

IMO/UNEP GUIDANCE MANUAL ON THE

Assessment and Restoration

of Environmental Damage following Marine Oil Spills

2009 EDITION



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Assessment and Restoration

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Foreword

On 27 July 2003, the oil tanker *Tasman Spirit* ran aground spilling a portion of its 67,000-tonne cargo of Iranian Light Crude Oil into Karachi Harbour, in Karachi, Pakistan. The loss of product resulted in environmental damage with heavy oiling of the shoreline in Karachi Harbour and surrounding areas.

Recognizing the need for international guidance to assist nations in assessing damage to natural resources following major oil spills in the aftermath of this incident, the United Nations Environment Programme (UNEP), soon thereafter, initiated the development of a manual on natural resource damage assessment and restoration following major oil spills. Given IMO's specialized expertise on preparedness for and response to accidental marine pollution issues and the long history of collaboration between IMO and UNEP, the two organizations agreed to the development of the Manual as a joint publication.

With a view to providing operational guidance, the *IMO/UNEP Guidance Manual on the Assessment and Restoration of Environmental Damage following Marine Oil Spills* has been developed through the OPRC-HNS Technical Group of the Marine Environment Protection Committee of IMO, in full collaboration and partnership with the United Nations Environment Programme.

The objective of the Manual is to provide guidance on strategies that may be used to assess the damage and subsequent recovery of the environment resulting from marine pollution incidents. Available techniques are considered together with criteria to help judge the feasibility of such measures to bring about successful recovery of those environments.

The Manual emphasizes the importance of pre-spill planning and provides an overview of assessment techniques and restoration measures in various ecosystems. It also provides guidance on opportunities for compensation through the international oil compensation schemes. Practical examples of natural resource assessment and restoration are provided through a series of case studies.

Acknowledgement

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1 Introduction

Following large oil spills, immediate impacts on the marine environment and coastal resources are often severe and in some cases catastrophic. However, oil spills are often relatively short duration events followed by rapid weathering and longer term degradation of the oil by natural processes. Medium-term and long-term impacts of oil spills can often be more difficult to discern, particularly given the high natural variability that exists in most marine ecosystems. In many cases natural *recovery*^{*†} of a contaminated environment can result in no detectable long-term impacts, while in other cases effects associated with an oil spill may be observable for many years.

The general public has a high and increasing interest and concern for marine and coastal habitats and wildlife, while environmental scientists consistently highlight the need for more information to help them understand the effects of oil spills on those resources. International and national law incorporate a number of rights and obligations on States for protection, conservation and sustainable development of the marine and coastal environment, habitats and marine living resources. In this context, government agencies may propose or implement control and monitoring programmes following an oil spill that they judge are necessary for the response, and to gather relevant information about the spill to assess the resultant damage.

There are three primary purposes for a Government to conduct a damage assessment programme subsequent to a significant oil pollution incident:

- to determine the extent and severity of ecological impact;
- to provide detailed information upon which to develop and implement a restoration[‡] programme and base claims; and
- to inform the public, particularly those in the affected area, in a transparent and accurate manner, of the extent of environmental damage.

* Italicised text indicates a technical term that is described in the glossary (see section 7).

† Recovery is the natural process through which ecosystems return to their original functions and to similar structural conditions, even though the species composition may differ from the original.

‡ For the scope of this manual the term restoration will be used rather than reinstatement, as this refers to the general management measures that are employed to accelerate natural recovery. Because of this, restoration is more frequently used and better understood than reinstatement and therefore more suitable for the “technical” aim of the manual. Nevertheless it is important to stress that the two terms carry very different meanings when dealing with admissible measures and compensations (see section 5). Reinstatement is the term used in the Claims Manual by the International Oil Pollution Compensation Fund (IOPCF).

The scope and objectives of post-spill studies will vary widely to reflect the roles and focus of the specific response and environmental agencies involved. The need to provide guidance about the type of monitoring required, damage assessment methodologies and restoration techniques has been widely recognized.

The aim of this manual is therefore to provide guidance on strategies that may be used to assess the damage and subsequent recovery of the environment resulting from marine pollution incidents. Available techniques are considered together with criteria to help judge the feasibility of such measures to bring about successful recovery of those environments. Some case studies have been included to illustrate the types of investigation that have been undertaken following spills and offer options that could be used to promote the restoration of the impacted environment. The manual is primarily intended for the following:

- Senior managers in government agencies responsible for initiating a damage assessment who need to understand the scale and costs of the studies and any restoration, the likely limitations of those studies and restoration actions, the relevant legislation and the criteria for compensation;
- Project managers in government agencies responsible for prioritizing damage assessment studies, preparing the scope of work for each study (initiating the study and interpreting the results) who need to understand the value of early reconnaissance work and baseline data, the factors to consider when selecting and scoping appropriate studies, and the likely limitations of those studies; and
- Scientists and environmental contractors responsible for carrying out damage assessment studies who should already be familiar with standard technical operating procedures for surveying and analysing the natural resources they are studying (which are therefore not included in this manual), but who also need to understand the typical sensitivities of those resources to oil, the survey strategies that have been shown to be appropriate for detecting damage, any potential indicators of oil impact and other methodological guidance that may be particularly important in oil spill studies.

