Marine Pollution Bulletin 60 (2010) 797–803

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Viewpoint

Accidental spills at sea – Risk, impact, mitigation and the need for co-ordinated post-incident monitoring

Mark F. Kirby *, Robin J. Law

The Centre for Environment, Fisheries and Aquaculture Science, Cefas Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK

ARTICLE INFO

Keywords:
Oil spill
Chemical spill
Impact assessment
Monitoring
Emergency response
Shipping accidents

ABSTRACT

A fully integrated and effective response to an oil or chemical spill at sea must include a well planned and executed post-incident assessment of environmental contamination and damage. While salvage, rescue and clean-up operations are generally well considered, including reviews and exercises, the expertise, resources, networks and logistical planning required to achieve prompt and effective post-spill impact assessment and monitoring are not generally well established.

The arrangement and co-ordination of post-incident monitoring and impact assessment need to consider sampling design, biological effects, chemical analysis and collection/interpretation of expert local knowledge. This paper discusses the risks, impacts and mitigation options associated with accidental spills and considers the importance of pre-considered impact assessment and monitoring programmes in the wider response cycle. The PREMIAM (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring; www.premiam.org) project is considered as an example of an improved approach to the planning, co-ordination and conduct of post-incident monitoring.

1. Introduction

Spills of oils and chemicals in the marine environment remain a significant threat. Although there is evidence that the number of oil spills, for example, has decreased in recent decades (Huijer, 2005; Burgherr, 2007) the record is still regularly punctuated by large, high profile incidents (e.g. *Prestige*, *MSC Napoli*, *Hebei Spirit* and *Tasman Spirit*). Furthermore, reports of smaller spills and potential incidents are occurring on a daily basis. It also has to be recognised that for some areas of the world (e.g. China (Woolgar, 2008)) spill risk is probably increasing due to increased traffic. This is also the case for European coasts bordering the Baltic, Barents and North Seas and the English Channel due to the increased transport of heavy and residual fuel oils from the former Soviet Union. The situation for chemical, or hazardous and noxious substances (HNS), spill risk and incidents is less well defined than that for oils. Essentially the volume of transport of chemicals is less than that for oils (especially when one considers the fuel oils that all large ships carry for propulsion) but the wide range of chemicals transported includes some that, if released, have the potential for causing much greater environmental damage. Also, the options for treatment and mitigation are fewer. A recent review (Purnell, 2009) concluded that, on the basis that risk = frequency × consequence, oil and HNS spills 'may come out even' in terms of their overall risk to the marine environment.

So what distinguishes the threat to our seas, estuaries and coastlines from accidental spills, compared to that from other sources of chemical contaminants? Inputs to these water bodies from terrestrial-based sources, domestic and industrial discharges, diffuse origins and from the legacy of contaminated sediments all remain highly important sources of potential impact. However, accidental spills at sea pose a very specific threat, in terms of both catastrophic release and damage and the unpredictability of their occurrence. Furthermore, while on a purely volumetric basis (though statistics almost never include the probable bulk of oil release which occurs as innumerable small discharges/spills from vessels) spills at sea will not appear as significant compared to land-based sources of marine pollution, marine spills also have a very strong capacity to induce a phenomenon known as 'social amplification' (Leschine, 2002). Social amplification is the process by which the concerns of sectors of environmental stakeholders, often the general public, can be intensified by social values and then further exacerbated by the politics of media coverage (Anderson, 2002). The weight of public perception might act as a force to push attention away from other marine pollution issues, but that is not the reason for the scientific community to ignore it and, indeed, it is a driver to ensure that the significance and impacts of spills are properly assessed using a "best practice" science approach.

* Corresponding author. Tel.: +44 1502 527796; fax: +44 1502 513865.
E-mail address: mark.kirby@cefas.co.uk (M.F. Kirby).

0025-326X/$ - see front matter Crown Copyright © 2010 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2010.03.015

