NOPSEMA
Australia's offshore energy regulator

INFORMATION PAPER

Operational and Scientific Monitoring Programs

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Summary

Oil spills are an inherent risk associated with offshore petroleum activities. While these events are very unlikely, they pose a threat to the marine environment and the values it supports.

An outcome of the Montara Commission of Inquiry, and the Australian Government Final Response and Implementation Plan is the expectation that titleholders develop suitable operational and scientific monitoring programs (OSMP) and be ready to promptly implement them in the event of an oil spill.

The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) produced this Information Paper as an output from the Australian Government's Implementation Plan for Recommendation 90 of the Montara Commission of Inquiry.

The paper provides general advice and information to assist titleholders to develop fit-for-purpose OSMPs and to demonstrate an appropriate degree of readiness to implement those programs in the event of an oil spill. Titleholders should be able to apply information presented here to prepare OSMPs that could meet the requirements of the *Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2023.*

The OSMP is a key part of an integrated package of environmental management documentation that also includes the environment plan (EP) and the oil pollution emergency plan (OPEP). The OSMP is the principle tool for determining the extent, severity and persistence of environmental impacts from an oil spill, and allows titleholders to determine whether their environmental protection goals are met. The OSMP can also be used to test how effective the oil spill response is being in protecting the environment. Scientific monitoring in the OSMP may also have secondary aims such as to improve predictive and response capacity for future oil spills or to help direct remediation efforts.

The focus of this paper is on the design and implementation of scientific monitoring, including the collection of baseline environmental data. Advice on operational monitoring during the response phase of an oil spill can be found in existing guidance.

Abbreviations/acronyms

AIIMS	Australasian Inter-service Incident Management System
ALARP	As Low as Reasonably Practicable
AMOSC	Australian Marine Oil Spill Centre
AMOSPlan	Australian Industry Cooperative Oil Spill Response Arrangements
AMSA	Australian Maritime Safety Authority
AS/NZS ISO	Australian Standard/New Zealand Standard International Organisation for Standardisation
DIIS	Department of Industry, Innovation and Science
DoE	Department of Environment
EMBA	Environment that May be Affected
EP	Environment Plan
ERA	Environment Risk Assessment
ESD	Ecologically Sustainable Development
GGS	Greenhouse Gas Storage
IMT	Incident Management Team
MNES	Matters of National Environmental Significance
National Plan	The National Plan to Combat Pollution of the Sea by Oil and other Noxious and Hazardous Substances
NEBA	Net Environmental Benefit Assessment
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
OHS	Occupational Health and Safety
OPGGS Act	Offshore Petroleum and Greenhouse Gas Storage Act 2006
OPRC	International Convention on Oil Pollution Preparedness, Response and Co-operation
OPEP	Oil Pollution Emergency Plan
OSRICS	Oil Spill Response Incident Control System
OSTM	Oil Spill Trajectory Modelling
WAF	Water Accommodated Fraction

CONTEXT

1. Introduction

1.1. Information paper series

This Information Paper forms part of a series of documents published by the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) that provide information relevant to the environmental management of offshore petroleum and greenhouse gas storage (GGS) activities in Australian Commonwealth waters, which are subject to the provisions of the Commonwealth *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (OPGGS Act) and the Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2023 (the Environment Regulations). The Information Paper series outlines aspects of good environmental management practice relevant to Australia's offshore petroleum industry.

This Information Paper provides information and general advice to assist titleholders to plan for and implement Operational and Scientific Monitoring Programs (OSMPs) for oil spills from offshore activities. It should be read in conjunction with other relevant information available on the NOPSEMA website, particularly guidance for the preparation of environment plans (EP) and oil pollution emergency plans (OPEP).

It should be noted that while there are regulatory requirements that relate to monitoring of oil and gas activities (planned and emergency conditions), it is not a Regulatory requirement, or otherwise mandatory, to apply the information or advice presented in this paper. It is expected that titleholders would provide sound justification for any approaches adopted in the EP.

1.2. Purpose of this paper

Since the uncontrolled release of hydrocarbons at the Montara oil field in the Timor Sea in 2009, the Australian Government has strengthened the regulatory requirements and expectations of industry with regard to implementation of environmental monitoring in the event of an oil spill from an offshore petroleum activity. The overarching purpose of this Information Paper is to provide information and advice to assist titleholders in meeting the Government's expectations for oil spill environmental monitoring programs.

More specifically, this Information Paper:

- sets out general principles and practical advice to assist titleholders in their planning for, and application of, fit-for-purpose OSMPs. Emphasis is on information concerning why and when an OSMP should be included in an EP submission and possible approaches to monitoring
- addresses the findings and recommendations of the Montara Commission of Inquiry, and implements the Final Australian Government Response to the Inquiry in relation to environmental monitoring for petroleum activities (see Section 2.2)
- incorporates lessons learned from recent marine oil spills, where relevant; and
- captures the information relevant to matters protected under Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act).

1.3. Scope and structure of this paper

Environmental monitoring is a key activity undertaken during any activity and particularly following an oil spill. Oil spill monitoring can be undertaken for two distinct, but closely related purposes. As an integral part of the response to an oil spill 'Type I', 'response phase' or 'operational monitoring', is used to collect information about the oil spill and associated response operations for the purposes of aiding decision-making during the response. In particular, it provides verifiable information on the extent and quantity of contamination and effectiveness of response operations (including controls), including clean-up. Operational monitoring should provide a measurable demonstration of specific end-point criteria for the purposes of terminating the response (i.e. the point at which no further environmental improvement outcomes can be achieved through continued response implementation). Operational monitoring typically ceases once all aspects of response implementation have terminated.

The other type of monitoring, which is commonly referred to as 'Type II', 'recovery phase' or 'scientific monitoring', addresses defined objectives and collects information for the purposes of determining short and long term environmental impacts (both from the spill and the response), post-spill and post-response recovery studies, remediation efforts and scientific research. Scientific monitoring may also demonstrate whether a titleholder's goals for environmental protection were met. Scientific monitoring plans should demonstrate an appropriate level of rigour and address important design considerations such as statistical power, effectiveness of monitoring techniques, quality control and data analysis to address the inherent complexities of the marine environment and challenges associated with detecting impacts attributed to an oil spill event. Scientific monitoring may continue from some time following the termination of the operational response.

This document is focussed on scientific monitoring. This focus reflects the findings of the Montara Commission of Inquiry, which found that the full environmental consequences of the blowout will never be known, due in part to the absence of solid reliable baseline data and the slow response in putting in place the monitoring plan. A focus on scientific monitoring also complements NOPSEMA's (2014) guidance on oil pollution risk management and oil spill response and monitoring guidance published by the Australian Maritime Safety Authority.

The Information Paper scope covers a range of activities from analysing the existing environment, looking at potential impacts, designing the monitoring program, planning for monitoring through to responding to the results.

The paper is structured around three main components – context, planning and application. Topics covered under each of the components are summarised in the schematic diagram in Figure . This represents a logical order of steps similar to the process that titleholders may follow when preparing an OSMP. The order presented and colour code assigned to the components below are reflected the document for ease of navigation.

As an additional feature to assist users of this document, 'break out boxes' such as the one below are used to highlight and summarise important information and general principles discussed in preceding text. Additional information and advice which may also assist understanding is included in Technical Appendices at the back of this document.

The overarching purpose of this Information Paper is to provide information to assist titleholders to develop and apply fit-for-purpose operational and scientific monitoring programs (OSMPs).

This information paper is an output from the Australian Government's Implementation Plan for Recommendation 90 of the Montara Commission of Inquiry.

The use of information presented in this paper is not mandatory, however it has been specifically designed with the intent of assisting titleholders meet the regulatory requirements relevant to monitoring the impacts on the environment from oil pollution and response activities.

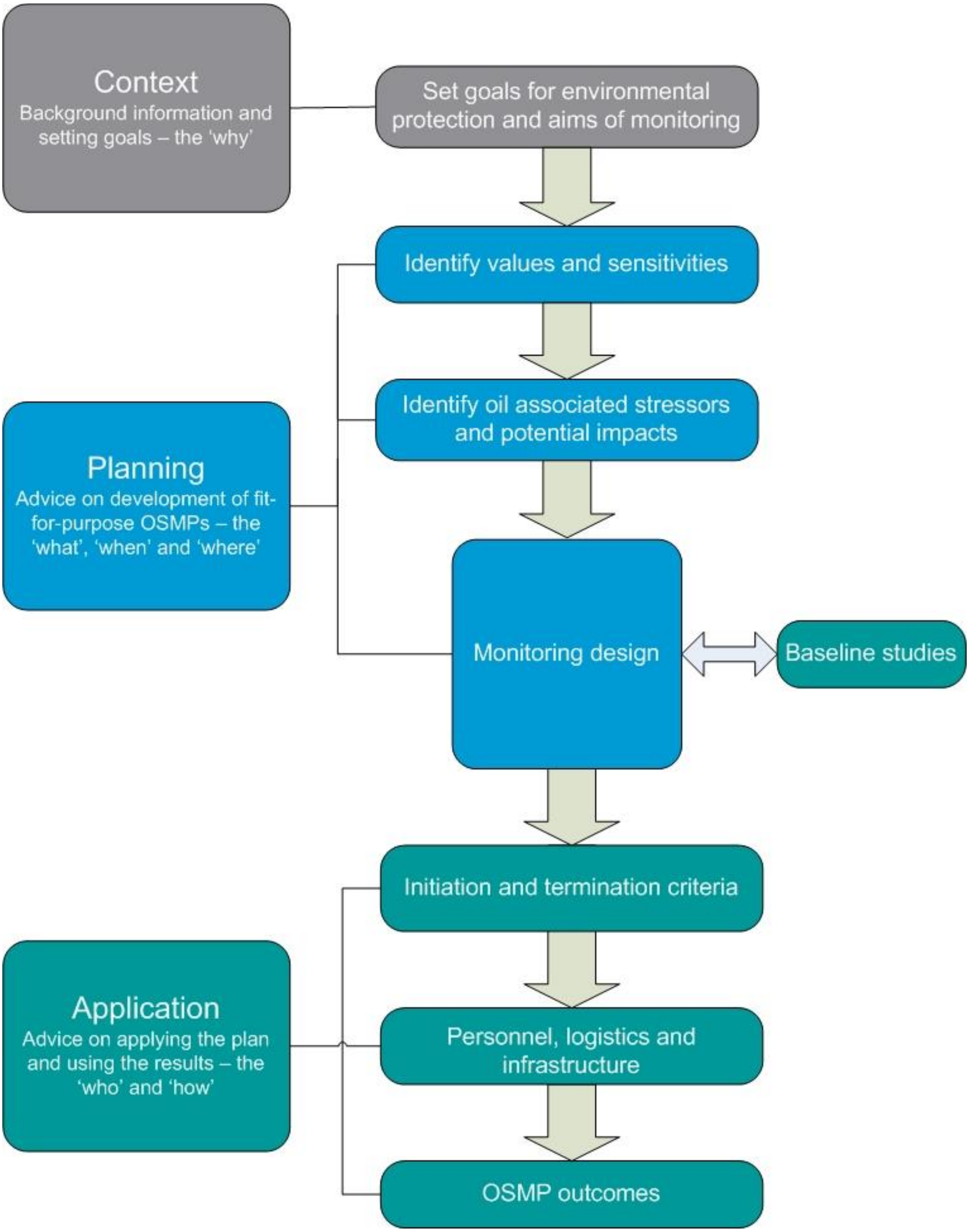

Figure 1 Document structure and OSMP design process

1.4. Legislative and other considerations

1.4.1. Offshore Petroleum and Greenhouse Gas Storage Act 2006

The *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (OPGGS Act) provides the legislative framework for all offshore petroleum exploration and production, and greenhouse gas activities in Commonwealth waters and in State waters where powers have been conferred. The OPGGS Act is supported by Regulations covering matters such as safety, well integrity and environmental management.

The OPGGS Act is an objective/performance based regime that encourages an improvement rather than compliance mentality. The regime ensures flexibility in operational matters to meet the unique nature of differing projects. Industry must demonstrate to regulators - and regulators must assess and accept or not accept – that a titleholder has reduced the risks of an activity to 'as low as reasonably practicable' (ALARP). These risks must also be acceptably low. With respect to environmental management, this approach enables titleholders to employ innovative environment protection measures tailored to specific circumstances to achieve good environmental practise and outcomes. This encourages improvements in standards over time.

1.4.2. The Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2023

The Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2023 (the Environment Regulations) have the primary objective of ensuring any petroleum activity in Commonwealth waters is consistent with the principles of ecologically sustainable development (ESD) and is carried out in activity manner by which the environmental impacts and risks will be reduced to ALARP and of an acceptable level. NOPSEMA has published further advice on its interpretation of the Environment Regulations in its Guidance Note for EP content requirements. Guidance Notes and Information Papers are available on NOPSEMA's website.

Together with the OPGGS Act, the Environment Regulations are designed to promote innovation and afford flexibility for titleholders to tailor environmental management solutions to their particular operating environment. For OSMPs, the flexibility afforded by this regime means that titleholders are able to determine the scope, design and methodologies of programs that are appropriate to nature and scale of the activity and its environmental impacts and risks. While this flexibility opens up significant opportunities for titleholders, it also presents considerable challenges, particularly in terms of understanding what would allow the Regulator to be reasonably satisfied with what is presented. An intended outcome of this Information Paper is clarity to help address this challenge.

1.4.3. Environmental Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is Australia's principal piece of environmental protection and conservation legislation. Prior to 2014, for petroleum activities which were likely to have a significant impact on matters of national environmental significance (MNES), separate approvals were also required from the Minister for the Environment.

In February 2014, NOPSEMA's environmental management authorisation process was endorsed by the Federal Minister as a Program (the Program) that meets the requirements of Part 10, section 146, of the EPBC Act. As a result, the Minister for the Environment approved a class of actions which, if undertaken in accordance with the endorsed Program, does not require separate referral, assessment and approval under the EPBC Act. The Program streamlined environmental regulation of petroleum activities by making NOPSEMA the sole regulator for these activities in Commonwealth waters. Further information regarding this process can be found on NOPSEMA's website.

The Australian Government, through the Department of the Environment (DoE), publishes EPBC Act policy statements, recovery plans, conservation advices and other advisory documents which provide guidance on the practical application of the EPBC Act, and which may be relevant to offshore activities and the development of OSMPs.

The EPBC Act also provides the foundation for the Government's bioregional marine planning initiative and the associated Commonwealth Marine Reserve (CMR) networks in Australia's offshore marine area. Bioregional planning documents and CMR information, including management plans and other information on the DoE website is relevant to OSMPs development and implementation this provides information on the natural and social values of Australia's Commonwealth Marine Area and the management arrangements that apply.

Titleholders should be aware that international environmental conventions and agreements to which Australia is a signatory or a party to may be relevant considerations when designing an OSMP. The Bonn Convention on migratory species, the World Heritage Convention, the Ramsar Convention for the protection of internationally important wetlands and the various agreements with China (China Australia Migratory Bird Agreement - CAMBA), Japan (Japan Australia Migratory Bird Agreement - JAMBA) and the Republic of Korea (Republic of Korea Australia Migratory Bird Agreement - ROKAMBA) for the protection of birds that migrate between these countries and Australia are some examples of key international conventions and agreements that may warrant specific attention.

In all cases, titleholders should refer to the DoE website for complete and up-to-date information.

1.4.4. Other consideration for monitoring

Some examples of the types of legislative requirements and other considerations that titleholders may need to take into account include State or Northern Territory laws and existing management arrangements for designated sites and areas (e.g. marine conservation reserve management plans) and specific approval conditions placed on operations by third parties. As a general principle, where parts of a potentially-affected area overlap areas where specific values or management plans have been defined or are proposed through legislative or other formal processes, those values and/or management plans should be taken into account when describing the environment, evaluating impacts and risks, setting environmental performance outcomes and planning OSMPs.

Since oil spills can affect areas long distances from the spill site, they have potential to impact areas and their associated environmental values within the Commonwealth marine area and the nearshore waters and coastlines of the continental mainland and shelf islands under the jurisdiction of States or the Northern Territory. Some potentially impacted areas may be formally or informally recognised for the important ecological, biodiversity, cultural (e.g. European or Indigenous) and/or socio-economic (e.g. fisheries, tourism) values they support. In view of this, titleholders should ensure that proposed monitoring activities in such areas are lawful (e.g. appropriate approvals are secured before implementing monitoring) and take the values and any specific management targets into account, while also ensuring that the EP submission complies with the Environment Regulations.

There may also be some circumstances where trans-national boundary issues may warrant attention by titleholders.

With regard to legislative and other considerations, when planning and applying OSMPs titleholders should:

- note that key pieces of legislation relevant to OSMPs for offshore petroleum activities include the OPGGS Act, Regulations and the EPBC Act
- aim to make the most of the opportunities and flexibility afforded by the objective-based regime
- ensure that the planning for monitoring programs considers the need for those programs to comply with the relevant Commonwealth, State and Northern Territory laws
- address the values and any specific management targets for designated sites and areas.

1.5. The EP, OPEP and OSMP

The EP, oil pollution emergency plan (OPEP) and OSMP are parts of an integrated package of environmental management documents designed to manage environmental issues and protect the environment during routine operations and emergency incidents associated with offshore petroleum activities. With emphasis on oil spill monitoring, the general purposes of, and relationships between, these documents are outlined in this section.

In very simple terms, the EP provides fundamental information including a description of the environment that may be affected by an oil spill, an evaluation of the impacts and risks associated with such a spill, the titleholder’s goal(s) for protection of the environment and standards for performance of control measures. Throughout, levels of impacts and risks need to be shown to be acceptable. The EP also sets out an implementation strategy that describes how the various aspects of environmental performance management will be rolled out by the titleholder during the operations phase of the activity.

By providing this information, the EP sets the foundation for the response strategies described in the OPEP that will be employed to combat a spill with the broad aim of achieving the titleholder’s goal for environmental protection that is set in the EP. NOPSEMA has published specific guidance on oil pollution emergency planning, which titleholders are encouraged to consult.

Again in simple terms, information within the EP informs the form and content of the OSMP by identifying aspects of the operating environment that should be protected and monitored during an oil spill. Monitoring detailed in the OSMP may also provide a basis for:

- determining if (and/or when) the goals set for environmental protection are achieved
- ‘testing’ the efficacy of predictions of impact presented in the EP
- ‘testing’ the effectiveness of the oil spill response within the OPEP in protecting the environment to achieve the titleholder’s goal.

An OSMP should be designed as a part of an integrated package of environmental management documentation that includes the EP and the OPEP.

2. Background

2.1. A brief overview of Australia's marine environment

With the recent proclamation of the extended continental shelf, Australia now has the world's third largest national marine territory, which includes parts of the Indian, Southern and Pacific oceans. Figure 1 Document structure and OSMP design process shows Australia's offshore maritime jurisdiction relevant to petroleum exploration and development activities and illustrates the vastness of this offshore area.

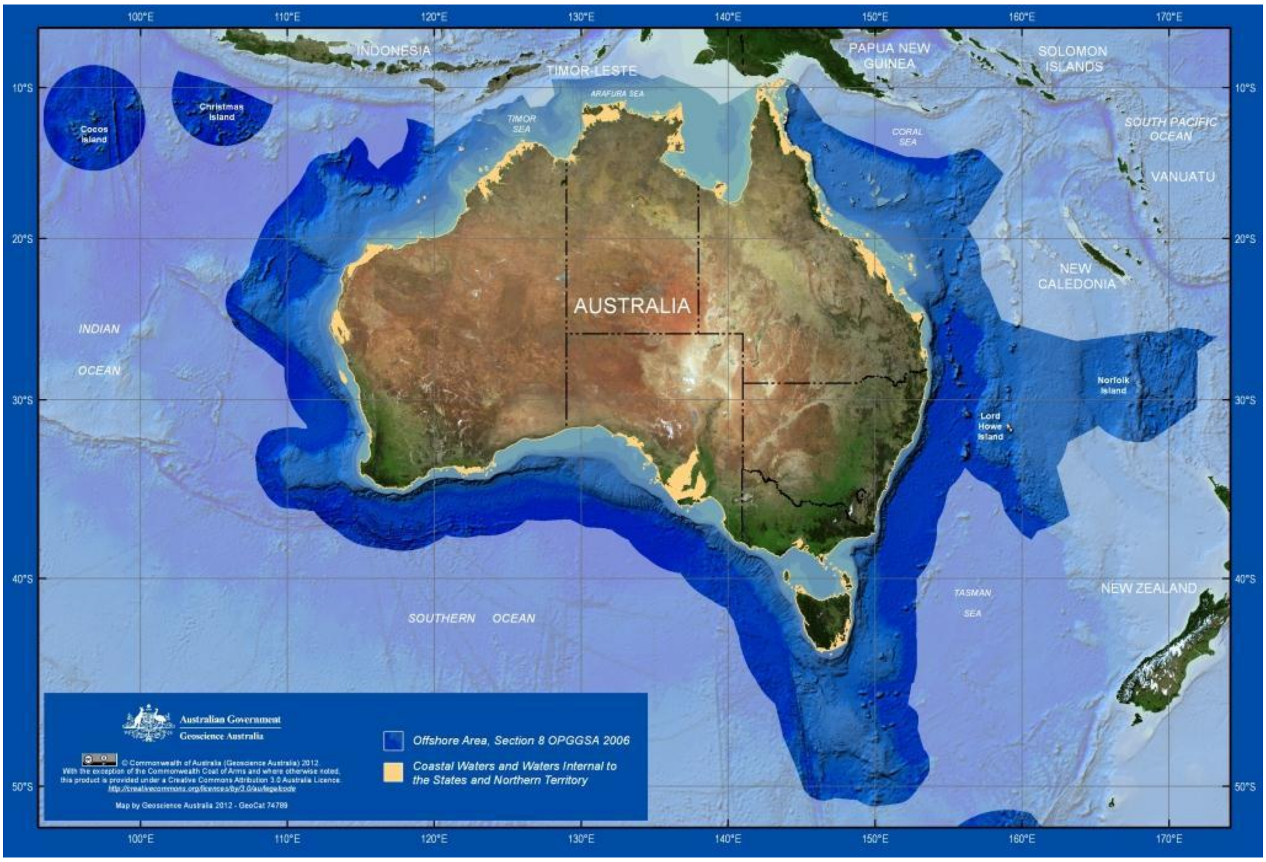

Figure 2 Australia's offshore area relevant to petroleum exploration and development activities.

Map Courtesy of GeoScience Australia
Note: The boundaries depicted do not necessarily show the full extent of Australian jurisdiction and are without prejudice to Australia's maritime claims.

The vast geographic extent of the Australian offshore area, and its varied climactic, geological and oceanographic settings, mean that it supports a rich diversity of species and ecosystems. Australia's marine jurisdiction extends from the tropics in the north to cool temperate waters in the south and approximately 200 nautical miles from the continental mainland. It also takes in areas of deep ocean beyond the continental shelf and includes waters around offshore islands, such as Christmas, Cocos, Norfolk and Lord Howe islands, which are well offshore from mainland Australia (Figure 2).

While detailed knowledge of Australia's offshore marine environment remains patchy, there is a broad understanding of key features and values, and there are knowledge hotspots, particularly in areas known to be important for their biodiversity and ecological values, fisheries management and offshore hydrocarbon reserves. Through the Commonwealth's bioregional marine planning initiative, plans have been developed for four Australian Commonwealth marine bioregions. These plans bring together information about key biophysical features and conservation values, and identify key ecological features (KEFs) that are critical to the ecological functioning, integrity and/or biodiversity of the Commonwealth marine environment. Bioregional planning and the international Census of Marine Life initiative have also highlighted that Australia's oceans support globally-significant biodiversity and high levels endemicity in some regions. Halpern et al. (2008) in their assessment of the condition of the world's oceans also noted that the marine environment off northern Australia supports among the least impacted marine ecosystems in the world along with high latitude polar regions. The authors suggest these waters represent one of the very few tropical marine areas remaining in a "very low impact" state.

As an island nation Australians have a strong affinity to the coast and ocean. Human uses of Australia's marine environment are varied and contribute significantly to the national economy through energy and food production, transport, industry, recreation, tourism and defence (AIMS, 2010). In 2009-2010, the reported fish landings (including mariculture) in Australia's Economic Exclusion Zone were 241,100 tonnes, with a gross value of $2.2 billion (ABS, 2012). Further, there is a high participation rate in marine recreational pursuits in Australia (e.g. an estimated 5 million people participate in recreational fishing each year), which highlights a strong public affinity with the ocean and it's biological resources. It is important to note, that many of these uses particularly those based around fisheries, recreation and tourism but also including transport and other marine industry depend on a clean and healthy marine environment.

The Australian State of the Environment Report (State of the Environment 2011 Committee, 2011), suggested that around 90% of Australia's liquid hydrocarbon and 74% of the nation's natural gas production is extracted from ocean areas. The estimated $145 billion worth of new gas projects currently under construction in Australia are expected to have general long-term economic and social benefits for the nation, in the form of export revenue, employment opportunities and tax payments (APPEA, 2011). Indeed it has been reported that offshore oil and gas activities make up over 50% of the economic value of Australia's marine industry (AIMS, 2010). With increasing global demand of energy, it could be expected that oil exploration and the natural gas part of the sector will continue to expand.

2.2. The Montara Commission of Inquiry

On 5 November 2009, the Commonwealth Minister for Resources and Energy announced a Commission of Inquiry into the uncontrolled release of oil and gas from the Montara Wellhead Platform in the Timor Sea, which commenced on 21 August 2009. The Inquiry investigated the likely causes of the incident and made recommendations to the Government on how to prevent and, if necessary, manage future incidents, including environment management matters.

The June 2010 Report of the Montara Commission of Inquiry made 105 recommendations which have implications for governments, regulators and the operational procedures and practices of the offshore petroleum industry. In the Final Government Response, the Government accepted 92 recommendations and noted 10. It did not accept three Montara Commission of Inquiry recommendations because they were technically inappropriate. Implementation of the Government's response has included a suite of initiatives, including amendments to legislation and improvements to strengthen institutional arrangements.