The manual makes a basic analysis of the international regime that provides compensation for pollution damage caused by tankers: i.e. the 1992 Civil Liability Convention (CLC 92), the 1992 Fund Convention (Fund 92) and the 2003 Supplementary Fund Protocol. It also mentions the 2001 International

Convention on Civil Liability for Bunker Oil Pollution Damage. In particular, the manual addresses the aspect of damage assessment to non-economic resources* and describes criteria for restoration measures that may be supported through the international compensation regime. The manual does not address studies that may be required to evaluate effects on other resources such as commercial fisheries, mariculture or tourism. Some reference is also given to damage assessment methods and restoration measures that are used in some countries that may be considered useful, but which are not eligible for compensation under the international regime.

2 Pre-spill planning

It may be advisable to prepare for the occurrence of a spill by undertaking certain pre-spill planning measures. Such measures can streamline assessment efforts by improving scientific understanding of potentially affected resources and addressing important administrative issues in advance of an incident. The costs of pre-spill planning measures are not reimbursed under the international compensation regime, but they may help to support the validity of post-spill studies.

This chapter summarizes important pre-spill measures. Existing contingency plans may already include some of these measures, but they should be reviewed to ensure that they are adequate for the purposes of a potential damage assessment:

- prepare maps of resources that are *sensitive* to oil spills;
- develop a plan for assessment and restoration of environmental damage following oil spills;
- integrate the plan into relevant oil spill response contingency plan(s) and assign institutional responsibilities;
- consider establishing a funding mechanism to respond to oil spills and assess and restore impacted environments;
- review relevant legislation;
- carry out pre-spill training and simulations, as needed;
- identify high risk areas and resources; and
- collect and collate baseline data on priority areas.

* Non-economic resources: any natural resource that is not characterized by a commercial value.

2.1 *Preparation of oil spill sensitivity maps*

Oil spill sensitivity maps should be an essential element of a national oil spill contingency plan and will also provide a valuable basis from which to plan an oil spill damage assessment. The maps should show the locations of the different coastal and nearshore resources and indicate environmentally sensitive areas. A number of guidance documents are available.*

2.2 *Developing a plan for assessment and restoration of environmental damage following oil spills*

Governments should develop a plan for assessment and restoration of environmental damage following marine oil spills which can be used in the preparedness phase and be readily implemented when there is a major oil spill. It should indicate immediate and longer term assessment actions, data collection protocols, sampling methodologies, standard operating procedures, laboratory analysis, etc. This manual aims to provide generic advice to assist the development of such a plan.

Various national and international[†] agencies have developed comprehensive methods for environmental damage assessment, some of which have become standard procedures that are now used internationally. However, Governments that have ratified the CLC 92 and Fund 92 Conventions wishing to base their damage assessment plans on another country's model should appreciate that some methodologies will not be eligible for compensation under the international compensation regime. More details are given in sections 4 and 5.

2.3 *Integration with oil spill response contingency plan(s) and assigning institutional responsibilities*

To avoid confusion in the event of a spill, it is important that the assessment plan is integrated into relevant existing oil spill contingency plans. Most importantly, all institutions and entities involved in response, assessment and restoration activities should be identified and clear responsibilities assigned. To ensure proper co-ordination, a simple interagency co-ordination system should be established with a mechanism for frequent updates and assignment

* IMO/IPIECA (1996). *Sensitivity mapping for oil spill response*. IMO/IPIECA Report Series, Volume 1. London: International Petroleum Industry Environmental Conservation Association. 24pp. www.ipieca.org/publications/publications_summary.php?id=41 NOAA ESI mapping. <http://response.restoration.noaa.gov>.

[†] ROPME/MEMAC, 2006. Regional oil spill damage assessment guidelines of the Regional Organization for the Protection of the Marine Environment/Marine Emergency Mutual Aid Centre.

of tasks. All parties should aim at a collaborative approach when it comes to damage assessment studies, so potential conflicts between agencies can be considered and ideally resolved in advance. A Memorandum of Understanding can assist in outlining how co-operation among agencies will occur, particularly with regard to the arrangements for the administration of funding.

If there is potential for other political jurisdictions or countries being affected, then integration with the national contingency plan should also provide procedures for cross-jurisdiction interaction and co-ordination. The plan should be discussed amongst all stakeholders, approved, tested and updated on a regular basis and should serve as a basis for training and simulations.

Ideally, studies should be undertaken jointly, involving both government agencies and those concerned with paying compensation such as the shipping industry, their insurers and the IOPC Fund, when appropriate. This provides opportunities for co-operation and sharing of expertise, taking advantage of local knowledge of the species under study, while drawing upon international expertise on the effects of pollution on the marine environment. The early involvement of those organizations concerned with paying compensation also avoids the risk of duplicated effort in gathering data and is likely to facilitate the timely settlement of any subsequent claims for compensation.

2.4 *Establishing a funding mechanism to respond to oil spills and assess and restore impacted environments*

In the immediate aftermath of a spill there is a need for significant mobilization of human and financial resources to respond and minimize impact. Delays in the availability of financial and other resources can result in increased damage, as the protection measures needed may not be deployed in time. It is therefore desirable to establish a funding mechanism to support response, assessment and restoration. Consideration could be given to a revolving fund which could be financed through a combination of public and private sources. Public sources can include direct levies or surcharges (e.g. per barrel of oil import) or tax-related funding. Some countries may already have oil spill response funds.

2.5 *Review of relevant legislation*

Review of national legislation and regulations in relation to oil spill prevention, response, assessment and restoration, as well as, liabilities should be undertaken. Of particular interest would be the national status, including

obligations and rights in relation to relevant international conventions, agreements and institutions such as:

- the 1992 International Convention on Civil Liability for Oil Pollution Damage;
- the 1992 International Convention on the Establishment of an International Fund for Compensation for Oil Damage;
- the 2003 Supplementary Fund Protocol (to the 1992 Fund Convention); and
- the 1990 International Convention on Oil Pollution Preparedness, Response and Co-operation.