Even a cursory interrogation of the published literature reveals an abundance of studies that have demonstrated the capacity of accidental spills to have a significant environmental impact. Take, for example, the *Prestige* oil spill off the Galician coast of Spain in 2002. Coastal impacts resulted in a loss of 66% of species richness in some areas (de la Huz et al., 2005), detectable impacts on sediment quality (Morales-Caselles et al., 2007) and impacts on offshore fish and crustacean fisheries (Sánchez et al., 2006). Moreover, impacts are not restricted to the environment as socio-economic impacts can be both high and wide ranging (Garza-Gil et al., 2006; Garcia Negro et al., 2008). Most of the environmental impact studies take place in the short term to medium term following the spill, and the potential for long-term impacts is often overlooked. The scientific literature abounds with options for the measurement of sub-lethal impacts in a range of species and communities but, in most cases, these are not comprehensively used in long-term spill monitoring. Several methods of assessing sub-lethal impacts were used following the *Sea Empress* spill off the coast of Wales in 1997 including lysosomal stability in mussels (Fernley et al., 2000), ethoxyresorufin-*o*-deethylase (EROD), a hepatic detoxifying enzyme, induction in flatfish (Kirby et al., 1999); genotoxic DNA damage in a range of invertebrates and fish (Harvey et al., 1999); and immune function in mussels (Dyrynda et al., 1997, 2000), and all identified measurable impacts. Long-term studies using a range of bioindicators of genotoxic exposure in fish and shellfish were conducted following the *Haven* oil spill in Italy in 1991 (Bolognesi et al., 2006) and effects were still apparent in the impacted area 10 years after the spill. Kingston (2002) in a review on the long-term environmental impacts of oil spills states that, in most cases, environmental recovery is generally considered complete within 2–10 years after an incident. However, there have been cases, for example, following the *Exxon Valdez* spill in Alaska, when continuing impacts are claimed up to 10–20 years after the spill (Peterson et al., 2003; Guterman, 2009), though these claims are routinely disputed (Guterman, 2009). There are also compelling evidences in the literature that in a specific spill incident in the US, involving a spill of 700,000 L of No. 2 fuel oil, petroleum-derived hydrocarbons persist in sediments (Reddy et al., 2002; White et al., 2005; Peacock et al., 2007) and that detectable sub-lethal biological impacts in fiddler crabs (Culbertson et al., 2007), salt marsh grasses (Culbertson et al., 2008a) and ribbed mussels (Culbertson et al., 2008b) are still evident 40 years after the original spill. It is apparent, therefore, that recovery from marine spills can be quite rapid but that the potential for long-term impacts will depend on the severity of the spill, the nature of the chemical/oil spilled, and the type and sensitivity of the receiving environment and exposed species. In general, the lower the level of contamination present in the spill area pre-incident, the higher the likelihood of being able to detect long-term impacts as the "background signals" due to other sources are lower. However, disentangling these multiple sources can be complex (see, for example, Page et al., 1995). There is no doubt though that the potential for long-term impacts exists, and that the nature and significance of these are quite poorly understood.

Examples of impact assessments for chemical spills in the scientific literature are few in comparison to those for oil spills. However, marine chemical spills do occur, such as that associated with the loss of the chemical tanker *Ievoli Sun* in the English Channel in 2000, in which styrene, methyl ethyl ketone and *iso*-propyl alcohol were released (Law et al., 2003). Significant environmental impact resulting from that particular incident was not considered likely, but edible tissues from crabs recovered from a string of pots laid nearby prior to the sinking were analysed for residues of styrene. The concentrations found were detectable but low (<100 μg kg^{-1} fresh weight in edible tissues) and considered to present a negligible risk to human consumers even close to the point of release (<1 km distant) (Law et al., 2003). As a result, no fishery closure was implemented. In an earlier review of the effects of oil and chemical spills, Law and Campbell (1998) considered a potential 'worst case' scenario and concluded that a 10-tonne spill of an organophosphorus insecticide, pirimiphos-ethyl, might seriously impact crustacean fisheries in an area of the English Channel up to 10,000 km^2, with a regeneration time for the fisheries of 5 years. French McCay et al. (2006) used chemical spill modelling in conjunction with chemical hazard quotients to estimate areas of impact for given chemical types in specific scenarios. This study identified a number of selected chemicals that presented the highest hazard and, depending clearly on the volumes spilled (the study considered spills up to 1000 tonnes), estimated areas in excess of 90 km^2 where the predicted no effect concentration (PNEC) might be exceeded.