Recommendations 90, 95 and 96 are considered in this Information Paper. In particular, Recommendation 90 stated that 'off the shelf' monitoring programs should be developed that could be rapidly implemented in the event of a future spill from an offshore facility. NOPSEMA has led the implementation of this recommendation through robust regulatory oversight under the Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2023, including the provision of guidance in this Information Paper on monitoring programs. Under the Environment Regulations, a titleholder must have an accepted environment plan that is fit-for-purpose and specific to the activity and its environment in order to operate. An environment plan should include an OSMP that is similarly fit-for-purpose and specific to the activity and to the environment at risk. Each OSMP will be different as the environmental setting and, impacts and risks associated with each petroleum activity will be different (i.e. the OSMP for an offshore petroleum activity in Bass Strait may bear little resemblance to the OSMP for an activity in proximity to sensitive marine environment such as the Ningaloo Reef). Under these regulatory arrangements, petroleum activities should have an OSMP which is appropriate to nature and scale and the environmental impacts and risks, and is sufficient to inform remediation activities.

The Montara Commission of Inquiry also refers to aspects of the 'polluter pays' principle in its analysis and recommendations relating to the environmental response to the incident (Recommendations 95 and 96 of the Montara Commission of Inquiry Report). The Inquiry report points to scientific monitoring with an aim of assessing environmental impact as being a key part of 'polluter pays'. The Australian Government's final response to the Inquiry's recommendations signalled its support for the 'polluter pays' principle and amendments have been made to the OPGGS Act to strengthen these requirements. Accordingly, titleholders are reminded that, in accordance with the 'polluter pays' principle, it is the titleholder who must bear the cost associated with all monitoring activities outlined in an OSMP, as well as any monitoring activities that are necessary in the event of an incident, even if they are not envisaged in the relevant OSMP.

2.3. Lessons learned from oil spill incidents

The Montara incident was Australia's third largest with respect to volume of oil spilled and it put spill response arrangements, including environmental monitoring capacity, to the test in a remote environmentally sensitive offshore area.

Together with the Macondo incident in the Gulf of Mexico in April 2010, these incidents serve to highlight there is no place for complacency when it comes to planning for the 'consequence' side of the risk equation (i.e. risk = likelihood x consequence), despite the very low likelihood of a major spill occurring. The immediate impacts of marine oil spills can be quite obvious, attract immense public attention and consequently both incidents, no doubt, adversely impacted the offshore petroleum industry's social licence to operate. On the other hand, the levels and types of environmental impacts that may be more subtle, take time to manifest, occur at places distant from the spill site or effect organisms indirectly, are much more difficult to determine. The challenge in determining these impacts may be even greater in situations where forward planning and preparation is inadequate or does not occur at all.

The Montara Commission of Inquiry found that the absence of solid reliable baseline data rendered the environmental monitoring arrangements in place for that spill inadequate. Similar concerns were raised with respect to aspects of the post-Macondo monitoring (e.g. Ragen, 2010). Underdeveloped planning for environmental monitoring of the Montara incident contributed to a delay in the implementation of environmental monitoring and lost opportunities for maximising returns from work that was being done.

"It is unlikely that the full impact of the blowout will ever be known. This reflects the vast and remote area affected by the spill; the absence of solid reliable baseline data on species and ecosystems, and the slow response in putting together a monitoring plan."

Montara Commission of Inquiry, 2010

There are a number of areas where environmental monitoring of offshore petroleum incidents may be improved in the aftermath of the Montara Incident, including:

- improved prior planning for environmental monitoring in the event of a spill, including the establishment of appropriate environmental baselines to inform environment damage assessment
- better integration of 'operational' and 'scientific' monitoring
- reducing the time taken to implement scientific monitoring
- the utilisation of water sampling undertaken during the response to inform assessments of the transport, fate and impact of dispersed oil
- the rigor of detailed design and implementation aspects of scientific monitoring
- the efficacy of monitoring triggers.

Governments (see Commonwealth of Australia, 2011) and industry (see APPEA, 2011) are taking steps to address the broad array is issues raised by the Montara and Macondo incidents. The lessons learnt specifically relevant to environmental monitoring of spill impacts are addressed in this Information Paper.

When planning and applying OSMPs titleholders should bear in mind:

1. the vastness and remoteness of the offshore area when justifying their readiness;
2. the global significance of a number of environmental values as part of their considerations of nature and scale
3. seasonal variation in relation to the environmental values, in particular critical life stages susceptible to oil spill and response impacts
4. that many values of Australia's offshore area rely on the maintenance of a clean and healthy marine environment
5. the findings and recommendations of the Montara Commission of Inquiry and the Government's final response and implementation plan
6. lessons learned from recent offshore incidents in the Timor Sea and Gulf of Mexico.

PLANNING

3. Planning for scientific monitoring

3.1. A fit-for-purpose OSMP

It is a requirement of the Environment Regulations that an EP's implementation strategy provides for monitoring of the impacts to the environment from oil pollution and response activities that is appropriate to the nature and scale of the risk of environmental impacts for the activity and is sufficient to inform any remediation activities. A key purpose of this Information Paper is to provide information that can be used by titleholders to develop fit-for-purpose OSMPs that suit their particular circumstances. It is therefore necessary to detail what might constitute a fit-for-purpose program.

One of the first steps that a titleholder will need to take is to decide what would be considered fit-for-purpose. Key considerations for this risk-based decision are the nature and scale of the activity, its environmental setting and predictions of impacts and risks associated with credible spill scenarios. Technical and predictive uncertainties also warrant careful consideration. .

Some general principles are suggested in Table 1 to provide some practical advice on what 'fit-for-purpose' might mean for the scientific monitoring elements of the OSMP. These principles are simply designed as prompts for titleholders to consider when evaluating whether their oil spill environmental monitoring programs may be fit-for-purpose.

Principle	Example questions to assist in the application of principles
Appropriate	Is the OMSP appropriate to the nature and scale of the activity and its impacts and risks? Does it address baseline data requirements for detecting and measuring impacts to an appropriate suite of indicators that would inform remediation activities?
Comprehensive	Does the OSMP comprehensively address relevant impacts and risks and meet all relevant legislative requirements?
Achievable	Will the design allow the titleholder to determine if the aims of the monitoring program and goal(s) for protection of the environment have been achieved?
Adaptable	Is the monitoring program design flexible enough to accommodate change that may be required to suit the scenario that unfolds in the event of an actual spill?
Ready	Does the plan demonstrate readiness with the people (e.g. suitably qualified and inducted personnel), logistics (e.g. vessels, accommodation), physical infrastructure (e.g. telecommunications) and adequate baseline data to promptly apply operational and scientific monitoring?
Timely	Can the scientific monitoring element be executed promptly to ensure that the timeframe for sampling to assess short term impact does not lapse?

Triggered	Does the program include clear and measurable initiation and termination criteria that ensure monitoring commences before opportunities are lost and is not terminated before relevant aims are demonstrably achieved?
Optimised	Will the design make the best use of data collected during operational monitoring for scientific monitoring purposes?
Justified	How will society judge the monitoring efforts - are the efforts to determine impacts justifiable? Is the monitoring logical, scientifically sound and have adequate statistical power to detect impacts and inform future remediation activities if necessary?
Communicative	Does the plan include an appropriate strategy for reporting and communicating findings to relevant audiences?

Table 1 Suggested fit-for-purpose principles

3.2. Monitoring aims

A broad aim for an OSMP should be to collect data that can be used to determine if the related goals for environmental protection set by the titleholder in the EP were met. Once a decision is made that a fit-for-purpose OSMP should be included in the submission, then a set of broad aims for the monitoring itself need to be determined.

The primary aim of scientific monitoring should be to determine the magnitude of environmental impacts arising from an oil spill, where magnitude has extent, severity and persistence (including recovery) dimensions.

It will often be necessary to establish more specific aims for individual features that are the focus of scientific monitoring. Marine conservation reserve documents often contain important information about the management targets, priorities, strategies, and actions for the reserve and its values. This information can serve as valuable context for the setting of aims for the OSMP for specific receptors. For example, an appropriate monitoring aim for a particular receptor may be to collect data about that receptor that will allow the titleholder to determine whether a relevant management target set in a marine conservation reserve management plan is being achieved.

For scientific monitoring to achieve its aims, it may be necessary for monitoring activities to continue to occur for some time following the cessation of the response. By providing the basis for assessments of impacts over the short- and long-term following a spill, scientific monitoring data should be used inform priorities for recovery/remediation actions, as appropriate. Data collected by scientific monitoring should also provide for assessments of environmental performance based on termination criteria (see Section 9) and the titleholders' goals for environmental protection.

Although environmental impacts from oil spills can be significant, these events offer a rare opportunity to conduct research into the effects of oil on the environment in 'real world' settings. Capitalizing on these rare opportunities has potential to deliver large dividends in the form of improved fundamental understanding and the ability to test the effectiveness of control measures implemented during a spill and the veracity of impact predictions, and validate the findings of previous laboratory-based research. Accordingly, a secondary broad aim of scientific monitoring may be to continually improve predictive capacities and response effectiveness. Monitoring activities to address research-orientated aims may or may not be linked to the monitoring carried out to achieve the primary overarching aim to assess the magnitude of environmental impacts.

3.3. Defining the area of interest

Determining a study area is necessary for the planning and design of all environmental monitoring programs. In an EP, titleholders commonly present a spatially-defined area of the environment that may be affected (EMBA) by an oil spill from an offshore activity. Titleholders should refer to NOPSEMA (2015) for further general guidance relevant to generating the EMBA and evaluating environmental risks within that zone.

The EMBA provides important spatial context for the OSMP, but titleholders should be mindful of a number of important factors when considering applying the EMBA to the OSMP. Firstly, because the EMBA is often generated from stochastic modelling, it generally does not represent the possible outcome from a single spill scenario. Rather, it often represents the compilation of possible outcomes and encompasses the area predicted to be affected from a number of spill simulations (often somewhere in the range of 50-100 simulations). Because of this the EMBA is often large, covering areas that may not be affected by any single spill event. Furthermore, since the EMBA is most often generated with the help of predictive tools such as numerical models and research findings which are often not verified under field conditions (e.g. toxicity testing to derive effects thresholds), it will carry a degree of uncertainty.

In view of the above, it is very important that planning for an OSMP takes EMBA uncertainty into account and applies the precautionary principle as appropriate. For example, an OSMP may be designed with the entire extent of the EMBA in mind but include systems that allow the program to be adapted and applied in a way that is best-suited to the situation as it unfolds.

As noted above, the EMBA general provides only part of the spatial context for an OSMP. In many cases, the 'area of interest' for the OSMP may need to be larger than the EMBA, but includes it as a subset. This is primarily because the area of interest should not only include areas that might be impacted by a spill but also include areas that are unlikely to be impacted that could serve as reference or control sites in the monitoring program design. An alternative approach might be to limit the area of interest to the EMBA, but use a program design that allows the area of interest and the purpose of individual monitoring sites throughout the EMBA to be fine-tuned depending on the actual event. In such cases it may be necessary for the OSMP to detail clear points for decision-making about which sites within the EMBA will be used to assess impact and which of the remaining ones would serve as control or reference sites. The information to inform this decision-making could be collected and interpreted in near real-time with the operational monitoring component of an OSMP.

The claim is often made that large modelled EMBAs are conservative and represent worst case scenarios. Since the resources required (and cost) for monitoring will be positively correlated to the extent of the area and diversity of receptors that should be monitored, evidence to support downward adjustment of the area of interest could have considerable benefits. Strategies to reduce or modify the boundaries of the area of interest as a spill unfolds could be considered, but they should be accompanied by strong technical justification, particularly where such strategies could have implications for the ability of scientific monitoring to achieve its aim(s).

General principles:

- OSMPs should be fit for purpose and this should be clearly demonstrated.
- OSMPs should be designed to provide data that determine if the environmental protection goals of a titleholder were met.
- Scientific monitoring should be designed with the aim of determining the extent, severity and persistence of environmental impacts.
- Scientific monitoring may have secondary aims (e.g. studies to improve predictive and response capacity for oil spills or to direct remediation efforts).
- OSMP design should be spatially-based, considering the need for both potential impact and reference/control sites.
- The OSMP may be designed to accommodate flexibility in the area of interest and the assigning of impact monitoring and reference sites based on information about the incident.

4. Identifying environmental values and sensitivities

The broad definition of the environment in the Environment Regulations can mean that, for some activities and particularly oil spills, it may be necessary to identify a wide range of environmental features, values and sensitivities over large geographic areas that may be affected. This can be a demanding task but it is a very important one, because the scope of features potentially affected by an oil spill will be one of the key determinants for the scope for the OSMP. Another key determinant for the scope of the OSMP relates to the types and levels of impacts and risks. Titleholders should note that the need to evaluate *all* the environmental impacts and risks for the activity may necessitate taking a broad view of environmental features and potential impact that goes beyond just those that are considered likely to be significant, or relevant to listed species and communities, and areas that are afforded special protection.

In the following sections, information is presented about existing sources of information and management/planning frameworks that titleholders may choose to adopt to help identify environmental features that may be affected by offshore petroleum activities. The information resources, existing management frameworks and an approach to assist in the assembly of information outlined below may be used to scope, rationalise and prioritise environmental features, including any particular values and sensitivities, which may be relevant to the OSMP.

A broad knowledge of the types of environmental features expected to be present in the area of interest and a general understanding of their potential vulnerability to the effects of oil spills and the associated response activities are worthwhile foundations for the steps that follow involving more specific identification of relevant environmental features. Users of this document are also referred to Section 5.1, which provides information on the use of cause-effect pathways for the development of OSMPs.

4.1. Possible information sources, frameworks and approaches

There are numerous approaches and resources available for identifying the environmental features that warrant consideration for the OSMP. In view of this, titleholders are encouraged to set about identifying environmental values and sensitivities by considering a variety approaches and information to identify the parts of the environment relevant to their particular activity and area of interest. Titleholders should detail the approaches and methods used in order to demonstrate to the Regulator that the approach used and resultant outcomes are valid and appropriate. Whichever approaches are adopted for the identification and prioritisation relevant environmental features, their application should be logical, clearly described and allow titleholders to systematically demonstrate their rationale as to why some environmental features are given attention in the OSMP and, in some cases, why some others are not.

4.1.1. MNES, marine planning and conservation management resources

A considerable amount of information about environmental features of Australia's marine area can be found in documents describing MNES, marine planning and conservation management. This information may be used to describe the EMBA, evaluate impacts and risks, define environmental performance outcomes and generally inform the development of OSMP.

In an EP, titleholders must demonstrate that impacts and risks on the Commonwealth Marine Area (CMA) and relevant CMRs from both planned petroleum activities and emergency response activities will be reduced to ALARP and will not result in unacceptable impacts to the environment. CMRs are areas established by proclamation under the EPBC Act for the purpose of protecting and maintaining biological diversity in the reserves and contributing to the objectives of the national representative system of marine protected areas.

Titleholders must also be able to demonstrate that throughout an activity that impacts and risks to CMRs are consistent with relevant CMR management plans and any associated requirements.

- If there is no CMR management plan in place, titleholders should ensure that their activities are consistent with the Australian IUCN reserve management principles for the IUCN category to which the reserve or reserve zone was most recently assigned by proclamation.
- A review of the CMR Network began in 2014. For the current status of the review and its outcomes, titleholders are encouraged to refer to DoE's website.

In addition to the CMA including CMRs, all MNES should be identified and considered in the EP in relation to the EMBA. There are a number of resources from which MNES can be identified and their values understood, including spatial tools, descriptive tools, recovery plans and marine bioregional plans. Databases are available on the DoE web site that can be searched to provide information about MNES, including listed threatened species, listed migratory species, listed marine and cetacean species, heritage values, threatened ecological communities and critical habitat. For further information on the 'protected matters search tool', titleholders should refer to http://www.environment.gov.au/epbc/publications/index.html#databases.

In addition, information from relevant State or Northern Territory agencies is likely to provide additional information on habitats for threatened or migratory species within areas under their jurisdiction. In considering this type of information, titleholders should be mindful that species and threatened communities listed under Commonwealth and State legislation may differ and these lists alone are unlikely to cover off all relevant features necessary to comply with requirements of the Environment Regulations.

Values are articulated for areas internationally-recognised for their environmental importance (e.g. Ramsar wetlands, World Heritage sites). When developing OSMPs that address the values of Ramsar sites for example, consideration should be given to the components, processes, benefits and services that form the ecological character of the site.

Marine bioregional plans are a valuable resource to guide the identification of environmental features within the Commonwealth marine area (www.environment.gov.au/marineplans). Advice designed to provide context for decision-making by proponents about what may constitute a significant impact to MNES is also provided in marine bioregional planning documents. Marine bioregional plans also contain information on protected species, protected places and key ecological features (KEFs). KEFs are elements of the Commonwealth marine environment that are of particular importance for ecosystem integrity and biodiversity conservation. The locations and descriptions of KEFs are presented in the bioregional plans and supporting documents. The location and extent of each KEF can also be viewed in a Conservation Values Atlas available on the DoE website (www.environment.gov.au/cva). The Conservation Values Atlas also identifies biologically-important areas for a number of marine species. These biologically-important areas show where species are known to undertake certain behaviours (such as breeding, foraging, resting) and can provide additional insight into potential impact of proposed activities. While the KEFs can serve to focus studies and prioritise effort, consideration of impact on the Commonwealth marine environment outside the boundaries of the KEFs is still required.

Where the EMBA for a potential oil spill scenario or an area of interest coincides with an existing or proposed marine conservation reserve in Commonwealth or State/Northern Territory waters, titleholders should refer to the relevant planning and management documentation for information about the values of that reserve.

4.1.2. National Water Quality Management Strategy

The *National Water Quality Management Strategy* was jointly developed by two Ministerial Councils and provides detail around implementing a coordinated nationally-consistent water quality management system, based on input from the community to inform the setting of environmental values, management goals and objectives and criteria. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ, 2000) which are a part of the strategy documentation define the notion of 'environmental values' (EVs) as:

> the particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharges and deposits. They include those values, which the local community and other stakeholders want to protect and enjoy now and in the future.

This notion of EVs is clearly relevant to oil spills and damage assessment and reflects key elements of definition of environment in the Environment Regulations (i.e. it covers ecological and social matters) and the intent of ESD (e.g. considers intergenerational equity).

ANZECC/ARMCANZ (2000) provides guidance on a 'default' set of EVs and suggests that all water resources (including the marine environment) should be subject to at least one of these, and in most cases more than one could be expected to apply. Default EVs that may be relevant to OSMPs are shown in Table 1. While the default EVs provide a common high-level starting point for identifying the intrinsically important features of the environment that warrant protection from oil spills, for OSMP purposes it would be necessary to more-specifically define the component parts of the EVs that might be affected by spills and become the focus of monitoring.

ANZECC/ARMCANZ (2000)
Aquatic ecosystems
Primary industries (e.g. aquaculture and human consumption of aquatic foods)
Recreation and aesthetics
Industrial
Cultural and Spiritual values

Table 2 Environmental values that may be relevant to oil spill risk and impact monitoring

The EVs in Table 2 represent only a small part of the overall ANZECC/ARMCANZ (2000) framework for water quality management. Titleholders looking to apply the EVs approach to their activities are strongly encouraged to refer to the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Paper No.4* (ANZECC/ARMCANZ, 2000) in the first instance for more detailed guidance.

It should be noted that the Western Australian Government, through a community consultation process, has developed and spatially-defined interim EVs and Environmental Quality Objectives for the State's coastal waters on the northwest shelf (DoE, 2006), based on the national guidelines. Where relevant, titleholders should consider this information when identifying the features, and particular values and sensitivities of the environment that may be affected by their activities.

4.1.3. Other sources of information

Consultation with relevant stakeholders is an important element of the regulatory process under the Environment Regulations. It is another important means by which titleholders can identify important features of the environment (e.g. including social, cultural and heritage values) that may be vulnerable to an oil spill and should be taken into account when developing the OSMP. Consultation outcomes should therefore be carefully considered as an integral part of the OSMP development. Furthermore, consultation can assist in the identification of relevant standards, guidelines and codes of good practice and/or sources of existing environmental data, including baseline.

The Atlas of Living Australia (http://www.ala.org.au/) is an on-line resource that contains information on all the known species in Australia aggregated from a wide range of data providers. It provides a searchable database that may assist titleholders in identifying environmental features relevant to their particular activity and area of interest.

4.1.4. Conceptual models

The environments that may be affected by oil spills are extremely complex and may be comprised of many and varied features. In view of this, there may be considerable benefits associated with the use of tools that assist in the orderly assembly and consideration of knowledge about of how the environment is structured and functions, and how it might be affect by oil-associated stressors. Conceptual models offer one possible approach. Using a conceptual model to present information can help in the identification and prioritisation of sensitive receptors, interrelationships and potential responses of the environment to oil-associated stressors which and, in turn, inform development of the OSMP. It is not necessarily expected that titleholders would develop conceptual models and present them in the EP or OSMP. They are simply outlined here as a potential approach to identifying and assembling complex information about the environment for the planning of the OSMP.

An example schematic of a conceptual model is shown in Figure 3. It clearly identifies important environmental features and illustrates the level of detail that may be appropriate for those features. For each feature, the model provides basic information relevant to the value, including its structure and function, and potential impact from an oil spill. The model in Figure 3 combines ecological and social features but if they are treated separately it may be necessary to consider how interactions between ecological features and social uses would be accounted for (e.g. effects of a spill on a fishery may be manifest through impacts on both ecological and social values of the environment).

As shown by Figure 3, a conceptual model developed for the purposes outlined above need not be overly complex, quantitative or produce empirical outputs. However, if they are applied then they should aim to capture key environmental features and processes at scales relevant to oil spill impacts. In this way, the model might reveal that some features would be at very high or low risk of impact and that some features may not be expected to be affected at all.

Conceptual models can also serve to identify where there are gaps in knowledge that need to be filled in order to predict and measure impacts or prioritise what to monitor. Under some circumstances it may be necessary to make assumptions to take account of knowledge gaps or predictive uncertainty. It is expected that any assumptions used in the design of the OSMP will be clearly stated and their implications evaluated.

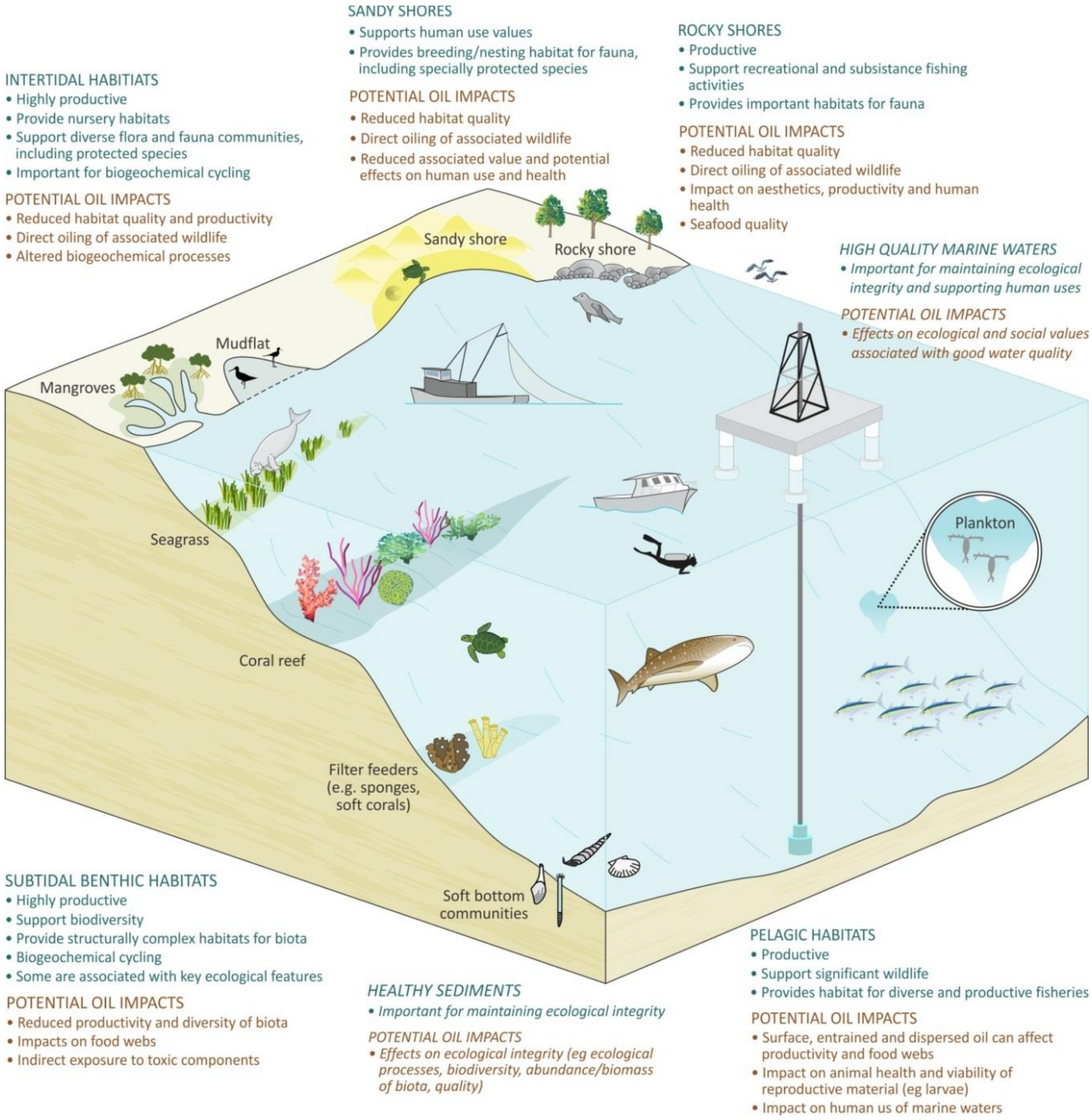

Figure 3 Example conceptual process model for oil spills

4.2. Environmental values and sensitivities

4.2.1. Physical and chemical receptors

Key physical and chemical features of marine ecosystems include light regimes, temperature, large and small scale oceanographic regimes, organic and inorganic carbon, oxygen status, nutrients, salinity and the range of biogeochemical and ecological processes associated with these elements. The physical and chemical features of an ecosystem strongly influence the types of biota present and their key population processes such as survival, growth and reproduction. Furthermore, disturbance or modification of the physical and chemical components of marine ecosystems has the potential to significantly affect elements of ecological integrity, including environmental quality. Accordingly, the states of these features are often used as indicators of environmental quality and the ecological integrity (see ANZECC/ARMCANZ, 2000).

