*	0.396	0.396
Northern Fulmar	*Fulmarus glacialis*	0.391	0.421
Northern Gannet	*Morus bassanus*	0.391	0.447
Herring Gull	*Larus argentatus*	0.389	0.389
Mediterranean Gull	*Ichthyaetus melanocephalus*	0.382	0.382
Little Tern	*Sternula albifrons*	0.374	0.389
Roseate Tern	*Sterna dougallii*	0.339	0.35
Common Tern	*Sterna hirundo*	0.326	0.339
Black-backed Gull	*Larus fuscus/Larus marinus*	0.312	0.312
Long-tailed Skua	*Stercorarius longicaudus*	0.306	0.306
Little Gull	*Larus minutus*	0.305	0.278
Cory's Shearwater	*Calonectris borealis*	0.28	0.28

Table 16 continued:

Species		Winter	Summer
Great Shearwater	*Puffinus gravis*	0.28	0.28
Common/Arctic Tern	*Sterna hirundo/Sterna paradisaea*	0.271	0.282
Sandwich Tern	*Thalasseus sandvicensis*	0.271	0.291
Arctic Tern	*Sterna paradisaea*	0.268	0.279
Sooty Shearwater	*Ardenna grisea*	0.266	0.266
Pomarine Skua	*Stercorarius pomarinus*	0.244	0.244
Sabine's Gull	*Larus sabini*	0.236	0.236
Glaucous Gull	*Larus hyperboreus*	0.208	0.208
European Storm-petrel	*Hydrobates pelagicus*	0.144	0.148
Leach's Storm-petrel	*Hydrobates leucorhous*	0.144	0.144
Black Tern	*Chlidonias niger*	0.124	0.124
Grey Phalarope	*Phalaropus fulicarius*	0.063	0.063

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

Within the last 30 years, oil spills in the northwest Atlantic (*Braer, Sea Empress, Erika, Prestige, Tricolor*) killed large numbers of seabirds, particularly guillemots and razorbills, with moderate but important numbers of other species including shag and kittiwakes. Descriptions of these impacts are given in Heubeck (1997), SEEEC (1998), Castège *et al*. (2004) and Camphuysen and Leopold (2004). It should be noted that impact is not simply a function of the numbers of birds killed and the species affected, but also the age of the birds killed. Most seabird species are long-lived and annual adult survival is relatively high, so that only low rates of recruitment of immature birds are required each year to sustain the breeding population. Therefore, if most birds killed are immature, the impact on the population is likely to be less than if large numbers of adults are killed (Mitchell and Parsons, 2007). Recovery of affected populations then depends either on the existence of a reservoir of young non-breeding adults from which breeding colonies can be replenished, or on a high reproductive rate.

Although the apparent impact of oil spills on seabirds is obvious from the numbers of oiled birds that are collected, the resulting impact on their populations, and the time it takes for those populations to recover, is not always so apparent. Seabird colonies are monitored regularly in many locations around the British Isles within the Seabird Monitoring Programme[23], and there are more and better monitoring data for these species than any other vulnerable (to oil and chemical spills) species of mammal, invertebrate or plant. Comparison of reliable colony count data from pre- and post-incident surveys (e.g. Heubeck, 1997 and Haycock *et al*., 1998) has identified significant (though not necessarily large) reductions in some seabird species, which have correlated well with the dead bird data. Evidence from UK spills suggests that increases in colony counts to pre-incident levels occur within two or three years, as long as other factors (e.g. food availability) are not limiting. The recovery rate will depend largely on the scale of mortality and the age of the birds affected.

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

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

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

It is also worth noting that the spill response activities themselves can also cause disturbance of nesting grounds when eggs and chicks are present. Terns and some gulls, which nest on sand/shingle beaches and small islands, are particularly vulnerable.

23 https://www.bto.org/get-involved/volunteer/projects/seabird-monitoring-programme

Impact assessment method and strategy

The initial focus of the impact assessment conducted for seabirds should consider the following elements:

1. Recording dead wildlife: Camphuysen *et al.* (2007) provide detailed methodologies for post-incident surveys. Counts of dead and contaminated birds will provide the best evidence of actual impact; this requires the urgent mobilisation of beach patrols to collect contaminated birds. Reasonable steps/analysis should be taken to check that death/oiling was caused by the oil or chemical spill. Carcass recovery experiments (preferably using dummy birds or drift blocks, which are wooden blocks with steel plate ballast designed to mimic seabird carcass drift patterns, Munilla *et al.*, 2011) may help to provide better estimates of the proportion of dead birds that were not collected. It is essential that surveyors inspect all birds for rings and report details to the British Trust for Ornithology (BTO). Other data to collect from corpses and live contaminated birds include a range of biometric measurements (see Camphuysen *et al.*, 2007) and other details that will help to determine the origin of the birds. Recording of clinical symptoms from sick birds taken to rehabilitation centres, and post-mortem analysis of dead birds will need to be organised. It may provide useful data to support assessments, including indicating which colonies are likely to be most adversely affected.
2. Biological survey attributes: the priority should be to mobilise seabird at sea surveys to assess the locations of seabird concentrations liable to be impacted by drifting oil or chemical. Surveys will depend on suitable weather conditions and are usually carried out most efficiently from the air. The existing Seabird Monitoring Programme[24] may provide adequate data from seabird colonies, but studies at colonies likely to be affected should be boosted to ensure good information on changes in numbers and in breeding success. Counts of each species are the primary attributes and the standardised survey methods and protocols are well developed for each seabird species, both at their breeding sites (Walsh *et al.*, 1995; Gilbert *et al.*, 1998) and at sea, using digital aerial survey techniques (Thaxter and Burton, 2009; Buckland *et al.*, 2012). Annual survival rates and measurements of breeding success (e.g. numbers of eggs/hatchlings/fledglings) will also be very useful where adequate pre-incident data exist. Other sub-lethal effects indices may also be useful if good pre-incident data are available.

   [Note: catching and taking samples from birds will require an official licence.]

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

- Comparison between pre- and post-incident trends in annual survival rates at seabird colonies will provide the best evidence of impacts to seabird populations, where adequate pre-incident data are available.
- Comparison between pre- and post-spill trends in counts from seabird colony counts and seabirds at sea surveys will be available for more species and sites and will provide next best evidence. If the quality of the pre-incident data is poor, the assessment will rely primarily on the data from corpses, including age structure and ring recoveries.
- Comparison of data on sub-lethal effects indices (e.g. breeding success and other indices of reproductive capacity) between different colonies may provide some evidence of impacts in severe cases, but is unlikely to provide proof without pre-incident data and will be a low priority for study.
- QA/QC: identification and counting of seabirds, at breeding sites, at sea and in digital video, will require training. Accredited courses are available. Repeat recording and data checks by other surveyors will also be appropriate.

24 https://jncc.gov.uk/our-work/seabird-monitoring-programme/

6.4.2 Other marine waterfowl: sea ducks and divers

Characteristics of species

This group of marine waterfowl includes sea duck species such as eider, scaup, long-tailed duck, scoter and goldeneye, as well as divers, grebes, goosanders and mergansers. They are considered separately from seabirds because they mainly have an inshore distribution in the non-breeding season, very few breed in the UK (most wintering sea ducks breed in the Arctic or elsewhere in Europe) and where they do breed, their nests are not aggregated in colonies. They feed, roost and congregate in estuaries, sheltered bays, tidal rivers, lagoons and coastal wetlands. Many species are strongly tied to intertidal habitats (mudflats, sandflats, saltmarsh edges) and can occur in large numbers at predictable sites, particularly during migration and wintering. Their close association with shorelines and shallow waters means they can be exposed to oil and other pollutants stranded on sediments, trapped in saltmarsh creeks, or present as surface films. Exposure may occur through direct contact (oiling of plumage and legs), ingestion during feeding and preening, and through contaminated prey (e.g. worms, bivalves, crustaceans, small fish). Disturbance from response activities can also be significant because many species rely on limited high-tide roosts and have constrained feeding windows around tidal cycles.

Known vulnerability and sensitivity

However, they all form non-breeding concentrations in certain shallow coastal areas. They spend most of the time on the water, diving in shallow areas for bivalve molluscs, or small fish/invertebrates, and are therefore very vulnerable to oil spills. Summaries of the effects of oil spills on birds are given in NOAA (1992) and Clark (1984). Effects can also be expected from exposure to spilled chemicals, but empirical evidence has not been found. Effects will depend on the intrinsic properties of the chemical.

Sea ducks and divers are extremely vulnerable to water-borne pollution, and the three species of divers are within the top six most sensitive ‘seabird’ species (refer to Table 16 of seabird oil sensitivity index in Seabird Section 6.4.1 above). Ecologically highly significant numbers of sea duck and divers have been killed by oil spills in the UK, including *Braer* (Heubeck 1997) and *Sea Empress* (SEEEC, 1998; Banks *et al.*, 2008). Changes in distribution of inshore waterbirds may also result, perhaps in response to impacts on supporting habitats or prey (Castege *et al.*, 2004; Banks *et al.*, 2008).

Although the apparent impacts on these birds may be obvious when contaminated corpses are collected, the resulting impact on their populations, and the time it takes for those populations to recover, is not always so apparent. It has been suggested (National Research Council, 1985) that the high reproductive potential of many sea ducks may allow more rapid recovery of their populations compared to many seabirds, and evidence from the UK supports relatively rapid recovery (Banks *et al.*, 2008). Scoter and diver concentrations at sea have been surveyed, and to a certain extent monitored, in some locations around the UK, including within marine Special Protection Areas (Carmarthen Bay, Liverpool Bay and Outer Thames Estuary SPAs). Future monitoring data may also become available for a new suite of marine SPAs around the UK (in consultation at the time of writing), when classified. Standardised techniques have been developed, and digital aerial surveys are typically quick, targeted and precise (e.g. Thaxter and Burton, 2009; Buckland *et al.*, 2012).

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

Impact assessment method and strategy

The initial focus of the impact assessment conducted for inshore waterbirds should consider the following elements:

1. Recording dead wildlife: Camphuysen *et al.* (2007) provide detailed methodologies for post-spill surveys. Counts of dead contaminated birds will provide the best evidence of actual impact; therefore, requiring urgent mobilisation of beach patrols to collect contaminated birds. Reasonable steps/analysis should be taken to check that contamination was caused by the spill. Counts of birds that are cleaned and released should also be recorded, as most are unlikely to survive for very long after release. Carcass recovery experiments (preferably using dummy birds) may help to provide better estimates of the proportion of dead birds that were not collected. It is essential that surveyors inspect all birds for rings and report them to the BTO. Other data to collect from corpses and live contaminated birds include a range of biometrics (see Camphuysen *et al.*, 2007) and other details that will help to determine the origin of the birds. Recording of clinical symptoms from sick birds taken to rehabilitation centres, and post-mortem analysis of dead birds will therefore need to be organised. It may provide useful data to support assessments.
2. Biological survey attributes: priority should be to mobilise seabirds at sea surveys to assess location of concentrations of sea duck and divers liable to be impacted by drifting oil or chemical. Surveys will depend on suitable weather conditions and are usually carried out most efficiently from the air. Counts of each species are the primary attributes and the standardised survey methods and protocols are well developed yet flexible (e.g. Thaxter and Burton, 2009; Buckland *et al.*, 2012). Annual survival rates and measurements of breeding success (e.g. numbers of eggs/hatchlings/fledglings) will also be very useful where adequate pre-incident data exists. Other sub-lethal effects indices might also be useful if good pre-incident data happens to be available.
   [Note: catching and taking samples from birds will require an official licence.]

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

- Comparison between pre- and post-spill trends in counts from surveys at sea will provide best evidence. If the quality of the pre-incident data is poor, the assessment will rely primarily on the data from corpses, including age structure and ring recoveries.
- QA/QC: identification and counting of water birds, at breeding sites, at sea and in digital video, will require training. Repeat recording and data checks by other surveyors will also be appropriate.

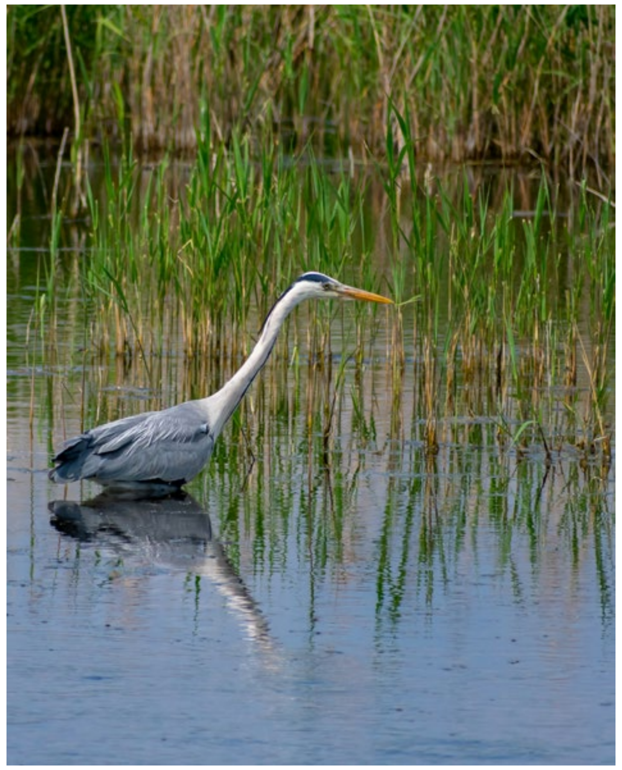
6.4.3 Other inshore wetland birds

Characteristics of species

Inshore wetland birds include a wide range of species such as waders, ducks, geese and swans, associated with freshwater and brackish wetlands such as reedbeds, marshes, swamps, fens, wet grassland, ponds, lakes and slow-flowing rivers. Many species are relatively site-faithful at key wetlands for breeding, moulting, roosting or wintering, and can occur in high densities where suitable habitat is limited. Because these birds often feed and rest in shallow water or on saturated substrates, they may be exposed to pollutants deposited on water surfaces, stranded along margins, or bound to fine sediments and organic-rich muds. Exposure can occur through direct contact (oiling of plumage/legs), ingestion during feeding and preening, and via contaminated prey (aquatic invertebrates, amphibians, fish, plants and seeds). Impacts may be acute (e.g. external oiling) or sub-lethal (reduced condition, altered behaviour, lowered reproductive success), and can be compounded by disturbance or habitat disruption during response activities.

Known vulnerability and sensitivity

Inshore wetland birds appear to have a relatively low vulnerability to the direct effects of oil spills. It is very unusual for these species to become oiled whilst on the shore (this is an unexplained characteristic but seems to be an avoidance reaction) and relatively few spend time on the water in vulnerable areas. The primary concern for wetland birds during oil spills is the effects of the oil and the clean-up on their feeding and roosting resources (Henkel *et al.*, 2014). Avoidance of oiled sediment flats, which can be exacerbated by disturbance from clean-up activity, drives the birds away to find feeding and roosting areas elsewhere. If a spill affects a large proportion of the locally available feeding and roosting area, the birds may struggle to find alternative resources. In a worst-case situation, where birds are already stressed by other factors, the effects could result in starvation or other significant sub-lethal impacts.