In terms of chemicals of highest concern, French McCay et al. (2006), using a predictive modelling approach for a selected range of chemicals that are transported by sea in bulk concluded that phenol and formaldehyde present the greatest hazard to aquatic biota. The UN group of experts on scientific aspects of marine environmental protection (GESAMP) has established a process for the evaluation of the hazards of harmful substances carried by ships (Wells et al., 1999; GESAMP, 2002). The GESAMP hazard rating takes account of physico-chemical properties that place the chemicals into a number of behaviour categories (e.g. floater, evaporator, dissolver, sinker and various combinations of these) which can help to determine which compartment of the environment the chemical would have its primary impact on. The potential severity of the chemical hazard is determined by identification of those chemicals that also have other combinations of harmful characteristics, namely, the level of biodegradability that will affect its ability to persist (P) in the marine environment, its propensity to bioaccumulate (B) in exposed biota and its level of acute toxicity (T) to relevant biota – the PBT characteristics. However, the assessment of risk to the marine environment also has to take account of the likelihood of a spill occurring which will, in turn, be related to the tonnage and frequency of transport. A European-funded project monitoring the volume of chemicals transported in bulk or packaged form (HASREP, 2005) tackled the issue of transport volumes, identifying the top 100 chemicals transported between major European ports and including trade through the English Channel to the wider world. Through an assessment of both volume transported and the GESAMP hazard profile, a number of chemicals of concern were highlighted, including; benzene, styrene, vegetable oil, xylene, methanol, molasses, sulphuric acid, phenol, vinyl acetate, toluene and acrylonitrile. Although it was recognised that these have a relatively high probability of spillage they may not result in significant environmental impact. Perhaps more concern should be shown for highly biologically active chemicals, such as a range of pesticides, although they are not transported in such large tonnages. In reality, the chemicals of real concern will vary depending on the marine area for which the risk assessment is being conducted, and will take account of the types of chemical primarily transported in that area and the types of sensitive species/communities in the vicinity.

Of course the environmental risk from shipping is not restricted to spills and includes issues such as threats to ecosystems and biodiversity from ballast water discharges (Endresen et al., 2004) and the shipping industries' contribution to atmospheric pollution and climate change (Eyring et al., in press), which contribute to a wider environmental impact 'footprint'. However, while the environmental management of shipping has attracted a great deal of debate (e.g. Smith, 1995), the continued importance of shipping to the global economy, with world sea borne trade having doubled in the last 20 years (Eyring et al., in press), will mean that in the short term to medium term the risks are unlikely to substantially reduce. In reality, therefore, both oil and chemical spills will continue to occur and some commercial drivers are, perhaps, making them more likely. Therefore environmental managers, regulators and the response and scientific communities need to continue to improve current practices in order to aid our understanding of the significance of spills to the marine environment. The implementation of appropriate legislation and conventions is a strong method through which to achieve this and the Oil Pollution Act (OPA), 1990 (Homan and Steiner, 2008) has been successful in the USA. Also, the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), 1990, requires that parties to the convention establish measures for dealing with pollution incidents, either nationally or in co-operation with other countries. At the time of writing, the OPRC has 98 contracting states representing 67% of world tonnage, a very substantial uptake, however, the protocol on Preparedness, Response and Co-operation to pollution incidents by Hazardous and Noxious Substances, 2000 (OPRC–HNS protocol) so far has only 24 contracting parties representing 33% of world tonnage (www.imo.org/conventions). The ultimate success of these influential legislative drivers will depend on the extent to which the response and preparedness cycle is developed and implemented in individual countries.

One area of continued scientific and technological development is with respect to the methods for treating and mitigating the impacts of marine spills. Treatment options open to the responder include manual recovery, chemical oil dispersants, sorbents and bioremediation products (Kirby and Law, 2008) and the appropriate use of, for example, chemical oil dispersants can be of great value to the responder and in protecting wildlife (Lessard and Demarco, 2000), and they have been successfully used to mitigate the impacts of large spills such as the *Sea Empress* oil spill in the United Kingdom in 1996 (Lunel and Elliot, 1998). However, while the treatment options for oils are well established, the options for treating chemical spills at sea are less so. Certainly, those classified as floaters would have the potential to be contained using booms and recovered using physical methods (e.g. skimmers) or sorbents. It is also possible that certain hydrophobic chemicals (and vegetable/mineral oils) may be chemically dispersible and Koh and Tan (2008) reported a preliminary laboratory-based assessment of the potential for a dispersant to disperse a range of oleophilic chemicals. This study found that some chemicals, including decane, ethylbenzene, toluene, vegetable oil and 2-ethyl hexanol, showed good levels of dispersibility, though clearly the possibility of increased environmental impacts occurring as a result requires further research before this can become an accepted method. While this certainly indicates that more work is warranted on the in situ treatment of chemical spills there is no doubt that, in general, established treatment and mitigation options for chemical spills are meagre in comparison to those available for oils. So, for chemical spills (and often for many oil spills), methods to minimise the chemical exposure to the marine environment either do not exist, will not be 100% effective, or cannot be deployed in time. It is critical, therefore, that effective environmental monitoring and impact assessment practices are in place, using the most appropriate scientific techniques, to enable the response, conservation and scientific communities to properly assess the real significance of the spill (and any subsequent clean-up activity) and to learn lessons for future events. Therefore, the requirement for response capability, improved preparedness and effective post-incident monitoring and assessment remains undiminished.