A consequence of hydrocarbons being released into the marine environment from an offshore petroleum activity primarily involves the contamination of affected marine waters and sediments, which in turn may degrade key elements of ecological integrity (e.g., diversity, abundance and biomass of biota), including environmental quality, particular levels of which are prerequisites for certain human uses of the environment.

Even though there are strong dependencies and intrinsic links between the physical and chemical features of the marine environment and its biological ecology and quality for human use purposes, physical and chemical features are sometimes overlooked as attention is placed on biological features. In many cases, this would mean that important information about the spill and its effects would not be collected. Accordingly, to address this gap, titleholders should identify the key physical and chemical features of the environment that could provide direct information about the state of environmental quality and other valuable information that may support inference concerning potential impacts on biological features and their ecology, and human uses. Relevant features should be addressed in the planning for the OSMP.

Further information about particular biological features of Australia's marine environment and why they are considered important and potentially warrant explicit attention within the OSMP can be found in Appendix 1.

The importance of considering physical and chemical components of the marine environment (e.g., the impact of oil-associated stressors on indicators of marine water and sediment quality) is discussed further in Section 5.

In general, when identifying the environmental values and sensitivities to be taken into account within an OSMP, titleholders should:

- aim to make the most of the information in various published resources and existing frameworks
- identify and consider MNES
- be mindful of and where appropriate apply the various tools (e.g., search tools) available
- note the information presented above that outlines considerations relevant to a range of biophysical receptors that may be relevant to an OSMP.

5. Oil in the environment

5.1. Cause and effect

In order to select appropriate indicators, prioritise the receptors that will be monitored, design monitoring programs and set triggers to achieve aims of the OSMP, it is necessary to have an understanding of the way the spilled oil and response strategies interact with receptors to cause impacts.

Cause-effect relationships for potentially-affected environmental features use existing knowledge to describe how oil-associated stressors would be expected to interact with and impact parts of the receiving environment. They can be logically extended to describe recovery processes and trajectories for impacted receptors. However, it is important to note recovery (if it occurs at all) may not simply proceed in a reverse direction along the cause-effect pathway. In view of this, titleholders should be mindful it may be necessary to monitor different indicators to assess impacts and measure recovery.

In this paper, 'cause' is the physical and/or chemical presence of an oil-associated stressor (including co-occurring contaminants and spill response interventions) in water or sediment to which a receptor may be exposed. Receptors in this case may be ecological (e.g. biota, an ecological community such as a coral community) or social (e.g. a heritage site, human use of the environment that depends on a certain quality being maintained) features or values of the environment.

At the other end of the cause-effect relationship, an 'effect' is any adverse impact to receptors which occurs in response to exposure to the oil-associated stressor. The response to a stressor may include both direct effects (e.g. toxicity to marine biota and oiling of wildlife, oil contamination of seawater rendering it inappropriate for use in cooling or desalination processes) and indirect effects (e.g. interruption of food chain linkage and habitat contamination, impact on a fishery due to effects of oil on fish stocks).

Cause-effect relationships generally involve more than one discrete response in the receptor before an end point is reached. More often than not, as the degree of exposure (e.g. level and/or duration) increases, the associated cause-effect relationship involves increasingly more severe responses until the end point is reached. In general, full recovery from an end point is unlikely (e.g. mortality of biota, collapse or gross change of an ecological community or quality declining to a point where a human use is no longer supported or safe).

Cause-effect relationships can be used to guide the selection of monitoring indicators that are likely to show a response in the target receptor, deliver monitoring efficiencies and address the goal of a titleholder for environmental protection. For example, OSMP design may reflect a risk-based approach where, with good knowledge of the cause-effect relationship, it may be appropriate and efficient to focus monitoring initially on response indicators that lie early along the cause-effect pathway and signal only early warning signs of effect in the receptor. Under a risk based approach a shift in the focus of monitoring to response indicators located further along the cause-effect pathway would be triggered if pre-defined levels of response in the early warning indicator are breached.

Cause effect relationships also assist in the selection of appropriate monitoring indicators that minimise the risk of impacts going undetected or unmeasured. For example, it would be inappropriate to terminate an element of the OSMP before the time required for an effect to be realised has elapsed. Information about the timeframes for effects to occur can be gleaned from development of cause-effect relationships and this information can be used when establishing appropriate termination triggers for the OSMP.

Cause-effect relationships can also have application in operational response and management strategies by offering insights into potential effects and, how and when to arrest the cause of those effects before an end-point is reached to provide the best opportunities for recovery and effective adaptive management. In this way, cause-effect relationships may help identify operational response strategies (e.g. preventative controls or barriers) that could prevent potential adverse effects proceeding towards broad scale impacts.

The cause-effect relationships should be logical and scientifically defensible. Ideally they should be based on peer-reviewed science, though because knowledge of the marine environment and how it is affected by oil is far from complete, it is recognised that in some cases it may be necessary to apply professional judgement and assumptions. Where assumptions are made, they should be documented and effort made to take the uncertainty they create into account in the design of the monitoring program. For example, where a high degree of uncertainty exists as to whether a receptor or indicator is best-suited to detecting and measuring impact, then multiple receptors or indicators should be monitored in an effort to address uncertainty.

The behaviour and fate of oil in the environment is complex and variable, depending on the properties of the oil itself and the conditions into which it is released. In view of this, and given that some understanding of oil properties and its environmental fate is a prerequisite for establishing cause-effect relationships for potentially affected receptors, there are some important things to know about oil when establishing cause-effect relationships. Some key aspects and processes include the:

- composition of oil associated stressors
- partitioning and weathering processes
- bioavailability.

5.2. Composition of the oil associated stressor

The composition of a crude oil or condensate is usually dominated by hydrocarbon classed compounds, which may include saturated hydrocarbons (aliphatic and alicyclic), unsaturated hydrocarbons (alkenes and alkynes) and aromatic hydrocarbons (monocyclic and polycyclic aromatics). Due to the broad range of petroleum hydrocarbon chemical species potentially present within a crude oil or condensate, the limitations for identifying and quantifying specific hydrocarbon classed compounds will be defined by the analytical methodology applied. For example, simple gravimetric-based methods are useful for screening the total concentration of heavier petroleum hydrocarbon compounds in a sample (i.e., $>C_{15}$) and will generally be expressed as a single combined concentration. However, gas chromatography-based methods may be required to separate, identify and quantify individual petroleum hydrocarbon constituents. Given the ecological risks for individual oil-associated stressor compounds will vary widely, identifying the chemical constituents to a greater resolution is considered more appropriate when monitoring potential impacts from specific contaminants of concern.

In addition to petroleum hydrocarbons, it is also important to consider the presence of non-hydrocarbon constituents which co-occur in the crude oil or condensate. Non-hydrocarbon classed constituents potentially present within an oil cover a wide variety of contaminants of potential concern. This may include non-hydrocarbon polar organic compounds (resin and asphaltene containing sulfur, nitrogen or oxygen), trace inorganics (including metals, metalloid compounds and radionuclides), major ions (such as salts and sulfur) and nutrients. Furthermore, the application of a chemical dispersants during a spill response may also be considered a non-hydrocarbon classed oil-associated stressor. Common examples of hydrocarbon and non-hydrocarbon classed contaminants of potential concern have been provided in Table 3.

Oil-associated Stressor	Contaminant class	Examples of chemical species [1]
Petroleum Hydrocarbons	Aliphatic hydrocarbons (saturated)	n-alkanes, e.g., C_6-C_{36} (hexane – hexatriacontane, respectively)
	Alicyclic hydrocarbons (saturated)	mono-, di- and poly- cyclic alkanes, e.g., cyclohexane, decalin and cubane (respectively)
	Alkene hydrocarbons (unsaturated)	pentene, hexene, hexadecane, dimethylethylene
	Alkyne hydrocarbons (unsaturated)	methylacetylene, butyne, hexyne, decyne
	Monocyclic aromatic hydrocarbons	BTEX, e.g., benzene, toluene, ethyl-benzene, xylene
	Polycyclic aromatic hydrocarbons	PAHs, e.g., naphthalene, phenanthrene, fluoranthene, benzo(a)pyrene
Non-petroleum Hydrocarbons	Polar organic compounds	nitrobenzenes, phenols, propionic acid, pyrrole, thiophenes
	Chemical dispersants	potentially containing solvents and surfactants
	Metals and metalloids	arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium, zinc
	Radionuclides	radium-226, radium-228, uranium-238, uranium-234, thorium-232, lead-201, lead-212, lead-214
	Major ions	bicarbonate, chloride, sodium, sulfate, potassium, sulfur
	Nutrients	ammonia, nitrogen (total, nitrite, nitrate) and phosphorous (total, orthophosphate)

Table 3 Examples of hydrocarbon and non-hydrocarbon classed oil-associated stressors

Note that examples of chemical species are not intended to be an exhaustive representation of the petroleum hydrocarbon and non-petroleum hydrocarbon chemical classes.

Identifying the potential risks and impacts associated with hydrocarbon and non-hydrocarbon contaminants of potential concern will also depend on the extent to which the oil-associated stressors partition between water and sediment phases within the receiving environment, i.e. dissolved, dispersed and particulate phases. Partitioning to dissolved, dispersed and particulate phases will strongly influence the bioavailability of a contaminant, i.e. the fraction of the contaminant available for uptake and assimilation by the biological receptor with the potential to cause an adverse effect. Factors such as the chemical speciation of the oil-associated stressor, and the biological receptor uptake exposure pathways, physiology and behaviour should be considered when attempting to understand the bioavailability of an oil-associated stressor.

5.3. General partitioning of the oil-associated stressor in the receiving environment

The distribution of oil-associated stressors within the ecosystem compartments (broadly defined here as the sea surface, water column, sea floor and the shoreline areas of emergent land) will be influenced by metocean factors and the physico-chemical properties of the oil. The spatial and temporal distribution of uncontained oil within the marine environment will depend on the volume released, type and physico-chemical characteristics of the oil (e.g. density, viscosity, asphaltene content, wax content), and the geographical location and timing (including seasonal weather patterns and oceanic conditions). However, the presence of oil in the marine environment does not remain static, with natural weathering processes (such as evaporation, emulsification, spreading, physical dispersion, dissolution, biodegradation, precipitation, sedimentation and adsorption) and emergency response interventions (e.g. dispersant application, booming, in-situ burning) altering the physico-chemical properties of the spilled oil and subsequent distribution of dissolved, dispersed or particulate phases to the sea surface, water column, seabed and shoreline compartments of the receiving environment (Figure 4).

For example, lighter hydrocarbon fractions of the oil (e.g. volatiles and semi-volatiles) may evaporate to the atmosphere and/or dissolute into the water column as dissolved phases, reducing the total volume of oil at the sea surface. Non-hydrocarbon contaminants associated with oil (such as trace metals and metalloids) may also enter the water column as dissolved phases. By contrast, the formation of water-in-oil emulsions (often associated with heavier crudes containing wax, resin and asphaltene) may encourage persistence of the oil at the sea surface, potentially resulting in shoreline contact.

In addition to dissolution, oil may enter the water column as dispersed whole oil droplets (containing both hydrocarbon and non-hydrocarbon constituents) following physical disturbances such as wave turbulence, and response strategies such as the application of chemical dispersants. The dissolved and dispersed whole oil phases may then contact sub-surface features or shorelines where residence time in the water column is sufficient, or accumulate at the seabed following precipitation or adsorption to particulate matter in the water column (promoting sedimentation and deposition), or through direct contact with sediments at the seabed.

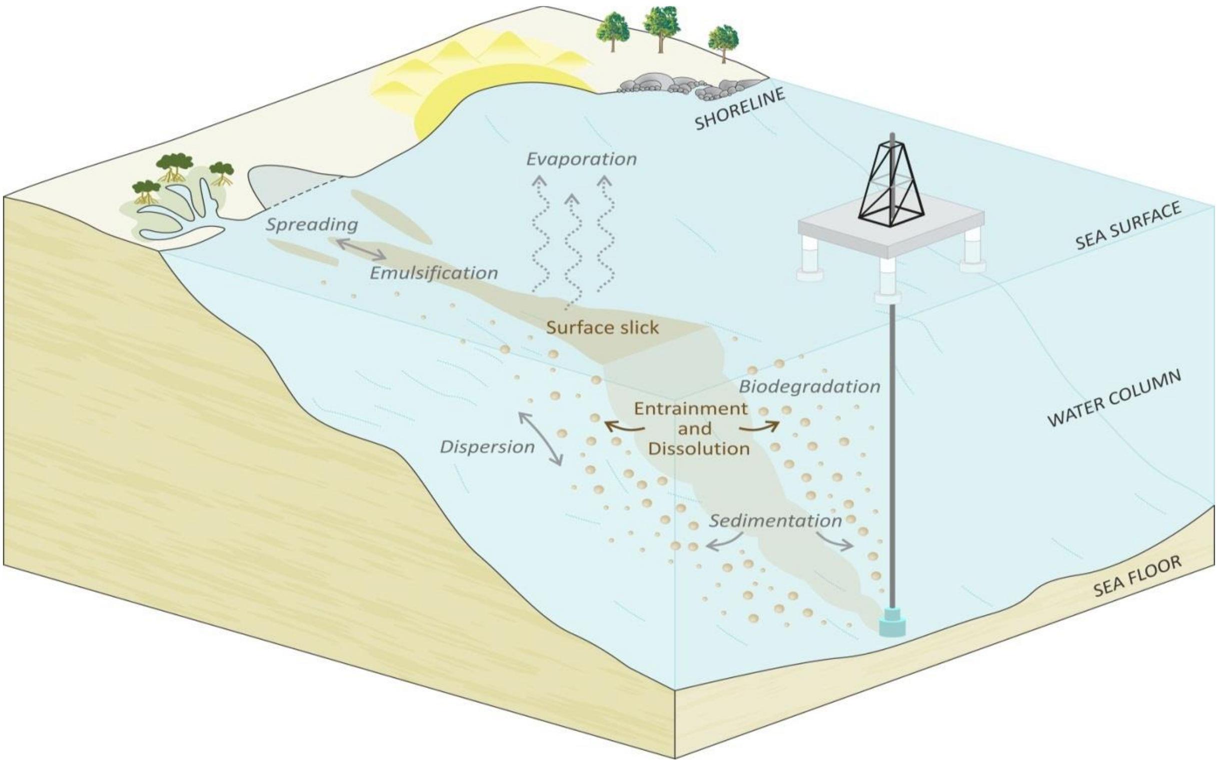

Figure 4 Weathering processes conceptual model

The extent of oil weathering and distribution to the sea surface, water column, seabed and shoreline is variable and will depend on the volume released, type and physico-chemical characteristics of the oil, as well as the seasonal weather patterns and ocean conditions. While these factors are acknowledged as being important for understanding the processes which influence the distribution of oil within the receiving environment, accurately identifying and quantifying the presence of an oil-associated stressor in the water and/or sediments should be a priority when investigating the cause of potential impacts to biological receptors.

However, identifying an oil-associated stressor in the water or sediment of the receiving environment does not necessarily indicate the presence of risk to a biological receptor. The potential for an adverse biological effect will depend on the bioavailability of an oil-associated stressor in the water and sediments.

5.4. Bioavailability of the oil-associated stressor

The bioavailability of an oil-associated stressor is defined herein as the fraction of the contaminant which is available for uptake and assimilation by a biological receptor with the potential to cause an adverse effect. The likelihood of an adverse biological effect occurring from hydrocarbon and non-hydrocarbon classed contaminant (present as a surface slick, or as dissolved, dispersed and particulate phase) increases with bioavailability.

- In general, knowledge of spilled hydrocarbons and how they may interact with, and behave in, the receiving environment is very important to ensure that predictions of impact and risk are sound and appropriate indicators are selected for inclusion in the OSMP.
- It is equally important to consider how response activities may affect the environment in order to target the OSMP appropriately.
- Cause-effect relationships offer one possible approach for selecting monitoring indicators.
- Composition, partitioning and bioavailability of spilled hydrocarbons are key determinants of how hydrocarbons will interact with the environment. These factors should be considered when planning an OSMP.

While some factors known to modify the bioavailability of selected contaminants have been well described, clear links to long-term biological effects are not fully understood with significant deviations from the estimated impacts frequently observed (Simpson and Batley, 2007; Driscoll and Burgess, 2007; Chapman et al., 2002; O'Conner et al., 1998; Word et al., 2005). The bioavailability of an oil-associated stressor will depend on (i) the chemical speciation of the contaminant, (ii) the organism exposure pathways, and (iii) the physiology and behaviour of a seabed organism. Further information on these three aspects of bioavailability is presented in Appendix 2.

6. Potential impacts of oil on the environment

The effects of spilled oil on environmental receptors are many and varied. For the purposes of planning a monitoring program to assess these effects, the likely impacts can be informed by previous oil spill incidents and experimental research. This information should be applied to the evaluation, prioritisation and types of monitoring activities planned for. In the ever developing field of petroleum exploration and production, consideration should also be given, however, to the development of monitoring programs to assess impacts that have not been previously investigated in line with the agenda of continual improvement. An example of this may be the effects of oil deposits on deep water filter feeding assemblages located in continental margin habitats or the effects of condensate on intertidal shorelines.

There are a number of ways to categorise the impacts of an oil spill on biota. At the highest level, impacts may be *direct* and immediate or *indirect* and manifest over the longer term. Direct effects include smothering by and inhalation or ingestion of the oil and occur in the short term i.e. days, weeks and months following a spill. Direct effects may also include not only the *physical* impacts of the oil itself, but also *chemical* impacts resulting from contact with the more toxic components of the oil stressor. In addition to the direct impacts of the oil itself and its toxic components, there may also be direct impacts related to the oil spill response activities, for example, the use of chemical dispersants in the open ocean, in situ burning of oil at sea, cleaning of shorelines and trampling of sensitive coastal habitats during booming and recovery operations.

Oil and spill response impacts may affect individual adult biota but may also impact different reproductive life stages such as eggs, larvae and/or juveniles. Impacts on reproduction may subsequently affect populations over medium (1 to 5 years) to longer (over 5 years) terms, essentially becoming indirect effects. Indirect effects include both ecological and social impacts. Indirect ecological impacts include, for example, effects on long term population viability, effects on food or habitats that support populations of other species, effects on keystone or ecologically important species. Examples of social impacts include those that affect indigenous, tourism, heritage, fisheries, aquaculture, recreational or other human activities.

Information on potential direct and indirect impacts of oil on the environment is provided below with further detail provided in Appendix 3. This information is not intended to detail all of the potential impacts. Rather, it highlights some of the important ecological processes and environmental receptors that may be impacted to assist with the scoping of an oil impact evaluation process for a specific location.

6.1. Direct impacts

Biota known to be highly susceptible to the direct impacts of oil include those that primarily utilise the shoreline, sea surface and to some extent seabed compartments of the marine environment. Due to the nature of oil to float on water, mobile marine species may be able to avoid contact in the water column. Shoreline and seabed, seabed flora and fauna are particularly at risk of physical contact with oil, especially those that occur in the intertidal zone where oil may be washed up, however previous incidents have also demonstrated the potential effects on seabed biota at depths greater than 50m. Marine birds, reptiles and mammals are also at high risk of oil contact due to their interaction with the sea surface for breathing and foraging. Slow moving fisheries species such as scallops and echinoderms, fish that show high fidelity to a site and sessile invertebrates, and fish constrained by aquaculture cages will be more susceptible to direct oil exposure than free swimming pelagic fish. Biota may also come into direct contact with the toxic components of oil contaminants via slow leaching from sediments on the seabed or shoreline, contact in the water column, or contact at the sea surface where inhalation of fumes can also occur. Contact with physical or chemical components of oil may result in mortality.

In addition to lethal effects, physical or chemical contact with oil may result in sub-lethal effects such as reduced growth, increased susceptibility to disease, reduced reproductive viability of adults, and mortality of eggs, larvae or juveniles, all of which may affect long term viability of populations. Many marine species including plants (e.g. mangroves, macroalgae), invertebrates (e.g. rock lobster, echinoderms) and fishes (e.g. tuna, reef fish) have pelagic eggs and/or larvae that float on or swim close to the sea surface rendering them susceptible to direct contact by oil even where adults are unaffected. Species that undergo mass spawning at specific locations and times, for example corals, sea cucumbers or fishes such as snappers and groupers, may be susceptible to loss of a cohort, which may be an issue for commercial species. Given that many different types of biota reproduce during a ‘reproductive season’ that is common across taxa, the sub-lethal effects of an oil spill on biological receptors is likely to be exacerbated if it occurs during the reproductive season of the area of interest.

As well as the impact of the oil itself, the response activities designed to mitigate the oil damage may have impacts of their own. Laboratory studies indicate that dispersants and dispersed crude oil together may be more toxic to corals than water soluble fractions of crude oil (Negri and Heyward 2000), and can increase the risk of PAH toxicity to nektonic fish (Ramachandran *et al.* 2004). It has been reported that dolphins have moved under booms, then surfaced and fed in oil affected water (see Ragen 2010), possibly because fish may be aggregated there. Physical mitigation activities may result in seagrass plants being torn or pulled out by vessel propellers and boom anchors or suffer other physical damage from trampling, vehicles and boat activity in shallow water (Premiam 2011). Rocky shore assemblages have previously been severely impacted by shoreline clean-up activities including shoreline cleaning with detergents, high pressure or hot water washing and scrubbing (IPEICA 1996). Recovery of these habitats ranged from a few years to a decade meaning that there may be a requirement for long-term monitoring of the impacts of the oil response. Certainly for sensitive saltmarsh assemblages, it is thought that clean-up activities may do more environmental damage than the spill itself (Premiam 2011). During the planning stages for an OSMP consideration should be given to monitoring of impacts that result from response activities as well as the oil itself.

6.2. Indirect impacts

While direct impacts are those where oil affects organisms, indirect impacts are where oil affects the ecosystem, which then affects organisms. Over the long term, oil spill impacts on individuals can have consequences for populations which may not become apparent until a considerable period of time has elapsed after a spill. Higher rates of mortality and reduced reproductive potential can have negative impacts for the size and structure of animal populations' years from the spill incident. The severity of population-scale impacts will depend on a number of factors including: the magnitude of immediate impacts of the spill and response activities; the persistence of oil and oil-dispersant mixtures in the environment and their ongoing potential to cause negative effects on individuals and the components of the ecosystem on which those animals depend; and the inherent potential for populations to recover. Where populations of keystone habitat or food species are impacted, this can have flow on effects for other species present in the ecosystem. Subsequently, indirectly impacted species are also candidates that should be considered for scientific monitoring in the event of an oil spill. Flow on effects may also impact human users of the environment such as indigenous hunters, tourism operations or the fishing industry.

- The design of OSMPs should take into account that hydrocarbon spills may have wide range of direct and indirect impact.
- Direct and indirect impacts suggest the need for careful selection of indicators, spatial scales and timeframes in the design of an OSMP.
- Consideration should be given to the need for the OSMP to target both ecological and socio-economic receptors.

7. Monitoring design considerations

Where a high degree of confidence in a cause-effect pathway can be demonstrated, it may be possible to justify a risk-based monitoring design, which focuses initially on relatively easy to measure early warning indicators of potential effect that are situated early along cause effect pathway. For example, if effects of hydrocarbon contamination of shoreline sediment on the health of shorebirds are well understood, it may be possible focus monitoring initially on an early warning indicator of potential effects such as the concentrations of hydrocarbons in sediments at a number of depths and locations along shorelines. Fingerprinting of detected hydrocarbon material may also be considered. With this approach and by monitoring appropriate indicators with a robust experimental design it may be possible to conclude that impacts to steps further along the effect pathway are highly unlikely. Conversely, if monitoring data from measurement of early-warning indicators suggest uncertainty regarding further ecological effect, under a risk-based approach it may be necessary to step along the cause-effect pathway to include monitoring of more definitive indicators of the ultimate ecological impact. Decisions to step along the cause-effect pathway should be based on clear pre-defined criteria that reflect risk and scientific uncertainty regarding impact.

An alternative to the risk-based approach is to immediately and simultaneously focus monitoring on multiple indicators of effects. This approach would be particularly warranted where confidence in a cause-effect relationship is low or marginal, and/or the environmental receptors are particularly highly valued. Such an approach might involve rapid and simultaneous implementation of hydrocarbon contamination assessments, biota health and habitat condition monitoring and initiation of population studies.

Several approaches could be taken to select an overall framework for monitoring design to address the aims of scientific monitoring. Two approaches only are discussed briefly above. It should be noted that the information presented here serves to illustrate that different approaches can be considered and that scientific uncertainty/predictive confidence should be a key factor in decision-making with respect to the overall approach for OSMP design.

7.1. Key concepts for water and sediment quality assessment

In the event of an unplanned release of oil into the marine environment, the extent, severity and persistence of environmental impacts from the oil-associated stressors should be evaluated. A critical component of the initial monitoring response is an investigation of the distribution and bioavailability of the oil-associated stressor within water and/or sediments of the receiving environment (as described in Sections 5.3 and 5.4, respectively). This may be achieved using an established water and sediment quality assessment framework to demonstrate the presence or absence of environmental impacts.