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

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

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

Impact assessment method and strategy

The initial focus of the impact assessment conducted for wetland birds should consider the following elements:

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

2. Biological survey attributes: counts of each species in feeding and roosting areas are the primary attributes and standardised survey methods and protocols are well developed. These can show changes in numbers of birds visiting affected feeding areas, but are unlikely to detect changes in populations, due to natural fluctuations and survey limitations, unless there is other evidence that a species has been affected (e.g. large numbers of corpses).

Low tide counts[25], if sufficiently detailed, may provide better information on changes in bird distributions due to oil or chemical spills.

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

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

Sub-lethal effects from ingestion of contaminated prey could theoretically affect bird condition (blood anaemia, etc.) and breeding success, but detection of a significant impact would be very difficult and such studies would have a low priority.

[Note: catching and taking samples from birds would require an official licence.]

25 https://app.bto.org/webs-reporting/numbers.jsp

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

- Comparison between pre- and post-incident data (particularly count data) will provide the best evidence of impacts to wetland bird distributions and populations. If the quality of the pre-incident data is poor, the impact assessment will rely primarily on dead bird data.
- Comparison of data between different breeding sites (occupancy or breeding success) will only be useful if there is a strong correlation between feeding areas and breeding sites, and even then, it is unlikely to provide proof without pre-incident data.
- Monitoring changes in any of the above attributes at intervals following the incident is unlikely to provide proof without pre-incident data.
- Effects of clean-up: the most likely impacts are from disturbance during feeding and roosting; impact assessment should be based on standard survey methods described above and basic ecological observation.
- QA/QC: identification and counting of wetland birds will require training. Training courses are available. Repeat recording and data checks by other surveyors will also be appropriate.

"The primary concern for wetland birds during oil spills is the effects of the oil and the clean-up on their feeding and roosting resources."

6.5 Marine and coastal fauna

6.5.1 Seals

Characteristic of species

Seals are marine mammals that spend much of their time at sea but depend on land (or ice in some regions) for resting, moulting and breeding. Many species show strong site fidelity to haulout and pupping areas, which can concentrate exposure risk if these locations are contaminated.

Known vulnerability and sensitivity

Seals are vulnerable to oil and chemical spills through direct contact at the water surface and along shorelines where oil accumulates, inhalation of volatile hydrocarbons, and ingestion of contaminated prey or oil during grooming. Disturbance associated with spill response operations at haul-out, breeding and moulting sites may also result in behavioural changes, displacement and reduced breeding success if not carefully managed.

Adult seals generally appear less susceptible to external oil fouling than species that rely on fur for insulation (e.g. otters). Seal pups are considered more vulnerable than adults (Geraci and St. Aubin, 1990; Ipieca, 2015; NOAA, 2023). Exposure to oil can result in irritation of the skin and eyes, contamination of mucous membranes, ingestion of oil during grooming, and physiological stress. Inhalation of volatile hydrocarbons, particularly from fresh light crude oils or refined products with high aromatic hydrocarbon content, may cause respiratory and neurological effects and, in severe cases, mortality. Seal pups are considered more vulnerable than adults because of their limited mobility, greater likelihood of remaining on contaminated beaches, and increased susceptibility during the breeding season.

Published evidence describing population-level impacts remains limited and is often based on opportunistic observations following spill incidents. Consequently, where evidence is incomplete, a precautionary approach should be adopted when assessing potential impacts, particularly where breeding colonies, pupping beaches or important haul-out sites may be affected. Similar pathways of exposure are expected following spills of HNS, although effects will depend on the physical and toxicological properties of the substance involved.

Impact assessment method and strategy

The initial focus of the impact assessment conducted for seals should consider the following elements:

1. Recording dead or contaminated wildlife: Counts of dead, contaminated or visibly sick seals provide the strongest evidence of direct impacts, although reasonable steps should be taken to establish whether mortality or illness is attributable to the spill. Clinical observations from animals admitted to recognised wildlife rehabilitation facilities and post-mortem findings from stranded animals can provide valuable supporting evidence. Estimating the post-mortem interval may also assist in determining whether deaths are temporally associated with the incident. Within the UK, existing national monitoring programmes, including the Scottish Marine Animal Strandings Scheme (SMASS) and the Cetacean Strandings Investigation Programme (CSIP) where appropriate, should be used to support investigations. The Sea Mammal Research Unit (SMRU) and experienced wildlife rescue organisations such as the British Divers Marine Life Rescue (BDMLR) should be engaged where appropriate to support monitoring, animal welfare and incident response.
2. Biological survey attributes: some of the more likely potential indicators include *in situ* recording of respiratory symptoms (and other signs possibly related to oil or chemical contamination injury) of seals at haul-out sites (likely to be the best short-term indicator of stress); counts of adult seals and pups at haul-out sites and pupping sites are the primary measure for population effects and standardised census methods are well developed, although annual fluctuations will greatly limit the detection of any impacts (e.g. Westcott, 2002).

[Note: Seals are protected under wildlife legislation in many jurisdictions. Survey work involving disturbance, handling or other invasive techniques may require permits or licences from the relevant competent authority. In all cases, the appropriate statutory nature conservation or wildlife management authority should be consulted before undertaking survey or response activities that could disturb seals or their breeding or haul-out sites.]

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

- Comparison between pre- and post-spill count data for adults and pup production will provide the best evidence of impacts to seal populations.
- Post-spill monitoring should be proportionate to the scale and duration of the incident and continue beyond the initial response where there is potential for longer-term effects. Follow-up surveys should include at least the next relevant breeding and/or moulting season to assess pup production, haul-out use and any persistent changes in behaviour or distribution. Where key seal habitat has been significantly contaminated, longer-term monitoring may be required to distinguish spill-related effects from natural interannual variability in seal abundance and demographic rates (Harwood & King, 2014).
- Comparison between pre- and post-spill respiratory symptom data will be greatly affected by natural seasonal and annual fluctuations, requiring large amounts of pre- and post-spill data to separate natural from oil spill effects.
- Comparison of data on respiratory symptoms between different haul-outs (contaminated and uncontaminated, or along a gradient of contamination) is likely to provide the best evidence of short-term impacts, if surveys are carried out at the same time of year (to allow for seasonal effects).

- Comparison of data on post-spill pup productivity between different haul-outs (contaminated and uncontaminated) may be useful in severe cases (and when contamination of the area where the seals are present occurs within a few weeks of the breeding season) but is unlikely to provide proof without pre-incident data.
- Effects of clean-up: methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with areas where dispersants were sprayed), with some additional considerations for site selection. Methods to study effects of the clean-up response on behaviour of seals are currently limited to basic observations.
- QA/QC: Assessment of respiratory signs and other clinical observations should be undertaken using standardised recording protocols by suitably trained personnel. Seal counts from ground-based or aerial surveys should follow established census methodologies to ensure consistency and comparability. Wherever possible, surveys should be undertaken or overseen by organisations with established expertise in seal monitoring (e.g. SMRU, NatureScot, SMASS and BDMLR where appropriate), with appropriate quality assurance through repeat counts and independent data validation.

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

6.5.2 Otters

Characteristics of species

Otters are semi-aquatic mammals that use coastal, estuarine and freshwater habitats for feeding but rely on bankside/terrestrial areas for resting and breeding (holts). They are wide-ranging yet often locally resident, with strong dependence on specific river corridors, wetlands and sheltered coastal margins.

Known vulnerability and sensitivity

Otters are vulnerable to pollutants because they spend time in the water and in shoreline vegetation where oil and other contaminants can strand, and because they have high energetic demands and consume large quantities of prey. Exposure can occur through direct contact with contaminated water and sediments (oiling of fur and skin), ingestion during grooming, and through contaminated prey (fish, crustaceans and other aquatic organisms). Loss of fur insulation due to oiling can increase heat loss and energetic stress, and disturbance or contamination of resting/breeding sites can exacerbate impacts.

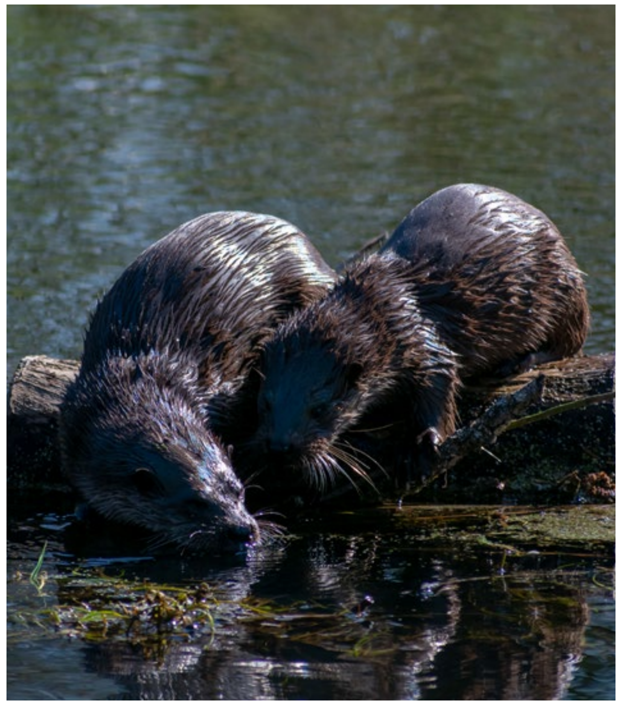
Otters are undoubtedly sensitive to oil (Geraci and S. Aubin, 1990), but the vulnerability of otter populations to marine oil or chemical spills is not well understood. Some coastal otters feed in nearshore and intertidal areas, but their reliance on these habitats and associated food resources is not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

Impact assessment method and strategy

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

1. Recording dead otters: counts of dead, contaminated or sick otters will provide the best evidence of actual impact, although reasonable steps/analysis should be taken to check that death/oiling/sickness was caused by the oil or chemical spill.
2. Biological survey attributes: some of the more likely potential indicators are: signs of otter presence/activity (spraints, etc.) (these are the primary attributes and standardised survey methods and protocols have been developed (e.g. Crawford, 2011)); records of otter sightings at known sites close to the spill area.

"Otters are vulnerable to pollutants because they spend time in the water and in shoreline vegetation where oil and other contaminants can strand, and because they have high energetic demands and consume large quantities of prey."



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

- Comparison between pre- and post-incident data will provide the best evidence of impacts to otter populations; preferably with some monitoring of activity over a few months.
- Comparison of otter activity/records between contaminated and uncontaminated areas is very unlikely to be of any value, due to natural variation.
- QA/QC: Otter survey techniques require appropriately trained personnel. Repeat surveys, independent verification of records, and data quality checks by experienced surveyors are recommended to improve confidence in the results.

[Note: Otters are protected under wildlife legislation in many countries. Survey methods that involve capture, handling, disturbance of breeding or resting sites, or other invasive techniques may require permits or authorisation from the relevant national or regional wildlife authority. Survey programmes should be designed and undertaken in accordance with applicable legislation, permitting requirements, and recognised best-practice guidance.]

6.5.3 Sea turtles

Characteristics of species

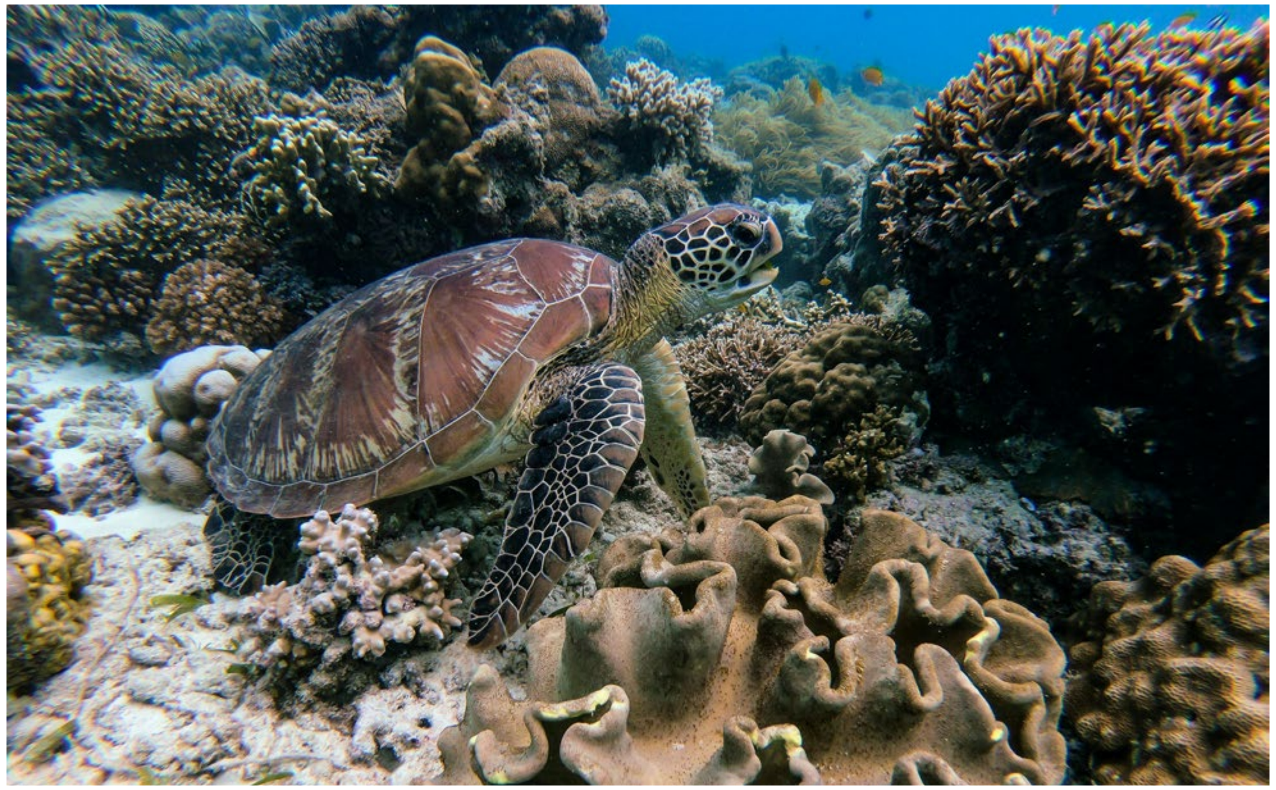
Marine turtles are long-lived, wide-ranging reptiles that use different habitats at different life stages, including offshore waters, coastal foraging areas, nesting beaches, and (for some species) nearshore developmental habitats. Although highly mobile, turtles often show seasonal use of specific foraging grounds and strong fidelity to nesting areas.