2.6 *Pre-spill training and simulations*

Pre-spill training and simulations would greatly assist the institutions and entities with responsibility for response, assessment and restoration activities. These would help to develop the knowledge and skills needed to be immediately operational at the time of an incident. Simulations can help identify gaps in knowledge and responsibility and build confidence and relationships, as well as fine tune co-ordination through networking and team building.

2.7 *Identification of high risk areas and resources*

Determining which areas are subject to a greater risk of environmental damage allows agencies and scientists to put more emphasis on evaluating baseline environmental conditions in those areas so that if a spill does occur the extent of damage can be assessed with greater confidence.

Two components are involved in assessing risk of damage – i) risk of oil spills within defined geographic areas, and ii) the *vulnerability*^{*} and *sensitivity*[†] to oil of the environmental resources present. Guidance on oil spill risk assessment is given in the IMO-IPIECA Manual on oil spill risk evaluation and assessment of response preparedness.[‡] Some guidance on the vulnerability and sensitivity of environmental resources to oil is given in this manual (section 3.3 and annex 1), with references to additional guidance literature.

^{*} *Vulnerable* – a resource that is likely to be exposed to oil spilled in the vicinity, but may or may not be sensitive to that oil.

[†] *Sensitive* – a resource that would be acutely affected by oil from a spill, if it was exposed to it. It is considered even more sensitive if it also has a low recovery potential.

[‡] *Manual on oil spill risk evaluation and assessment of response preparedness*, IMO/IPIECA 2009.

An oil spill risk assessment should also provide information on the cargoes/pollutants most likely to be spilled (including their physical and chemical properties), which will allow the assessment of vulnerability and sensitivity of the resources.

2.8 Baseline data on priority areas

It is easier to assess damages attributable to a spill if objective information is available on the environmental conditions prior to the spill. It must be appreciated, however, that the scale of natural variability is often so high that comparisons between *pre-spill*^{*} and post-spill data may only reliably identify gross effects. More subtle effects are usually very difficult to distinguish from natural variability. Indeed the main value of pre-spill data has often been to allay uninformed fears about damage to the overall condition of a natural resource. To develop and maintain good *baseline data*[†] requires considerable effort and funds, but can provide many benefits for long-term environmental management.

The kind of baseline information likely to be useful in the event of a spill includes ecological data on the main components of the ecosystem considered, including information on their levels of natural variability, and data on *background*[‡] chemical contaminant levels in the main habitats. Evidence of chronic contamination or other environmental stresses at a site will also be important. Existing environmental studies for an area should be collated and analysed for gaps and missing information, paying close attention to the quality of the data (see below). Then, new studies could be directed to fill those gaps. Ideally, baseline studies should cover the full spectrum of ecosystem components that may be damaged by a spill such as primary producers, zooplankton, *benthic* invertebrates, fish, birds, mammals, etc. Realistically, this is unlikely to be possible unless environmental managers can persuade their Governments of the many other uses for such information; so

* *Pre-spill data* – simply refers to data collected at some time before a spill, typically from a single ‘snap-shot’ survey.

† *Baseline data* – incorporating the concept of a defined condition from which you can objectively measure change. A defined baseline condition is not necessarily static as it may include information on known levels of natural variability in the resource. If it does not include that information then interpretation of a measured change from the baseline should recognise some uncertainty about the cause of the change. To maintain baseline data requires on-going collection (monitoring) to describe natural change, including long term change in factors like the climate.

‡ *Background levels* – used here to refer to the typically low concentrations of chemical contaminants that are generally present in the environment away from ‘polluted’ areas. Usually defined for a particular component of the environment (e.g. water column or a sediment type) within a particular region.

some prioritization is appropriate. For the purpose of pre-spill planning at least a limited programme of study should be undertaken for high-risk areas. If resources are available, then more detailed studies could be undertaken.

Pre-spill baseline information that will be most useful are:

- (a) **background levels of contaminants:** information on background petroleum hydrocarbons (particularly Polycyclic Aromatic Hydrocarbons (PAHs)) and other contaminant levels in the water column and muddy sediments, as well as background contaminant levels in biological tissues of known indicator species (e.g. shellfish). Particular attention should be devoted to background levels of specific potential pollutants identified in the risk assessment
- (b) **population data for key species:** information on populations of species that are known to be both very *vulnerable* and very *sensitive* to oil spills. Particular emphasis should be placed on species that are also ecologically and commercially important in the priority area. Information to be collected should include their distribution and abundance and seasonal and geographic variability

Potential sources of baseline data include environmental studies performed for purposes other than pre-spill planning, such as environmental impact assessments (EIA) for coastal developments or monitoring of commercial fisheries.

When collating existing data or planning baseline surveys, be aware that the quality of pre-spill data can greatly affect its value as a baseline. Common problems with pre-spill data include:

- Old data – a snap-shot survey undertaken many years ago may not represent the recent pre-spill conditions;
- Lack of replication – inadequate sample replication will cast doubt on how well it represents the pre-spill conditions;
- Inappropriate or undescribed methods – survey methods not adequately described or not appropriate;
- Data unintelligible or not found – inadequate storage and cataloguing of data and meta-data;
- Different locations – None of the pre-spill survey sites were oiled; and
- Sites not locatable – locations of pre-spill sites not adequately described. This is often the case for rocky habitats, which are extremely patchy.