Water and sediment quality assessment guidelines aim to define the extent of environmental risk through considerations of acceptable contaminant concentrations in the receiving environment. In Australia, the ANZECC/ARMCANZ (2000) water and sediment quality guidelines outline a flexible framework for examining the impacts and risks from an environmental stressor. Within the context of an of an oil-associated stressor, the framework may be adapted to consider chemical characterisation, ecotoxicology, biodegradation and bioaccumulation potential, and ecological community patterns as effective measures of an environmental impact. The OSMP should make allowance for further impact assessment following the identification of an oil-associated stressor in the water or sediments of the receiving environment. This may include an expansion of the chemical characterisation to consider the bioavailability of an oil-associated stressor using ecotoxicological testing.

It is also important to note that while several oil-associated stressors may be present at concentrations below the acute, sub-lethal or chronic biological effect thresholds (i.e. below the concentration at which an organism exhibits toxicity), the potential risk of contaminant persistence should not be discounted. The potential for an oil-associated stressor to biodegrade and bioaccumulate in the marine environment should be evaluated.

Certain contaminants which are available for bioaccumulation within an organism may also undergo trophic transfer up food chains and biomagnify (i.e. increase in concentration through three or more trophic levels). Common examples of contaminants present in crude oil or condensate with the potential for biomagnification may be include lipophilic organic contaminants such as PAHs (including PAH metabolites), and organo-metals such as methyl-mercury. The persistence of an oil-associated stressor should be monitored closely when assessing long-term environmental impacts.

Further information on these topics is presented in Appendix 4.

7.1.1. Ecological community assessment

Ecological communities are a critical component of the marine environment and influence surface productivity, the physical and chemical condition of the water column and sediment, and provide food sources to higher trophic levels (Gaston et al., 1998). The impacts of contaminated water and sediments on ecosystem community health may be measured directly through the examination of differences in communities between impacted and reference locations.

The purpose of an ecological assessment is to identify whether any components of the community have been adversely impacted by the contaminants identified in an area of interest. The underlying assumption of ecological assessment is that the oil-associated contaminants can induce stress that will affect the community structure and stability. The intimate association of a faunal group with the water or sediment means that any adverse effects to individuals resulting from oil-associated stressors are well-reflected in detrimental changes to the structure of their assemblages. Unlike short-term water or sediment toxicity tests, which generally measure acute or sub-lethal endpoints, more subtle and often undetected effects on reproduction and fecundity resulting from long-term chronic exposure to an oil-associated stressor can be more sensitively demonstrated from an examination of the ecological community (Chariton et al., 2010).

While ecological community assessments are a key consideration for assessing impacts from an oil-associated stressor, a more detailed discussion of seabed flora and fauna, fish and fisheries and wildlife has been provided in Appendix 3. The aim of chemical characterisation, ecotoxicology, biodegradation and bioaccumulation studies are to better define the ecological risks and impacts from an oil-associated stressor in the receiving environment, and provide scientifically defensible evidence supporting observations from the ecological impact assessments.

7.2. Selection of biological indicators

The next step in monitoring program design involves selecting the actual biological and ecological indicators that will become the focus of the OSMP.

Since the environment is extremely complex and the areas of interest potentially large, it is not practicable or even possible to measure every possible biological and ecological response variable in the environment, even for a single issue like an oil spill. However, where an oil spill is predicted to affect a KEF as identified by the Commonwealth bioregional marine planning process, the characteristics that defined the KEF may lend themselves to be biological indicators for monitoring purposes. Indicator species also provide a practical way to track the response and recovery of the environment to an oil spill. Selecting the right indicator species is a critical part of monitoring program design and is fundamental to ensure that the program will achieve its overarching aim(s). Moreover, since the process of selecting the right things to monitor is so critical, to impart confidence in monitoring it is important that the selection process itself is logical and scientifically sound. Conceptual environmental process models and cause-effect pathways offer approaches to effectively guide and prioritise the selection of relevant and appropriate indicators for oil spill environmental monitoring. Selecting the right indicators to monitor is a key to success of a monitoring program that aims to determine magnitude of impact from an oil spill. It is recommended that the use of subject matter experts be consulted for the all aspects of the OSMP including selection of indicator species.

Selection of appropriate species should consider a number of factors, probably the most important being the selection of species that are sensitive to oil exposure and likely to be exposed to oil spill impacts owing to their location both vertically in the water column but also in the area of interest, food sources, site attachment etc. They should also have a wide distribution and sufficient abundance to permit efficient data collection and have a sufficient historical baseline data for the area of interest to allow pre- and post-spill comparison. The degree of reliability in taxonomic identification should also be considered, and this will vary with taxa and methodology. There is a substantial literature on the choice of species for monitoring programs, and these can be used to guide approaches (e.g. Freegard and Williams 2009, PREMIAM 2011). Furthermore, a review of effective biological indicators from previous spills e.g. bioaccumulation in bivalves, changes in the abundance of hydrocarbon degrading bacteria or exposure biomarkers in fish can be used to support choice of indicators in monitoring plans.

Where there is less confidence in cause-effect relationships or impacts are greater, it is likely that a greater number of species will need to be selected for environmental monitoring. Changes in community structure resulting from a spill impact would require the monitoring at an assemblage level for parameters such as species richness, diversity, abundance, biomass, health or percentage cover. Furthermore, most assemblages do not occur as monospecific aggregations, but are inherently mixed even at the habitat-forming level e.g., filter feeding assemblages of sponges, soft corals, ascidians (Heyward et al. 2010a), habitat mosaics of seagrass, macroalgae and corals (Heyward et al. 1997b, Heyward et al. 2010c). Ideally a number of species varying in their susceptibility to oil stressors should be investigated, and one approach may be to monitor ecological parameters of an assemblage such as species diversity (which requires estimates of both species presence and abundance) but to also focus on a number of indicator species to obtain in depth information about the impacts of oil on population parameters and individual health. Indicator species need to be chosen taking into consideration factors such as their functional importance, sensitivity and social importance, the knowledge base upon which the monitoring program can rely e.g. previous ecotoxicity studies or other relevant factors.

7.2.1. Habitat formers

Seabed flora and fauna are commonly an appropriate target for monitoring after an environmental impact for a number of reasons, including their importance in establishing indirect impacts (Section 8.2.1). They are sometimes long-lived and therefore integrate environmental change over long periods of time (e.g. corals, mangrove trees). They are macroscopic and sessile, which means they are relatively easy to sample quantitatively, and as a result have been well-studied scientifically and therefore have coarse taxonomic keys available. Their community structure often responds in a predictable manner to known environmental impacts i.e. variation in the abundance, diversity and distribution of organisms, and therefore the results of change can be interpreted with a degree of statistical confidence. Furthermore, there may be direct links with commercially valued resources such as fisheries, which provides added incentives for monitoring.

7.2.2. Keystone species

Keystone species have a substantial effect on the ecology of biota in an area. In some circumstances, monitoring these species can infer health of the ecosystem or the status of other species because the keystone species manages the population numbers of other species at the location. Understanding keystone species requires exceptional knowledge of the ecosystem and the interactions between species and the environment over time. Some examples of species thought to be keystone species include: the Western rock lobster that is thought to be a species with a regionally important trophic role in the south-west marine region (Department of the Environment and Water Resources 2007), coral reef fishes such as batfishes (Bellwood et al. 2006) and triggerfishes (McClanahan 1995), which are thought to influence algal growth and the abundance of urchins respectively and grapsid crabs, which have numerous effects on mangrove ecology such as community composition, sediment characteristics and nutrient recycling (Lee, 1998). They may range from apex predators to a prey type with an exceptionally large biomass. All of these species have significant roles in an ecosystem, and an oil spill impact that affects them may have long term consequences on their community (see Section 8.2.2). Consideration of ecological functions and processes are required in determining the importance of individual species.

7.2.3. Rare, threatened, endangered and iconic species or habitats

Monitoring wildlife species that are the subjects of recovery plans is likely to be important, since impacts from an oil spill are likely to be contrary to objectives of the relevant recovery plans. Furthermore, monitoring species that are the subjects of international conventions/agreements to which Australia is a signatory or party would demonstrate commitment to obligations to protect the listed species. A small number of species of seabed flora and fauna are protected under legislative frameworks such as the EPBC Act. Examples of these include listed threatened or vulnerable species e.g. Tasmanian sea stars, *Marginaster littoralis* and *Patiriella vivipara* and listed threatened ecosystems e.g. Giant Kelp Marine Forests of South East Australia. A number of Australian marine wildlife and fish species are listed as threatened fauna including Critically Endangered, Endangered, Vulnerable and Conservation Dependent including species from a number of taxonomic groups such as sharks, seasnakes, seabirds, whales, turtles and fishes. Furthermore, the incidence of any listed species relevant to the EPBC Act in the area of interest should also be investigated for OSMP purposes, as many of these are also iconic species (e.g. seals and sealions, turtles, dugongs, whales and dolphins or habitats such ascoral reefs as discussed in Section 8.2.3). The KEFs identified through the Commonwealth marine bioregional planning and described in the Conservation Values Atlas, should also be considered to guide the focus of monitoring in view of their important in relation to the Commonwealth marine area.

7.2.4. Sentinel and sensitive species

Indicator species chosen may be so-called sentinel species, which are sensitive and therefore an early warning system of an impact. Amphipods (e.g. *Ampelisca spp*. a filter-feeding tube-dwelling species,), filter feeding bivalves (e.g. *Ensis spp*. (razorshells)) and burrowing urchins (e.g. *Echinocardium cordatum* (heart urchin)) have been identified as the main casualties at a number of oil spills in the northern hemisphere, washing up on the beaches after spills. Densities of *Ampelisca spp*. were dramatically reduced over large areas of seabed following the Amoco Cadiz spill, and populations took 15 years to return to pre-incident levels (Dauvin, 1998). A similarly widespread impact was shown after the Sea Empress spills. Growth inhibition after one day of oiling in the brown alga *Fucus vesiculosis* led Wrabel and Peckol 2000 to suggest it to be a potential indicator species, and *Fucus gardneri* was also affected by the Exxon Valdez spill (Stekoli and Deysher 2000). Similarly coral species differ in their tolerance to disturbances (Yee et al. 2008; Golbuu et al. 2008) and these studies could be used to inform the choice of sentinel species for an assemblage. Good background knowledge of the species in general, as well as it's ecology in the area of interest will be required prior to use as an indicator.

Species may also be chosen according to hydrocarbon uptake. Hydrocarbon uptake potential in marine species will be influenced by feeding methods (e.g. greater in filter feeding species such as mussels), duration of exposure (i.e. highly mobile species less susceptible to oil exposure) and trophic level (greater uptake potential in higher trophic level fish, e.g. Xu et al. (2011)). Previous studies on hydrocarbon uptake (e.g. Nandini Menon and Menon 1999, Watts et al. 2006, Cheney et al. 2009) can potentially be used to inform decisions about choice of sensitive species as well as measurement thresholds.

7.2.5. Ecotoxicological knowledge

Prior knowledge of ecotoxicology can also be valuable in choosing indicator species. Where there is confidence in cause – effect pathways, the titleholder will have more flexibility in selection of indicators (multiple lines of evidence to choose from). This allows titleholders to match the level of monitoring effort with the level of environmental impact. An example of this flexibility and efficiency is the application to monitoring oil effects on mariculture production. If appropriate eco-toxicity studies were available to add confidence to cause-effect relationships in cultured species, water quality (in terms of oil concentration) could be an appropriate indicator of effects, providing an appropriate 'trigger' value (relating to an EC50 value for example) is set for implementation of fish monitoring. This would provide efficiencies as time and resource intensive fish monitoring would not be required unless oil concentration exceeded the trigger level. Furthermore, with appropriate water quality monitoring site selection, the program could provide early warning that oil concentration is reaching a level of concern and trigger additional management measures to protect sensitive resources.

For ecosystems in the northern hemisphere there is an abundance of published ecotoxicological methodologies using representative species of particular habitats that have been carried out in response to marine oil spills. Examples include periwinkles (*Littorina littorea*) (Livingstone et al., 1985), limpets (*Patella vulgata*) (Glegg et al. 1999), mussels (Livingstone et al. 1985, Lima et al. 2008a) microalgae (Gaur and Kumar 1981, Bratbak et al. 1982) and green algae (Tukaj 1987), shannys (*Lipophrys pholis*) (Lima et al. (2008b) and Santos et al. (2010), the common goby (*Pomatoschistus microps*) (Vieira et al. 2008). 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 can be amended to what is readily available and may be different for a range of habitats. However, it should be noted that there is currently a poor understanding of ecotoxicology for tropical and deep water species and hence caution is required when using northern hemisphere species as standards. Pilot studies using locally relevant species should be considered.

7.3. Spatial and temporal variation

Monitoring programs need to be designed to collect information over appropriate spatial and temporal scales. Determining what constitutes an appropriate scale requires consideration of factors including the nature and scale of the spill, the associated area of interest and response activities, the at-risk resources and uses, and knowledge of likely impact and recovery processes. The environment varies on a hierarchy of temporal and spatial scales, as does use of particular parts of the environment by biota e.g. migrations, nursery habitats. Therefore it will be difficult to detect oil spill impacts due beyond natural variation unless concentrations of oil or chemicals are very high, hence the importance of monitoring at an appropriate scale. An understanding of metocean conditions and the likely scale over which effects may be spread is required in order to determine the correct scales for monitoring. Well thought out cause-effect pathways should offer some guidance in determining the appropriate scales of monitoring. Environmental spatial and temporal variation is especially important in the design of an adequate baseline data set and should be applied to initiation and termination criteria for the OSMP. Spatial and temporal variation is discussed in Section 8 on Baselines and Section 9 on Initiation and Termination Criteria, and is a crucial element in determining the success of any monitoring program.

7.4. Selection of monitoring techniques

The next important step in the monitoring design process is to determine appropriate monitoring techniques. It may be appropriate to review the literature generated following previous spills, both petroleum and maritime, to determine which monitoring techniques have been most effective. These should be capable of being implemented, when the need arises to detect and measure the magnitude of environmental response(s) in the indicators selected. This Information Paper will not attempt to outline all potential monitoring techniques, or evaluate which techniques are most appropriate. An evaluation should be completed for each monitoring activity required in order to select techniques that are fit-for-purpose. It is likely that a suite of different techniques will be required for the range of predicted causes and effects. Where the effectiveness of monitoring techniques in a specific environment is uncertain, the use of pilot studies should be considered. It is recommended that the use of subject matter experts be consulted for the all aspects of the OMSP including selection of monitoring techniques.

Some important items for consideration in the selection of monitoring techniques include:

- assessing the comparability with techniques used to collect available baseline data, especially where primary purpose for data collection was not directly related to oil spill impact assessment
- considering factors such as seasonality or particular times of day when monitoring is most appropriate and effective (for example, presence of migratory species may be seasonal and species such may display marked diurnal movement patterns)
- assessing the needs for, and securing, any conservation and animal ethics approvals before undertaking proposed monitoring
- providing assurance that techniques proposed will allow collection of sufficient numbers of samples to meet a high standard of scientific rigor, noting that the monitoring may need to occur for some time following the spill to detect the less obvious effects of hydrocarbon contamination
- determining if the technique is suitable for the receiving environment (e.g. demonstrating that any risks posed by a particular technique do not outweigh the benefits of conducting monitoring in that way)
- with respect to maximising integration, evaluating whether techniques applied in operational monitoring and response activities provide data in a format and timeframe that allows it to provide timely context for scientific monitoring
- determining the requirements for subject matter experts required to implement certain monitoring techniques and in turn ensuring that those experts are available and operationally ready
- relevance of technique to applicable standards, i.e. where the intent, for example, is to compare hydrocarbon levels measured in shellfish tissues with available seafood safety standards
- will the technique provide data in a format and timeframe that allows a timely management response to mitigate further impacts, i.e. lead time for laboratory to provide result in relation to time till expected oil impact on sensitive resource
- whether appropriate non-extractive monitoring techniques are available to minimise the environment impacts of monitoring (e.g. use of video technique to measure fish population structure as opposed to trawl surveys, use of genomic techniques)

These items apply to the monitoring of all biological receptors, considerations more specific to the different kinds of biota are presented in Appendix 5.

7.5. Selection of potential impact and reference/control sites

Care needs to be taken when selecting monitoring sites to ensure that the distribution of sites is as representative as possible of the area of interest. The selection of sampling sites and spatial distribution of individual sampling points is best decided after detailed appraisal of baseline data from a sufficient number of sampling locations and times to provide information on spatial and temporal variability.

The process of choosing individual sampling points should consider a number of factors, including the particular oil-associated stressor being investigated, its effects on selected receptors, the variability in the indicators of interest, factors influencing that variability and the magnitude of variations which require characterisation.

Potential impact monitoring sites should be located within the area predicted to be impacted by credible spill scenarios and associated planned response activities. Their specific locations and distribution should be informed by the predicted behaviour and fate of oil, the likely response activities and the distribution of sensitive receptors. Sites should be positioned relative to the spill source to allow the full extent, severity and persistence of impacts to each sensitive receptor to be determined. As data from monitoring sites become available and are interpreted, if it becomes evident that some sites initially predicted to be influenced by the spill were actually not influenced in any way, a case may be presented for these sites to be transitioned into reference sites for the remainder of the monitoring program. Depending on the monitoring design, a modification of this nature can have the effect of increasing the power of the monitoring program to detect change.

Suitable reference/control sites should be as similar as possible to the associated potential impact monitoring sites, but be located to ensure they are not influenced in any way by the spill or response activities. In this way, data from reference/control sites provide information about the background condition of the environmental features being monitored at potential impact sites. In simple terms, data from suitable reference and control sites serve as a basis for interpreting data collected at monitoring sites. Data collected from reference sites during a spill also serve to maintain contemporary baseline information to complement that already collected.

Titleholders should be mindful that spills which potentially influence very large areas, can present problems for establishing suitable reference sites due to the large geographic separation of un-influenced areas from potential impact monitoring sites. In these situations, adequate baseline data will be critical for ensuring that the monitoring program will achieve its overarching objectives.

There needs to be a degree of flexibility, and possibly redundancy, built into the planning of potential impact and reference/control sites. This is to allow scientific monitoring program design to be adaptable to data coming in from operational monitoring, which documents key characteristics of the actual spill. Adaptability will ensure that data collected at each site can fulfil its purpose (e.g. to indicate impact or background conditions).

7.6. Replication, precision and power

A critical aspect of monitoring program design is to determine the number of samples required to achieve the objectives of the program. The variability inherent in natural systems gives rise to statistical uncertainty, which can be controlled by sampling an appropriate number of representative sites and taking an appropriate number of replicate samples at each site.

Insufficient site and sample replication can bias findings of monitoring programs in one of two ways. Type I errors are effectively false positive outcomes (a cause for concern when it is in fact not warranted) and Type II errors give rise to a 'false sense of security' when it is concluded that there is no effect when, in fact, there is one. Monitoring program design should aim to minimise Type I and Type II error rates and at the same time maximise cost effectiveness and scientific rigour.

Statistical power is a relevant consideration in this regard. In simple terms, statistic power is a measure of the likelihood that a monitoring program will detect an effect when there is an effect there to be detected. When statistical power is high, then the probability of making a Type II error is reduced.

Statistical power that can be achieved by a monitoring design is affected by the magnitude of effect the program aims to detect and the size of the sample used to detect it. Essentially, bigger effects are easier to detect than smaller effects, while larger numbers of samples tend to produce greater test precision than a small number of samples.

While power, replication and precision are key issues for consideration, it is strongly recommended that specialist statistical advice be sought on matters of experimental design and statistics.

7.7. Quality control

Quality assurance (QA) and quality control (QC) is a key part of instilling confidence in the program. QA/QC measures that should be considered include:

- establishing clear chains of custody, roles and lines of responsibility and processes for sampling, data collection, data entry/management, statistical analyses and interpretation
- maintenance of systems to ensure that those responsible for packages of work are appropriately qualified/accredited to do the work and are competent in the specific tasks
- maintenance of metadata
- processes for data backup, storage and archiving
- establishing process for regular review of the OSMP.

7.8. Data analysis and interpretation

There are no specific requirements for the use of particular data analysis tools or methods, however titleholders are encouraged to seek specialist advice in relation to experimental design, data analysis and interpretation matters during the planning phase to assure credibility of interpretation and that the objectives of the program can be achieved.

7.9. Peer review

Peer review, particularly for specialist or technical elements of an OSMP, is highly recommended at the drafting stage. The Montara Commission of Inquiry also found that monitoring programs should be subject to peer review. Peer reviewers should be suitably-qualified and well-regarded amongst their peers for work in the area they are being asked to review. Terms of reference for peer reviews should set out clear tasks and ideally be made available with the final OSMP, along with a peer reviewer's close out report that describes the degree to which the peer reviewer considers their comments have and have not been addressed. Titleholders should note that while peer review is considered a valuable process by the regulator, it does not remove the need for NOPSEMA to assess the full EP for compliance with the Environment Regulations.

Consideration should be given to the conceptual and technical information and principles presented in this section regarding monitoring design.

APPLICATION

Marine environments are inherently complex, diverse and spatially and temporally variable and it is therefore critical that appropriate levels of prior planning are completed to ensure that a rigorous monitoring program can be rapidly implemented in the event of an oil spill. If no or only very limited prior planning has occurred, it would be extremely difficult to implement a robust and scientifically sound monitoring program in an appropriate timeframe in an emergency situation. The following advice provides a possible approach to the practical application of an OSMP. With the planning and design work completed, a titleholder should be well placed to effectively mount an environmental monitoring response to an oil spill incident; however it is also important that appropriate system level measures (specific systems, practices, procedures, roles and responsibilities, competency and training) are in place to ensure that a titleholder is, and remains, ready to apply the program.

Titleholders should be prepared for requests from third-parties (e.g. Government agencies or parties acting for them) to facilitate access to areas near by a facility for the purpose of environmental monitoring. Titleholders are therefore strongly encouraged to include arrangements within the OSMPs to facilitate reasonable requests for such access, subject to the proper consideration of safety and other relevant matters under the OPGGS Act. Furthermore, implementation arrangement for OSMPs should plan for higher expectations for transparency of findings than might have been the case in the past. Titleholders should plan to share findings of their OSMP as they become available with relevant authorities. Consistent with maintaining a social licence to operate, titleholders should also plan strategies for disclosing findings with relevant stakeholders.

8. Baseline studies and data

Various inquiries into the environmental management aspects of the Montara and Macondo incidents have found that a lack of adequate baseline data was among the major impediments to determining the environmental effects of the incidents. Accordingly, it is critical that performance in the area of understanding the pre-spill or baseline environment is significantly improved.

Titleholders should consider identifying and then to the extent possible, making the most of any overlap of the general information requirements for the EP and the OSMP (e.g. description of the existing environment and the evaluation of impacts and risks), when compiling baseline information. This should reduce duplication of effort and to help focus attention on the parts of the existing environment for which further baseline information is required to design and implement the OSMP. Notwithstanding, titleholders should be mindful that specific tasks may demand differing levels of detail. For example, while a relatively general level of baseline information about the structure and function of coral reefs within an area of interest may be adequate for impact and risk assessment purposes, considerably more resolute baseline ecological data may be necessary to design and implement coral reef monitoring elements of the OSMP. Where necessary, or if in doubt, titleholders should seek their own specialist advice on the specific baseline information requirements for various impact and risk assessment and monitoring tasks.

There are considerable benefits associated with having baseline data. Since natural systems vary in time and space due to natural events (e.g. tropical cyclones) or other non-spill related anthropogenic influences (e.g. climate change effects), good baseline data can allow titleholders to discriminate effects of a spill from change in the environment attributable to other factors. Similarly, investigations aimed at identifying chemical characteristics (e.g. finger printing) and toxicity of reservoir hydrocarbons at a number of stages of the weathering process should also be considered part of baseline studies. Data on the breakdown products, toxicity and predicted environmental fate of oil-dispersant mixtures are also likely to be valuable assets. For example, this type of information would be useful for interpreting data from post-spill studies aimed at monitoring the fate and impacts of oil-associated, particularly in areas known for their natural hydrocarbon seeps where it would be important to have capacity to discriminate potential sources of any detected hydrocarbons.

In the following sections, general advice is provided on each of the topics above with a focus on their application to the design of scientific components of a fit-for purpose oil spill environmental monitoring program.

8.1. An adequate environmental baseline

Once key environmental values and sensitivities within the area of interest have been identified and indicators selected for the monitoring design, it is necessary to understand their baseline condition. Importantly, this evaluation of baseline environmental conditions should consider physical (e.g. water and sediment) as well as biological aspects of the environment and extend to socioeconomic values (e.g. human uses). A possible framework based on the use of conceptual process models and cause-effect pathways to link oil-associated stressors with responses in sensitive environmental receptors as a means of identifying indicators is outlined in Section 4.

While it is generally accepted that baseline environmental data is necessary to interpret environmental monitoring data in the context of natural variability, there are no specific criteria that signify that a baseline data set is adequate. This is hardly surprising given the vastness of Australia's offshore area, the diversity of environmental values that could be affected by a spill, the range of possible responses those values might display and the wide array of different techniques available for monitoring. Nevertheless general advice on what might reasonably constitute an adequate environmental baseline can be gleaned from general knowledge of the ecology of Australia's marine environment, the overarching aim(s) of the scientific element of an OSMP as well as relevant findings of the Montara Commission of Inquiry.

In all cases, titleholders should be able to demonstrate that their experimental design would allow environmental impacts arising from an oil spill to be detected and separated from natural variation. Baseline sample points should be representative of the receptor's distribution and there should be a sufficient number of sample points spread over a suitable area and timeframe to properly characterise spatial and temporal variability. Further, the indicators monitored for a given value should be relevant to that value's response to oil-associated stressors.