Known vulnerability and sensitivity

Exposure can occur through external contact (oiling of skin, eyes and mouth), inhalation of fumes at the surface, and ingestion of oil directly or indirectly via contaminated prey or particulate matter. Their surfacing behaviour (to breathe) and frequent use of the sea surface can increase exposure to floating oil, surface films and associated volatile compounds, while foraging in coastal waters can increase exposure where contaminants strand or persist. Eggs and hatchlings can be particularly vulnerable where nesting beaches are contaminated, and impacts at key nesting sites can be disproportionate because many populations have low reproductive output and delayed maturity.

Marine turtles are vulnerable to oil and chemical spills at all life stages, although the nature and severity of impacts vary with age class, habitat use and spill characteristics. Reviews by Lutcavage *et al.* (1997), Milton *et al.* (2003) and NOAA (2019) indicate that turtles can be affected through direct external fouling, inhalation of volatile hydrocarbons at the sea surface, ingestion of oil (either directly or via contaminated prey), and contamination of nesting beaches (Lutcavage *et al.*, 1997; Shigenaka, 2003).

Adult and juvenile turtles are particularly at risk when surfacing to breathe in areas with fresh oil slicks, as they may inhale volatile compounds concentrated at the air–sea interface. Exposure to aromatic hydrocarbons and other toxic fractions can result in irritation and inflammation of the respiratory tract, neurological impairment, and systemic toxicity (Milton *et al.*, 2003; NOAA, 2019). External oiling may cause skin and eye irritation and, in heavy contamination events, can impair swimming, diving, and thermoregulation.



Surface-pelagic juveniles, which often associate with floating sargassum and debris, may be especially vulnerable to oil slicks that accumulate in convergence zones (Witherington *et al.*, 2012). Ingestion of oil-contaminated prey or tar balls has been documented and may lead to gastrointestinal blockage, ulceration, and sublethal toxic effects (Lutcavage *et al.*, 1997; Camacho *et al.*, 2013).

Eggs and hatchlings are particularly sensitive to contamination of nesting beaches. Oil deposited on sand can reduce gas exchange within nests, increase embryonic mortality, and impair hatchling fitness and orientation (Fritts and McGehee, 1982; NOAA, 2019). There is therefore a strong seasonal component to vulnerability, with highest risk during nesting and hatching periods. Nesting females may also be deterred from coming ashore on oiled beaches.

As with other taxa, effects from exposure to spilled chemicals (e.g. refined products, dispersants, or hazardous and noxious substances) will depend on the intrinsic properties of the substance, including volatility, solubility, and toxicity. Empirical evidence for many chemicals remains limited, but experimental and post-spill observations suggest that dispersants and dispersed oil mixtures can cause additional dermal and mucosal irritation and may increase bioavailability of toxic components (Milton *et al.*, 2003; NOAA, 2010).

> **“Baseline data on nesting female abundance, clutch frequency, hatching success, and juvenile/adult abundance at foraging sites provide the strongest evidence of population-level impacts.”**

Impact assessment method and strategy

The initial focus of the impact assessment conducted for marine turtles should consider the following elements:

1. Recording dead/contaminated wildlife: Counts of dead, visibly oiled, or sick turtles will provide the most direct evidence of impact, although reasonable steps/analysis should be taken to confirm that mortality or morbidity is attributable to the spill. Necropsies conducted by trained veterinarians can identify evidence of oil exposure (e.g. hydrocarbons in gastrointestinal contents, lung pathology). Stranding network data (e.g. national marine turtle stranding schemes) should be collated and compared with baseline seasonal stranding rates. Estimation of time since death can assist in determining whether the pollution incident is a credible cause. Tissue sampling for hydrocarbon analysis may provide supporting evidence of exposure.
2. Biological survey attributes:
   Likely indicators include:
   - *In situ* observations of behaviour (e.g. abnormal surfacing frequency, lethargy, impaired diving).
   - Documentation of external oiling (carapace, plastron, eyes, nares).
   - Monitoring of nesting activity (number of nesting females, clutch frequency, nest success, hatching success).
   - Hatchling emergence counts and assessments of deformities or reduced vigour.
   - Monitoring of foraging aggregations in affected nearshore or pelagic habitats.

Aerial and vessel-based surveys may be used to detect turtles in offshore slicks, though detectability is influenced by sea state and turtle surfacing behaviour. Beach surveys during nesting season are essential where shoreline contamination occurs.

The detailed strategy for assessing impacts to marine turtles should consider the following points:

- Baseline data on nesting female abundance, clutch frequency, hatching success, and juvenile/adult abundance at foraging sites provide the strongest evidence of population-level impacts. Comparison with long-term datasets (where available) is essential to account for natural interannual variability (Schroeder and Murphy, 1999).
- For nesting beaches, comparison of nest density and hatching success between oiled and unaffected beaches during the same breeding season may provide evidence of short-term impacts, particularly where contamination occurs shortly before or during nesting. However, interpretation must account for natural spatial variability in nesting distribution.
- Clinical examination of live-stranded or rehabilitated turtles may reveal respiratory irritation, ocular lesions, or haematological and biochemical indicators of hydrocarbon exposure. Such data can support evaluation of physiological stress but require veterinary expertise and appropriate controls.
- Given the longevity and delayed maturity of marine turtles, population-level effects may not be detectable for many years. Continued monitoring of nesting output and survival rates at index beaches is recommended where significant contamination has occurred.
- Mechanical beach cleaning may compact sand or disturb nests if conducted during nesting season. Relocation of at-risk nests may be considered in severe cases but must follow established conservation protocols. Methods to assess effects of dispersed oil are similar to those for naturally dispersed oil, with correlation to treated areas. Disturbance to nesting females from response activities (lighting, vehicle use, human presence) should also be evaluated.
- Turtle identification, nesting surveys, and clinical assessments require trained personnel following standardised protocols (e.g. Schroeder and Murphy, 1999; NOAA, 2019). Repeat counts, inter-observer calibration, and data verification procedures should be implemented. Hydrocarbon analyses should be conducted by accredited laboratories using validated methods.

6.5.4 Cetaceans: whales, dolphins and porpoises

Characteristics of species

Cetaceans (whales, dolphins and porpoises) are long-lived, wide-ranging marine mammals that rely on air breathing and spend their entire lives in the marine environment. Species differ in distribution (coastal vs offshore), diving behaviour, prey preferences and social structure, which influences where and how they may encounter pollutants.

Known vulnerability and sensitivity

Exposure can occur at the sea surface (including contact with surface films and slicks, and inhalation of volatile compounds during surfacing), within the water column (especially for deep-diving species in the presence of submerged plumes), and through ingestion of contaminated prey. Because cetaceans have high lipid reserves, some contaminants can partition into blubber, and mobilisation of fat reserves (e.g. during fasting, migration or lactation) can influence internal exposure. Many populations are slow to recover due to low reproductive rates and long calving intervals, and impacts on adults or breeding females can therefore be particularly significant. Detecting impacts can be challenging because affected animals may not strand, carcasses may be lost at sea, and sub-lethal effects can be difficult to attribute without sustained monitoring.

Geraci and St Aubin (1990) and Gubbay and Earll (2000) summarise the limited evidence for impacts of oil on cetaceans up to and including studies from the 1989 *Exxon Valdez* spill in Alaska. More recently, studies following the 2010 *Deepwater Horizon* spill have suggested notable impacts on dolphins in the Gulf of Mexico. No studies of the effects of spilled chemicals on cetaceans have been conducted to our knowledge. However, evidence from studies of persistent chemical pollutants demonstrates that cetaceans are susceptible to long-term contaminant exposure. High tissue burdens of persistent organic pollutants, particularly polychlorinated biphenyls (PCBs), have been associated with adverse effects including impaired reproduction, immune suppression and population-level impacts in several cetacean species (Jepson *et al.*, 2016; Williams *et al.*, 2021). These studies highlight the sensitivity of cetaceans to chemical contaminants, although the toxicological pathways and exposure scenarios associated with acute chemical spills may differ depending on the properties of the released substance.

Individuals and small groups of cetaceans have occasionally been seen at the surface near oil spills, sometimes being attracted to the spill area by the response activity and may therefore encounter oil. While their skin is not thought to be particularly sensitive to oil, any accidental ingestion or breathing of oily fumes could cause physiological stress (Takeshita *et al*., 2017). However, until the recent *Deepwater Horizon* studies, very few examples of actual injury to cetaceans had been reported and much of the evidence of injuries from spills is circumstantial. Some empirical evidence of a direct effect comes from the monitoring of killer whale (Orcinus orca) populations following the *Exxon Valdez* oil spill. Matkin *et al.* (2008) describe notable reductions in the numbers of two pods that had been observed near the spill and showed that they did not follow the population increases shown by other Alaskan pods. Some reviewers have suggested other possible causes for the reductions, but the debate continues.

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

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

Cetaceans are protected under a range of international, regional and national legislation and conservation agreements throughout their range. These protections generally apply across their natural distribution, rather than only within designated protected areas, and should be considered when assessing the potential impacts of pollution incidents and planning response activities. Where relevant, applicable national legislation and regional conservation agreements should be considered.

Impact assessment method and strategy

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

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

- Record and collate any observations of cetaceans in the spill area, during and in the weeks after the spill; particularly any observations of cetaceans close to slicks and any signs of ill health or unusual behaviour. An aerial survey may be appropriate if casual sightings of ill animals are reported;
- Any dead, moribund or stranded cetaceans should be studied (species, sex, dimensions etc.) and photographed. Tissue samples and an autopsy may be appropriate to determine cause of death; this will require a cetacean/veterinary specialist. In some cases, an estimate of the length of time an animal has been dead can be useful in establishing whether the pollution incident is a credible cause or not;
- Passive acoustic monitoring methods are available for continuous (24-hour) recording of cetacean occurrence in spill-affected areas and may also provide information on behavioural responses to the spill and associated response activities. These methods can determine the occurrence of vocalising species but generally cannot be used to estimate abundance;
- Gubbay and Earll (1999) developed proposed guidelines for dealing with cetaceans in the event of an oil spill in the Moray Firth, Scotland. These are currently being reviewed and updated, but they provide useful background material;
- Effects of clean-up: methods to study effects of chemically dispersed oil will be the same as those for naturally dispersed oil (and results simply correlated with oil in water concentrations). Methods to study effects of the response (e.g. boat activity) on behaviour of cetaceans are currently limited to basic observations;
- QA/QC: Identification and counting of cetaceans, and sea and from digital video, will require training. Accredited Marine Mammal Observer courses are available. Repeat recording and data checks by other surveyors will also be appropriate.

6.6 Affected wildlife

6.6.1 Role of wildlife casualties in impact assessment

Wildlife affected by spills may include live animals showing evidence of contamination or other adverse effects, as well as dead animals recovered during or following an incident. Systematic recording and investigation of affected wildlife can provide important evidence of the nature, scale and distribution of ecological impacts and should therefore form part of the overall environmental impact assessment where wildlife casualties occur. The selection and prioritisation of resources for monitoring should follow the general principles described in Section 2.3.

Counts of dead, contaminated or visibly affected wildlife can provide some of the strongest direct evidence of impact, although reasonable steps should be taken to establish whether observed mortality, contamination or illness is attributable to the incident. Clinical observations from live casualties and post-mortem examination of dead animals may provide additional evidence of exposure and effects. The wider principles for defining impact-assessment questions and the limitations associated with estimating wildlife mortality are described in Section 3.4.

Wildlife casualty data should not, however, be assumed to represent total mortality. Not all affected animals will be detected or recovered, and the likelihood of recovery will vary according to species, location, environmental conditions and the circumstances of the incident. Where appropriate, casualty data may therefore need to be interpreted alongside other ecological information and population monitoring.

6.6.2 Collection, recording and investigation of dead wildlife

Where dead wildlife is recovered, a coordinated system should be established for its collection, identification, recording and, where appropriate, storage for subsequent examination. Records should include, as a minimum, species, location and date of collection, together with relevant observations on the condition and apparent contamination of the animal. Collection of dead wildlife for post-mortem examination, morphometric studies and contaminant analysis can provide valuable information for determining the nature and extent of impacts. General principles for sample management, labelling, tracking and chain of custody are provided in Sections 4.4 and 4.5. Where whole wildlife casualties or tissue samples are retained for analysis, storage and transport requirements should be agreed with the receiving laboratory because these may differ according to the intended post-mortem or analytical investigation.

Where appropriate, post-mortem examination and chemical analysis should be used to investigate whether mortality or observed effects are consistent with exposure to the spilled oil or chemical. Analytical approaches for identifying and characterising hydrocarbon contamination are described in Section 5.3. Existing national monitoring and stranding programmes should be used where relevant, particularly for marine mammals and other protected species.

Effective collection and maintenance of casualty records is a specialist task and should be undertaken using consistent procedures and appropriate quality assurance. It will rarely be possible to recover all animals killed as a result of an incident; this limitation should be recognised when casualty numbers are interpreted or extrapolated.

For birds, additional information should be collected where practicable to help determine the populations affected. Recovered birds should be checked systematically for rings and relevant ring information reported through the appropriate national ringing scheme. Biometric measurements and other information that may assist in determining population origin, age structure and provenance should also be recorded.

For significant seabird mortality events, carcass-recovery studies may help estimate the proportion of casualties that are not recovered. The existing guidance identifies dummy birds or drift blocks as possible approaches for investigating carcass recovery and drift.

6.6.3 Live wildlife and rehabilitation

Live wildlife casualties may require capture, triage, treatment and rehabilitation. Wildlife rehabilitation is a specialised activity and should be undertaken by appropriately trained and experienced organisations and personnel. Wildlife response should, where possible, be integrated with the wider incident response and environmental assessment so that information collected from live casualties can contribute to understanding ecological impacts. The general principles for integrating specialist monitoring activities within the wider incident response are described in Section 2.7. The existing guidance identifies established networks and specialist organisations as important mechanisms for sharing expertise and implementing good practice in oiled-wildlife response.

Clinical observations from animals admitted to recognised rehabilitation facilities should be recorded systematically and may provide useful supporting evidence of exposure and effects. Where animals do not survive during treatment or are euthanised, they should be incorporated into casualty records and considered for appropriate post-mortem investigation.

For rehabilitated animals, the number entering care should not in itself be treated as a measure of successful response or ecological recovery. Where feasible, information on release and subsequent survival should be collected to provide a more meaningful indication of rehabilitation outcomes.

6.6.4 Use of casualty data in ecological assessment

Casualty records should be considered alongside other lines of ecological evidence when assessing the consequences of an incident. Depending on the species and availability of baseline information, this may include pre- and post-incident population counts, distribution and abundance data, breeding success, observations of behaviour or condition, and information from affected and reference areas. The general approaches to impact-assessment study design, including comparisons with pre-incident data, reference sites and subsequent recovery, are described in Section 3.1. The limitations of casualty data should be explicitly recognised. The number of animals recovered will generally represent only a proportion of those affected, and absence of recorded casualties should not necessarily be interpreted as evidence of absence of ecological impact. The wider evidential limitations associated with estimating mortality and demonstrating population-level change are discussed in Section 3.4.