Even if the quality of the pre-spill data is inadequate for confirming any impacts from the spill, it can often provide valuable information for post-spill survey design and, in addition, comparisons with post-spill data may at least provide some evidence of the scale of impact.

3 Assessment of environmental damage

3.1 Introduction

The first consideration of an environmental damage assessment is deciding whether it is necessary to conduct such an assessment. The decision will depend on the scale of the pollution, the vulnerability and sensitivity of natural resources (taking account of seasonal differences and current weather conditions) and the level of concern of the authorities and public. Very little generic advice can be given to aid this decision, which will necessarily involve many subjective values. Section 3.5 provides further guidance on how to assess the value of individual studies. It is recognized that even if the scale of pollution and risk of damage are relatively small, it may still be politically advisable for damage assessment to be initiated, if only to demonstrate to the public that no significant damage occurred. In this case, however, the availability of compensation for expenditure on the studies may be very limited.

If a decision cannot be made immediately on whether or not to carry out an assessment, it is important that time is not lost in the early stages of the oil spill. Information on levels of hydrocarbon concentrations in the water column and records of conspicuous transitory biological impacts gathered in the first few days and weeks of a spill can greatly improve the value of the assessment. Sections 3.2 and 3.3 summarize relevant tasks.

If it is decided that an assessment is to be made, it is then necessary to define the purpose and scale of the work. A key decision will be to determine whether the primary objective of the assessment is to gather information for compensable restoration or for other purposes. Compensation under the international regime will not be available for environmental studies that are carried out for academic purposes without relevance to potential restoration. If other funding is not available, this may limit the scale of survey and sampling programmes. Section 5.1 summarizes the criteria for compensation under the international regime.

The next stage is to define the scope of the assessment. This will require information collated and summarized from many sources; some of which may already be available (see section 2.8) and some of which will come from the



Figure 1 – A stretch of sandy coast and a breakwater affected by an oil spill (Arenzano, Italy, April 1991)

records collected in the first days and weeks of the spill. The scope will need to include the following:

- the geographical extent of the area to be studied which will be based on the oil distribution (see section 3.2), and may also include reference sites in unaffected areas outside that zone;
- a list of the resources that are to be studied based on the likelihood that they may be damaged (see section 3.4) and a prioritization process (see section 3.5);
- the time scale for the assessment. This should not be left open-ended as some monitoring studies could take many years to come to definitive conclusions;
- a management structure defining which authorities will be responsible for managing the various parts of the assessment; and
- the financial budget.

It is also advisable at this stage to inform relevant insurers and/or the IOPC Fund that an assessment is being carried out. They may be able to provide useful advice on available compensation.

With the scope of work defined, the project stage of the assessment can start. Most assessment studies are likely to require the establishment of study sites and the collection of samples and other field data. Before establishing sites, one must be aware that oil distribution may change until bulk oil has stopped moving around in the study area. Section 3.6 describes a logical process for designing and initiating damage assessment studies.

Note: Assessment of damage to natural resources through the use of field survey and laboratory analysis of samples is costly and time consuming and will not necessarily provide precise, if any, quantification of damage. Alternative methods exist for estimating damage using computer-based theoretical models of oil distribution, resource distribution and toxicity. However useful these methods are considered for assessment, it must be appreciated that calculation of damage using such theoretical models is not eligible for compensation under the international compensation regime (see section 5.1).

The following sections summarize features of a structured environmental damage assessment:

- oil fate and distribution;
- biological data collection in the early stages of the oil spill;
- sensitivity and vulnerability of resources to oil;
- prioritising assessment studies; and
- designing and initiating damage assessment studies – including appropriate strategies, parameters and methods.

3.2 *Oil fate and distribution*

Determining the geographic extent of the spill and mapping the distribution of the oil within that area is a key element of the damage assessment. Oil spilled into the sea is subject to a complex range of physical, chemical and biological processes which can carry it long distances, distribute it in many different environments and eventually change its composition. Depending on the density, viscosity and distillation characteristics of the oil, a proportion is likely to evaporate, some will disperse into the water column, a small proportion will dissolve, some may reach the sea floor, and usually, the remainder will float on the water surface and become stranded on shorelines. In the medium term the physical oceanographic processes tend to concentrate the oil in

certain environments, while levels in most areas return to background levels. Longer term processes also tend to reduce the oil concentrations to background levels and eventually break most of it down into its constituent parts, though this may take a very long time.

The damage assessment needs to identify the environments where oil has gone and where it has concentrated, and to monitor its return to background levels. This will require most or all of the following tasks:

- trajectory analysis to predict the oil movement;
- tracking oil movement on the sea surface;
- collection of oil from the source in sufficient quantities to allow its characterization;
- sampling and analysing hydrocarbons present in water from points throughout relevant areas and at a range of depths, repeated at intervals until concentrations return to background levels;
- sampling and analysing hydrocarbons present in sediments from points throughout relevant areas, repeated at intervals until concentrations return to background levels;
- sampling and analysing hydrocarbons present in animal tissues (e.g. bivalve shellfish) from points throughout relevant areas, repeated at intervals until concentrations return to background levels; and
- mapping oil distribution on shorelines, preferably using a standard shoreline assessment methodology.



Figure 2 – *Sampling superficial water for oil detection close to mariculture activity*

Some of these tasks may already be carried out as a part of oil spill response activities. More detail is given in the sub-sections below.