Scientific monitoring may require a multi-year commitment. Based on experience from previous incidents such as the Exxon Valdez spill, monitoring of wildlife populations for example has been occurring at varying frequencies since the spill in 1989. In view of this, adequate baseline data for the indicators to be measured by scientific monitoring is of utmost importance if the monitoring is to allow impacts to be detected and disentangled from natural variability in population parameters. It is acknowledged that long term data sets focussing on appropriate indicators are not easy to collect or readily available. It is common for titleholders to refer to data collected by others as forming a part of the baseline information on species and populations. While this is a generally legitimate approach to acquiring adequate baseline data, it is important to recognise potential limitations. For example, while existing data may focus on an indicator suitable to meet the requirements and standards of the original collector, this does not necessarily mean that data for that indicator would constitute an adequate baseline to support a fit for purpose OSMP

As a general principle, an environmental baseline data set may be considered adequate if it would allow the titleholder to confidently detect spill effects in view of natural background spatial and temporal variability, and determine the extent, severity and persistence of oil spill impacts on environmental values and sensitivities relevant to the area of interest.

Overall, the success of the OSMP is dependent on a strong understanding of baseline environmental condition including information about the characteristics of reservoir hydrocarbons.

8.2. Natural variability

The natural environment and society's use of it is inherently variable. This environmental variability occurs over a range of spatial and temporal scales.

Knowledge of inherent spatial and temporal variability in the environment is required to ensure that monitoring activities collect appropriate data and those data are interpreted correctly. General considerations and sources of variability that may be relevant to the design and application of the OSMP, including associated baseline studies, are listed briefly below.

Spatial Variation

Variation on general themes:

Habitats of a similar general type vary, sometimes subtly and sometimes grossly, in space across gradients of exposure, temperature, water depth and other environmental variables. Application of the OSMP, including baseline studies, should aim to prevent (or where prevention is not possible minimise) the influence of environmental variables such as those above from confounding the interpretation of monitoring data.

Small-scale patchiness:

Besides the larger scale and more obvious patterns of variation that can be evident in the distribution and abundance of marine flora and fauna, small-scale patchiness that results from variation in microhabitats may also need to be considered. Spatial extent and replication of sampling may help to control for the influence of small-scale variability on monitoring data and its interpretation.

Vertical zonation/distributions:

The distributions, presence and abundances of marine biota often vary across environmental gradients. For example, biota and the associations they form vary across vertical gradients from the supratidal zone, through the water column and on the seabed with increasing water depth. Gradients in water temperature and light availability are key drivers of the types and distributions of biological communities present, while a water depth is important factor influencing commercial fisheries for example. Since the location of receptors along environmental gradients influences the risk of exposure to oil-associated stressors and the interpretation of monitoring data, spatial zonation may an important consideration for the design of many OSMPs.

Temporal variation

Diurnal variation:

The time of day can be an important consideration for timing of sampling, particularly when abundance is a key indicator for some fauna species, to ensure comparability of data. Peoples' use of the environment also varies markedly between day and night.

Seasonality:

Many plant and animal species exhibit marked and readily-predictable seasonality with respect to their abundance, distribution and key ecological processes such as reproduction - aspects that influence a species' susceptibility to the effects of oil-associated stressors. Similarly, since socio-economic effects of spills can be strongly influenced by the time of year that impacts occur (e.g., impacts on strongly seasonal tourism or fishing activities). Accordingly, to ensure that appropriate indicators are selected and monitoring data are interpreted correctly, capturing seasonality will be an important design consideration for some receptors.

Inter-annual variability:

The shorter scale diurnal and seasonal variability introduced above almost always vary to some degree between years. Inter-annual variability in the environment may be influenced by large-scale climate processes such as El Nino-El Nina for example or longer term ecological processes such as succession. As a spill event is unpredictable, an understanding of inter-annual variability is important for interpreting monitoring data, particularly for indicators that might be monitored for some period of time following a spill event.

8.3. General approaches to conducting baseline studies

Planning to collect baseline data should always be complete well in advance of any spill occurring. This principle applies to baseline studies that are conducted well in advance of an oil spill and is particularly important for reactive baseline studies where timeframes for successful implementation might be short. A further design principle is that baseline studies should allow the natural spatial and temporal variability of sensitive receptors to be described at scales and using indicators relevant and appropriate to oil spill monitoring. Furthermore, as for all monitoring studies, titleholders should demonstrate a sound scientific basis for their baseline studies and describe selection criteria for impact and un-impacted control/reference sites. The scientific design, including site selection should consider the end use of the data in interpreting data collected through the OSMP. Operations are also encouraged to give attention to information in published guidelines when planning surveys on specific groups of biota or species (e.g. EPBC Act policy statements and guidelines published at www.environment.gov.au).

Baseline environmental data may be obtained through desktop studies, dedicated field surveys or environmental monitoring programs conducted during routine operations. Strategic partnership arrangements might also be considered as a means of developing regional baseline understanding, including the maintenance of an up-to-date baseline.

For some locations or specific environmental values there may be sufficient existing and available data to justify a desk top study as the primary means of drawing together an adequate baseline data set. Some general points to consider when deciding whether existing data may be sufficient to justify a desk-top study include:

- assurances that existing environmental data are available and accessible
- confirmation that raw data are accompanied by appropriate metadata that describes how, when and why they were collected, who collected them and caveats that need to be observed
- considering the above, assessments of whether the existing data actually represent baseline conditions
- spatial coverage of data that includes the EMBA from largest credible spill scenario, and extends to outer parts of the area of interest where it may be appropriate to establish reference sites
- the time elapsed since data were collected and the potential risk that recent natural disturbances such as those associated with tropical cyclones will not have been accounted for
- appropriate temporal coverage to allow understanding of natural temporal variation at diurnal, seasonal and inter-annual variations as relevant
- considerations around whether the available data are directly related to what is being measured in the OSMP.

Where gaps in pre-existing data are identified, attention should be given to collecting data to address those gaps, with priority given to selected indicators for the OSMP relevant to the values/receptors considered particularly vulnerable to oil-associated stressors and ecologically and/or commercially important (IMO, 2009).

Attempts are often made to establish environmental baselines by conducting a one-off field program or by assembling information from other one-off field studies with a desk-top study. While a one-off study may be adequate to develop an understanding of the environment at one point in time, a single baseline study is, by definition, inadequate for determining patterns of natural temporal variability. For example, a one off baseline study will not characterise patterns of habitat utilisation by highly mobile or migratory species or the longer term changes to species, populations, communities and ecosystems that might occur in the face of climate change effects. One-off studies are also likely to fail to identify key ecological windows, such as readily predictable periods of the year or sites known to be important for key ecosystem processes (e.g. reproduction in corals fish and turtles) or social uses (e.g. aquaculture leases or commercial fishing areas). In principle, baseline studies should be designed with the scientific component of the OSMP in mind to maximise the utility of baseline data for achieving the overarching aim of the program.

Environmental monitoring conducted during routine operations (e.g. to determine whether environmental performance outcomes and standards are being achieved) can make valuable contributions to baseline data sets. Monitoring conducted during routine operations can serve to establish time series data and maintain up-to-date environmental baseline data sets for environmental values and sensitivities at reference sites that are not influenced by routine operations but which are predicted to be impacted by a spill. Data from routine monitoring may be particularly valuable in situations where the initial baseline data has coarse resolution or was collected with only limited survey effort. For example a time series of water quality data collected during routine operations at un-impacted reference sites can be used to derive site-specific water quality guideline values (i.e. using methods set out in ANZECC & ARMCANZ, 2000) which may be valuable for evaluating the performance of spill response activities or forming the basis of initiation/termination triggers for the OSMP.

While tactical activity-specific baseline studies can provide information that meets the standard of an adequate baseline, consideration may also be given to more strategic approaches to characterising the existing environment. Strategic approaches might involve partnerships or collaborative arrangements to allow cost and data sharing. By bringing resources together from a number of parties, baseline studies may be able to be extended over larger regional or sub-regional spatial scales and for longer periods of time, than what might be achievable without pooling resources. Strategic approaches have the potential benefit of delivering more consistent data that may have broader utility. Truly collaborative programs can have benefits over more tactical activity-specific studies in that they can allow better characterisation of natural environmental variability and provide resultant data to each collaborating partner at a cost to each partner that may be comparable to the cost of conducting a series of local and less resolute short term baseline studies.

Developing an understanding of the variability of natural systems is best achieved though longer term baseline studies which, by definition, should be planned and executed well in advance of a spill occurring. However, there may be some environmental values for which titleholders might wish to present a case to substitute more proactive baseline studies with 'reactive' baseline studies. A reactive approach should generally be a last resort or used to update existing baseline data with 'up to the minute' information. A reactive baseline study would target at-risk sensitive environmental receptors and be conducted after a spill commences but before those receptors are exposed to any oil-associated stressor. In proposing a reactive baseline study, titleholders would be expected to demonstrate that relevant scientific issues have been evaluated and the approach is appropriate to the nature and scale of the activity. An example of one such issue would be provision for the proposed reactive baseline study to not only collect data on the receptor of interest, but concurrently demonstrate that the receptor not been exposed to an oil-associated stressor at the time data were collected. It may also be necessary to consider contingency measures in the event that the receptors of interest are shown to have been exposed to an oil-associated stressor. Similarly, titleholders would also be expected to carefully appraise practicalities and logistical issues that are key determinants of the success of a reactive baseline. For example, travel/mobilisation times for people and equipment, and access to certain areas (e.g. for health and safety reasons) should be carefully considered as these issues have potential to compromise the ability of a reactive program to provide adequate baseline data. With these issues in mind, titleholders should expect particular scrutiny of cases to conduct reactive baseline studies in remote or particularly sensitive areas. In presenting their case, titleholders should be mindful that the same general adequacy principle that applies to more proactive baselines should also be applied to reactive baseline studies – effectively that pre-impact environmental data should be adequate to allow the titleholder to detect environmental impacts attributable to an oil spill and disentangle impacts from natural temporal and variability.

8.4. Water sediment quality baseline considerations

The availability of robust water and sediment quality baseline data is a basic requirement when investigating a potential ecological impact from an oil-associated stressor. In the context of water and sediment quality monitoring, an evaluation of the distribution and bioavailability of an oil-associated stressor should consider key concepts such as chemical characterisation, ecotoxicology, biodegradation and bioaccumulation using a variety of both laboratory-based simulations and field-based studies. Planned environmental monitoring activities that are informed by baseline data will improve incident response time and greatly enhance monitoring efficiency by minimising unnecessary (and potentially costly) field based activities.

An important prerequisite for undertaking water and sediment quality baseline studies is prior knowledge of the oil-associated stressor, although often the reservoir specific crude oil or condensate may not be available, e.g. exploration drilling activities. Under such circumstances, a suitably representative analogue (in association with relevant literature) will provide equally useful information, however the baseline studies should be updated using the actual reservoir specific hydrocarbon product, when this material becomes available. The type and complexity of the baseline studies will also depend on considerations for the nature and scale of the activity (see Section 15).

Robust baseline studies incorporating key concepts such as chemical characterisation, ecotoxicology, biodegradation and bioaccumulation provide useful information regarding the fate, toxicity and persistence of an oil-associated stressor in the water and/or sediment. Examples of water and sediment quality baseline studies may include (though are not limited to) background water and sediment quality surveys, simulated weathering studies with dispersant efficacy testing, and deriving reliable species protection trigger values. The availability of baseline data will provide greater confidence for evaluating impacts in the event of an oil spill and may assist with prioritising appropriate monitoring activities. The following examples have been selected to demonstrate studies which provide useful information for evaluating the distribution and bioavailability of an oil-associated stressor in water, sediments and biota

8.4.1. Background water and sediment quality

Hydrocarbon and non-hydrocarbon oil-associated stressors released into the marine environment will partition to the water and/or sediments within the ecosystem compartments. Establishing the existing background levels of an oil-associated stressor in the water and sediment provides a useful reference for determining the extent of distribution, change in environmental concentrations, and potential risk to biological receptors exposed within the area of interest.

The analysis of target analytes in the baseline field survey should be quantitative to allow direct comparison with post spill levels. However, semi-quantitative methods may be acceptable for the purposes of screening and identifying the oil-associated stressors when characterising a crude-oil or condensate. Similarly, where a baseline field survey is unavailable or out-dated, a semi-quantitative approach may be useful for determining the presence or absence of oil-associated stressors in the water, sediment and biota for further investigation.

Detailed further reading on baseline water and sediment quality and various approaches is presented in Appendix 5.

8.5. Maintaining the baseline

As noted earlier, since large scale influences such as large scale climate variability or extreme weather event can affect the baseline condition of the environment, maintaining a current baseline can be very valuable for correctly attributing potential causes of change. If for example a marine oil spill occurred around the time and in the vicinity of a large coral bleaching event, in the absence of supporting data observers may suggest that bleaching of corals occurred as a direct result of the spill. However, up to date baseline data for sea water temperature and regional reef health, would provide a strong line of evidence to suggest that observed coral bleaching is unlikely to have occurred as a direct result of the spill and more likely to be a result of thermal stress for example. Notwithstanding, effects of the spill may influence the capacity for and rate of recovery from bleaching.

There are a number of means by which titleholders could consider maintaining an up to date baseline. As already mentioned, environmental monitoring during routine operations can be used to develop time series data and in doing so provide contemporary empirical data on the condition of the environment. Similarly, strategic data acquisition programs can also provide for longer-term surveillance of the environment than might be possible under a localised activity-specific study. Data sharing among users of the environment can also help maintain a contemporary baseline data set, but careful consideration needs to be given to methodological and data consistency issues to maximise utility of shared data. Finally and also as already discussed, reactive baseline studies can be considered for providing very up to date pre-impact information, if well justified.

Environmental baseline data set may be considered adequate if it would allow the titleholder to confidently detect spill effects in view of natural background spatial and temporal variability, and determine the extent, severity and persistence of oil spill impacts on environmental values and sensitivities in affect parts of an area of interest.

As a general rule, studies designed to establish an adequate environmental baseline should be planned and executed well in advance of any spill occurring.

Proactive baseline studies may be desk-top, field-based or utilise other monitoring data (or be a combination of these approaches) and should aim to define natural spatial and temporal variability of sensitive receptors at relevant and appropriate scales.

Titleholders may consider presenting a well-supported case to justify 'reactive' baseline studies where there are inadequate baseline data.

Baseline studies should consider the benefits in the OSMP have a multiple-lines-of-evidence approach to measurement of impact.

It is important to maintain an up-to-date baseline data set.

9. Initiation and termination triggers

The OSMP should include initiation and termination triggers for the various elements of environmental monitoring. These may be empirical values or narrative statements that relate directly to the threats that an oil spill would pose to environmental features, sensitive receptors or an environmental performance outcome set in the EP. In all cases, initiation and termination criteria should be specific to stressors and receptors, measurable and have a time component.

The description of the environmental values and sensitivities and evaluation of impacts and risks that is set out in the EP should provide valuable context for the setting of initiation and termination criteria for inclusion in the OSMP. For example, triggers may reflect a defined level of protection for environmental values and/or achievement of appropriate environmental performance outcomes and standards that are identified in the EP. Alternatively, they may be informed by a detailed description of the baseline or another suitable reference conditions

When setting the triggers, careful consideration will need to be given to ensuring that appropriate information would be available to allow assessments against the triggers. This is particularly relevant where triggers for initiating elements of the scientific monitoring are based on findings of operational monitoring. In these cases, titleholders should ensure that the relevant components operational monitoring are sufficiently rigorous to minimise the chance of not triggering scientific monitoring when in fact it should have been triggered (i.e. a Type II error).

Initiation triggers for scientific monitoring may not always rely on empirical data from operational monitoring. In some cases it may be appropriate to initiate scientific monitoring based on the nature and scale of the spill event itself or decisions to implement a particular response activity. For example, depending on the nature and scale of a credible spill scenario or how events play out on the day, it may be appropriate for initiation triggers for all scientific monitoring elements of the OSMP to be simply based on the occurrence of a spill. In such a case, particular aspects of monitoring may be terminated if compelling evidence can be produced to justify the termination of those aspects. Similarly, monitoring programs to determine impacts on seabed and pelagic species and communities may be triggered by a subsurface spill incident or a decision to apply dispersant to spilled hydrocarbon.

Termination criteria should be based on measurable points that demonstrate environmental values and ecological structure and function have been fully restored, either naturally or through active management intervention. Where there is a high degree of scientific uncertainty regarding the recovery potential and timeframes for some environmental features, this should be explicitly recognised in termination criteria. The framework based on the environmental values as described in the National Water Quality Management Strategy and outlined in Section 4 may provide helpful guidance.

If initiation or termination criteria comprise multiple components, then it is important to clearly define how a breach of a trigger (which would lead to initiation or termination of an OSMP element) would be interpreted. It would be appropriate to consider the precautionary principle (a foundation principle of ESD), when defining what would constitute triggering of any multifaceted criteria (i.e. a breach of a single component of the trigger would initiate monitoring).

Titleholders may wish to consider a ‘sign-off’ procedure for decision-making around the implementation and termination triggers. The intent of a sign-off procedure would be to provide for expert and/or stakeholder oversight of the suitability of information used for assessment against the triggers and the decisions taken in concerning the triggers. Where triggers are reflected in environmental performance outcomes and/or standards, a sign-off procedure would provide a mechanism for validating the titleholder’s environmental performance with respect to application of the triggers. Some guidance, including a possible template for a sign-off procedure is provided on the Environment and Science Coordinators Toolbox section of the AMSA web site[1].

> Appropriate initiation and termination triggers should be provided for elements of the OSMP. The triggers should be measurable and reduce ambiguity in their interpretation.
>
> Careful consideration is needed to ensure that appropriate information will be available to make assessments against the triggers.

In all cases, time is particularly important when considering initiation criteria for the scientific component of the OSMP. Accordingly, it is important that the triggers themselves and the triggering mechanisms eliminate or at least reduce 'grey areas' of interpretation. To effect sufficiently prompt implementation triggers should be constructed such that it can be clearly and consistently determined if they are breached or not. Speedy implementation also relies on an appropriate degree of readiness to execute scientific monitoring to ensure that sampling windows for evaluating short term effects do not close before monitoring can commence.

10. Personnel, logistics and infrastructure

When considering whether an OSMP is fit-for-purpose it is important to consider readiness, and more specifically:

- Is the plan ready with the people (e.g. suitably qualified personnel), logistics (e.g. vessels, accommodation), physical infrastructure (e.g. telecommunications) and adequate baseline data to promptly apply operational and scientific monitoring?

In answering this question of readiness, there are a number of tests that could be applied, including:

- Are the resources identified suitable for the task and location?
- Are these resources available and how will availability be maintained for the duration of the petroleum activity?
- Are the resources operationally ready and how will readiness be maintained for the duration of the petroleum activity?

The suitability of logistics resources to support monitoring efforts should consider the site specific constraints such as water depth in relation to vessel draft and safe diving or telecommunications network coverage in relation to data transmission. Suitability should also be considered in terms of whether equipment will be appropriately supported by vessels, e.g. is appropriate lifting equipment available. Important considerations for personnel will include items such as experience and competency.

[1] http://www.amsa.gov.au/Marine_Environment_Protection/National_plan/Environment_and_Scientific_Coordinators_Toolbox/Foreshore_Assessment_and_Termination.pdf

The availability of resources should be considered in terms of contractual and logistics arrangements. For items of equipment that are critical for the success of monitoring, measures such as standby arrangements or contingency suppliers should be considered. The maintenance of availability may require regular testing of arrangements with relevant service providers.

Operational readiness of personnel and equipment is critical as the absence of appropriate operational readiness testing can result in significant delays, particularly in remote areas. Operational readiness assessment should consider what needs to happen before a person or a piece of equipment can be mobilised to a monitoring location and cover internal and external requirements. Important factors may include, but are not limited to, marine and terrestrial quarantine, training and induction requirements, compliance audits, fauna and flora collection permits, site access permissions and procedural documents (e.g. safe work instructions). These factors can present significant challenges and therefore close attention should be given to these issues early in the planning process.

It is also important to consider that the definition of operationally ready will differ depending on the nature and scale of the credible spill scenario. For example, if an oil spill scenario involved oil potentially contacting sensitive environmental receptors within a number of days a greater level of readiness would be expected to be demonstrated than for a scenario where the spill site is relatively distant from sensitive environmental values. The OSMP (or elsewhere in the submission) should demonstrate that resources can be mobilised within a timeframe that is appropriate to the nature and scale of the spill risk.

10.1. Demonstration of readiness

Evaluation of the readiness of required personnel, logistics and infrastructure should be documented to ensure that readiness can be demonstrated as part of an EP submission. This demonstration of readiness should include provision of appropriate evidence. Items that may need to be verified as part of a readiness demonstration may include, but are not limited to:

- Vessels are suitable to carry out OSMP scope, have met or will meet the titleholder's internal operational readiness requirements (e.g. HSE audits etc.) and have appropriate contracts in place.
- Environmental service providers have relevant experience and competencies, adequate resourcing, appropriate contracts in place, adequate understanding of the scope of work and have undergone an operational readiness assessment.
- Environmental monitoring equipment is available and ready to mobilise, including consideration of calibration and suitability for specific operating environments.
- Transport modes and routes, storage and accommodation for equipment and personnel have been assessed, with appropriate arrangements in place.
- Chain of custody procedures for environmental samples are established.
- Logistics issues such as marine and terrestrial quarantine requirements and specific training requirements have been addressed.

This evidence may take many forms, but one potential approach is to include the full text of consultation outcomes from readiness discussions with relevant OSMP service providers. Regardless of the approach, it is important that titleholders demonstrate readiness and not simply availability. An appropriate service provider may be 'available' to assist, but in the absence of an operational readiness check considering important items such as those above, it may be a matter of weeks or even months before they are ready to mobilise and safely and effectively implement the OSMP. on may include, but are not limited to:

10.2. Health and safety

Routine operations of the offshore petroleum industry carry a level of risk to human safety. Conducting activities in response to emergency events can be expected to present even higher levels of risk. Accordingly, it is essential that all necessary precautions are taken to ensure the health and safety of people involved in applying the OSMP. Potential hazards should be identified early in the planning process, with one approach being to facilitate a hazard identification workshop or similar to ensure all relevant hazards are identified and appropriate safety measures are in place prior to a spill event. The timely provision of training, procedural documents (e.g. safe work procedures), personal protective equipment and other safety measures identified should be incorporated into planning for the OSMP and demonstrated in the submission.

10.3. System level measures to ensure readiness

The review of personnel, logistics and infrastructure requirements to meet the environmental performance outcomes related to the OSMP should be supported by system level measures that will be implemented to ensure that these resources are ready and that the outcomes and standards can and will be met. These system level measures may include planned audits, operational readiness testing or training schedules and should be relevant to the roles and responsibilities of personnel, training and competency requirements, specialist equipment needs and health and safety considerations.

Drills, audits and exercises are one example of the kinds of measures that can be implemented to ensure readiness. Where measures of this nature are used they should be relevant to the specific OSMP requirements to ensure important shortfalls are identified early. Additionally, the description of drills, audits and exercises proposed to test OSMP readiness should include the additional measures or changes that will be taken to address any identified shortfalls.

10.4. Collaboration and partnerships

Implementing environmental monitoring programs can be resource intensive and require a wide variety of scientific and technical skills, all of which may not be immediately available to the titleholder. In view of this, consideration may be given to whether entering into collaborative or partnership arrangements may offer a suitable means of ensuring the right skills are applied and to share the burden of monitoring. Partnerships and collaborative approaches may be particularly beneficial for establishing appropriate environmental baselines in remote, biodiverse and/or geographically large areas.

Well-designed collaborative studies can bring greater levels of resourcing to bear on addressing an issue than might be possible with a tactical activity-specific approach. Benefits of collaborations include allowing for consistent approaches to data collection over larger spatial scales and for longer periods of time than what might be achievable without pooling resources. Truly strategic collaborative programs can allow better characterisation of the natural environment and by doing so provide a greater degree of confidence in the findings of post-spill studies aimed at measuring effects. Strategic collaboration can also result in lower cost to each collaborating partner for a comparable or even higher standard of information than might able to be delivered by conducting a series of local and less resolute short term studies.

Coordination of monitoring activities between different organisations is also critical to ensure that monitoring effort is focussed on relevant indicators of environmental condition and unnecessary duplication is avoided. Advice is offered in Section 4 on a framework for identifying indicators of the environment's response to oil.

11. OSMP outcomes

The results of the OSMP should be used to inform management actions at a variety of levels including; reporting, response actions, reflecting on goals, deciding if further studies are required and directing clean-up and remediation efforts if necessary. All management actions arising from monitoring results should be clearly outlined in the OSMP. These actions are described in further detail below.

11.1. Reporting results and performance monitoring

The Environment Regulations set out a range of reporting requirements. Titleholders should ensure that these requirements are appropriately reflected in their EPs and OSMP. Reporting the results of the monitoring programs should be of a sufficient level for the titleholder and the Regulator to determine if the goals of the titleholder in protecting the environment were met during the oil spill response operations. Titleholders should expect that scientific results of the OSMP, as well as operational details of OSMP implementation will need to be reported. The form, content and frequency of this reporting should be clearly outlined and be appropriate to the nature and scale of the activity.

The form and structure of reports needs to address requirements of the Environment Regulations and further information on these requirements can be sourced from published guidance on the NOPSEMA website. Where possible, titleholders may consider tailoring reports to suit multiple audiences such as NOPSEMA and a broader audience and stakeholders to inform the outcome of the spill and response efforts. A clear demonstration of a proactive response to the spill, monitoring its effects and commitment to clean-up if necessary will assist in maintaining a social licence to operate.

11.2. Spill response actions

In preparation for an oil spill response, preventative controls are firstly identified to try and prevent a spill and secondly mitigation controls are identified to contain spilled oil and prevent it from spreading further once a spill has occurred. Environmental performance standards are set which define the level of performance required of those controls and the results from the OSMP may be used to help determine if the spill response met those standards. This particularly applies to controls that were designed to prevent oil from spreading beyond pre-determined limits and reaching sensitive environmental receptors. The results from the operational monitoring under this scenario can also be used to trigger scientific monitoring as discussed earlier in Section 9. For further information on environmental performance standards please refer to published guidance on the NOPSEMA website for EP preparation.