Particular attention should be given to the temporal and spatial distribution of casualties, the species and life stages affected, evidence linking mortality or injury to the spilled substance, and the relationship between recorded casualties and populations of conservation importance. Where the population of origin can be established, casualty information may also help identify populations or breeding colonies for which subsequent monitoring is appropriate.

The limitations of casualty data should be explicitly recognised. The number of animals recovered will generally represent only a proportion of those affected, and absence of recorded casualties should not necessarily be interpreted as evidence of absence of ecological.

6.6.5 Affected birds

Birds affected by oil or chemicals can be divided into those which are alive and require rehabilitation if thought appropriate, and those which are dead and need to be stored for possible future necropsy and/or other studies. Statistics on contaminated birds also feed into any overall impact assessment of an incident. Such rehabilitation of affected birds has often been conducted following oil spills, but not following HNS spills, although there is no reason to think that this could not happen. Nijkamp (2006) noted that few response plans include information on dealing with oiled birds, mammals and reptiles. Because of this, the rescue and rehabilitation of such animals is usually left to local wildlife groups which are not integrated into the main response organisation and lack the training and resources to mount a fully effective operation. Nijkamp also recognised that making oiled wildlife response more professional presented an international challenge to key stakeholders, including governments, wildlife responders and the oil, shipping and response industries. Since 2000, the Sea Alarm Foundation has taken some initiatives to this end.

An active network of oiled wildlife responders has now been established across Europe, originally developed through EUROWA/GOWRS and now known as EMPOWER. This network brings together coastal rehabilitation groups, veterinarians, scientists, universities and national NGOs, supporting exchange of expertise and the development and implementation of good practice. At a global level, the International Alliance of Oiled Wildlife Responders provides a platform for exchange of expertise and experience and the development of practical standards and guidelines. Guidelines for oiled wildlife response planning and good practice have also been published (Nijkamp, 2007; Ipieca, 2014).

In the most recent significant UK incident, the grounding of the container ship *MSC Napoli* in Lyme Bay in 2007, analysis of affected seabirds formed part of the environmental impact assessment (Law, 2008). Natural England and the Joint Nature Conservation Committee developed guidelines for the collection and study of dead oiled birds, which are given below.

The rehabilitation of wildlife is a specialised area and should be undertaken by specialists. The Royal Society for the Prevention of Cruelty to Animals (RSPCA) is currently developing guidance to stand alongside the National Contingency Plan. The RSPCA has five regions for England and Wales: East, North, South East, South and South West and Wales and West. In the event of an incident, the RSPCA region in which the incident occurs will assess whether they have the capability to manage the incident without help from other regions. If the region identifies the incident as larger than they can cope with, then the response will be escalated to a national one. This information will be fed into the Standing Environment Group network during 2011. The RSPCA wishes to be more proactive than in the past and to form more formal relationships with the regional Standing Environment Groups.

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

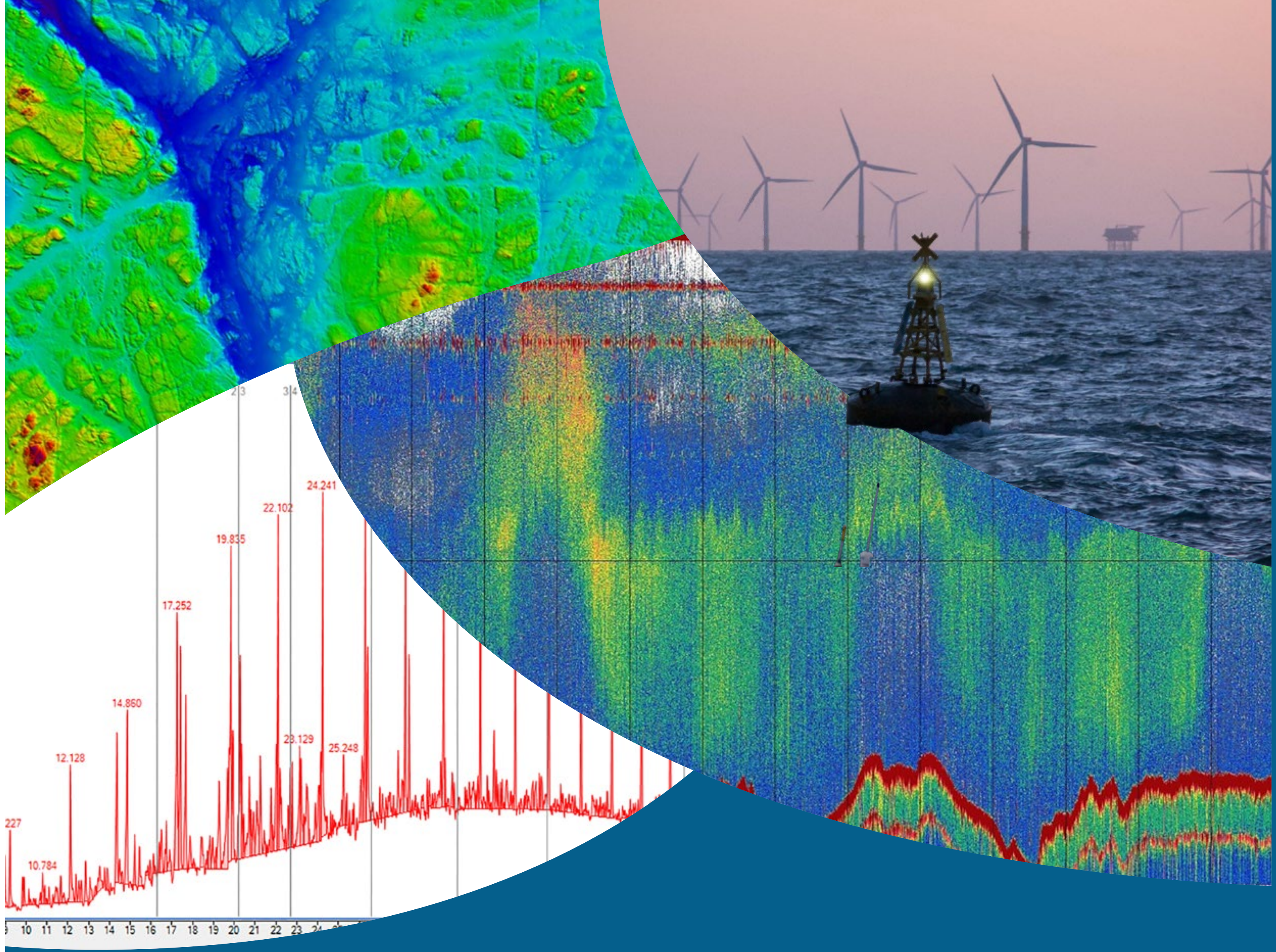
Dead casualties

Dead casualties need to be collected and stored at a central location with a system for logging them. If there are going to be a large number, then a freezer lorry/container should be made available at a suitable assembly point. On arrival, the number of each species from each location needs to be recorded and the legs of the birds checked for rings. Ring numbers should be reported to the BTO regularly so that identification of the populations involved can be assessed as the incident progresses. It is important that there is a later systematic rechecking for rings and that biometric measurements be taken to aid identification of populations and age structure of affected birds. Even when experienced people check for rings on heavily contaminated birds, some rings are missed when the number arriving is more than a few individuals per day. Although we have a reasonably good knowledge of the locations of concentrations of birds at sea, we often do not know the locations of their associated breeding colonies. This is especially true outside the breeding season, although, using new technologies, it is evident that breeding birds may travel long distances on feeding trips. The location of affected populations is important for future monitoring of changes in population size and breeding success.

Live casualties

Ensuring that all birds are taken to recognised cleaning centres where a proper triage procedure can be carried out is important. In the final reporting of an oil spill (or of a chemical that coats plumage), the number of birds taken into care is often taken as a measure of the effectiveness of the response. However, it is the number that are released and survive to re-enter the breeding population that is important. This can only be gauged over the long term by ringing all birds released and undertaking an analysis of the recoveries a decade later. Those that die in captivity or are euthanised should be added to the dead casualties.

Collection of dead wildlife for possible autopsies, morphometric studies and hydrocarbon analysis can provide valuable information. However, establishing an effective system for collecting dead wildlife, maintaining the necessary records (numbers, species, locations, dates, etc.) and producing relevant statistics is a specialist task that should not be underestimated (Ipieca, 2014) (see also Section 6.6.2). It will never be possible to record all wildlife deaths, and multiplication factors are typically applied to the statistics to give estimated totals.



Part 7

Data quality and management

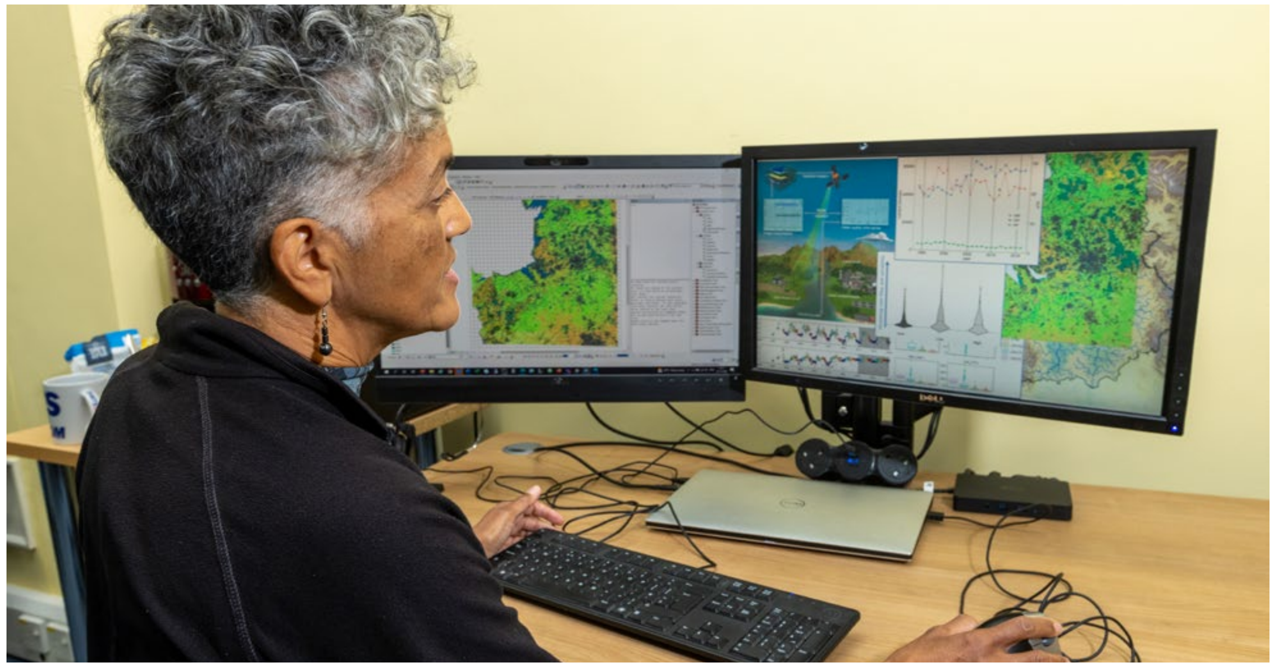
7. Data quality and management

7.1 General considerations

Data that are collected, acquired, or generated should be of high quality to ensure that decisions are robust and defensible. To maximise value, maintain data integrity, and improve efficiency, data handling should be considered across the full data lifecycle, from planning and acquisition through use, maintenance, archiving, and closure.

Integration of QFAIR principles (Quality, Findable, Accessible, Interoperable and Re-usable) supports the production of high-quality data that are discoverable, accessible, shareable among stakeholders, interoperable across systems, and reusable beyond their original purpose. Widely adopted within the international scientific community, QFAIR is increasingly recognised as a general standard for data management, data infrastructure development, and service delivery. Additional data quality and control standards may be applied at specific stages of the data lifecycle, including sample collection and management, laboratory analysis, metadata recording and curation, and data dissemination.

Pre-incident planning and preparedness are essential to ensure that all participants are aligned with the data requirements and responsibilities outlined in this section. A comprehensive Data Management Plan (DMP) can be developed in advance of any incident, refined through training exercises or trial scenarios, and maintained as a live document during incidents. Use of a DMP helps ensure that roles and responsibilities for data collection, generation, management, and delivery are clearly defined, supporting effective coordination and the timely provision of data to meet scientific and operational needs. DMPs can be scaled to suit the scope and complexity of individual incidents, and template DMPs are available and discussed further in this section. Organisations working through the Incident Management System may establish a Data Management Unit within the Planning Section, in more complex incidents. This Unit should provide a framework through which an environmental monitoring programme can be coordinated, further enhancing integration across the overall response effort.



To maximise the value of data, effective data management should be applied throughout the entire data lifecycle, from planning and collection to response close-out. Approaches established during planning and pre-incident phases should align with existing approaches while remaining flexible enough to adapt to the specific needs of each incident. This flexibility should be enabled through early engagement and sustained coordination throughout the response. Where available, techniques should be conducted to internationally accepted standards and protocols (Table 17).

When procurement of external services is necessary, preference should be given to suppliers who can demonstrate that they have excellent quality control and quality assurance procedures in place for specific techniques (e.g. Good Laboratory Practice (GLP) certification or the use of UKAS accredited techniques). Further evidence of quality control (QC) could be provided by participation in and adherence to the principles of QC proficiency testing schemes such as:

- QUASIMEME (Quality Assurance of Information for Marine Environmental Monitoring in Europe);
- BEQUALM (Biological Effects Quality Assurance in Monitoring Programmes); and
- NMBAQC (National Marine Biological Association Quality Control).

Table 17: International quality standards and protocols specific to the different technical services.