Trajectory analysis

The geographic area that could potentially be impacted should be identified through a process of analysis of the existing spill data, oceanographic information, water current patterns and direction and wind behaviour. This information should be presented on a map. The trajectory analysis should include a record of time, quantity, duration and frequency of discharge of the oil. The resulting map can then be used to prioritize sampling areas. Trajectory modelling software is used routinely during spill response planning. Alternately, manual trajectory modelling can be undertaken. NOAA (2002) provides a handbook on trajectory analysis. It is important to remember that any trajectory modelling must be validated by direct observation of the actual location of the oil and future models updated accordingly.

Characterization of source oil

Samples of oil should be collected from the source (or sources). If the source is no longer accessible (e.g. a sunken vessel) fresh samples should be collected as close to the source as possible. Subsamples may be analysed to characterize the toxicity and physical and chemical attributes of the oil, with the remainder stored for later fingerprinting or *bioassay* studies. More guidance on taking samples of source oil is given in annex 2.

Tracking oil movement

Remote sensing – airborne sensors that can detect oil outside the visible spectrum can quickly map the distribution of oil slicks on the surface of the sea, even at night. They cannot normally provide reliable information on shoreline oiling and their use for impact assessment is therefore limited to providing broad scale information on sea areas that have been contaminated. The most commonly used systems include: Sideways-looking airborne radar (SLAR), downward looking thermal infra-red (IR) and ultra-violet (UV) detectors. Satellite imagery may also be useful (ITOPF, 2001).

Aerial surveillance by experienced observers – experienced observers record the locations, extent and character of oil on water and bulk oil on shorelines. Oil sheens adjacent to the coast can also indicate lesser shoreline contamination. Surveillance is typically carried out at various times during the spill response to aid response planning. Although not usually adequate on its own for damage assessment purposes, it provides broad scale information on the extent of the oiling and is useful for prioritization of more detailed mapping (ITOPF 2001).

Sampling water, sediments and animal tissues

Indicative estimates of concentrations can be made on the basis of the volume of oil lost into a body of water over a given area, limited by the depth of oil penetration into the water (typically found to be less than 10 metres) either due to sea conditions or dispersion. A comprehensive assessment of water-column contamination should be initiated as soon as possible to ascertain the distribution and dispersion of hydrocarbons. Ideally, measurements would be made using instruments such as towed fluorometers* to confirm that hydrocarbon concentrations are below those that might cause concern. However, it is rarely possible to mobilize the equipment and necessary logistical support sufficiently quickly to capture this data immediately after a spill. In the absence of such information or indicative three-dimensional models, simplistic calculations can provide an indication of whether exposure levels are likely to be sufficiently high to cause harm and will help to determine whether further studies are merited. Taken together with the dilutory effects of currents, the period over which high concentrations would have persisted can be derived.

An assessment of oil contamination in *intertidal*, nearshore *subtidal*, and offshore bottom sediments is also advisable. The next section considers methods for mapping visible oil. However, if oil is not visible and contamination is suspected, it will be necessary to take samples for laboratory analysis.

Note: If oil is visible in the sample there is often little value in analysing it because the concentrations will inevitably be high (many 1000s of ppm†)– it would be better to describe the amount of oil seen. Exceptions to this are when it is necessary to identify the source of the oil (by *fingerprinting*) or if you want details on specific components of the oil (e.g. polycyclic aromatic hydrocarbons (PAHs)).

Oil contamination of the subtidal sea-bed can be difficult to locate. Most oils are buoyant but can end up on the bottom through interaction with sediments, particulate matter and floating debris or as residues following a fire. The transport mechanisms under such circumstances are difficult to predict as is the distribution of the pollutant across the sea floor. Very often, the first indication comes from fishermen complaining that fishing gear has become contaminated. Samples taken from known sediment sinks, within the vicinity of the release point, may also help to determine the fate of such

* <http://response.restoration.noaa.gov/oilaid/SMART/SMART.pdf>

† ppm = parts per million. 1ppm is equivalent to 1 mg per litre of water or to 1 mg per kg of sediment/tissue. ppb = parts per billion. 1ppb is equivalent to 1mcg per litre of water or to 1 mcg per kg of sediment/tissue.

materials. In the case of oil spills in the open sea, the oil is usually so widely distributed that the concentration of oil associated with sediments is below detection limits. However, nearshore oiling of subtidal sediments, particularly associated with some sandy beaches, is more easily detectable.



Figure 3 – *Bituminous residues on the sea floor*

Animal tissues may be sampled and analysed for hydrocarbons for a number of reasons: 1) as part of a screening test for human consumption (fisheries and aquaculture stock); 2) as part of a study on environmental health; or 3) as a surrogate for water or sediment samples. Bivalves (particularly mussels) are often collected for hydrocarbon analysis because they concentrate oil contamination present in the water and therefore act as useful *bioindicators*. Natural reduction of this hydrocarbon contamination (called depuration) is a useful indication of the improving quality of the water.

Plants contain complex vegetable oils and do not normally concentrate oil from spills in their tissues. It is therefore not normally appropriate to sample plants for hydrocarbon analysis.

Guidance on how to take samples of water, sediments or animal tissues, including the importance of chain-of-custody procedures, is given in annex 2. Guidance on hydrocarbon analysis is given in annex 3.

Information on the toxicity of hydrocarbons present in the marine environment (water, sediments and animals tissues) and environmental quality standards are published by authorities and organizations in some countries (see annex 3).

Mapping oil distribution on shorelines

Oil landing on shorelines after a spill is normally very patchy; both on a beach by beach scale and at much smaller scales. Some resources may be badly affected, while near or adjacent resources may be completely unaffected. Information on the extent and distribution of stranded oil on shorelines and the distribution of oil concentrations in water is therefore essential for any assessment of damage in areas of potential resource impact.