11.3. Reflecting on goals

Scientific monitoring results may be used to determine if the environmental protection goals of the titleholder, expressed as environmental performance outcomes in the EP, are being met. Goals related to the prevention of harm, or protection of particularly sensitive environmental features outside of the planned area of operations, may not be achieved during an unplanned oil spill event. This may then trigger internal and external reporting requirements. These outcomes should also inform lessons learnt for future prevention and preparedness actions. For further information on reporting requirements and environmental performance outcomes please refer to published guidance on the NOPSEMA website for EP contents.

During a successful emergency response, the ideal outcome would be that goals for the protection of sensitive environments were achieved. In this case, reporting full details of the successful outcome is extremely valuable both to the titleholder, in order to demonstrate compliance with the Environment Regulations and to maintain social license to operate, but also to the industry in terms of lessons learnt for their own prevention and preparedness planning. Sharing this information with industry is strongly encouraged.

Monitoring results will also indicate whether the primary aim of the monitoring itself was met; that is that the extent, severity and duration of the impact resulting from an oil spill were determined. The outcome in this case should inform future design considerations and planning for oil spill monitoring activities. If no impact could be measured due to failings of the monitoring design or implementation issues during the response, rather than there being no significant impact from the spill, this information should be used to prevent similar short-comings in monitoring design in the future. If the OSMP was implemented as designed, was able to achieve the aim of detecting impacts and was able to demonstrate that impacts from the spill were within acceptable limits, then this is also extremely valuable information and publication to a broader audience should be also considered as opportunities to learn from oil spill scenarios are very limited.

11.4. Further studies, clean-up and remediation

Scientific monitoring may reveal that significant impact to sensitive environmental receptors has occurred as a result of exposure to hydrocarbons or from response efforts. Scientific studies should continue to determine the long term effects from the spill, but should also consider if additional studies of other environmental receptors are required. If the design of the monitoring program took the approach of selecting indicators that were likely to exhibit a response to hydrocarbons then careful interpretation of the results is required to determine if further scientific studies are needed to uncover the full environmental impact from the spill. The requirement for further studies and the design of these studies will be heavily dependent on the indicators that were chosen and what level of the environment they represent. For example, impacts detected at a species level will have different outcomes in terms of future studies to impacts detected at a community level. The former example may require a higher level assessment of community and ecosystem level impacts and potentially also assessment of impacts to societal uses of the impacted species (e.g. impact to a fishery). The latter example may require a more detailed assessment of species within that community as well as ecosystem and/or social impacts.

If an oil spill was predicted to be of low consequence and no significant impacts were evident using a robust experimental design, further investigations may not be required.

If significant impacts are detected, clean-up operations should be considered to remove oil and to manage persistent contaminants. Clean-up operations need to be considered very carefully to ensure that the benefits of clean-up efforts out-weigh the potential for further damage resulting from those clean-up efforts. Please refer to the Net Environmental Benefit Process in the OPEP Guidance Note (NOPSEMA 2014) for further information.

It is possible that in some cases, damaged areas or impacted fauna may benefit from remediation efforts or even require remediation to ensure long term sustainability of communities or populations. Remediation efforts can be extremely costly and may have little benefit at a community level if not planned and implemented properly. Careful consideration should be given to any planned remediation efforts and these plans should be supported by evidence in the plan of stakeholder support and the appropriate approvals and licencing.

Recognition that timely and safe implementation of the OSMP is critical but presents a considerable challenge since there is uncertainty about how an emergency situation will play out on the day. Adding to the challenge is that an OSMP will require an array of specialist expertise and equipment.

Titleholders should therefore carefully consider how to demonstrate that they will maintain a suitable level of readiness with respect to the people, logistics and infrastructure required to implement the OSMP.

Titleholders should ensure that their reporting arrangements for outputs and outcomes of the OSMP address the requirements of the Regulations.

Titleholders should also consider what the results of the monitoring may lead to in terms of further studies, clean-up, remediation and lessons learnt.

12. Challenges and opportunities

The development of scientific monitoring programs to detect and quantify impacts from oil spills presents a number of challenges and opportunities. It is hoped that this information paper will assist titleholders to address some of the challenges as well as identify opportunities. Table 4 identifies some of the challenges and attempts to set out the potential opportunity(ies) presented by each challenge.

Challenges	Opportunities
Baseline surveys	
Overlap in areas surveyed by different titleholders	More strategic and regionally consistent approaches to baseline environmental surveys.
Extent of required baseline	Collaborative and partnership arrangements can reduce costs to individual titleholders.
Different survey techniques between titleholders impacting on the utility of data	Improve data consistency and utility through the development of appropriate standards for marine data collection.
Data sharing	
Concern about providing competitive advantage to other titleholders	Australian Oceans Data Network (AODN) is a potential resource for facilitating data discovery and access. Where commercial constraints exist, the metadata can be uploaded to the AODN to make the data

	discoverable, with caveats on accessibility. Other industry data sharing initiatives also exist.
Scientific uncertainty	
Conservative approaches to monitoring are resource intensive and costly.	Establish strategic initiatives to identify and address key sources of uncertainty in oil spill impact assessment (e.g. end-user driven strategic research initiatives).
Social license to operate	
Heightened public concern/scrutiny about oil spill risks post-Montara and Deepwater Horizon (Macondo)	Demonstrate appropriate planning and preparedness through the development of a fit-for-purpose monitoring program.
	Highlight the monitoring program provisions during the stakeholder consultation process.
Designing fit-for-purpose monitoring programs	
The OPGGS (E) Regulations are not prescriptive about monitoring requirements	Capitalise on this flexibility to develop a fit-for-purpose monitoring program that can be practically and efficiently implemented and deliver high quality environmental outcomes.

Table 4 Some examples of challenges and opportunities presented by the planning and application of scientific monitoring programs

13. Critical factors for success

This information paper is intended to provide an overview of a process for developing an OSMP and provide possible approaches and important matters to consider in demonstrating that an OSMP is rigorous, fit-for-purpose and meets the requirements of the Environment Regulations.

The information presented in this paper is not a template for developing an OSMP, nor is it a proxy for the assessment process undertaken by NOPSEMA. Notwithstanding, the factors outlined in Figure 5 below are considered critical to the success of an OSMP and therefore should be addressed where an OSMP is deemed to be an appropriate part of an EP submission.

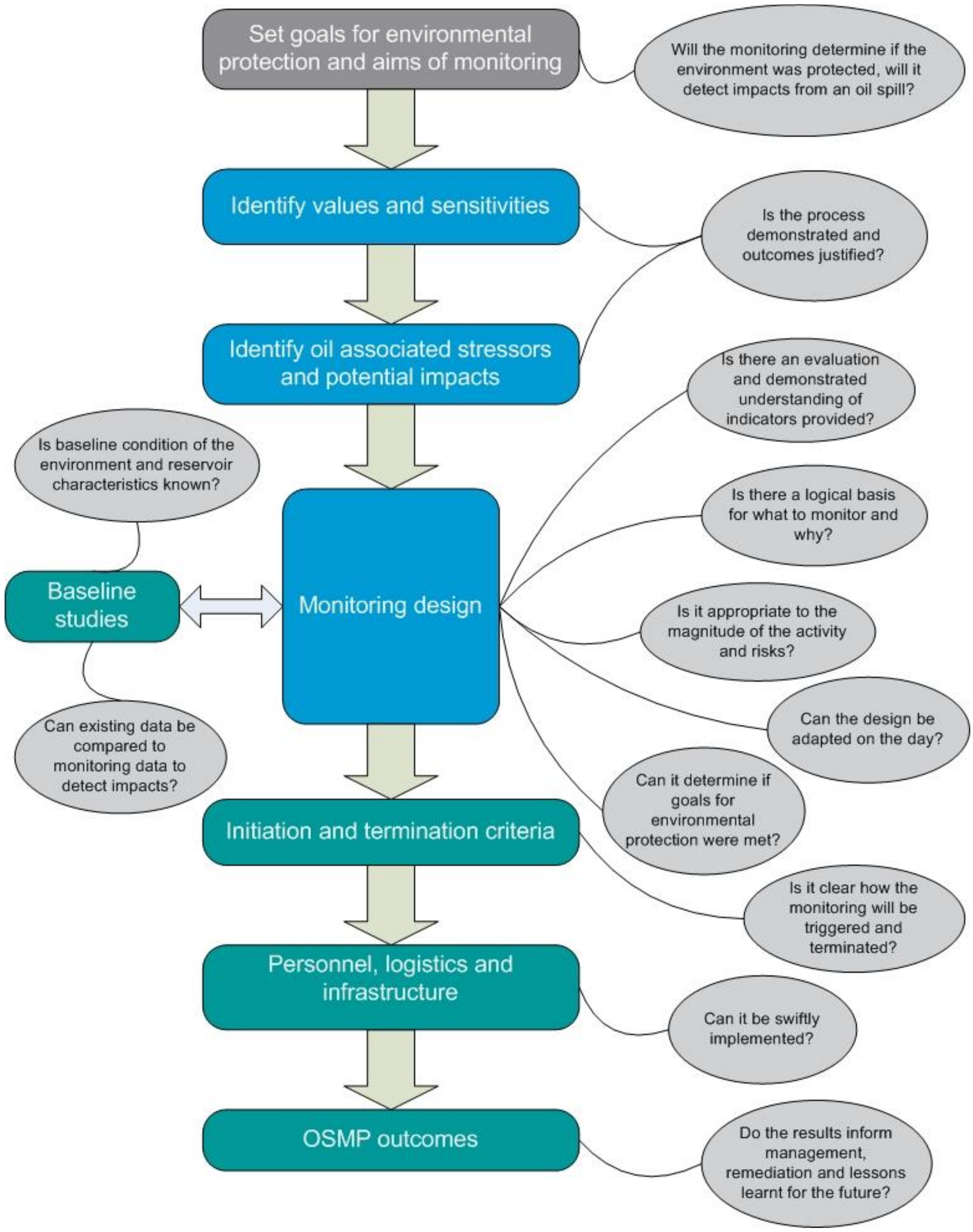

Figure 5 Critical success factors

14. Terminology

The environment and environmental impacts

Definitions of ‘environment’ and ‘environmental impact’ from the Environment Regulations are used in this Information Paper. Titleholders should refer to the Environment Regulations for complete definitions, but note that the Environment Regulations:

- take a broad view of the environment, with the definition covering ecosystems, natural and physical resources, qualities, heritage values and, socio-economic and cultural features

- take a similarly broad view that environmental impacts include any change that wholly or partially results from an activity.

This Information Paper places most emphasis on monitoring of physical and ecological parts of the marine environment following an oil spill. Nevertheless, titleholders need to be mindful of the breadth of the Regulation's definition of the environment when developing their OSMPs. Examples of various socio-economic and heritage considerations are presented, where pertinent.

Ecological integrity

Ecological integrity is a term referred to in this document. It is the ability of the ecosystem to support and maintain key ecological processes and a community of organisms with a species composition, diversity and functional organisation that is as comparable as possible to that occurring in natural habitats within a region.

Nature and scale

The concepts of *nature* and *scale* are enshrined in the Environment Regulations as considerations for the acceptance 'test' applied to EPs. Here the focus is on activities relevant to oil spills and the proposed responses to those incidents.

- With respect to oil spills, *nature* may encompass factors including:
- the inherent features of credible spill scenarios, including information about the facility (surface or subsurface spill source) and its location, and the timing of a spill
- properties of spilled hydrocarbons, including their physical and chemical characteristics, weathering properties and environmental toxicity at various time steps during and following a spill incident
- predicted environmental impacts of dispersants and oil-dispersant mixtures at various time steps;
- features of proposed response activities
- the environmental setting of the potential spill scenarios and response activities, including its natural variability and sensitivities such as matters of National Environmental Significance and other recognised values of marine conservation reserves

The notion of *scale* on the other hand might be explained by factors including the:

- spill volumes and durations
- predicted timeframe to stop the spill or mount effective response strategies
- extent of the area over which impacts are predicted to occur and the severity of those impacts
- scope and magnitude of response activities and time frame required to implement
- predicted persistence and toxicity of oil, and its impacts on the environment

There are many aspects relevant to nature and scale and the lists above should not be taken to be comprehensive or relevant to all situations. While the points above may provide a guide, titleholders should also ensure they take account of the views and perceptions of relevant stakeholders and be mindful of uncertainty when establishing the nature and scale of their oil spill related activities within the EP.

Environmental monitoring

For the purpose of this Information Paper, environmental monitoring is the systematic collection and analysis of environmental information to support response and assessment of impacts from an oil spill. Environmental monitoring is used to evaluate the performance of spill response strategies used to minimise environmental harm, to determine the magnitude of environmental impacts and to inform remediation activities if necessary and appropriate.

As noted earlier in this paper, operational and scientific monitoring activities are conducted following an oil spill to achieve different but related objectives. Since a key objective of scientific monitoring is to assess environmental impacts from a spill, an integral part of these studies involves the collection of baseline data to allow impacts attributable to an oil spill to be detected and separated from background levels of natural variation. Considerations relevant to environmental baselines are discussed in further in Section 8.

There are synergies and areas of overlap between operational and scientific monitoring that should be identified and addressed during the design of the OSMP with an aim of strengthening overall integration of monitoring activities. An end result should be a cohesive overall OSMP package that:

- allows titleholders to make the best use of information flowing from a sequence of monitoring activities
- is efficient to implement
- is effective in achieving specific monitoring objectives.

Oil spills and oil- associated stressors

Oil spills are unplanned releases of hydrocarbons to the marine environment from an offshore petroleum activity. Inherent features of oil spills such as the physical and/or chemical presence of the oil and any associated oil spill response activities that may impact the environment are collectively termed 'oil-associated stressors'.

Some examples of oil-associated stressors include:

- direct environmental toxicity of oil, dispersant and oil-dispersant mixtures
- indirect effects of oil that are not immediately obvious or which may manifest at locations distant from the spill site (e.g. trophic effects, reduced fecundity or recruitment failure in biota)
- inherent features of proposed shoreline deflection / protection and clean-up activities on shorelines.

Careful scoping of the range of oil-associated stressors is an important task for OSMP design. Oil-associated stressors constitute the 'cause' components of cause-effect relationships, which are discussed further in Section 5.1 as a possible framework for rationalising the process of selecting what to monitor.

Exposure

In this paper, refers to a part of the environment being subjected to the action or influence of an oil-associated stressor

15. References, Acknowledgements and Notes[2]

Legislation

Offshore Petroleum and Greenhouse Gas Storage Act 2006

Offshore Petroleum and Greenhouse Gas (Environment) Regulations 2023

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Notes

All regulatory references contained within this Guidance Note are from the Commonwealth *Offshore Petroleum and Greenhouse Gas Storage Act 2006* and the associated Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2023 unless otherwise stated.

For more information regarding this guidance note, contact the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA):

- Telephone: +61 (0)8 6188- 8700, or
- e-mail: information@nopsema.gov.au

Appendix A: Environmental features and sensitivities

A.1: Sensitive biological receptors

For the purpose of the following discussion, biological features that may be relevant to OSMPs have been split into three groups to provide broad guidance that can be applied to marine biota generally. The groups are 1) seabed flora and fauna, 2) fish and fisheries and 3) wildlife. These groups are highlighted here in view of their importance for the maintenance of marine ecological integrity and human uses and to provide prompts for their consideration in OSMPs, where appropriate.

The social and economic values are important to consider, however the summary below will focus on the ecological values of the three receptor groups. This ecological focus follows the premise that clean and healthy ecosystems are required to support safe and sustainable human use activities and protect socio-economic values.

Benthic flora and fauna

For the purpose of this information paper, flora and fauna are those biota that grow on or within seabed substrates in the intertidal, subtidal and deep ocean zones. Key groups of benthic flora and fauna that may warrant attention within the OSMP include:

- habitat-forming benthic primary producers such as corals, seagrasses, macroalgae, mangroves, salt marsh vegetation
- habitat-forming benthic filter feeders such as sponges, sea fans and sea whips
- biota that do not leave the substratum, including invertebrate fauna (those not commercially targeted), infauna and micro-algal communities associated with the habitat formers described above.

The habitats in which the benthic flora and fauna are the key structural components or are important parts, are intrinsically valuable for the productivity, biodiversity and associated human use they support. The 'iconic' benthic habitats such as coral reefs, seagrass meadows, saltmarshes and mangroves are relatively well-studied and so some level of relevant information for planning an OSMP is often available. Habitats such as coral reefs and deep-water sponge gardens are recognised fish nursery areas and provide an important source of food and shelter for a diversity of biota, while saltmarshes and mangroves provide an important link between marine and terrestrial ecosystems. The importance of some benthic habitats may also be formally recognised within marine reserve systems or other protection mechanisms such as World Heritage or Ramsar listing.

Other, less recognized, habitats can also have considerable environmental value but require additional effort to identify and evaluate. Examples of these habitat types include sandy, muddy and rocky shorelines, macroalgal reefs, mosaics comprised of corals, sponges, algae and/or seagrasses and deep-water substrata dominated by filter feeding communities or benthic infauna. Habitat mosaics can be difficult to characterise due to their patchy and dynamic nature. This will likely have implications for the design of the OSMP. Deep water habitats are difficult to evaluate due to their remoteness and/or logistical challenges encountered during sampling.

There is often a lack of information or scientific certainty for benthic habitats, though this alone is not a valid reason to exclude them from consideration in the EP and OSMP. Deep water sampling in recent years for example has discovered a number of undescribed species as well as previously unknown habitats of value. For example, highly diverse and dense sponge gardens have been described in the deeper waters off Ningaloo Reef (e.g., Heyward et al. 2010; Schonberg and Fromont, 2012). In view of these findings, appropriate sampling efforts are an important part of ensuring a thorough description of the environment that may be affected by deep-sea petroleum activities and measures are put in place to afford adequate protection and to measure impact if they occur.

It is also important to recognise that benthic habitats vary with change in latitude (e.g., tropical vs temperate), exposure and hydrodynamic regime, substratum type, water depth and sometimes season. These are factors that may require consideration when planning an OSMP.

Finally, if benthic habitats are identified early in the planning process, this may provide the opportunity to obtain further information to relevant to monitoring design. For example, if geophysical survey data collected early in the development of a petroleum activity identified benthic anomalies (e.g., pinnacles or coral bombora) in a Permit area, there may be an opportunity to obtain further information to guide the description of the environment, the evaluation of impacts and risks assessment and where relevant, design of the OSMP. In addition to field sampling, a thorough consultation process may assist with identifying benthic habitats.

Fish and fisheries

For the purpose of this information paper, the definition of fish will include all species of bony fish and cartilaginous fish (sharks and rays) and commercially targeted crustaceans, molluscs including cephalopods and echinoderms. The fish supported industries considered include fisheries (the capture of wild fish species) and mariculture (the cultivation of captive species in the marine environment). Mariculture refers to farming of captive bred stock or grow-out of naturally occurring larvae and juveniles of wild caught stocks.

The commercially targeted crustaceans are primarily the decapod crustaceans such as rock lobster, crabs and shrimps. Over 2,250 decapod crustacean species have been recorded from Australia with only a small proportion commercially targeted, for example 30 species of crustacean are targeted or occur as significant secondary catch on the east coast of Australia (Tzioumis and Keable, 2007). Despite the small number of species targeted, crustacean fisheries are highly valuable, for example the western rock lobster fishery is the most valuable single species fishery in Australia (DEWR, 2007). Decapod crustaceans such as rock lobsters, blue swimmer crabs and mud crabs are also highly sought after by recreational fishers.

There are an estimated 15,000 species of marine mollusc in Australian waters (Beesley et al. 1998 in DEWR, 2007) and a small number of these species are considered highly valuable. For example, the mobile cephalopods (e.g., squid, cuttlefish and octopus) are targeted by jig, pot and trawl fisheries as well as recreational fishers, while the sessile bivalves (e.g., mussels and oysters) support a valuable mariculture industry and are an important food source for indigenous Australians. Another highly valuable marine mollusc is the abalone, which supports significant commercial and recreational fisheries. Echinoderms are also commercially targeted to a lesser extent with fisheries in existence for sea cucumbers (beche-de-mer) and sea urchins.

Important information on commercially targeted fish species is provided by the relevant fisheries management agencies. Fisheries operating in Australian waters are managed by either the Australian Fisheries Management Authority (AFMA) or the relevant state agency depending on the location and fishing method. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) provides Fishery Status reports for AFMA managed fisheries, including information on the biological, environmental and commercial status of the fisheries. State agencies such as the Department of Fisheries, Western Australia and the Department of Primary Industries, Victoria also provide fishery status reports.

The environmental value of Australia's fish resources is evidenced by formal protection of important habitats under a National Marine Reserve System, for example the Cod Grounds Commonwealth Marine Reserve was declared to protect important habitat of the endangered grey nurse shark. Individual species are also provided formal protection under the EPBC Act and various pieces of state/Northern Territory legislation. For example, the green sawfish (*Pristis zijsron*) is currently protected (listed vulnerable) under the EPBC Act and is also protected in WA, NSW and NT waters under the various state/territory legislation. A number of Australian fish species are also listed internationally on the IUCN Red List of Threatened Species, for example the iconic Queensland grouper (*Epinephelus lanceolatus*). Titleholders are encouraged to review relevant legislation to identify listed threatened species in their area of interest, however it is important to recognise that the listed species may not adequately represent the fish species of value in a given area. For example, the fish species listed under the EPBC Act 1999 are primarily syngnathid species (seahorses and pipefish) and a number of shark species and these listed species will not adequately represent the commercially, recreationally or ecologically important fish species in a given area.

Where threatened or potentially threatened fish species are identified within an area of interest, it is important to determine whether formal action plans are in place which identifies critical habitats and conservation strategies for species survival. For example, the Conservation Overview and Action Plan for Australian threatened and potentially threatened marine and estuarine fishes (Pogonoski et al. 2002) provides important information on conservation status, critical habitats and recommended conservation priorities for Australia's threatened fishes. There are also a number of information papers that have been produced to identify marine environmental values within the Commonwealth marine regions that may provide useful information on potential fish values within an area of interest. For example, a description of key species groups in the East Marine Region was produced by the Australian Museum (Tzioumis and Keable, 2007).

Marine fishes that are not formally recognised by legislation may have perceived value due to their palatability (e.g., seafood products such as scallops and pink snapper), commercial value (e.g., pearl oyster), iconic nature (large groupers, whale sharks, barracuda) or ecological function (e.g., the role of small pelagic fishes as a food source for commercially targeted and/or protected pelagic predators). Mobile fish species such as bony fish and sharks may migrate over large distances and may only represent a value in an area of interest at a certain time of year, for example the annual whale shark feeding aggregation period at Ningaloo Reef. Times and locations of particular importance to fish for feeding, breeding or migration will need to be considered and understood in relation to seasonal and inter-annual variability, vulnerability to an oil spill and the design of an OSMP.

Wildlife

Australia's offshore marine environment supports a rich and diverse wildlife fauna. For the purpose of this information paper, wildlife are the larger species of mammals, reptiles and birds that either live in the ocean or are dependent on marine and coastal ecosystems for long term sustainability of populations and are considered to be vulnerable to the effects of oil spills. Examples of key groups of wildlife covered in this paper include cetaceans, dugong, pinnipeds, marine reptiles (turtles, sea snakes, crocodiles), shorebirds and seabirds.

Numerous species, which are either Australian residents or visit our waters and coasts during migration or utilise habitats for a key part of their life history are specially protected under Australian Commonwealth environmental law (i.e., EPBC Act). Some of these species and their critical habitats are the subjects of international conventions and agreements to which Australia is a signatory. Australia has international obligations to promote and enhance the survival and conservation of migratory species and their critical habitats under the Convention on Migratory Species (i.e., the Bonn Convention), and agreements entered into with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA) for the protection of migratory birds.

Numerous species are also protected because of their conservation status. The EPBC Act affords special protection to listed threatened species and communities. Threatened species and communities are classified in accordance with IUCN Red List categories (www.iucnredlist.org). They include Australian resident and migratory species from each of the groups classified here as wildlife.

Titleholders should review the information at www.environment.gov.au regarding the EPBC Act, relevant international conventions and agreements, and Australia's obligations when developing OSMPs.

Australia's wildlife species may also be considered culturally important, for example turtles and dugong are hunted and contribute to the diet of indigenous Australians. These activities may be restricted to certain times of year and locations. Baseline surveys and other planning activities for OSMPs should aim to determine the dynamics of cultural values of wildlife species as well as socio-economic values such as ecotourism so that monitoring in the event of a spill can be properly targeted to ensure it achieves its objectives.

Since some wildlife species utilise different habitats at different times of year, the potential for, and extent, severity and persistence of, ecological impacts to wildlife will often depend on when and where a spill occurs. Accordingly, the notion of sensitive ecological windows will often be a relevant consideration when planning wildlife aspects of OSMPs. In the context of wildlife, sensitive ecological windows are the readily predictable times of year, geographic locations or combinations of the two that are critical for the conservation and sustainability of populations. For example, sensitive ecological windows can be times of the year and locations known to be important for mating, spawning, feeding or nesting. They may also be an area of ocean known to be utilised as a migration corridor for a listed migratory species. Titleholders should review the relevance of sensitive ecological windows to wildlife within the defined area of interest and plan baseline studies and the OSMP accordingly, while being mindful of scientific uncertainty associated with current knowledge about a species' behaviour and its utilisation of habitat.

Appendix B: Oil in the environment

B.1: Chemical speciation

Chemical speciation is defined as the specific form of an element or compound based on isotopic composition, oxidation state and/or molecular structure (Campbell et al., 2006). Following the release of an oil-associated stressor into the marine receiving environment, a change in physico-chemistry will alter the speciation of a contaminant, and subsequently the bioavailability to a biological receptor.

The chemical speciation of hydrocarbon and non-hydrocarbon contaminants present as dissolved, dispersed and particulate phases is complex, and will be influenced by both the physical and chemical properties of the contaminant (e.g. solubility, volatility, reactivity, concentration), and the receiving environment (e.g. pH, dissolved oxygen, salinity, temperature, particle size, organic carbon). Before reaching equilibria within the water or sediments of the receiving environment, the oil-associated stressor may undergo several chemical and physical processes, including adsorption (e.g. organic matter and iron and manganese oxyhydroxides), dissolution (e.g. oxidation or transformation from mineralised/elemental states into ionic forms), complexation (e.g. with dissolved organic carbon or anions including carbonate, chloride, sulfate and hydroxide), ion exchange (e.g. interchange of ions on clay minerals) and precipitation (e.g. with ligands such as carbonate, hydroxide, silicate, phosphate and sulfide), (Chapman et al., 1998; Cantwell and Burgess, 2001; Fan and Wang, 2001; O'Day et al., 2000; Simpson et al., 2000).