Service	Sub-service	Quality/Safety system
Storage		Quality manual, standard protocols including international standards
Transport	Controlled temperature	Loggers
	RIB or small vessel	Small commercial vessel certificate
	Research/survey vessel	Maritime Mobile Service Identity (MMSI)
	Fishing vessel	Seafish inspection/Maritime and Coastguard Agency (MCA) safety inspection
Survey	Saltmarsh	Quality manual, standard protocols
	Intertidal ecology	Quality manual, standard protocols including international standards
	Plankton survey	UK Accreditation Service (UKAS)
	Fish and shellfish	
	Sea birds	Digital aerial survey
	Wetland birds	
	Marine mammals	JNCC accredited marine mammals OBSERVER
	Aerial imagery	Quality manual
	Shoreline clean-up (SCAT)	Training, UK guidelines
Analytical Chemistry		UKAS/proficiency testing (QUASIMEME)
Ecotox		GLP/Direct Toxicity Assessment Proficiency Scheme (DTAPS)/Biological Effects Quality Assurance in Monitoring Programmes (BEQUALM)
Modelling		Quality manual

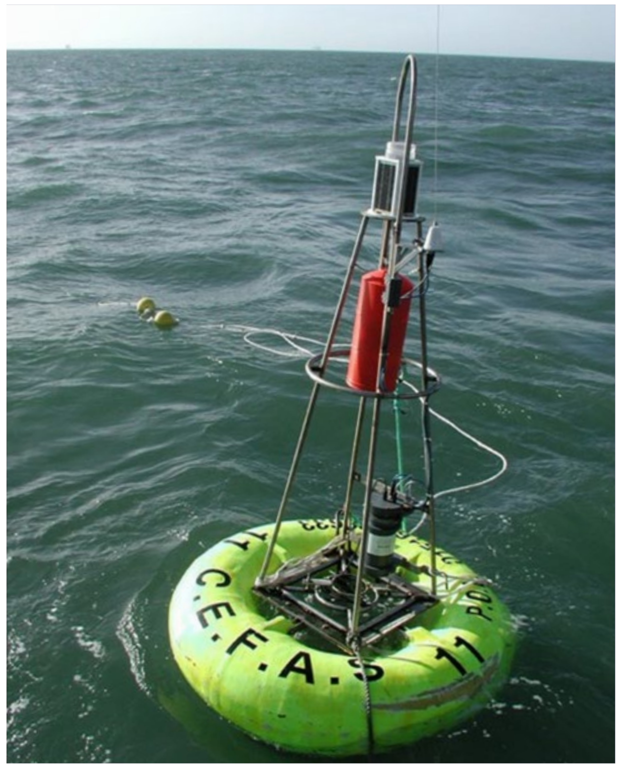
7. Data quality and management

7.2 Quality control considerations

The management of data supporting post-spill reporting and monitoring presents distinct challenges and requires careful planning to ensure effectiveness and efficiency. Proportionate time and resources should be invested in establishing and maintaining post-spill response mechanisms, including the availability of appropriate expertise, guidance, and tools for use during an incident.

In the absence of prior preparation and established structures, ad hoc data collection and processing are likely to result in reduced data quality, undermining reliability and the robustness of subsequent analysis and decision-making.

As part of broader efforts to promote data openness, information made available through monitoring programmes undertaken by relevant environmental regulators may provide valuable insights. National and regional marine monitoring programmes can also serve as important sources of data to support response activities.



7.2.1 Pre-incident data availability

A fast and effective incident response depends on the availability and accessibility of relevant, up-to-date data for the affected site, and on the ability of spill and incident management experts to access and use these data without delay. Open and accessible scientific data support both immediate response activities and future spill-related work.

Guidance on data sharing for national crisis response[26] is available from UK government sources and can be adapted as part of pre-incident planning. This guidance sets out principles for urgent data sharing, consolidates existing best practice (including the Code of Practice for Statistics[27]), and provides frameworks that can be tailored to develop team-specific procedures.

As part of wider efforts to promote data openness, environmental monitoring programmes operated by regulatory authorities can provide valuable baseline and contextual information. Long-term national or regional marine monitoring programmes are also important sources of data in many countries. Equivalent environmental regulators should be consulted where relevant.

Additional data may be held by national and local nature conservation bodies, biological recording centres, universities, and research institutes. While many organisations publish data in line with best practice principles, some datasets may require additional effort to locate or further engagement to make them openly available.

Although each spill incident presents unique data requirements, prior knowledge of national and regional datasets is invaluable. To support effective future incident management, standing response teams should identify, acquire, and integrate relevant datasets for their areas of responsibility in advance, updating these as new information becomes available.

26 https://analysisfunction.civilservice.gov.uk/policy-store/data-sharing-for-national-crisis-response/
27 https://code.statisticsauthority.gov.uk/

A range of international and national organisations provide online services that promote data sharing and reuse. Internationally, under the International Oceanographic Data and Information Exchange (IODE)[28] of the UNESCO-IOC.

- **Ocean InfoHub** – links existing and emerging ocean data systems.
- **OBIS** (**Ocean Biodiversity Information System**) – provide access to high-quality marine biodiversity and biogeography data.
- **OBPS** (**Ocean Best Practices System**) – is an open-access repository of community best practices in ocean science and applications.

A range of data portals can be consulted to identify national-scale and baseline data relevant to a site or incident type, with many resources increasingly becoming more interconnected and integrated (Section 3.2).

Teams responsible for post-spill monitoring and impact assessment can use these portals, alongside other relevant resources, to improve awareness of available data and identify specialist points of contact. In the UK, this activity is supported by the Premiam Monitoring Coordination Cell (PMCC) (Appendix 3); countries using the Incident Management System will assign this to the Environment Unit, working with the Data Management Unit. Even where directly relevant datasets are not immediately available, engagement with data creators and custodians working in similar regions or disciplines may reveal additional unpublished or emerging information.

28 https://iode.org/

7.2.2 Connections and storage

An efficient incident response often requires data to be collected and processed by multiple, potentially geographically dispersed, individuals and organisations. The provision of a centralised, accessible platform with integrated storage supports both the quality of data collected and the efficiency with which those data are made available for subsequent analysis and reporting.

Centralised data storage should be accessible to all relevant parties involved in the response, enabling data to be collated and processed as early as possible before, during, and after an incident. As part of pre-incident preparation, the platform or system for data integration, storage, and access should be agreed in advance and documented. Cloud-based solutions are typically the most efficient means of facilitating data sharing across spatially distributed response teams and offer advantages in terms of rapid mobilisation and reduced reliance on physical infrastructure. Where cloud-based solutions are not viable, local storage systems may be implemented to allow direct access for data generators and users.

Where possible, data from external portals or existing sources should be accessed via Application Programming Interface (API) connections rather than through manual downloads. Downloaded data snapshots may not reflect the most recent updates, whereas API-based access offers several advantages, including:

- Enabling live connections to data sources, ensuring access to the most up-to-date information, particularly for near real-time datasets such as meteorological or oceanographic data;
- Facilitating automated data flows, reducing the need for manual intervention and supporting data integrity and consistency across systems;
- Automatically managing and updating associated metadata, ensuring that datasets remain well documented and readily discoverable; and
- Reducing the need for local data storage by providing direct access to data held at source rather than maintaining duplicate copies.

In some cases, storage of external or baseline datasets may still be necessary or beneficial, depending on the applications and platforms in use. For compliance, audit, or data recovery purposes, it may be appropriate to retain data snapshots that record the specific datasets used at defined points in time.

7.2.3 Data governance: principles, roles and responsibilities

Data collected in response to an incident will vary in source (e.g. type of measurement), quality, completeness, and suitability for assessment or monitoring purposes. Due to the complex nature of incident response, data will also be provided by a variety of participating organisations, resulting in disparate data standards and collection protocols being used. Despite the inherent complexity of incident response, all participating organisations are encouraged to apply the "*collect once, use many times*" principle.

Clear definition of roles, responsibilities, and accountabilities is essential for effective incident response. The monitoring coordination cell (or equivalent) would benefit from nominating a designated Incident Data Lead (or Coordinator), responsible for the strategic planning and coordination of all data-related activities throughout the incident lifecycle. The Incident Data Lead provides coordination and support to contributing organisations but is not expected to undertake all data-related tasks directly.

The Incident Data Lead (or Coordinator) is responsible for the strategic planning, coordination, and oversight of all data, and information-related activities associated with an incident. Key responsibilities include:

- Coordinating data and information requirements relevant to the incident, including the location, status, and provenance of all data and samples being collected, used, or processed;
- Designing, adapting, and issuing standardised templates for use during the incident;
- Ensuring all participating organisations and individuals understand and fulfil their respective data-related roles and responsibilities;
- Coordinating the activities of Incident Data Managers, appointed as appropriate to the scale of the incident;
- Defining, implementing and overseeing appropriate quality assurance and quality control (QA/QC) procedures;
- Identifying and resolving data-sharing challenges, including clarification of data licensing arrangements to enable data use during response activities and subsequent reuse;
- Engaging with data archive centres, repositories, and relevant networks at an early stage;
- Advising on, or coordinating input to, legal considerations, including the handling of personal data and third-party licensed datasets;
- Arranging and agreeing data storage infrastructure requirements in advance of an incident;
- Defining data and file format standards to be applied during data collection, including:
  - Data structures (e.g. folder hierarchies); and
  - File and dataset naming conventions that are clear, consistent, and meaningful, incorporating elements such as location, date/time of collection, data type, and, where appropriate, collecting organisation;
- Ensuring that adequate metadata requirements are specified and met, including confirmation that external data providers supply sufficient methodological detail, particularly for bespoke or novel techniques, to support appropriate reuse.

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

7.2.3.1 Metadata

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

Creation of detailed metadata and adherence to existing standard operating procedures/ data standards will help ensure high-quality data and information is gathered throughout any post-incident monitoring work.

7.2.3.2 Data use conditions

Information on potential confidentiality/sensitivity as well as use/reuse conditions should also be gathered when both receiving existing or baseline data and be set for onward use. When receiving data from external sources, this information would ideally already be captured in supplementary discovery metadata they should provide along with the data. In many instances the data provider will provide this, or there will be a license attached, either directly, or else a specified standard Creative Commons CC license[29], will be noted. Where no conditions for licensing or terms are provided when receiving data, however, it is prudent to check and ask before making assumptions, in case of confidentiality, legalities or commercial-use clauses.

Equally, the same aspects of data use should be considered for any data collected post-incident and recorded alongside (or as part of) the metadata. Ideally, an open license should be applied to any data collected during an event, or analyses to enable efficient re-use. It is also essential that data use conditions or licensing conditions are followed when it comes to any subsequent publication of reports and/or data.

7.2.3.3 Post-incident data curation and sharing

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

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

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

7.2.4 Planning

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

- A list of individuals who are prepared to take on the role of Incident Data Manager/s, including contact details.
- A list of relevant data collection and processing organisations and points of contact, including contact details.
- Relevant data collection Standard Operating Procedures/guidance/templates and checklists.
- Location guides, including protected area information (e.g. Sites of Scientific Importance, marine protected areas), and coastal habitat, geological or archaeological sensitivities.
- Local stakeholder guides and contacts list template.
- Local maps and up-to-date charts.
- A centralised data platform to enable API links and a local data storage area with an agreed method of transfer from both field collection to storage, as well as from data users/analysts.
- Metadata recording templates/software.
- Station data recording templates/software.
- Sample tracking template/software.

29 https://creativecommons.org/cc-licenses/

Part 8

Communications and reporting

8. Communications and reporting

Effective communication of key findings from an environmental monitoring programme to relevant stakeholders is essential. Stakeholders may include responders (who may adjust response actions based on findings), the media, the public, government bodies, and non-governmental organisations.

A monitoring coordination cell can support effective engagement by ensuring communications are organised, consistent, and aligned, helping technical measures to be clearly understood and appropriately supported by stakeholders. Organisations working through the Incident Management System (IMS) may establish a Common Operating Picture (COP) through a Situation Unit within the Planning Section, in more complex incidents. This COP should be able to provide the view of monitoring activities within which an environmental monitoring programme can integrate. Furthermore, the Planning Cycle bedrock of IMS procedures facilitates and manages both internal and external communications.

Given the number of responders involved, the diversity of stakeholders, and the range of communication channels required, coordination of messaging is critical. Information should be communicated transparently during and after an incident to build trust and minimise the risk of misinformation. Regular training exercises and scenario-based planning can strengthen coordination across stakeholders and communication channels, improving overall preparedness. Communications should use pre-agreed channels, with clear identification of the organisations or individuals responsible for engaging with each stakeholder group.

Information generated through environmental monitoring and impact assessment is often of high interest, particularly where it relates to health, disease and environmental impacts. Such information may be sensitive and prone to misinterpretation if presented without appropriate context. In the UK, for example, the PMCC supports clear communication pathways and coordinated dissemination of information, including the production of reports and regular updates (see Appendix 3). The monitoring coordination cell is responsible for collating and distributing monitoring outputs and should operate within the overarching incident communications framework. Clear reporting lines, communication pathways, and defined roles and responsibilities should be established in advance of an incident wherever possible, or at the earliest stage of response.

Situation Reports (SITREPs) provide a concise and structured means of communicating the current status of environmental monitoring and impact assessment activities during an incident. They should be used to bring together key information from monitoring teams and other relevant sources, providing a clear and consistent summary of what is known at a given point in time, what activities have been undertaken or are planned, significant findings or emerging impacts, outstanding information requirements, and any issues requiring coordination or decision.

During an active response, SITREPs should be produced at a frequency appropriate to the scale, pace and information needs of the incident and aligned, where possible, with the wider incident management reporting cycle. Information should be clearly distinguished according to its status, for example whether findings are preliminary, validated or subject to further assessment, particularly where monitoring results may influence operational or policy decisions.

Where a Monitoring Coordination Cell is established, it should coordinate the preparation of monitoring SITREPs, drawing together relevant information from participating organisations and ensuring consistency with the wider COP and incident communications arrangements. SITREPs should complement, rather than replace, the underlying monitoring data, technical reports and direct communication required for urgent or significant findings.

A template PMCC Situation Report (SITREP) is provided in Appendix 5 and may be adapted to reflect the scale, complexity and reporting requirements of the incident.

8.1 Communications objectives

8.1.1 Monitoring team communications

Any cell responsible for coordinating post-spill monitoring may use communications to ensure that stakeholders:

- Remain informed of incident developments and aware of any exceptional events;
- Exchange knowledge to build collective capability;
- Support monitoring objectives by encouraging stakeholder engagement, leading to a more accurate and effective programme;
- Understand monitoring activities and experiences, providing reassurance that an appropriate programme is in place and reducing the risk of misinformation.

8.1.2 Stakeholder identification and mapping

Before developing a communications and engagement plan, teams should identify and map relevant stakeholders. Stakeholder groups, governance structures, and decision-making processes can vary significantly between countries, territories, and organisations. A stakeholder mapping exercise helps ensure that all relevant parties are identified and that engagement activities are tailored appropriately.

The stakeholder mapping process should:

- Identify individuals, groups, and organisations who may influence, be affected by, or have an interest in the project;
- Assess stakeholders' levels of influence, interest, and potential impact on project outcomes;
- Identify key decision-makers, partners, delivery organisations, and affected communities;
- Highlight relationships between stakeholders and any country-specific governance arrangements;
- Inform communication, engagement, and escalation plans.

Where appropriate, teams should undertake a dedicated stakeholder mapping exercise at the outset of a project before determining communication and engagement requirements.