Figure 4 – Oiled breakwater

Shoreline Clean-up and Assessment Team (SCAT) surveys are carefully structured and methodical surveys of oil distribution on sections of shoreline, using template proformas and trained survey staff are carried out. The surveys are normally undertaken jointly by environmental and oil spill response surveyors after oil has stopped moving around. In addition to describing the oil distribution, the SCAT survey is also designed to provide information and recommendations to aid clean-up decisions for specific beaches and resources. Training is required prior to the survey work to ‘calibrate’ the surveyors understanding of the various oiling categories.

Forms and instructions for SCAT surveys are available from United States* and Canadian† websites.

Oil budgets

Attempts are very often made to account for the distribution of spilled oil through the different environmental compartments by estimating an oil budget or mass balance. Such a mass balance estimate can serve as a useful guide to identifying the ultimate fate of a pollutant; however, understanding of the processes and pathways is usually limited and cannot provide definitive information about 'missing' oil. For example, a poor estimate of oil dispersion and evaporation rates may lead to the incorrect conclusion that some of the oil must have sunk. Computer models can only provide a rough estimation, as the algorithms used are based on fixed parameters and a multiplicity of variables are involved in the process. Results from the various techniques for describing oil distribution, described above, can be combined to develop an indicative oil budget (e.g. Wolfe et al., 1994, budget for the Exxon Valdez spill).

3.3 Biological data collection in the early stages of the oil spill

In the hours and first few days immediately following a spill, it is important to initiate a number of activities that can greatly improve the damage assessment.

3.3.1 Pre-oiling condition

Although oil spreads quickly, it may not reach some resources for a number of days. It may therefore be useful to make some qualitative inspections of the condition of vulnerable resources in the possible path of the oil slick (use of predictive computer modelling may help with this). It may also be possible to mobilize surveyors to unoiled shores to take samples of intertidal sediments and shellfish for hydrocarbon analysis, which will be very useful for the damage assessment and for post-spill monitoring of hydrocarbon concentrations. Guidance on sampling protocols is given in annex 2. Good records of all observations and samples should be taken, safely stored and made available for future reference.

3.3.2 Conspicuous impacts

Reliable records of conspicuous impacts to wildlife, particularly corpses, provide the most persuasive evidence of ecological damage. Some caution is necessary to ensure that the impacts are caused by the oil and are not just

* Shoreline Assessment Job Aid <http://response.restoration.noaa.gov>

† SCAT: Shoreline Clean-up Assessment www.etc-cte.ec.gc.ca/estd_west/ESTDwest_scat_e.html

coincidental, but it is obviously important to initiate recording schemes as early as possible before the evidence disappears.

Although corpses of dead wildlife may not come ashore for several days, it is important to establish procedures for recording and collating data as quickly as possible. Beached bird surveys can require considerable manpower (possibly by volunteers) to thoroughly survey the coastline (initially on a daily basis and then less frequently) (see annex 1).

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.*

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

Marine fish and invertebrates (including bivalves, crabs, sea urchins and starfish) that live in shallow coastal waters also sometimes wash up dead or moribund on the shore after an oil spill. Records of the numbers and species present should be collated, with photographs and at least some specimens taken for later analysis. Some specimens should be frozen for potential hydrocarbon analysis – this may be required if there is any doubt whether the animals were impacted by the oil or by a natural event (see annex 2), including chain-of-custody procedures.

Other conspicuous signs of impact from the oil spill may also appear over time, including the development of green algal ‘flushes’ (resulting from the reduced feeding of grazing animals), defoliation of mangrove trees and bleaching of corals and algae. Records of such changes should also be made and collated.

3.4 Sensitivity and vulnerability to oil

Section 3.5 describes a prioritization process for deciding what assessment studies should be carried out. However, a key element of that process is to

* IPIECA (2004) *A Guide to Oiled Wildlife Response Planning*. www.ipieca.org

† Camphuysen and Heubeck, 2001, see annex 1

first understand the sensitivity and vulnerability of environmental resources that have been exposed to oil. It is also important to understand the recovery potential of the resource. Thus, a biological community characterized by species with a low reproduction rate or with low mobility is likely to recover more slowly than a community characterized by wide-ranging species with high reproductive rates.

Experience from previous spills provides considerable information on the sensitivity and vulnerability of different resources. The following generalizations may help to decide which resources deserve a higher priority, but it is important to appreciate that they may not always be appropriate. More details are given in annex 1.

- The majority of serious long-term impacts occur from oil on the surface of the water and on shorelines, i.e. subtidal impacts are much less common and are generally shorter in duration. Even when high concentrations of toxic hydrocarbons are dispersed into the water column (naturally or with chemical agents), the resulting damage decreases rapidly as depth increases. It is therefore appropriate to put less emphasis on studies of subtidal resources, particularly in deep water, unless there is an overriding reason to do so (e.g. concern for a very important commercial fishery);
- Planktonic communities have generally been found to show no more than transient impacts from oil spills and are not normally studied for damage assessments;
- Most species of fish will move away from oil contaminated water if they can, so fish kills are unlikely in open coast spill situations and have not been reported in offshore spill situations;
- Amongst commercial stocks, crustacea (e.g. lobsters and crabs) and bivalves (e.g. mussels and clams) in shallow water are much more likely to be contaminated than finfish and this can lead to tainting;
- In shallow water, or in the case of sunken oil, mobile marine species (nekton) are at less risk of contamination than sessile species or slow moving species that spend all or part of their life cycle in proximity to the sea floor (benthos/benthic organisms);
- Wave-sheltered habitats are usually much more sensitive to oil spills than wave exposed habitats, due to the persistence of the oil. Similarly, habitats that are not well flushed by tidal movements will also tend to retain oil and have longer lasting impacts;
- Some intertidal habitats where oil may become trapped are more vulnerable to oil and suffer longer term damage. Many of these habitats are also important for their species richness. These include rockpools, underboulders, fissures and crevices;