For example, particulate organic carbon in sediment has been demonstrated as an important binding phase for hydrocarbon classed contaminants (e.g. polycyclic aromatic hydrocarbons), decreasing the bioavailability to biological receptors. Further reductions in the bioavailability of hydrocarbon contaminants may also occur through the evaporation of volatile aromatics (such as BTEX) and biodegradation of aliphatic hydrocarbons (such as n-alkanes). By comparison, other contaminants may be transformed to more bioavailable phases. Examples may include (though are not limited to) the dissolution of polar hydrocarbons from dispersed hydrocarbon phases (e.g. phenols) or the oxidation and dissolution mineralised metal phases associated with the reservoir geochemistry (e.g. metal-sulfide phases), both of which may increase the presence of bioavailable contaminants in the water column. This physico-chemical change in a dissolved, dispersed and particulate phase of an oil-associated stressor will also have implications for bio accessibility, which is essentially controlled by the contaminant exposure pathway of the biological receptor.

B.2: Organism exposure pathways

The assimilation of a dissolved, dispersed or particulate oil-associated stressor by a biological receptor may occur as the result of uptake through either dissolved or dietary exposure pathways (Rainbow, 2002; Luoma and Fisher, 1997; Luoma et al., 1992; Besser et al., 2005; Griscom and Fisher, 2004; Meyer et al., 2005). For the dissolved phase, the exposure may be via the water column, or pore water and burrow water in sediments. The dietary exposure route may include both biotic (e.g. algae, plant or other benthos) and abiotic (e.g. organic detritus or sediments) sources of particulate phases, though dispersed phases of whole-oil may also become ingested.

The range of potential biological receptors residing in the sea surface, water column, and sea floor and shoreline compartments of the receiving environment is diverse. Hence, the importance of the dissolved and dietary exposure pathways is likely to vary considerably (Wang and Fisher, 1999a; Warren et al., 1998;

Munger et al., 1997). For example, where the ingestion of particulate phases may be a major dietary exposure pathway for seabed invertebrates which filter feed or graze on sediment substrates, uptake from the dissolved and dispersed phases may be of more importance for phytoplankton or several pelagic fish which reside in the water column (Simpson and Batley, 2006; Selck et al., 1998; Tran et al., 2002). For this reason, the dissolved, dispersed and particulate phases of oil-associated stressors should be considered in both the water and sediments of the receiving environment compartments.

B.3: Organism physiology and behaviour

In addition to the exposure pathway, organism physiology will influence the assimilation of a dissolved, dispersed or particulate oil-associated stressor into the tissues of a biological receptor (Wang and Fisher, 1999b). The significance of an accumulated contaminant is species-specific and assimilation is dependent on the balance between increased bioavailability and the rate of metabolism and elimination (Ahearn et al., 2004; Rainbow, 2007; Wang et al., 1995). An oil-associated stressor has the potential to bind to any molecule with an affinity for that contaminant, rendering the complex potentially toxic through prevention of normal metabolic functionality. An ingested oil-associated stressor may be considered available until it is excreted, molecularly sequestered or detoxified to a less available form.

For example, a biological receptor may regulate, accumulate or excrete a detoxified store of non-hydrocarbon contaminants such as essential (e.g. copper, zinc and cobalt) and non-essential (e.g. cadmium, lead and mercury) trace metals. Non-ionic organic chemicals (such as lipophilic hydrocarbon classed contaminants) may be rapidly metabolised and accumulate in the tissues of the biological receptors (e.g. PAH metabolites in the biliary secretions of fish). Adverse biological effects may occur when the rate of uptake exceeds the rate of excretion and detoxification of metabolically available contaminant (Borgman and Norwood, 1997; Vijver et al., 2004).

The behaviour of a biological receptor also has the potential to influence exposure to an oil-associated stressor. For example, seabed invertebrate communities may resuspend contaminated sediments as a consequence of bioturbation and bioirrigation by the burrowing, feeding, tubing, excretion, respiration and locomotion activities of seabed animals. This activity may expose both the pore water and the sediment particles to the overlying water column, potentially allowing uptake by filter feeding organisms in the water column, or solubilising contaminants previously partitioned to the sediment phases (Roper et al., 1995; Wenzho and Glud, 2004).

Alternatively, other biological receptors may possess behavioural traits that may reduce the exposure duration and uptake of oil-associated stressors. For example, the exposure and uptake of a contaminant source is effectively reduced through selective feeding strategies (i.e. identifying and minimising dietary ingestion of contaminated sediments), or avoidance mechanisms (i.e. sensing and avoiding elevated concentrations of dissolved hydrocarbons in the water column).

The environmental impact of an unplanned release of crude oil or condensate into the marine environment will be influenced by the distribution (sea surface, water column, sea floor and shoreline) and bioavailability of the oil-associated stressor (including chemical speciation, and organism exposure pathways, physiology and behaviour). Therefore, the water and sediment quality monitoring program should be adequately developed to consider these key concepts when investigating the presence or absence of an adverse environmental impact. An understanding of the distribution and bioavailability of an oil-associated stressor in the receiving environment will enable the cause-effects pathways to be defined for specific ecological receptors and support ecological monitoring observations to determine if an impact has occurred.

Appendix C: Environmental impacts

C.1: Direct impacts

Seabed flora and fauna

Inter-tidal flora and fauna at risk if the shoreline is contacted by spilled oil include seabed phototrophs such as mangroves, saltmarshes, coral reefs, seagrass beds, macroalgal stands and their inhabitants, filter feeding organisms such as sponges and soft corals and their inhabitants, inhabitants of rocky and sedimentary shores, microalgal assemblages such as stromatolites and rhodoliths and any other living organisms and assemblages that occur on the sea bed or sea shore. For all marine seabed primary producers, mortality can result from oil covering photoreceptors and pores for oxygen exchange. All other organisms can still be wholly or partially smothered by oil which can inhibit normal breathing, feeding and reproducing activities. The leaves of the seagrass species Zostera become blackened where they come into contact with oil and they suffer reduced growth rates (e.g. Kenworthy et al. 1993, Dean et al., 1998). Mangroves, which are dependent on oxygen supplied via pores in their aerial roots and occur in the inter-tidal zone, are particularly susceptible to smothering. For mangroves, the toxic components of the oil, especially lower molecular weight aromatic compounds can also damage cell membranes in the subsurface roots, impair the normal salt exclusion process, and the resulting influx of salt interferes with the plants ability to maintain a salt balance (IPIECA 1993).

Topographically complex intertidal habitats such as mangroves, coral reefs and rocky shores that encompass a range of microhabitats such as cracks, crevices, rockpools and overhangs are at a greater risk, along with their inhabitants. These complex microhabitats tend to retain water during low tides and so are populated by diverse assemblages of soft bodied sessile animals such as sea anemones, sponges, echinoderms and sea-squirts as well as providing refuges for mobile animals such as molluscs, crustaceans and fish. The exposed surfaces of these shores are often quickly washed clean of oil; however, oil can become concentrated in these habitats where it will cause the greatest damage.

Seabed flora and fauna inhabiting sedimentary shores or in seabed sediments in other habitat types such as mangroves and seagrasses, including both inter-tidal and sub-tidal zones, may also be smothered by oil, particularly at low tide. Oil may penetrate burrows in the sediments, killing resident crabs and worms, or coat molluscs, barnacles and bivalves on the sediment surface. Weathered oil that sinks, oil particles that become entrained or attached to sediments, or other oil deposits can still cause damage. It is known that toxic sediments inhibit seed establishment in mangroves and may impact saltmarsh vegetation where asexual vegetative growth is often seasonal. Seagrasses which are often ephemeral are known to be reliant on seed banks to recolonise, therefore protecting and monitoring sediments containing seed banks from chronic oil contamination is probably equally as important as protecting seagrasses themselves for the long term persistence of seagrass ecosystems. If not cleaned up, oil can persist and remain toxic in sheltered muddy sediments for many years or decades, particularly in anoxic sediments such as are often found in the tropics (IPIECA 1991). The effects of residual oil on other seabed flora and fauna has been well studies in the northern hemisphere (e.g. see Penela-Arenaz et al. 2009), for example, survival and growth rates of intertidal clams and fisheswere still affected greater than 5 years following the Exxon Valdez oil spill (Fukuyama et al. 2000, Jewett et al. 2002).

A recent publication from the Macondo oil spill show stressed corals and a decline in the health of corals near the location of oil release from the Deepwater Horizon spill where brown flocculent material containing traces of weathered oil was found (White et al. 2012). Dinoflagellate function, either in terms of photosynthesis or bleaching, has been affected in corals exposed to mineral derived hydrocarbons and dispersant from accidental and experimental spills (Mercurio et al. 2004, Meehan and Ostrander, 1997). Oil and dispersant may also affect coral larval fertilisation, metamorphosis and survivorship (Land and Harrison 2000, Negri and Heyward 2000, Mercurio et al. 2004). Given the extension of the industry to deeper water drilling programs where corals and other seabed flora and fauna are being continually discovered, greater investigations of the effects of oil on lesser known deep water habitats is warranted (Peterson et al. 2012).

Fish and fisheries

While oil is in the open water mobile fishes and fisheries species may be able to avoid affected areas, however, previous research has found biomarker evidence of hydrocarbon exposure in both pelagic and demersal fishes (Gagnon and Rawson 2011). Mass mortalities of mobile species such as bony fish are rarely observed after oil spill incidents (IPIECA, 2000) and likely to be limited to circumstances where oil reaches enclosed or partially enclosed water bodies such as lagoons or bays with limited flushing potential. Direct oil pollution impacts to slow-moving seabed fisheries species such as scallops and echinoderms have been documented for previous major oil spills. Where oil reaches the seabed and persists on or in the sediments, however, there is the potential for seabed fish species such as flounder, or strongly habitat associated demersal fishes, including rare and endangered species e.g. seadragons and seahorses or handfishes to be affected by direct physical or chemical contact with oil.

Direct chemical impacts to fish will be greatest for eggs, embryos and larvae as they are particularly sensitive to oil pollution events (e.g. Paine et al. 1992, Carls et al. 2008, Carls and Thedinga 2010). Toxic compounds such as polycyclic aromatic hydrocarbons (PAHs) can result in effects on growth, development and survival of embryos and larvae even after substantial weathering (Paine et al. 1992). There is a greater probability of exposure for pelagic early life history stages which may become entrained in contaminated surface waters. However, some fish and invertebrate fisheries species are seabed egg layers (e.g. damselfishes, squid and triggerfishes) or have specific nursery habitats such as mangrove stands and seagrass beds. Oil in sediments or nearby oil deposits on the seabed could have potential impacts on egg development and survival of these species. Persistent oil in coastal sediments or degraded habitats could affect larval settlement and survival over many years.

Mariculture operations often involve the enclosure of bony fish (in pens or cages) or hanging of bivalve molluscs on ropes for grow-out and these fish are more vulnerable to oil exposure as they are unable to actively avoid areas of oil pollution. Fisheries species located within mariculture operations typically occur in nearshore waters, far removed from offshore petroleum operations, however it should be recognised that the shallow waters of offshore islands may be important mariculture sites, and also that the impact from a well blowout has the potential to extend to nearshore waters. The scale of impacts will depend on the concentration and composition of oil and the nature of the mariculture facility. Intertidal mollusc mariculture is considered particularly sensitive to oil spill impacts (IPIECA, 2000) with potential for sub-lethal effects to be long term where oil is entrained and retained in the sediments. Onshore tanks and sea impoundments are also considered sensitive as they require circulation of high quality marine water and a high stocking density may increase the severity of oil contamination effects. As well as contamination and toxic effects to mariculture fish stocks, the equipment itself is at risk of contamination, resulting in lengthy clean-up operations to prevent contamination of new stocks and delays to further production.

Fishing operations in Australia use a variety of gear to target fish in different environments with varying sensitivities to oil contamination (refer IPIECA, 2000 for a proposed sensitivity ranking). The fish targeted by fisheries have the potential to become contaminated through direct contact with oil in the marine environment or through contact with oil contaminated fishing gear. In either scenario, these fish will not be suitable for consumption due to flavour taint and/or toxic levels of hydrocarbons.

Tainting is an issue for both fisheries and mariculture operations and refers to the uptake of oil derived substances in the tissues of fish, which leads to an odour or flavour foreign to the food product (ISO, 1992). Tainting effects are generally more severe in cultivated fish as they are spatially restricted and unable to swim away. Tainting can occur through direct absorption from water and sediments as well as through consumption of contaminated prey species. Filter feeding species such as bivalve molluscs and fish species with a high fat content, such as tuna, are particularly vulnerable to tainting and bioaccumulation potential should also be considered. Tainting and potential toxic effects of hydrocarbons in fish has the potential to cause major economic impacts to fish supported industries as consumers may avoid seafood well after hydrocarbon levels in tissues have returned to background levels. It is therefore critical that a scientifically sound monitoring program is established to support decision making around closures and re-opening of fisheries and instil public confidence. A large body of literature exists on the role of science in managing seafood safety, with some examples provided below.

Further reading on the role of science in managing seafood safety

The management of fish taint impacts is important and complex, with many examples from around the world where poor management has resulted in a loss of confidence from the public in seafood safety, further exacerbating the economic impacts of an oil spill.

There is significant further reading available on this topic, often in the form of 'lessons learned' from previous incidents. Refer for example:

- Yender et al. 2002 for guidance on assessing likelihood of seafood contamination and effective monitoring for contamination.
  http://docs.lib.noaa.gov/noaa_documents/NOS/ORR/963_seafood2.pdf
- US EPA (2000) for guidance on fish sampling and analysis design to assess chemical contaminant levels.
- Moller et al. (year unknown) for a discussion on the importance of scientific criteria to inform fishery closure and re-opening decisions.
  http://www.itopf.com/_assets/documents/fishban.pdf
- Gohlke et al. (2011) for a review of seafood safety protocols after the Deepwater Horizon Blowout.

Wildlife

Direct contact with hydrocarbons can affect skin, fur and plumage and eyes of marine wildlife. In addition, wildlife may ingest contaminated water or prey or inhale volatile hydrocarbons when surfacing. Individual animals that are either in poor health (e.g. injured animals) or otherwise physiologically stressed (e.g.

pregnant females), may be more susceptible to exposure to oil, particularly if the release is protracted and spilled hydrocarbons are persistent in an animal's habitat.

Skin, fur or plumage is often the first part of the animal to come into direct contact with oil and/or oil-dispersant mixtures. For cetaceans and dugongs, skin-oil contact puts individuals at risk of skin irritation, inflammation, burns and necrosis. Open injuries and lesions have potential to expose affected animals to increased risk of secondary health problems such as infection (UC Davis School of Veterinary Medicine, 2012). When birds come into contact with oil, the complex structure of their feathers can be affected such that they do not provide effective insulation and repel water. Affected birds can have difficulty swimming, flying and foraging and many rescued birds show signs of hypothermia (Mazet et al. 2002). Like bird feathers, the haircoat of pinnipeds acts to regulate the animal's temperature and buoyancy. Oiling of the coat allows water to come into direct contact with the animal's skin, causing rapid onset of hypothermia. Oil can smother bird and reptile eggs, impacting gas exchange and therefore hatching success. There are also reports of developmental effects in embryos of eggs exposed to oil (US EPA 2000).

Direct contact with eyes has potential to cause significant effects in wildlife. Necropsies of harbour seals in the months immediately following the Exxon Valdez spill indicated, among other things, conjunctivitis (Spraker et al. 1994, Fall 1995) and though comparable studies on other wildlife are rare, similar effects could be anticipated in mammal and turtle species that may swim through, or regularly break the surface of, oil-affected water.

Marine wildlife species are susceptible to ingestion of oil due to their foraging and feeding behaviours. There is considerable risk of cetaceans, pinnipeds, dugong and birds ingesting hydrocarbons while foraging in oil-affected areas and consuming oil-affected food resources. Young animals may also ingest oil when suckling from an oiled mother or by consuming oil-contaminated food. The mouth anatomy and feeding behaviour of baleen whales makes these species particularly susceptible to ingestion of oil. Since baleen whales use comb-like keratinous plates (baleen) to filter food from large volumes of water, feeding in oil affected waters has potential to cause fouling of the baleen (Marine Mammal Commission 2011). This in turn may adversely affect the animal's ability to feed. Birds spend considerable time preening themselves to maintain the condition of their feathers. In an oiled bird, there is a high likelihood that preening would result in some ingestion of oil. In dugongs the sensory hairs around the mouth, which are thought to have a role in foraging, may be affected by oil in turn potentially impacting the animal's feeding.

Ingested oil can lead to a range of physical injuries and physiological effects. When oil or dispersed oil is ingested they can damage the gastrointestinal tract, which in turn can affect digestion and uptake of nutrients from food. Internal organs such as the kidneys and liver which have roles in the metabolism of waste and toxins can also be damaged by oil (see Integral Consulting Inc., 2006 [sea otters], see Mazet et al., 2002 [birds]). There have been reports of ulcers, diarrhoea and a decreased ability to absorb nutrients from food in oil-affected birds (UC Davis, 2012). Ingestion of oil by adult birds can also affect egg condition.

Inhalation of volatile hydrocarbons and oil droplets while breathing has potential to result in effects on mucous membranes and respiratory tissues of respiratory tracts and lungs of wildlife. Harbour seals were found with symptoms of pneumonia (Fall 1995) and interstitial pulmonary emphysema (Integral Consulting Inc. 2006) following oil exposure due to the Exxon Valdez spill and again similar effects might be anticipated in other mammals. Breathing hydrocarbon vapours is known to result in nerve damage and behavioural problems in humans and so it may be reasonable to assume similar effects in marine mammals (e.g. Loughlin et al. 1996). Monitoring for the chemical impacts, for which the cause is not always immediately visible, will be more challenging than monitoring for the physical impacts, which are clearly visible. However, any impacts to marine biota that occur shortly after an oil spill event in the area in which the oil is present will be assumed to have occurred as the result of the spill unless water quality and sediment studies can demonstrate otherwise.

Further reading on direct impacts of oil

There is significant further reading available about the environmental impacts of oil, often in the form of 'lessons learned' from previous incidents. Refer for example to the primary literature by the following authors:

- D.M Di Toro
- J.A. McGrath
- J.P. Incardona
- P.V. Hodson
- U. Varanasi,
- T.K. Collier.

C.2: Indirect impacts

Habitat and food species

Indirect impacts to biota may arise due to changes in the habitats and ecosystems on which they rely. For example, reduction in the quantity and quality of food resources may impact the health or survival of individual animals. Damage to populations of prey species has potential to have flow on consequences through food webs ultimately affecting high order consumers. Furthermore, populations may rely on specific habitat features to provide nursery, feeding and breeding areas and impacts to these habitats will result in indirect impacts on populations. The impacts may result from factors such as a reduction in available prey or suitable habitats for settlement of recruits.

Some assemblages are particularly important in terms of ecosystem services. For example, in seagrass assemblages, the oil and dispersed oil can have significant effects on fauna living in and on the sediments and on the seagrass leaves (e.g. Jewett et al., 1999). Furthermore, damage to the seagrass plants may also affect neighbouring ecosystems that rely on services from the seagrass e.g. fish nursery habitats. Mangrove habitats are also recognised as especially important in terms of the provision of ecosystem services to not only the immediate habitat that it forms, but also to species that inhabit nearby seagrass and reef habitats. Assessment of commercial fisheries in Australia now often includes an assessment of impacts to the ecosystem as a whole (e.g. AFMA's ecological risk assessment process for offshore fisheries). This ecological risk assessment recognises the importance of a healthy ecosystem for sustainable fisheries.

Ecosystem functions

Impacts of oil on environmental receptors may have flow on effects for other species in an ecosystem outside of habitat and predator-prey relationships. Crustaceans, such as amphipods and fiddler crabs, are often involved in detritus breakdown by taking leaves into burrows within the sediments. If these species are removed from an area the process of decomposition may be significantly slowed having flow-on effects such as on water quality. Similarly, a disruption in crab and starfish populations in any habitat may result in reduced predation on snails and mussels may upset grazing balances and competitive relationships for space. As an example, studies of the effects of the Prestige oil spill in Spain on rocky shore assemblages found decreases in biomass and, size and species abundance of algae six months after the event. Despite this, however, there were longer term increases in richness and diversity due to changes in the abundance of dominant species (Urgorri et al. 2004 cited in Penela-Arenaz et al. 2009). Similarly, species replacements have been found in saltmarsh plants impacted by oil spill, for example, where an experimental oiling in Wales eliminated presence of the sea rush Juncus and allowed the oil tolerant fast-growing creeping grass Agrostis to dominate IPIECA (1994). The flow-on effects of an oil spill on biological assemblages should not be underestimated.

Socio-economic impacts

In the Environment Regulations, the definition of environment means ecosystems and their constituent parts, including people and communities, natural and physical resources, qualities and characteristics of locations, places and areas, heritage value and social, economic and cultural features. Subsequently, there may be social impacts from an oil spill that require scientific monitoring as an assessment of impact. These may include effects on indigenous, tourism, heritage, fisheries, aquaculture, recreational, economic or other human activities. When designing a monitoring program thorough research on all aspects of the environment in the area of interest needs to be undertaken before evaluation and prioritisation of monitoring program activities can occur. Examples of socio-economic impacts include effects on species listed under State, Commonwealth or International legislation, which are also often the source of interest for tourism activities such as wildlife watching cruises or the targets of indigenous hunting. Impacts to iconic habitats such as coral reefs or regularly used amenities such as sandy beaches may also have economic repercussions. Fisheries and mariculture operations may be directly impacted by oil spills through interference with fishing activities, contamination of equipment and fish resources (tainting) and mortality of fish resources. As discussed above, oil pollution also has the potential to cause sub-lethal effects to fish such as retardation of growth and larval development, which may result in reductions in fishery yields.

Appendix D: Monitoring parameters

D.1: Chemical characterisation

Water and sediment quality guidelines aim to define the extent of environmental risk through considerations of acceptable contaminant concentrations in the receiving ecosystems. In Australia, the ANZECC/ARMCANZ (2000) water and sediment quality guidelines outline a range of trigger values for contaminants of potential concern which are designed to be protective of an ecosystem, and predictive of an adverse biological effect. Exceedance of a guideline trigger value generally indicates that there is potential for an impact to occur (or to have occurred), but does not provide any certainty that an impact will occur (or has occurred).

Ideally, water and sediment quality guideline trigger values should delineate between the presence or absence of an adverse biological effect. This usually involves identifying and quantifying contaminants present in water (e.g. dissolved and total concentrations) and sediments (e.g. pore water and particulate concentrations) for comparison with the respective guideline trigger values. However, given the chemical complexity of hydrocarbon and non-hydrocarbon oil-associated stressors, a comparison of water and sediment chemistry with guideline trigger values may not be sufficient to accurately predict the environmental risk associated with an exceedance due to the presence of co-occurring contaminants, the limited range of reliable trigger values, and the many physico-chemical factors known to influence bioavailability.

For example, using a gravimetric analytical method to quantify the petroleum hydrocarbon content of a water or sediment is useful for the purpose of estimating the combined total of hydrocarbon classed compounds. However, the measurement represents the combined concentration of all petroleum hydrocarbons in the complex mixture (as defined by the analytical method), for which the potential toxic properties of individual compounds will vary (TPH Criteria Working Group Series, 1998). Furthermore, the method does not account for non-hydrocarbon oil-associated stressors. While it is chemically possible to speciate and quantify the individual contaminants present, reliable water and sediment quality trigger values may not be available for comparison. Alternatively, where a reliable trigger values are available and have been exceeded, it is equally possible that the contaminant is non-bioavailable, which may lead to the implementation of unnecessary and potentially costly monitoring activities.

D.2: Ecotoxicology

While improvements have been made in distinguishing the bioavailable portion of contaminants within water and sediment, significant uncertainty still exists when attempting to predict biological effects from chemical estimates of contaminant bioavailability (Rainbow, 2002; Simpson and Batley, 2007). Adverse biological effects are often due to complex interactions between chemical speciation and organism exposure pathways, physiology and behaviour (Simpson, 2005; Louma and Rainbow, 2005; Rainbow, 2007). The combined influence from these interactions are not yet fully understood for predicting biological effects (Besser et al., 2003; Riba et al., 2004; Vijver et al., 2004; Simpson, 2005). Where contaminants are detected above guideline trigger values or background levels in-situ, or uncertainty relating the chemical characterisation exists; toxicity testing should be initiated to better understand the bioavailability and potential impacts of the oil-associated stressor.

For the purposes of water and sediment quality assessment, the uncertainty arising from the initial chemical measurements of contaminant concentrations is reduced using toxicity testing. Toxicity testing provides a biologically-based and more environmentally realistic representation of the contaminant bioavailability a marine organism is likely to encounter. Furthermore, the potentially complex chemical speciation of the contaminant can be assessed in association with organism physiology and behavioural influences on toxicity.

A range of tropical, sub-tropical and temperate bioassays are available for assessing water and sediment quality. These include standardised protocols for representative test organisms which reside in the water column and/or benthos (e.g. bacteria, microalgae, macroalgae, crustaceans, molluscs, echinoderms, polychaete worms and fish). The endpoints for the bioassays may measure either acute effects (e.g. mortality), or the more sensitive sub-lethal and chronic effects (e.g. inhibition of growth, fertilisation, larval development or reproduction).