For further guidance, see the Office for National Statistics (ONS) stakeholder mapping guidance: https://analysisfunction.civilservice.gov.uk/policy-store/stakeholder-mapping/

8.1.3 Stakeholder communications

Following stakeholder mapping, teams should determine what information needs to be shared, with whom, when, and through which channels. A wide range of stakeholder groups may have an interest in monitoring activities and in any specific events or notifications arising from the monitoring programme.

Key stakeholder groups include:

- **Incident responders** – require timely access to monitoring results to inform, and where necessary adapt, response activities and prepare for emerging issues.
- **Industry regulators** – these organisations need to ensure that regulatory responsibilities are met, and to be aware of, and contribute to, the development and application of best practice and Premiam guidelines.
- **Environmental regulators** – require updates where there may be breaches of health and safety or environmental regulations, or where environmental impact has occurred and enforcement or prosecution may be considered.

> **Effective communication helps build understanding of the importance of the monitoring programme and the role of industry within it."**

- **Other monitoring and research organisations** – may be able to offer specialist expertise, help avoid duplication of effort, and identify opportunities for collaboration.
- **National media** – play an important role in public reassurance and should be informed that a coordinated and comprehensive monitoring programme is in place to protect the marine environment. They should also be updated on any exceptional events through press releases and interviews, as appropriate.
- **General public** – should be able to access appropriate information on the monitoring programme and be reassured that it is well planned, proportionate, and effective.
- **Government and ministers** – require briefings and updates on the progress and status of the monitoring programme, as necessary.
- **Non-governmental organisations (NGOs)** – require reassurance that a coordinated and comprehensive monitoring programme is in place to protect the marine environment.
- **Local media** – may focus on specific monitoring locations and play an important role in reassuring affected communities that appropriate monitoring measures are being undertaken.
- **Industry and industry media** – engagement helps build understanding of the importance of the monitoring programme and the role of industry within it, ensuring that industry stakeholders feel informed, involved, and engaged throughout the monitoring process.
- **Fisheries industry** – requires timely monitoring information where findings may affect fishing grounds, seafood safety, stock health, access restrictions, or commercial operations. Engagement helps ensure operational concerns and local knowledge are considered while supporting confidence in monitoring measures.

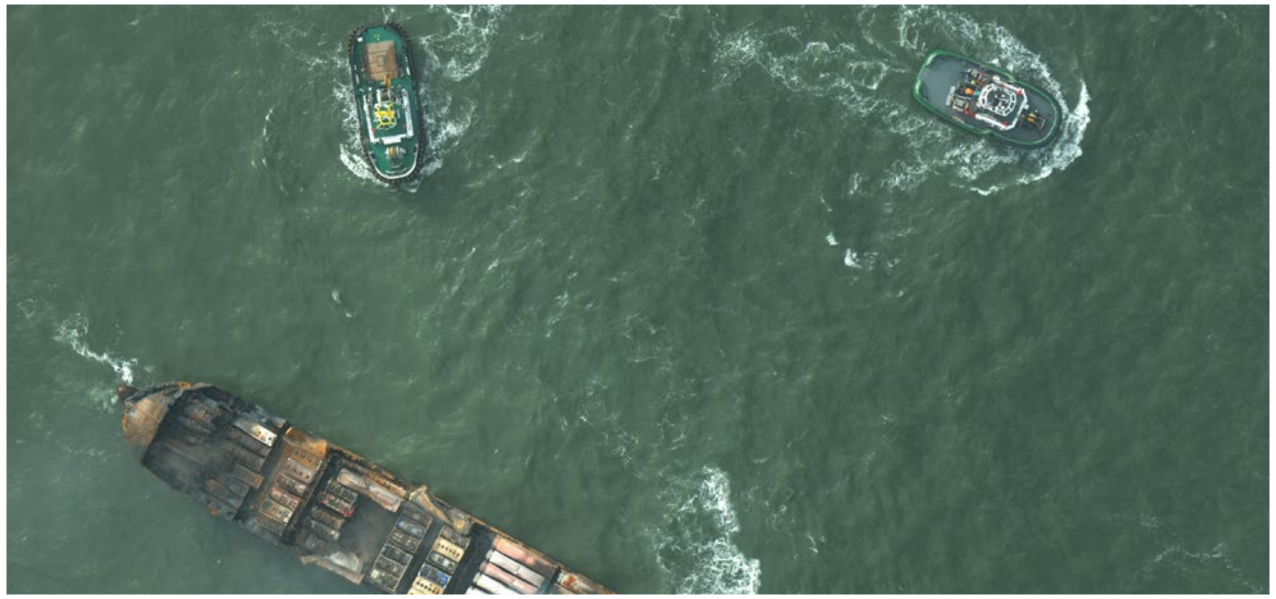
- **Aquaculture industry** – requires timely updates where monitoring outcomes may affect operations, stock health, water quality, biosecurity, or market confidence. Engagement supports informed decision-making and awareness of emerging issues.
- **Coastal and marine landowners** – require information where monitoring activities or outcomes may affect land access, infrastructure, environmental quality, or property interests. Engagement supports cooperation and consideration of local concerns.
- **Local authorities** – require updates where monitoring findings may affect public health, infrastructure, environmental management, tourism, recreation, coastal communities, or emergency planning responsibilities. Engagement supports coordinated decision-making and community reassurance.
- **Providers of coastal and marine amenities** – including tourism, recreation, and leisure operators, require timely information where monitoring outcomes may affect public access, environmental quality, or commercial activities. Engagement helps maintain public confidence and minimise disruption to services and amenities.

8.2 Communication channels

A range of communication channels may be used to disseminate findings from the monitoring programme to relevant stakeholders; a summary is provided in Table 18. Use of these channels should be managed through a coordinated communications plan to ensure that information is made accessible to stakeholders in an appropriate, timely, and consistent manner.

Table 18: Targeted communication channels for informing stakeholders of findings from the monitoring programme.

Communication channel	Purpose and use
Designated website	Regular progress updates may be published on a designated website, including routine notifications and updates triggered by specific monitoring events such as elevated readings. Exceptionally high readings will require careful management and appropriate contextual explanation. A designated website enables stakeholders to follow the monitoring process, understand mitigation actions when concerns are elevated, and be reassured when conditions return to normal levels.
Exceptional wider press releases	In certain circumstances, it may be necessary to communicate exceptional monitoring events to the wider public, for example where particularly high readings are recorded or where misinformation is circulating. In such cases, a wider press release may be issued to local, regional, and trade media.
Industry outreach contact list	Some monitoring information is primarily of interest to affected industry. An email contact list of key industry representatives can be used to ensure timely updates to nominated individuals responsible for engagement. This approach also supports two-way communication, enabling industry stakeholders to raise concerns and receive clarification promptly.
Social media	Social media channels may be used to respond rapidly to public concerns and emerging issues. Messages shared through partner organisations' social media accounts can provide timely reassurance that monitoring and response measures are in place. Social media also supports monitoring of public discourse and helps to prevent the spread of misinformation.
Industry forums	Industry forums may be used, where appropriate to provide timely updates to industry stakeholders. These platforms support rapid information sharing, raise awareness of monitoring activities, and help minimise the risk of misinformation.



8.2.1 Social media use

Organisations and individuals increasingly use social media to stay informed about news and scientific developments. When used proactively, transparently, and responsibly, social media can support the rapid dissemination of information to a wide audience, providing an effective means of near real-time communication. However, misinformation can also spread quickly via these platforms. It is therefore essential that accurate information is released promptly to the public to reduce the risk of speculation or rumour. In addition to proactive communication, it may be appropriate to assign responsibility for monitoring and responding to external social media content, in order to identify and correct inaccurate messaging and minimise potential impacts.

8.3 Communication recommendations

There is a range of communication channels available to a monitoring coordination cell for engagement with different stakeholder groups. Table 19 summarises how these channels may be used to communicate monitoring information effectively to specific audiences.

Table 19: Summary of the use of different channels to reach different stakeholders.

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

8.3.1 Communicating mitigation effectiveness

Information on the effectiveness of dispersant application should be reported to core stakeholders as soon as practicable to inform ongoing response operations and support decisions on the continuation or cessation of dispersant use. During the early stages of the response, when different mitigation techniques may be trialled, updates may be required on an hourly basis or, at a minimum, daily.

To support rapid and consistent dissemination of information, standardised reporting templates should be used to ensure that relevant information is captured at each update. Where appropriate, monitoring information should be consolidated through a Situation Report (SITREP), using or adapting the template provided in Appendix 5. These reports and supporting information would primarily be shared through the central data management system or database. Where findings are particularly significant, information may also be communicated more widely, for example via the designated notification website or, where appropriate, through media interviews.

8.3.2 Communicating monitoring results

Results generated by any monitoring programme are of interest to a wide range of stakeholders. Timely access to clear and relevant information enables stakeholders to develop a better understanding of the need for management actions (such as fishery closures) and the rationale for subsequent decisions, including reopening.

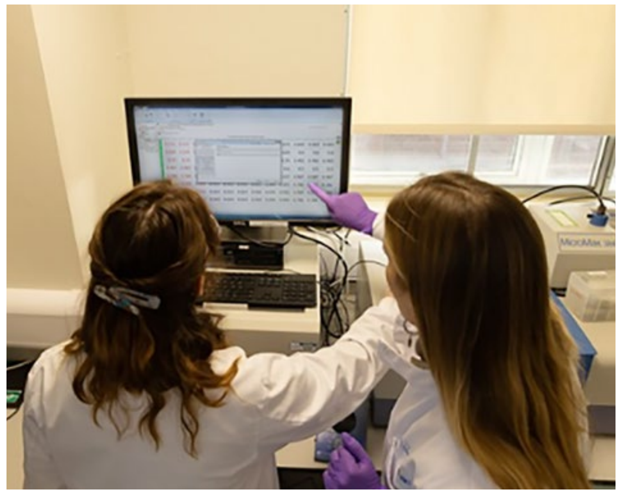
For example, during the *Sea Empress* incident, data from the monitoring programme, specifically polycyclic aromatic hydrocarbon (PAH) concentrations in fish and shellfish, were reported on a weekly basis to all stakeholders who had expressed an interest. This included fishermen, non-governmental organisations, and members of the public. Reports were accompanied by explanations of associated policy implications, particularly in relation to fishery closures (Law and Kelly, 2004).

A key advantage of this approach was that, when fishery restrictions, whether by species or area were lifted, decisions were rarely challenged. Such reporting can be delivered primarily through a designated notification website, supplemented by direct distribution via contact lists for interested organisations.

8.3.3 Exchanging data

Many organisations may be involved in post-spill monitoring data collection, and the results of any analysis should be coordinated to avoid duplication and ensure that all relevant evidence informs decisions on fishery closures, future monitoring requirements, and ongoing response options. During the active response phase, significant monitoring findings and changes in the status of the monitoring programme should also be captured through the agreed SITREP process (see Appendix 5), providing a consolidated record for the wider incident management structure. Data handling arrangements are described in more detail in Section 7 (Data Management).

In addition to a shared database and a designated notification website, regular meetings, virtual or face-to-face can help ensure that information is shared in a timely and appropriate manner. A centralised data and information-sharing platform can further support effective coordination between stakeholders, while providing a secure and accessible space for data storage and exchange.



8.3.4 Reporting to government

Any major spill that attracts public attention will also be subject to discussion within government and the devolved administrations, to ensure that response options are fully justified and that monitoring activities are of the highest standard while remaining proportionate, affordable, and efficient. Briefings to ministers should clearly outline both the benefits and the limitations or risks of the monitoring programme in supporting continued environmental protection and minimising impacts on the local and national economy.

Such impacts may include fishery closures, loss of income to businesses resulting from beach closures, or the temporary loss of other amenities.

8.3.5 Wider reporting

To support effective response activities, the environmental monitoring team should consider in advance the types of information that are likely to be required and communicated, ensuring that outputs from the monitoring programme are accessible to a wide range of stakeholders, including the public.

Potential questions and concise responses may be collated in a simple, living document that can be shared widely and updated as the incident progresses. This document could:

- Set out key information on the monitoring approach and scope, including the types of samples being collected and analysed, the monitoring timeline (what will happen and when), anticipated timescales, and likely next steps; and
- Distil key technical messages into accessible language, for example explaining why dispersants are being used rather than alternative response options, what evidence shows to be effective and safe to use, how dispersants work, and the advantages and limitations of their use. Explanations of acronyms and complex scientific concepts should be included where relevant.

A regularly updated monitoring progress report template could also support effective dissemination of information. The reporting frequency and level of detail should be proportionate to the scale and nature of the incident and agreed by key parties as part of the monitoring communications plan.

Monitoring progress reports may include, but are not limited to:

- Monitoring locations;
- Samples collected;
- Status of analysis and projected delivery timescales;
- Evidence of impacts on marine resources (for example, commercially exploited fisheries); and
- Other results relevant to environmental impact assessment.

Reports may also include a short "key facts" box summarising headline information and figures to support media engagement, where appropriate.

Clear and simple visual representations of information, focused on core messages, can support understanding among non-specialist audiences while also providing clarity for technical stakeholders. For example, traffic-light indicators (green, amber, red) or directional arrows (increasing, decreasing, ongoing) may be used to illustrate progress or the degree of impact. This approach is reflected in the Marine Climate Change Impacts Partnership (MCCIP)[30], which now publishes regular online updates of climate impacts evidence across individual topic areas, alongside an annual summary bringing together the evidence updates published during the year. Digital publication of reports also enables the use of interactive content, such as links to maps, photographs (including "before and after" imagery), and infographics.

Additional communication channels may be used where appropriate, including notifications, events, meetings, and specialist publications, to reach different audiences at different stages of the incident. However, the use of a clear and consistent monitoring report template should form the foundation for all communications, ensuring that accurate, up-to-date, and consistent information on monitoring activities and results is available across all engagement activities.

30 www.mccip.org.uk

Appendices

Appendix 1 – Preparedness matrix

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

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

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

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

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

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

The monitoring preparedness assessment matrix (or MPAM, see Table 20) is a tool that puts these types of preparedness questions into an organised framework for assessment purposes. Each of the eight principles of effective monitoring programmes is considered in the matrix as indicators of preparedness level against which the user can judge their own situation/scenario. The preparedness levels are rated on a 1 to 5 scale, representing a range of situations from underprepared to fully prepared, respectively. The preparedness level assignments for each of the principles can then be summed to provide an overall Monitoring Preparedness Assessment Score (MPAS) ranging between 8 and 40. The MPAS value can be considered as an overall indication of the preparedness level for the situation/scenario under consideration but, more importantly, the process can highlight specific areas in which improvement is needed.

Appendices

Table 20: The Monitoring Preparedness Assessment Matrix (or MPAM, adapted from Kirby *et al*., 2014).

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

Appendices

Table 21. Illustrative examples of monitoring preparedness assessments for a range of scenarios demonstrating how the monitoring preparedness assessment score (MPAS) is derived.
NB: The preparedness levels allocated to each scenario in Table 21 are indicative only for the purposes of this paper and have not been derived through thorough expert consultation.