- 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 the lower and middle shore habitats;
- Oil tends not to penetrate muddy sediments unless there are large crab burrows or the spill occurs during severe weather. However, muddy sediments tend to be anaerobic and therefore oil trapped in such sediments will be very persistent;
- Mangrove plants growing in sandy sediments appear to survive better than those growing in anoxic muds. However, effects may be subtle and it is possible that mortality may be delayed for some weeks or months;
- Birds that spend time on the surface of the water are most at risk from oil spills. Waders are not normally oiled, but may be affected if their feeding areas are oiled;
- Most marine algae, including intertidal species, can survive considerable oiling, likely due (in part) to their mucous coating; and
- Some groups of invertebrate animals are known to be particularly sensitive to oil. These are primarily the mobile forms, particularly small crustaceans (amphipods, isopods and shrimps), some types of intertidal snails (gastropods), burrowing clams in lower shore and very shallow subtidal (<5m) sediments, starfish and sea urchins on the lower shore and very shallow subtidal areas (<5m).

It is difficult to establish a precise relationship between oil concentration and damage and it is well established that there may be orders of magnitude of difference in concentrations required to cause impairment. For example, the scientific literature shows that even limited exposure of fish eggs and larvae to oil concentrations in the single figure parts per million (~1 ppm) range can cause mortality. By comparison some crustaceans, bivalves and polychaetes require exposure to one or two orders of magnitude concentrations of higher concentration to show effects (~10–100 ppm) and adult *pelagic* fish would require exposure to concentrations of three to four orders of magnitude higher (~1,000–10,000 ppm) for similar consequences, with sub-lethal effects often occurring well below these levels. As discussed above, much depends on the duration of exposure and the ability of mobile species to move away from the area of contamination.

By way of illustration we can consider an example of oil dispersing naturally in strong wave action along a coral reef which results in an average concentration of dispersed crude oil over the reef in the range 10–100 ppm

for a day or two. Given this scenario, what guidance can be given on whether or not studies of the effects on the reef would be justified? Reference to annex 1 indicates that many coral reef organisms are sensitive to dispersed hydrocarbons, but that reefs in deeper water are unlikely to be exposed to high concentrations. This may provide sufficient justification to carry out a visual survey of the shallow water corals and associated reef communities to look for signs of obvious damage, mortality, evident changes in the community structure and, if such impacts are observed, to set up a study to monitor recovery and consider the necessity of restoration measures.

3.5 *Prioritizing assessment studies*

Once the likelihood of adverse effects has been established, it may be necessary to proceed further with the damage assessment. In many instances, the primary focus of a study will be to assess which organisms have been killed by the spill and subsequently to monitor the recovery of the communities from which the individuals were lost. Seabird mortalities, for example, are likely to be immediate and obvious (see section 3.3.2), but what if there are no immediate and obvious effects? What studies should be initiated? The guidance in section 3.4 may indicate resources present in the spill area that are known to be sensitive and vulnerable. At this point, however, we must appreciate the complexity of the marine ecosystems and the typically high natural variability (both spatial and temporal) of many of the resources we may wish to study. In addition to the oil spill, it is likely that other human activities or pollutants may also affect the resource (confounding factors) and it may therefore be difficult to distinguish the impact of the oil.

Reviews of historical oil spill damage assessment programmes have highlighted that many studies detected no impacts and provided little value to the spill assessment except to prove that a resource was still present and apparently functioning– and that this result was predictable before the study was initiated. While it may be politically useful to show to the public that a natural resource was not damaged, this can be a waste of limited financial resources and, in addition, compensation for the cost of such studies may not be available under the international regime. Some prioritization of assessment studies is therefore appropriate. The considerable knowledge and experience available from previous spills can be used to assess the value of proposed studies. The main factors to consider when determining the necessity for post-spill studies are:

- *Contamination* – degree or likelihood of oil reaching the resource:
 - Observed degree of oiling
 - Vulnerability to oil

- *Importance of resource:*
 - Nature conservation importance
 - Rarity and distribution
 - Ecological/functional importance
 - Profile of resource – public/scientific expectations
- *Impact detection* – likelihood that you will be able to detect (and prove) an impact:
 - Known or likely sensitivity to oil spill (including recovery potential)(see section 3.4)
 - Quality of existing baseline information
 - Confounding factors (i.e. resource is influenced by other pollutants or human impacts)
 - Scale of natural fluctuations (temporal and spatial)
 - Existing methodological protocols/known indicators
- *Feasibility:*
 - Logistical factors – access, expertise, licensing, etc.
 - Available budget

Assessment of these factors may be carried out by the relevant authority or by an independent body.

3.6 *Designing and initiating damage assessment studies*

3.6.1 The design process

Designing a damage assessment study for a particular natural resource must be undertaken with considerable attention to detail. A large number of decisions need to be taken that will affect the value of the study and its ability to provide useful conclusions. The following sections aim to provide guidance on how to design appropriate studies, but more technical guidance on specific methods requires reference to other literature. Various methodological manuals are available, providing standard methods and procedures that have been used in previous oil spill studies (e.g. *AMSA Oil Spill Monitoring Handbook 2004* and the *Guidelines for the Scientific Study of Oil Spill Effects 2001*).