Biochemical and physiological responses following exposure to an oil-associated stressor may also be assessed using sub-lethal biomarker measurements (e.g. detoxification enzyme production, DNA damage). The use of sub-lethal biomarker tests are considered appropriate where a concentration-response relationship has been established for an oil-associated stressor and demonstrated to correspond with standardised biological endpoints, e.g. sub-lethal effects such as growth, development or reproduction. The selected tests should be appropriate to meet the objectives of the water and sediment quality assessment. Therefore, a justification for the selected toxicity tests should be provided in the proposed monitoring program. Criteria which are of relevance when selecting an appropriate toxicity test include considerations for:

- Relevance of the bioassay to the receiving environment
- Sensitivity to a broad range of oil-associated stressors
- Assessing dissolved and/or particulate phases of a contaminant
- Contaminant exposure pathways of the test organism (dietary versus dissolved uptake)
- Relevance of test endpoints (acute, sub-lethal and chronic effects) to short-term and long-term impacts.

D.3: Biodegradation and Bioaccumulation

Biodegradation is a weathering process which occurs when a component of the oil-associated stressor (e.g. organic compounds) is converted to simpler molecules via biological processes. The rate and extent of biodegradation will depend on the type of microorganisms present and the environmental conditions (including temperature, oxygen levels and nutrient availability). Naturally occurring bacteria in seawater and sediment generally control biodegradation in marine environments, with aerobic biodegradation more likely to occur in the water column, and either aerobic or anaerobic biodegradation occurring in the sediments. The susceptibility of an oil-associated stressor to biodegradation is also influenced by chemical structure. For example, low molecular weight compounds are readily broken down (e.g. short chain n-alkanes), while multi-ring aromatic hydrocarbons are relatively stable (e.g. naphthalene, phenanthrene).

Biodegradation contributes to minimising the persistence of an oil-associated stressor released into the receiving environment following conversion to a less toxic metabolite, or through complete removal. For example, while adverse effects to biological receptors may initially occur over the short-term, the extent may remain localised (provided secondary metabolites are non-toxic). However, the absence of biodegradation implies that an oil-associated stressor may have the ability to exert toxicity over a wide spatial and temporal scale as the crude oil or condensate becomes distributed across the environmental compartments.

The persistence of an oil-associated stressor may also be determined by the contaminants bioaccumulation potential. Bioaccumulation refers to the accumulation of contaminants in the tissues of organisms through any exposure route, including respiration, ingestion, or direct contact with contaminated sediment or water (USEPA, 2000; Moore et al., 2005). Bioavailability and organism exposure pathways strongly influence the uptake and retention of contaminants within the organism.

Regardless of the ecological niche, all biological receptors have the potential to accumulate oil-associated stressors. However, the extent of toxicity from the accumulated oil-associated stressor will depend on the biological receptors ability to metabolise, detoxify, excrete and/or store the contaminant. For example, while ambient concentrations may be below short-term effect thresholds (e.g. acute mortality effects), the continuous physiological effort required to process and detoxify an oil-associated stressor can give rise to chronic effects over longer term exposures (e.g. inhibition of development leading to reduced fecundity).

Appendix E: Monitoring techniques

E.1: Seabed flora and fauna

There are a number of techniques commonly used to monitoring seabed flora and fauna and a large body of literature available about different techniques. At a large qualitative scale, aerial surveys, remote sensing, bathymetry and other GIS applications are used to define spatial boundaries of habitat types. Ground-truthing of these techniques include quantitative field surveys either using video or in situ using transects and quadrats to quantify individuals or percentage cover. Finally any number of sampling techniques for the various different flora and fauna may be undertaken depending on the type of biota. At this fine scale where intimate knowledge of a particular ecological group is required, recognised taxonomists may be consulted. In the absence of taxonomic specialists, monitoring at a coarse level of taxonomy or functional group may be undertaken. But even at this level, personnel with some level of post-graduate studies, training in biological assessment, or a credible level of experience is usually required. Reference to known and commonly used scientific categories is recommended.

Aside from appropriate indicator species, commonly monitored ecological, population and community based parameters for seabed flora and fauna assemblages include:

- changes in the abundance of ephemeral versus perennial organisms e.g. marine plants such as algae, seagrasses, and salt marsh vegetation (Penela-Aremez 2009, IPIECA 1994), and similarly the polychaete/ amphipod ratio (Gesteira and Dauvin, 2000) have been suggested as an oil spill "bioindicators"; or alternatively simply relative percentage compositions where nature of organisms is as yet unknown.
- species richness, diversity or quantification of species of functional groups of habitat formers or their inhabitants
- species zonation patterns
- abundance, size frequency distribution, density and/or biomass of individual plants and animals including:
  - counts of adults
  - counts of dead animals e.g. shells or urchin tests washing up on the beach, vacant feeding scars from limpets
  - counts of recruits and juveniles.

Monitoring may also be carried out on the health and condition of individuals, for example measurement of growth rates, reproductive outputs or viability, ecotoxicity testing of tissues from crustaceans, bivalves, barnacles etc. Examples of parameters more specific to organism type commonly used to assess health include:

- corals: partial mortality, bleaching, growth rates, reproductive status, prevalence of disease, numbers of breaks, cover of mucous, number of corallivorous snails
- mangroves: height and diameter of trees, growth rates, density of seedlings, sediment monitoring and litter productivity, stem density, crown density, crab hole density i.e. direct relationship with soil drainage & oxidation

- saltmarshes: signs of decay or stress of leaves, stems and roots, growth status and evidence of new growth, reproductive status, abundance and diversity of gastropods on emergent vegetation, plant condition (signs of blackening and defoliation), opportunistic algal cover, and sediment macrofauna diversity (particularly amphipods and polychaetes).

E.2: Fish and fisheries

While an oil spill in open water is unlikely to cause catastrophic impacts in the sense of causing large scale fish kills (see section 8.1.2), it is likely that an oil spill may have sub-lethal effects on individuals and populations of fish and fisheries species. There are techniques available to measure sub-lethal effects of oil, such as biomarker studies, and the results of such studies may inform the need to initiate population level studies on fish growth, disease, reproductive output, recruitment or other features of populations.

The measurement of direct impacts on fish resources may require extractive sampling of fish to conduct, for example, sensory testing of seafood products for hydrocarbon taint (refer further reading in Section 8.1.2) and molecular biomarker analysis (see Kirby et al. 2000). Monitoring techniques for testing levels of petroleum hydrocarbons in fish tissues of commercial species require particular attention as the results will likely be used to inform fishery closure and re-opening decisions, for determining human health risks as well as physiological impacts to fish themselves.

The fish sampling techniques applied will depend on variables such as the life history stage targeted (for example mesh size considerations) or the position of targeted species in the water column (e.g. seabed otter trawls for seabed species as opposed to purse seines for pelagic species). The selection of techniques for these studies should be informed by consultation with the fisheries agencies responsible for management of the potentially effected fisheries, as well as relevant food safety authorities. This form of monitoring requires specialist skills and availability of appropriate facilities and personnel should be identified during the design process.

Measurement of indirect impacts on fish may involve for example, stomach composition analysis for food chain impacts or catch and release studies examining fish for evidence of disease or parasite loads. Seabed habitat condition surveys (e.g. drop camera or diver transect surveys) may also be used to determine levels of adult fish or nursery habitat degradation to infer likely effects on populations of fish and fisheries species. Guidance on the monitoring of seabed habitats that may provide important functions for fish assemblages, such as nursery areas, is provided in Section 10.4.1.

It is important to recognise that measuring effects of oil pollution on parameters such as recruitment success in fishes and invertebrate fisheries species can be very challenging given the degree of natural variability and uncertainty in fisheries science as to all the factors that contribute to the level of recruitment in a given year. This has led some researchers to suggest that modelling studies are the only effective way to estimate the likely impacts of oil pollution of fish recruitment (e.g. Reed et al. 1984). Quantitative data integrating models may provide a practical method of estimating the scale of impacts to inform decisions about the need for long term studies on fish population dynamics and recovery.

E.3: Wildlife

Monitoring techniques commonly employed to collect demographic data on wildlife populations involve direct counts or estimates of numbers of individuals, capture-measure-release of tagged individuals and deployment of remote sensing technology including satellite telemetry. The methods used will depend on features of the animal such as aspects of its life history, movement/migration patterns and its size. For example, while cetaceans are generally considered to be vulnerable to the effects of oil spills, empirical data on effects are few, largely because populations are difficult to monitor and there are only limited data from studies of oil-effects on captive animals that can be used to guide what and how to monitor potential effects.

The numbers of oil-affected and dead animals recorded from within known areas are sometimes used as indicators for assessing the severity of impact to wildlife. However, it is important to be aware that not all animals found deceased around the time of a spill may have died as a result of the spill or response activities. With this in mind titleholders should include procedures such as necropsies to determine cause of death. The advice of veterinary and marine fauna experts should be sought on appropriate necropsy techniques and indicators to be examined. A further consideration is that quantification of fauna mortality based on numbers of recovered/recorded dead animals may significantly underestimate the actual mortality rate if the animals in question sink when they die at sea. While consideration may be given to the application of adjustment factors to take potential underestimation into account, this should only be done with full appreciation of the scientific uncertainty associated with choosing an adjustment factor.

While monitoring the short term effects of a spill on wildlife is not without its challenges, evaluating the longer term consequences for individual animals and populations is even more challenging. Tissue biopsies of animals that survive the spill can be used to provide information about hydrocarbon exposure and chronic health concerns associated with that exposure. Assessments of animal exposure and health have been made studying the tissue burden of hydrocarbons and associated metabolites and biomarkers (e.g. Ballachey, 1995). Biopsy samples are used to assess the body burdens of selected toxicants and toxicity-related biomarkers in wild animals. Here too, advice should be sought from veterinary and marine fauna experts on techniques appropriate for various animals where this appropriate is to be part of the OSMP. Biopsies and the measures taken and selection of biomarkers warrants careful consideration, as illustrated by the 2005 assessment of lingering oil from the Exxon Valdez spill. In its final report, Integral Consulting Inc. (2006) details the findings of studies of the polycyclic aromatic hydrocarbon (PAH) content of tissue collected from oiled and control populations of harbour seals. These studies found that while concentrations of PAH in blubber indicated a spill-related signal, similar analysis of brain, liver and muscle tissue returned concentrations near or below limits of detection for all samples. Sampling of aromatic compounds in bile samples from oiled and control harbour seal populations was able to be used to infer spill effects and declining patterns in oil exposure in individual animals.

Observations of the behaviour of animals affected by an oil spill may also provide insight into the spill's effects. This could include collecting animal movement and habitat utilisation data, which can be used to identify potential overlap of important habitat with areas affected by a spill as determined from information collected by operational monitoring (e.g. aerial surveillance of surface slicks). Survey guidelines for Australia's threatened birds have been published (DEWHA, 2010). While the overarching purpose of these DoE guidelines differs from the overarching aim that should be achieved by an OSMP, DoE's survey guidelines offer general advice on considerations that may be relevant to any bird monitoring element of an OSMP.

Titleholders should aim to integrate wildlife response activities with scientific monitoring. Integration could be achieved by aiming to measure some common indicators during both oiled wildlife response activities and scientific monitoring (e.g. tissue biopsy data) and/or track the condition of captured and cleaned animals over time as part of the scientific monitoring. For example, the numbers of recorded deceased and cleaned and released animals can provide context for on-going measures of key indicators of population size during scientific monitoring. Similarly, carefully considered monitoring that is allows patterns of oil-related exposure and health implications in individual animals to be tracked over time while coincidentally measuring population parameters can enhance the understanding of cause-effect relationships. Resultant improved understanding can be applied in the future to make more accurate predictions of impact and inform better decision-making in relation to how and where to allocate environmental management resources to minimise impacts of hydrocarbon spills on wildlife.

Where demonstrable risk to wildlife populations is evident or impacts are likely it is expected that titleholders would commit to monitoring those at-risk/impacted populations to determine, to the extent possible, the impacts. Since population-level impacts may not be immediately obvious following as spill and determining impacts to populations is challenging and not generally something that is achieved in the short term, careful consideration needs to be given to the selection of population-level indicators that will be the focus of monitoring. Population-level indicators should lie along a cause-effect pathway relevant to hydrocarbon effects and hence be likely to show a response to oil-associated stressors. For example, if a cause-effect relationship and associated risk and impact assessment ascertains that hydrocarbon contamination of shorelines affects the quality and quantity of food resources for wading shorebirds, which in turn affects the health of individual adult and hatchling birds, then in addition to indicators of habitat contamination, suitable demographic indicators such as mortality rate, age structure and fecundity along with physiological indicators of health should be considered for inclusion in the monitoring program. Other indicators of populations that might be affected by hydrocarbon spills include measures of breeding success, age-at-first-breeding and rates of transition from one stage in the life history to the next.

Appendix F: Baseline studies

F.1: Baseline water and sediment quality

The primary advantage of undertaking a baseline evaluation of water and sediment quality is the capacity to delineate contributions from the activity from sources that are either naturally occurring (e.g. natural oil seeps or mineralised phases of metals in sediments) or present as a result of cumulative inputs from neighbouring activities (e.g. planned discharges of drilling muds or produced formation water from nearby exploration activities or production facilities, respectively). This is particularly relevant where the concentration of an oil-associated stressor quantified in the post-spill monitoring program is exaggerated due to the previously existing background levels, which has the additive effect of overestimating the ecological risk and potential for impacts.

Surveying the background levels within the area of interest requires understanding the chemical composition of both the oil-associated stressor and the existing concentrations within the water and sediment. The chemical characterisation should be comprehensive enough to enable oil-associated stressors to be quantified in the water, sediment or biota to inform both the baseline and emergency monitoring activities. Characterising the chemical composition of an oil or condensate identifies the hydrocarbon and non-hydrocarbon contaminants of concern which effectively minimises the replication of unnecessary chemical analyses in the monitoring program by targeting specific analytes in the water, sediment or biota.

The identification of hydrocarbon and non-hydrocarbon oil-associated stressors within an oil or condensate may be undertaken on the whole oil, or a representative fraction of the whole oil which has relevance to the receiving environment, e.g. the water accommodated fraction (WAF, discussed further below). Given a broad range of hydrocarbon and non-hydrocarbon analytes will be present within a range of variable water, sediment, biological tissue and whole-oil matrices, the appropriate analytical method should be carefully selected. General considerations may include:

- Suitable analytical instrumentation (e.g. GC-MS, ICP-MS)
- Sample processing methods (e.g. solvent extraction and clean-up)
- Practical quantification limits
- Matrix interferences and method limitations
- Quality assurance and quality control (e.g. instrument calibration, reference standards, drift correction, blanks and triplicates)
- Laboratory accreditation (e.g. NATA, GLP).

While undertaking a chemical characterisation of the oil, an extension to include both diagnostic chemical (e.g. PAH isomer profile, aromatic sulphur heterocyclic compound profile, vanadium/nickel ratio) and biological (e.g. acyclic terpenoids or isoprenoids such as pristine/phytane ratio) fingerprinting analyses may also be beneficial. The primary advantage of undertaking fingerprinting is the ability to delineate the source oil from that observed in the receiving environment during an unplanned release. This is particularly useful when attempting to define the spatial distribution (i.e. area of interest) for ongoing scientific monitoring activities which may be corrupted by detection of naturally occurring seeps or cumulative impacts from neighbouring petroleum activities.

The oil-associated stressors identified in the chemical characterisation may then be targeted to establish pre-spill background levels in water, sediment and biota. The field sampling program should adequately represent the area of interest, and be designed considering key principles outlined in Section 3. If a sample analysis plan (SAP) has been developed for the baseline area of interest, the structure may be readily modified and applied in an emergency monitoring response. Examples of key principles for inclusion within a field SAP may include details outlining:

- Location and timing
- Sampling program design (e.g. randomised or targeted)
- Sample collection techniques for water sediment and biota
- Field records, measurements and observations
- Field processing, transport and storage (e.g. preservation of sample integrity)
- Quality assurance and quality control (e.g. triplicate samples, field blanks, holding times)
- Key personnel and subcontractor services
- Turn-around-time and reporting arrangements

In addition, physico-chemical properties which are known to modify the bioavailability of dissolved or particulate contaminants should also be measured in the baseline study to enable comparison with available guideline values (e.g. normalisation of sediment-associated petroleum hydrocarbons to 1% organic carbon).

In situations where the field survey identifies locally elevated background levels of an oil-associated stressor in water, sediment or biota (by comparison with relevant guideline trigger values or background levels for the broader survey area), the baseline assessment can proceed to an ecotoxicological investigation to determine the bioavailability of the contaminants. Alternatively, it may also be possible to determine if the existing oil-associated stressors have affected the community structure where a concurrent ecological community baseline survey has been undertaken.

F.2: Simulated weathering studies with dispersant efficacy testing

The potential for a crude-oil or condensate to persist in the marine receiving environment will depend on the extent of natural weathering and spill response interventions, e.g. the application of chemical dispersants. Subsequently, these factors may also influence the spatial and temporal distribution and bioavailability of an oil-associated stressor within the area of interest.

Existing literature and computer simulation models based on a representative crude oil or condensate spill parameters (e.g. volume, composition, slick thickness and metocean conditions) provide useful estimations for the behaviour and fate of the spill, which is of importance when planning appropriate operational response strategies. However, under circumstances where greater certainty is required (e.g. probable contact sensitive environmental receptors), laboratory-based simulated weathering studies and dispersant efficacy tests provide an understanding of the persistence and transformation for the specific oil-associated stressors within the receiving environment.

For example, oil weathering studies involve introducing a representative sample crude oil or condensate into seawater under the abiotic and physico-chemical conditions expected in-situ, e.g. Mackay MNS test apparatus, (Mackay and Szeto, 1982; AMSA, 2012). Generally, the hydrocarbon content of the whole oil and/or water accommodated fraction (WAF) is monitored over a designated period of time to assess the extent of natural weathering with results reported in terms of percentage composition evaporated to the atmosphere, dissolved or dispersed in the water column or remaining at the water surface. A reduction in the concentration of hydrocarbons over a period of time is indicative of persistence within a designated compartment of the receiving environment.

Dispersant efficacy tests are fundamentally similar to weathering studies in terms of assessing the composition, behaviour and fate of hydrocarbons, though a dispersant is added to the crude oil or condensate to assess the appropriateness of the dispersant type, ability to disperse oil into the water column and to identify the timeframe for which a dispersant will be effective. Under amenable oceanic conditions, dispersants are usually applied as an operational response strategy to prevent shoreline contact and oiling of wildlife. While dispersant efficacy testing is useful for informing the operational response strategy, an acknowledgement of the impacts and risks from dispersed or entrained hydrocarbon is often neglected.

Simulated weathering studies and dispersant efficacy tests are generally limited to an understanding of changes in chemical composition of the whole oil and water accommodated fraction, from which little information can be ascertained with respect to the bioavailability of the oil-associated stressors following natural weathering and dispersant use. However, in keeping with the key concepts required to assess the distribution and bioavailability of an oil-associated stressor, the simulated weathering studies and dispersant efficacy tests can expand to include considerations for the bioavailability. Ideally, this would include a suite of toxicity tests (selected in accordance with criteria outlined in Section 8.1.2) to demonstrate the changes in the bioavailability of an oil-associated stressor in the simulated WAF following natural weathering and dispersant application. From this, an enhanced understanding of any potential change in chemical composition could be directly related to the toxicity of an oil-associated stressor to better inform the relationship between persistence and potential impacts to organisms residing in the receiving environment.

For example, simulated weathering studies will likely indicate a reduction in the total mass of hydrocarbons over time, with lighter fractions in the whole oil and WAF dissipating rapidly. Alternatively, the application of a chemical dispersant may initially increase the load of hydrocarbons within the water column, followed by gradual weathering. An assessment of bioavailability over this time scale aims to validate assumptions that a change in chemical composition is associated with a reduced risk to sensitive biological receptors within the receiving environment.

Key benefits for undertaking expanded simulated weathering studies and dispersant efficacy tests may include:

- Estimating the rate of weathering for a representative crude oil or condensate to validate trajectory modelling parameters and inform spill response Net Environment Benefit Analysis (NEBA)
- Understanding the oil-associated stressor fate and persistence to inform scientific monitoring program design within the area of interest (e.g. distribution from sea surface to dissolved and entrained phases may focus monitoring efforts toward sub-surface features within the water column)
- Demonstrating changes in oil-associated stressor toxicity over time following natural weathering, as well as an assessment of additive effects from combined dispersant and oil-associated stressor mixtures

- Determining spray zone boundaries within the area of interest by evaluating risk of dispersing oil into the water column
- Identifying the presence and bioavailability of non-hydrocarbon oil-associated stressors generally not measured in standard simulated weathering and dispersant efficacy tests.

F.3: Deriving a reliable species protection trigger value

The water and sediment quality monitoring component of the scientific monitoring program should at a minimum aim to identify and quantify the distribution of oil-associated stressors within the receiving environment. However, a comparison of water and sediment quality data (collected during the emergency response monitoring) with guideline trigger values or background levels may not be sufficient for evaluating the ecological risk from the oil-associated stressors identified. This is primarily due to the presence of co-occurring contaminants and the many physico-chemical factors known to influence the bioavailability of an oil-associated stressor. Understanding the bioavailability of an oil-associated stressor prior to an unplanned release greatly assists with validating cause-effect linkages between the oil-associated stressor and the ecological indicators within the area of interest.

For example, as part of the initial scientific monitoring response to an oil spill, a water and sediment quality assessment may be undertaken within the area of interest to better define the distribution. Where an oil-associated stressor has been identified at concentrations exceeding the guideline trigger values and/or background levels, further assessment of the bioavailability can be undertaken to determine the risk of adverse biological effects occurring (e.g. toxicity testing). However, determining the bioavailability of an oil-associated stressor for multiple sites exceeding guideline trigger values and/or background may not always be practical or useful due to the many constraints associated with logistics (including the initial analysis, confirmation of the exceedance, resampling of a remote site, followed by dispatch to a service provider), during which time the chemical composition (and bioavailability) may have changed significantly from that initially detected. Furthermore, it may be cost prohibitive to assess the bioavailability of many samples in situations where the oil-associated stressors are broadly distributed.

An effective alternative is to derive a species protection trigger value which is specific to the crude oil or condensate of interest. The species protection trigger value is analogous to the water and sediment quality guideline trigger values outlined in ANZECC/ARMCANZ (2000), in which a threshold concentration is intended to be predictive of adverse biological effects occurring, and protective of the aquatic organisms residing in the marine environment. The application is also similar; in that water and sediment quality parameters measured during the spill event can be directly compared to a more predictive and protective trigger value derived from the representative oil-associated stressors.

An appropriate species protection trigger value reduces the need to assess bioavailability for every sample exceeding guideline trigger values and/or baseline levels, and provides valuable insight with respect to establishing cause-effect relationships between the oil-associated stressor and supporting observations of potential ecological impacts. Species protection trigger values for a crude oil or condensate can be derived for both water and sediments. The derivation of a species protection trigger value is a laboratory-based baseline study using a statistical a comparison of biological effects from a range of representative toxicity test species exposed to the chemically characterised oil-associated stressors which have been artificially introduced into a water or sediment medium.

Given the species protection trigger value is intended to be used as a reference in the event of an unplanned release of oil, the crude oil or condensate should therefore be sufficiently characterised prior to undertaking this approach to ensure the predictors of chemical bioavailability are well established. This is particularly important for complex petroleum hydrocarbon mixtures that often contain co-occurring contaminants (i.e. additive toxicity from non-petroleum classed contaminants) which may also undergo natural weathering processes (i.e. biodegradation that reduces toxicity over extended periods of exposure).

For example, preparation of a WAF is more suitable for the purposes of deriving a trigger value for dissolved oil-associated stressors, compared to sediment spiking approaches which are more appropriate for deriving a sediment quality trigger value. In both cases, careful documentation of the preparation techniques, physico-chemical properties, equilibration time and chemical characterisation of oil-associated stressors is required for interpretation of the WAF and spiked sediment toxicity testing results. Suitable methods for the preparation of an artificially contaminated WAF and spiked sediments may be found in the 'Guidance for testing of poorly soluble substances' (GHS, 2010) and 'Handbook for sediment quality assessment' (Simpson et al., 2005), respectively.

The selection of appropriate toxicity tests is discussed in Section 8.1.2, though it is noted that one bioassay result will not be sufficient for deriving a biological effects threshold. In accordance with ANZECC/ARMCANZ (2000), the species protection trigger value should be derived using the EC10 data (i.e. 10% biological effect) from a minimum of five representative species from four taxonomic groups. The biological effects data is then statistically analysed (Campbell et al., 2000) to derive a desired level of species protection, i.e. usually 99% for pristine ecosystems, 95% for moderately-slightly disturbed ecosystems. For example, organisms exposed to the artificially prepared WAF or spiked sediment concentration at or below the 95% species protection trigger value (based on EC10 values) will theoretically result in <5% of the exposed organisms showing <10% biological effect (i.e. <10% inhibition of the biological effect endpoint). Confidence in the trigger values ability to predict adverse biological effects increases with the number and diversity of test species utilised, and sensitivity of the test species endpoint (e.g. sub-lethal and chronic endpoints will be more sensitive than acute endpoints).

The limitation of the species protection trigger value for predicting adverse biological effects will be influenced by the toxicity testing exposure regime selected. For example, sessile or site attached organisms residing in the receiving environment are more likely to be exposed to an oil-associated stressor over longer-term durations than mobile organisms, which may potentially avoid areas of degraded water and sediment quality. For sessile and site attached organisms, a species protection trigger value derived using a continuous-exposure regime will be more appropriate, though will overestimate the potential toxicity to mobile organisms. For mobile organisms, assessing the toxicity after a short-term exposure to an oil-associated stressor may be undertaken using standardised pulsed-exposure toxicity testing methods. By comparison, the pulsed-exposure regime may underestimate the potential toxicity to sessile and site attached organisms.

Given the intended application of a derived water or sediment quality trigger value, it is strongly recommended that specialist technical advice be obtained. However, the key advantage of deriving an appropriate species protection trigger value is to provide greater confidence in validating the presence or absence of impacts from ecological monitoring observations, while eliminating the need to undertake bioavailability testing for all samples exceeding guideline trigger values and/or background levels.