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

Examples of how a monitoring preparedness assessment score (MPAS) is derived are shown in Table 21 by referring to several scenarios for illustrative purposes. Using a red-amber-green (RAG) approach in the assessment also allows a more visual representation to be generated which is useful for comparing several scenarios on a qualitative basis.

Application of the process

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

i. National/regional/local assessment

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

ii. Organisation/team assessment

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

iii. Specific scenario assessment

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

iv. Preparedness auditing and improvement monitoring

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

v. Preparedness perception and reassurance

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

Appendix 2 – Impacts on human health

As well as having a significant ecological impact, maritime incidents involving oil or chemicals can also impact upon human health. Furthermore, the planned transition from oil to alternative maritime fuels such as ammonia, methanol and lithium ion batteries could further increase risks to human health from maritime incidents.

As such, it is important to initiate post-spill monitoring for human exposure at an early stage to inform the risk assessment process. As in the classical paradigm (WHO[31]), risk assessment for human health is based upon the source-pathway-receptor approach, requiring information on the nature of the pollution released, the likely human receptors and the routes by which pollution can reach these.

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

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

Any post-spill monitoring will need input from agencies responsible for public health, and food and fisheries. For example, UK response plans define establishment and operation of Environment Groups during incidents[32] to provide advice regarding risks to public health as well as to the environment. This is in addition to ensuring full implementation of health and safety measures for personnel working in the field on their behalf, and addresses potential risks to the wider population. Key tasks for the EG in this regard are:

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

As well as core membership from the UK Health Security Agency (UKHSA)[33], Public Health Wales, Public Health Scotland, or the Public Health Agency in Northern Ireland, as appropriate, membership can be augmented with additional relevant expertise and may include:

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

31 http://apps.who.int/iris/bitstream/10665/44127/1/9789241598149_eng.pdf
32 https://www.gov.uk/government/publications/scientific-technical-and-operational-advice-notes-stop-notes
33 https://www.gov.uk/guidance/emergency-contacts-public-health

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

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

Agencies within these groups in the UK can request the deployment of mobile monitoring facilities to obtain data on airborne pollutants rapidly (Environment Agency, 2018). This can also be supplemented by monitoring capabilities provided by specialist FRS teams and spill contractors.[34]

In addition, such groups can often request and interpret fate and transport modelling. In the UK, basic modelling is usually provided in the form of CHEMETs issued by the Met Office. A CHEMET provides information on plume direction and dispersion in the form of a map image, based upon prevailing atmospheric and meteorological conditions. It does not, however, model pollutant concentrations within the plume, although this can be requested providing sufficient data are available regarding the pollutant source and ambient concentrations. A CHEMET can be used to model plumes from volatile chemicals as well as plumes from combustion events. A CHEMET can be requested by fire and police services or by UKHSA, EA in England and NRW in Wales, and other relevant advisors.

Depending on the scale and type of incident, short- or longer-term health surveillance (for responders and/or members of the public) and social impact assessment may also be necessary. Examples of incidents in which such assessments have been undertaken include the *Sea Empress* incident in Wales in 1996, the *Braer* incident in Shetland in 1993, the *Prestige* incident in Spain in 2002, the *Erika* incident in France in 1999, the *Exxon Valdez* incident in Alaska in 1989, the *Nakhodka* incident in Japan in 1997 and the *Hebei Spirit* incident in Korea in 2007. Post-spill monitoring activities undertaken following a number of incidents have been reviewed, and health impacts of the *Deepwater Horizon* oil spill in the Gulf of Mexico have also been considered recently, and long-term health studies of personnel involved in the response are being undertaken as part of the GuLF Project by the US Department of Health[35].

34 https://uk-air.defra.gov.uk/
35 https://gulfstudy.nih.gov/en/index.html

Appendices

Appendix 3 – Premiam Monitoring Coordination Cell (PMCC)

Introduction

To enable the timely initiation of environmental monitoring following a significant marine pollution incident, the decision-making process for mobilising initial sampling and analytical activities should be straightforward, with clearly defined roles and responsibilities. Early mobilisation, sampling and laboratory analysis inevitably incur costs; therefore, a pre-established mechanism for authorising and funding these initial activities should be in place to avoid delays during the critical early stages of an incident.

Environmental monitoring following a significant marine pollution incident is often complex, requiring coordination between multiple organisations, scientific institutions, response agencies and other partners while adapting to rapidly evolving operational circumstances. To support this process, a dedicated Monitoring Coordination Cell (MCC) should be established, either physically or virtually depending on the scale and nature of the incident. The MCC is used here as a generic term for this coordination function and may be adapted to existing structures and terminology in different jurisdictions. The MCC is responsible for coordinating monitoring activities, facilitating information exchange between participating organisations, developing and implementing monitoring strategies, and ensuring that monitoring activities remain aligned with incident objectives and emerging response needs. The MCC should maintain close links with the wider incident management structure, including any scientific, technical or environmental advisory groups established to support decision-making.

Different jurisdictions may adopt different governance arrangements and terminology for this function. In England, this role is fulfilled through the Premiam Monitoring Coordination Cell (PMCC). The guidance presented in this appendix therefore describes the PMCC, while recognising that equivalent monitoring coordination arrangements may exist elsewhere.

This guidance has been developed through consultation with organisations responsible for authorising, delivering and funding post-incident environmental monitoring. It outlines recommended processes for governance, decision-making, resource mobilisation, implementation, funding, review and cessation of monitoring activities following marine pollution incidents. Although based on the Premiam framework, the principles described are intended to be sufficiently flexible to be adapted to different national, regional and organisational response arrangements.

Premiam Monitoring Coordination Cell (PMCC)

The PMCC will be the group responsible for the overall conduct and integrated coordination of monitoring and impact assessment activities following a marine incident. In this respect, it serves a distinct but complementary role from that of an Environment Group (EG), ensuring effective alignment of monitoring efforts and assessment outcomes.

Specific responsibilities will include:

- Developing and maintaining a coordinated environmental monitoring strategy in accordance with the Premiam post-spill monitoring guidelines;
- Establishing and overseeing the monitoring programme, including the formation and management of monitoring teams and the coordination of monitoring activities;
- Maintaining effective communication and coordination with the Environmental Group (EG), Scientific Advisory Group for Emergencies (SAGE), where established, and other response and advisory groups as appropriate (see Appendix 5 for the situation report template and communication strategy);
- Managing and maintaining records of expenditure associated with initial monitoring activities, including liaison with and payment of any specialist contractors, where required; and
- Overseeing the preparation and publication of monitoring outputs, including routine situation reports for Premiam partners and the EG, together with interim and final monitoring and impact assessment reports.

The initial PMCC will be established as soon as practicable following an incident, typically within hours of the event being reported through established emergency response notification procedures (e.g. POLREPs and other relevant reporting mechanisms). Responsibility for convening the PMCC will rest with the pre-designated chair and/or deputy chair. The chair (Cefas) and deputy chair (EA) will be drawn from the organisations with primary responsibility for the conduct of marine monitoring, namely Cefas and the Environment Agency.

Membership

The Monitoring Coordination Cell should comprise a core group of organisations with responsibilities for environmental monitoring, assessment, and incident response. The Chair (Cefas) and Deputy Chair (EA) should be drawn from organisations with primary responsibility for coordinating marine environmental monitoring and scientific advice within the relevant jurisdiction.

Additional membership should be determined by the nature, scale, location, and potential impacts of the incident. Depending on the monitoring objectives, representation may be required from organisations with responsibilities for:

- Environmental protection and regulation
- Marine and fisheries management
- Food safety and public health
- Nature conservation and biodiversity
- Protected areas management
- Pollution response and maritime safety
- Energy and offshore infrastructure regulation
- Water quality management
- Local and regional government
- Natural resource management

The initial membership of the Monitoring Coordination Cell should be determined by the Chair, in consultation with key partners as necessary. As the incident develops, membership should remain flexible and be reviewed regularly to ensure that the Cell continues to have access to the expertise and authorities required to support decision-making and monitoring activities.

Additional advice and technical input may be sought from a wider network of organisations and individuals, including scientific experts, academic institutions, public health specialists, industry representatives, environmental non-governmental organisations, local community groups, specialist contractors, and organisations contributing resources to the monitoring programme.

The composition of the Monitoring Coordination Cell should evolve in line with changing priorities throughout the incident lifecycle, as monitoring progresses from initial assessment and impact characterisation through to recovery assessment and eventual cessation of monitoring activities.

In England, the PMCC is chaired by Cefas, with the Environment Agency acting as Deputy Chair. Typical membership may include representatives from the Food Standards Agency, Marine Management Organisation, Inshore Fisheries and Conservation Authorities, Natural England, Joint Nature Conservation Committee, Maritime and Coastguard Agency, Defra, UK Health Security Agency (UKHSA), local authorities, and other organisations as required by the incident.

Links with the EG

It is essential that the PMCC maintains strong communication links with any formed EG established as part of the incident response. The expert environmental advice generated by the EG will provide key input into the design, implementation, review and adaptation of the monitoring programme as the incident develops. The monitoring coordination process will provide a rapid and effective mechanism through which monitoring recommendations from the EG can be translated into practical actions. Equally, the EG will require prompt and effective feedback from the monitoring programme, so that emerging evidence, analytical results, operational constraints and environmental observations can inform and update their advice and plans.

To facilitate this relationship and ensure an effective flow of advice and information between the groups, a Premiam liaison officer should be appointed to act as the main link between the PMCC and EG. This role should include facilitating communication, sharing relevant outputs, ensuring that monitoring recommendations are captured and progressed, and highlighting any issues requiring further discussion (a schematic of the group links is shown in Figure 22).

The PMCC should develop regular situation reports (sitreps) (see Appendix 5 for template) to support communication between the EG and relevant authorities. These reports should summarise operational monitoring activities, issues encountered, partnerships established, analytical progress, funding arrangements, and any key decisions made. In addition to supporting coordination, the situation reports should provide an auditable record of the decision-making process used to develop and refine the post-incident monitoring programme.

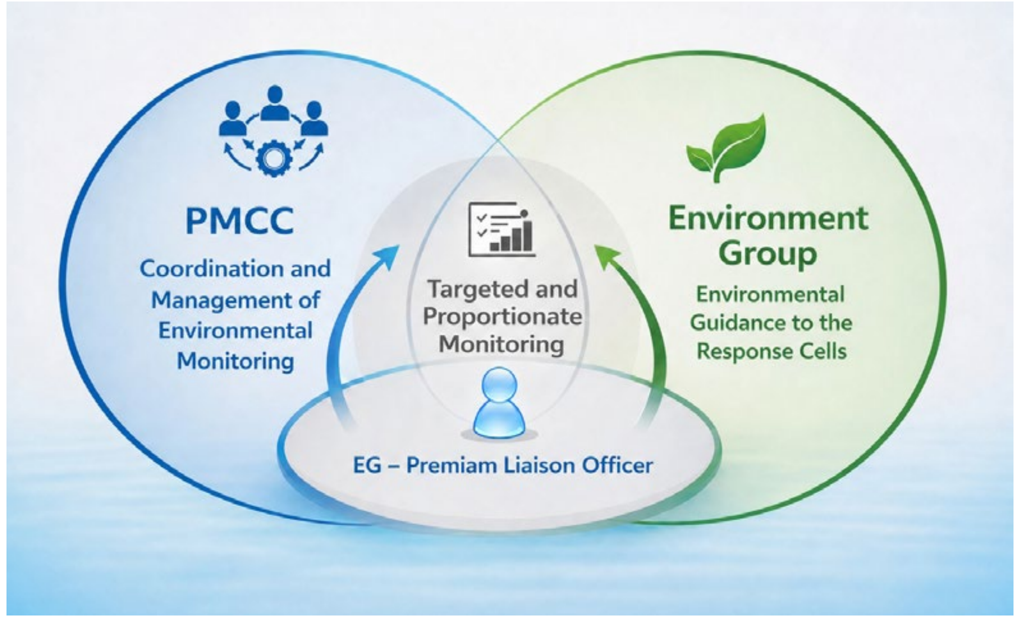


Figure 22: The integrated relationship between the PMCC and the EG.

Monitoring phases

A. Initial response phase (0-96 hours)

Decision to initiate monitoring activity

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

Management and coordination

Initial management and coordination will be overseen by the PMCC chair with input and support from other PMCC members as necessary.

B. Ongoing phase (96 hours onwards)

Decision to maintain, expand or reduce monitoring activities

Where an incident requires monitoring activities to continue beyond the initial response period, a more consultative decision-making process will be adopted. The overall decision-making process will continue to be overseen and managed by the PMCC chair, but it is anticipated that time will allow full consultation with the other PMCC members, the EG chair and the identified monitoring funders.

Funding

Where monitoring activities are expected to continue for an extended period or require significant expansion beyond the initial response, additional funding sources should be identified and secured. Funding arrangements for ongoing monitoring and impact assessment activities will normally be separate from, or supplementary to, any authorised expenditure used for initiating monitoring during the early response phase.

To avoid unnecessary delays in the immediate response, the PMCC Chair may authorise the initiation of essential monitoring activities in accordance with agreed governance, with costs recovered from the responsible party where appropriate. This enables critical monitoring to commence during the first hours or days of an incident while longer-term funding arrangements are considered.

Where it becomes apparent that monitoring will need to continue or expand beyond the initial response, the PMCC Chair should communicate this requirement to potential funding authorities as early as possible, allowing sufficient time for appropriate funding mechanisms to be identified and agreed.

Potential funding sources may include:

- National, regional, or local government agencies;
- Environmental regulators;
- International organisations;
- Industry stakeholders;
- Private sector organisations;
- Research institutions; and
- Non-governmental organisations.

Where responsibility for the incident can be attributed to an identified polluter, cost recovery may be pursued in accordance with applicable legislation and the polluter pays principle, ensuring that costs recovered are reasonable, proportionate, and legally justified.

Management and coordination

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

Where a monitoring programme expands to a scale that requires formal project management, a suitably experienced and qualified Project Manager should be appointed. This individual would normally be separate from the PMCC Chair and existing PMCC members, whose primary role is to provide strategic oversight, scientific advice and coordination rather than dedicated project management. Once appointed, the Project Manager should become a member of the PMCC and be responsible for maintaining project plans, coordinating delivery against agreed objectives, timescales, quality standards and budgets, and providing regular financial and progress updates to the PMCC and funding organisations, including forecasts of future resource requirements.

C. Monitoring cessation phase

Decision to cease activity

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

The decision to cease monitoring activities will be the responsibility of the PMCC, taking full account of any recommendations provided by the Environmental Group (EG). In complex incidents, cessation is likely to be implemented progressively as different monitoring objectives are achieved. A guiding principle of the PMCC will be to ensure that monitoring activities continue only for as long as they are necessary to meet agreed objectives, statutory requirements, and stakeholder evidence needs.