After careful prioritization, each damage assessment study should typically be based on:

- key indicators of selected biological features, chosen according to their ecological significance and their sensitivity;

- essential environmental parameters i.e. chemical/physical characteristics of the habitat which help identify changes from previous environmental conditions; and
- chemical analysis of the pollutant to confirm its identity and to allow monitoring of the decline of the pollutant toward baseline level.

It is not usually necessary to investigate all the ecosystems' components in order to build an accurate picture of the damage caused by the incident. Sometimes indicator species can be selected to give a general indication of the scale and extent of pollution. For example, mussels have often been selected to provide an indication of water quality following a spill as the filter-feeding habit of this species exposes them to any contaminants which are present in seawater. They are widespread throughout the world and in contaminated waters accumulate many types of marine pollutant, including oil. Analysis of their tissues allows tracking of the uptake and subsequent depuration of contaminants.

Studies should also aim to establish a link of causation between the damage and the spill. Such an approach to a damage assessment study would also meet the criteria of eligibility under the International Oil Pollution Compensation Conventions (see section 5).

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

- define aims and objectives of the study – first understand clearly what question(s) you want answered. If any of those questions are essentially academic, with little or no relevance to potential restoration, it must be appreciated that compensation for the cost of the studies may not be available under the international regime;
- define the geographic scope, time limits and the scale of the study;
- analyse existing pre-spill data from the site or from similar resources elsewhere to understand the potential levels of natural variability (temporal fluctuations and spatial patchiness) (see section 2.8);
- decide on the level of accuracy that is required;
- decide on a basic strategy/approach (see section 3.6.2);
- select suitable parameters/attributes for measurement (see section 3.6.3) – ensuring that they are suitable for detecting relevant change, that they are technically and logistically feasible within the timescale of the study, and that they will produce reliable and reproducible results;

- select or design an appropriate method to obtain the necessary data (see section 3.6.4);
- consider the likely data analytical requirements – it is often advisable to obtain guidance on appropriate statistical methods and computer software packages before collecting data;
- decide how many impacted sites and reference sites to survey and/or sample, how many replicate samples and records to take at each site and how frequently to carry out surveys and sampling (see section 3.6.4); such decisions must take into account financial constraints and the need for statistical rigour;
- decide or estimate the duration of the study – you may wish to monitor until levels return to a pre-defined baseline, but this may take a much longer or shorter time than you predict (see section 3.6.6);
- define procedures for tracking samples and data, and other chain-of-custody requirements; and
- prepare relevant health and safety risk assessments, organize logistics and plan the work schedule.

Biological and chemical sampling and surveys are typically carried out by different personnel and often by different organizations due to their very different academic disciplines. Unfortunately, this can often result in a lack of co-ordination between the collection of biological and chemical data, with consequent difficulties for comparison and correlation. It is therefore advisable that liaison between the relevant personnel is established at an early stage in the planning.

3.6.2 Survey strategy/approach

There are three main approaches to oil spill damage assessment studies:

- comparison of post-spill data with pre-spill data;
- comparison of data from oiled sites with data from reference sites; and
- analysing post-spill data, monitored over a period of time, to identify a recovery process.

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

Comparison of post-spill data with pre-spill data

Pre-spill data is very valuable for damage assessment studies, so this is the best approach if the data is available. However, even if pre-spill data exists, the quality of the data will greatly affect the conclusions that can be derived from it, i.e. there will be a level of uncertainty if the pre-spill data is old, from a site that was not badly oiled, doesn't include some important parameters (such as PAHs, background hydrocarbon levels etc.) or from a location (for which pre-spill data is available) that cannot be found precisely enough for reliable direct comparison with the impacted area. It is often advisable to carry out additional studies using other approaches to provide additional evidence.

Comparison of data from oiled sites with data from reference sites

This is the most common approach for assessing oil spill damage and has many advantages for practical planning purposes, as sites can be carefully chosen to be representative of the various levels of oiling and you are free to select the most appropriate parameters to record. However, it is important to note that reference sites are not *control* sites in a scientific sense and it will never be possible to select reference sites that have exactly the same environmental conditions as the impacted sites prior to the spill. It is, therefore, rarely possible to demonstrate with certainty that differences in the parameters you record between the reference sites and the impacted sites are due to the oil. However, while proof is not possible, through careful selection of the reference sites and by collecting good quality data from as many sites as reasonably feasible, it is possible to provide a weight of evidence that goes beyond reasonable doubt. It is important that a damage assessment includes the impact on biological communities. In order to allow statistical inference for surveys of biological communities and populations, which are typically very patchy, it is recommended that samples be collected at numerous properly allocated stations. Researchers typically select at least ten impacted sites and at least five reference sites, though the appropriate level of sampling will differ based on the circumstances of the spill. Further to a statistical analysis, even this number of samples may be found to be inadequate to detect an impact, but such a sampling effort will typically provide a practical compromise that takes account of available time, financial budgets and statistical rigour. Surveys of chemical contaminants usually require much fewer samples, due to their more consistent distribution and the relatively low concentrations that are naturally present in the environment.

Analysing post-spill data monitored over a period of time to identify a recovery process

If pre-spill data is not available and the impacted resource is fairly discrete (therefore not possible to collect data from many sites and there are no