Funding

Any residual financial issues following cessation of a monitoring programme will be handled by the project manager. In the event of a major pollution incident which has had adverse impacts on sensitive coastal or marine habitats, interim reports will also need to be produced. These will help form the strategy for the longer-term management and restoration of these sites.

Final reporting

Following completion of the monitoring programme, a final report should be prepared addressing all agreed objectives and stakeholder information requirements.

Production of the report will be overseen by the PMCC Chair or a delegated representative, with progress and delivery tracked by the Project Manager.

A post-incident review should also be undertaken to identify lessons learned, evaluate the effectiveness of monitoring activities, and incorporate improvements into future incident response and monitoring programmes.

Evidence needs and regulatory requirements

Monitoring programmes should be designed to provide evidence that supports the needs of relevant authorities and stakeholders, including:

- Assessment of actual and potential risks to human health, the environment, and socio-economic resources;
- Evaluation of impacts on ecosystem structure, function, services, and natural capital;
- Identification of short-, medium-, and long-term environmental consequences;
- Support for regulatory decision-making, enforcement, remediation, and restoration activities;
- Documentation of impacts for legal, compensation, or cost-recovery purposes; and
- Provision of timely information to support public communication and stakeholder engagement.

During major incidents, monitoring information may need to be updated frequently, potentially multiple times per day during the initial response phase, to support operational and strategic decision-making.

Appendix 4 – Compensation for pollution damage from ships and environmental regulations

The UK is a signatory to two international conventions governing claims and compensation following oil spills from tankers carrying persistent oil as cargo: the International Convention on Civil Liability for Oil Pollution Damage (1992 CLC) and the 1992 International Convention on the Fund for Compensation for Oil Pollution Damage (1992 Fund Convention). The UK has also ratified the Supplementary Fund Protocol, which provides an additional layer of compensation over that provided for by the 1992 Fund Convention, in States that ratify that Protocol. Internationally, 122 States have ratified the 1992 Fund Convention, and there are 33 States parties to the Supplementary Fund Protocol.

In addition to the above instruments covering spills of persistent oil from tankers, the UK is also a signatory to the 2001 International Convention on Civil Liability for Bunker Oil Pollution Damage (Bunker Convention 2001). This convention establishes liability for spills of oil carried as fuel in ships' bunkers and applies to all types of ships, which are not covered by the 1992 CLC and Fund Conventions.

With regard to chemical spills, the conditions for the entry into force for the Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances were formally met on 29 May 2026, following the accession of 12 Contracting States. The 2010 HNS Convention will therefore formally enter into force on 29 November 2027. However, at the moment of producing these guidelines, there was no international convention covering compensation for chemical spills, with the exception of the LLMC 76/96 (where applicable), which establishes limits of liability for the shipowner, on a sliding scale depending on the ship's tonnage and the type of damage sustained.

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

The handling of claims generated by a given incident is typically undertaken by the ship-owner's Protection and Indemnity (P&I) insurer in cases falling under the Bunker Convention 2001 (for vessels other than tankers carrying persistent oil), and under the 1992 CLC for spills of persistent oils, from tankers and other sea-going barges. In cases where the ship owner's liability under the 1992 CLC is exceeded, the International Oil Pollution Compensation Funds (IOPC Funds), the organisation that administers the 1992 Fund and Supplementary Fund, will handle claims in conjunction with the P&I insurer. In the absence of an insurer, the claims will be handled by the IOPC Funds.

It is typical for the ship owner's insurer and/or IOPC Funds to appoint experts to provide input on various technical aspects following an incident, including the planning, design and implementation of post-incident studies. Early engagement and close liaison between the PMCC and the ship owner's insurer and/or IOPC Funds, and their experts, is therefore encouraged to ensure that the reinstatement measures and post-spill studies comply with the internationally-agreed criteria necessary to receive compensation.

Detailed guidance on the preparation and submission of claims for incidents involving the IOPC Funds is available on the IOPC Funds website[36]. Information on all the IOPC Funds publications and how the IOPC Funds

36 http://www.iopcfunds.org/publications/iopc-publications

assess claims for environmental damage and environmental studies can be found in the 1992 Fund Claims Manual, also available on the IOPC Funds' website.

Additionally, guidance documents produced by the IOPC Fund for presenting claims for environmental damage and environmental studies are available on the IOPC Funds' website, along with the IOPC Funds' Claims Manual, which provides further details on the claims criteria and assessment process which apply to all claims submitted to them worldwide. Similarly, the IOPC Funds have published a guidance document for Member States on the criteria for imposing and lifting fisheries closures, which is also available at the URL mentioned in the footnotes below.

Environmental Damage Regulations

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

The regulations require the operator of a public or private economic activity that is causing, or has caused, environmental damage (as defined under the regulations) to prevent further damage occurring and/or to take remediation action in respect of the damage that has occurred. The regulations define environmental damage to biodiversity as damage to the favourable conservation status of a European protected species or habitat, or damage to the integrity of a Site of Special Scientific Interest (SSSI). There are a considerable number of SSSIs in the marine environment; examples of the largest sites in England (larger than 100 hectares (or 1km^2)) can be found on Wikipedia[37].

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

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

37 List of the largest Sites of Special Scientific Interest in England: http://en.wikipedia.org/wiki/List_of_the_largest_Sites_of_Special_Scientific_Interest_in_England

Appendix 5 – Premiam Monitoring Coordination Cell (PMCC) Situation Report (SitRep) template

Situation report

Premiam Monitoring Coordination Cell (PMCC)

Field	Information
Incident Name	
Incident Phase/Status	☐ Response ☐ Recovery ☐ Monitoring ☐ Stand Down
SitRep Number (Issued)	Sequential issued number (final reports only)
Reporting period	From: To:
Completed by	Name/role:
Approved by	Name/role:
Date issued	
Time issued	
Draft version	For drafting only – remove before issue

Appendices

1. Introduction
Provide a brief overview of the incident and the purpose of this SitRep. Include: ■ The nature of the incident or environmental event. ■ The reporting period covered by the SitRep. ■ The purpose of the report (e.g. to summarise PMCC monitoring activities, findings and coordination during the reporting period). ■ Any significant change in the incident status since the previous SitRep (or state "No significant change" if applicable).
2. Highlights
Provide 3–5 key points summarising the most significant developments since the previous SitRep. If there has been no significant change, state: No significant change since SitRep XX.
3. Current situation/assessment progress
Brief summary (2–4 sentences) of the current environmental situation. Current monitoring evidence. Key uncertainties or evidence gaps. This section can be updated rather than rewritten each time.
4. Situation update (new developments)
Summarise activities and developments since the previous SitRep. Include: ■ Significant monitoring activities completed ■ Key findings ■ Monitoring, analysis or modelling underway ■ Important operational developments ■ Reference any maps or figures included as annexes

>>

5. Issues and risks
Identify known or anticipated issues before the next reporting period. Examples include resource shortages, deployment delays, health and safety concerns, weather constraints and data limitations. Record significant achievements or lessons learned where appropriate.
6. Partnership and coordination
Summarise key coordination activities undertaken during the reporting period. Include: ■ Current PMCC core membership (if changed since the previous SitRep). ■ Date and time of the latest PMCC meeting. ■ Key engagement with the Environment Group (EG), response cells or partner organisations. ■ Significant coordination outcomes, decisions or agreements. ■ Any cross-agency issues requiring ongoing coordination.
7. Information requests

>>

8. Next steps
Reference the current monitoring objectives. Record the key monitoring activities planned before the next SitRep, including priority, lead, target date and current status.
9. Funding update (optional)
Include additional monitoring funding requests, funding status, government contacts and any financial constraints.
10. Communications (optional)
Report communications provided to the Communications Cell, key messages shared and any media issues requiring EG awareness.
11. Annexes (optional)
Include maps, model outputs, sampling locations, figures and tables. Ensure each annex includes the date, time, version and copyright statement where appropriate.

Drafting principles

- Report developments since the previous SitRep but retain a concise Current Situation summary so each SitRep can be read as a standalone document.
- Be factual and evidence-based.
- Avoid interpretation or speculation.
- Be readable in 3–5 minutes.
- Focus solely on PMCC activities.
- State 'No significant change' where appropriate.
- Save each SitRep as a new document with updated numbering and footer information.

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Acronyms and abbreviations

AChE	Acetylcholinesterase
AI	Artificial Intelligence
API	Application Programming Interface
AURIS	Aberdeen University Research & Industrial Services
AUV	Autonomous Underwater Vehicle
BEQUALM	Biological Effects Quality Assurance in Monitoring Programmes
BTEX	Benzene, toluene, ethylbenzene and xylenes
BTO	British Trust for Ornithology
C1–C4	Alkylated homologues with one to four carbon substituents
CDOM	Coloured Dissolved Organic Matter
CEDRE	Centre for Documentation, Research and Experimentation on Accidental Water Pollution
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEMP	Coordinated Environmental Monitoring Programme (OSPAR)/Clean Environmental Monitoring Programme (as referenced)
CEMS	Copernicus Emergency Management Service
CNES	Centre National d'Études Spatiales (French Space Agency)
COP	Common Operating Picture
CPR	Continuous Plankton Recorder
CSEMP UK	Clean Seas Environment Monitoring Programme
CSIP	Cetacean Strandings Investigation programme
CTD	Conductivity, Temperature and Depth
CYP1A	Cytochrome P450 1A
DAC	Data Archive Centre
DASSH	The UK Data Archive Centre for Marine Biodiversity Data
Defra	Department for Environment, Food and Rural Affairs
DMP	Data Management Plan
DR CALU X	Dioxin-responsive chemically activated luciferase gene expression
DSC	Differential Scanning Calorimetry
DTAPS	Direct Toxicity Assessment Proficiency Scheme
EA	Environment Agency (England)
eDNA	Environmental DNA
EG	Environment Group
EO	Earth Observation
EOCoE	Earth Observation Centre of Excellence
EMODnet	European Marine Observation and Data Network
ER-CALU X	Estrogen-responsive chemically activated luciferase gene expression
EROCIPS	Emergency Response to Coastal Oil, Chemical and Inert Pollution from Shipping
EROD	Ethoxyresorufin-O-deethylase
ESA	European Space Agency
GC	Gas Chromatography
GCxGC	Two-dimensional Gas Chromatography
GC×GC–ToF-MS	Comprehensive Two-dimensional Gas Chromatography–Time-of-Flight Mass Spectrometry
GC×GC–ToF-HRMS	Comprehensive Two-dimensional Gas Chromatography–Time-of-Flight High-Resolution Mass Spectrometry
GC-MS	Gas Chromatography-Mass Spectrometry

GIS	Geographic Information System
GLP	Good Laboratory Practice
GMT	Greenwich Mean Time
GPS	Global Positioning System
GUI	Graphical User Interface
HAPS	High-Altitude Pseudo-Satellite
HNS	Hazardous and Noxious Substances
HPLC	High-performance liquid chromatography
HRMS	High-Resolution Mass Spectrometry
ICES	International Council for the Exploration of the Sea
ICP-MS	Inductively-coupled plasma-mass spectrometry
ICP-OES	Inductively-coupled plasma-optical emission spectrometry
IFCA	Association of Inshore Fisheries and Conservation Authorities
IMO	International Maritime Organization
IMS	Incident Management System
IODE	International Oceanographic Data and Information Exchange
IOPC FUNDS	The International Oil Pollution Compensation Funds
IQI	Infaunal Quality Index
ISO	International Organization for Standardization
ITOPF	International Tanker Owners Pollution Federation
JAMP	Joint Assessment and Monitoring Programme
JEU	Joint Environment Unit
JNCC	UK Joint Nature Conservation Committee
LC-MS	Liquid chromatography – mass spectrometry
LSFO	Low Sulphur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MCA	Maritime and Coastguard Agency
MCCIP	Marine Climate Change Impacts Partnership
MCZ	Marine Conservation Zone
MEDIN	Marine Environmental Data and Information Network
MERMAN	Marine Environmental Monitoring and Assessment National Database
MMO	UK Marine Management Organisation
MMSI	Maritime Mobile Service Identity
MOA	Mode of Action
MODIS	Moderate Resolution Imaging Spectroradiometer
MPA(s)	Marine Protected Area(s)
MSFD	EU Marine Strategy Framework Directive
MSI	MultiSpectral Instrument
NCP	UK National Contingency Plan for Marine Pollution from Shipping and Offshore Installations
NGO	Non-Governmental Organisation
NIOZ	Royal Netherlands Institute for Sea Research
NMBAQC UK	National Marine Biological Association Quality Control scheme
NOAA	US National Oceanic and Atmospheric Administration
NVC	National Vegetation Classification
OCHA	Office for the Coordination of Humanitarian Affairs

OSI	Oil Spill Index
OSPAR	Oslo and Paris Commissions
OSPAR CEMP	OSPAR Coordinated Environmental Monitoring Programme
OSRL	Oil Spill Response Limited
PACs	Polycyclic aromatic compounds
PAH	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PMCC	Premiam Monitoring Coordination Cell
PPE	Personal Protective Equipment
PREMIAM	Pollution Response in Emergencies: Marine Impact Assessment and Monitoring
PSA	Particle Size Analysis
PTFE	Polytetrafluoroethylene
pyr-GC–MS	Pyrolysis–Gas Chromatography–Mass Spectrometry
QC	Quality Control
QFAIR	Quality, Findable, Accessible, Interoperable and Reusable
QSR	Quality Status Report
QUASIMEME	Quality Assurance of Information for Marine Environmental Monitoring in Europe
RGB	Red, Green, Blue (imagery)
RNA	Ribonucleic acid
ROV	Remotely Operated Vehicle
RPA	Remotely Piloted Aircraft
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SAR	Synthetic Aperture Radar
SCAT	Shoreline Cleanup Assessment Technique
SEEEC	Sea Empress Environmental Evaluation Committee
SLAR	Side-Looking Airborne Radar
SSPCA	Scottish Society for the Prevention of Cruelty to Animals
ToF-MS	Time-of-Flight Mass Spectrometer
TGA	Thermogravimetric Analysis
UKAS	United Kingdom Accreditation Service
UKDMOS	United Kingdom Directory of Marine Observing Systems
UNEP	United Nations Environment Programme
UNOSAT	United Nations Satellite Centre
USEPA/USEPA	United States Environmental Protection Agency
USPCA	Ulster Society for the Prevention of Cruelty to Animals
USV	Unmanned Surface Vehicle
UTC	Coordinated Universal Time
UV	Ultraviolet light
VIIRS	Visible Infrared Imaging Radiometer Suite
WeBS	Wetland Bird Survey
WFD	EU Water Framework Directive
YAS	Yeast Androgen Screen
YES	Yeast EstrogenScreen

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