2. The response cycle

As mentioned above, international conventions, such as the OPRC, help to provide a basic framework for spill preparedness and response plans. The final approach, management and element prioritisation will, however, differ widely from country to country. In general, however, most will capture their approach in a plan and operate a system that could be captured as a 'response cycle' (an example of what elements might be included is shown in Fig. 1).

In the United Kingdom, for example, relevant parts of the OPRC (and other legislation) are enacted through the National Contingency Plan (NCP) which is maintained by the Maritime and Coastguard Agency (MCA), an agency of the Department for Transport. The full plan can be viewed at www.mcga.gov.uk.

The UK NCP is an excellent example of an overarching plan that helps to enable an effective national response in the event of marine spills and includes guidance on elements such as the setting up of a salvage control unit, at-sea and shoreline response cells, and making arrangements for finance, media and enforcement. The NCP also includes a section on environmental advice and monitoring, including the establishment of Environment Groups (EGs) in certain scenarios. In order to maximise the speed with which the EGs can provide advice following an incident, most operate continuously as Standing Environment Groups, organised on a regional basis. The UK's Marine and Fisheries Agency (an agency of the Department for Environment, Food and Rural Affairs) also maintains a Marine Pollution Contingency Plan, which also recognises the need for appropriate post-incident monitoring and impact assessment. However, there are no established expert guidelines in the UK for post-incident monitoring and impact assessment nor, indeed, is there a fully co-ordinated mechanism for overseeing the practical aspects of the programme (e.g. survey design, sampling, analysis and interpretation). Following the *Sea Empress* spill in 1996, Lord Donaldson's Report (Donaldson, 1999) recommended the setting up of EGs to provide the response units with environmental advice and guidance and, as mentioned above, this has been implemented by the MCA. However, the EGs are purely advisory groups and do not have an established role in the operational conduct of the monitoring itself, although some of the constituent organisations (e.g. Environment Agency and Cefas) may have. The establishment of an 'Impact Assessment Group' was recommended in the Sea Empress Environmental Evaluation Committee (SEEEC) report (SEEEC, 1998) but no operational monitoring and impact assessment co-ordinating body has been established as yet.

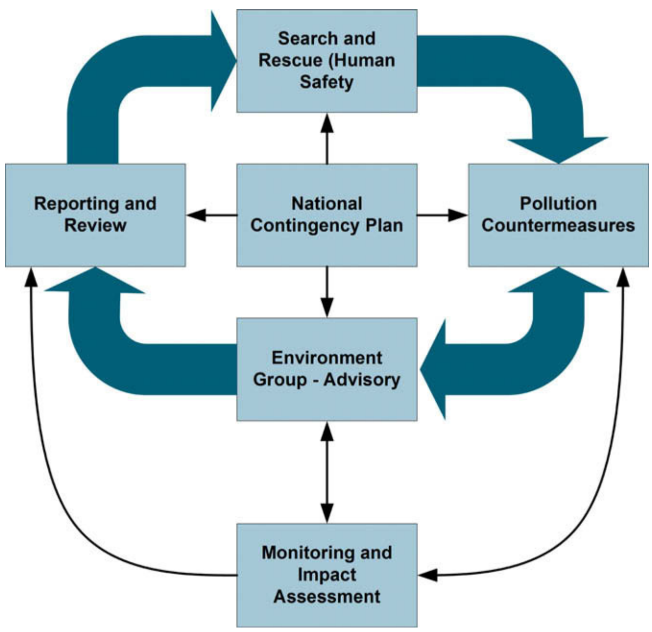

Fig. 1. An example 'response cycle' diagram.

This is just one example, from the UK, which is not intended to suggest a sub-standard approach. On the contrary, plans, skills and response capability in the UK are well developed. However, it does raise an important issue prevalent in many countries around the world and recently highlighted by Kirby and Law (2009) that planning, conduct and co-ordination of post-incident monitoring and impact assessment, while mentioned in appropriate plans, have not afforded the necessary priority to ensure that it is conducted effectively.

3. Post-incident monitoring

Definition. *Environmental monitoring is a set of integrated data-collecting activities to characterise and monitor the quality of a defined environment. Monitoring data may be used to compare spatial or temporal trends in relevant parameters as required for the preparation of an environmental impact assessment.*

The above definition holds true for post-incident monitoring though, of course, the character of this activity will differ substantially from general environmental monitoring. For example, rapid deployment is essential and specific considerations need to be given to design a programme based on the specific oil/chemicals spilled and the character of the receiving environment and the resources at risk.

In considering the question, 'Why is effective and pre-considered post-incident monitoring necessary?' six key reasons are proposed (though there are many others):

1. *Primary impact:* The need to provide early evidence of potential environmental and economic impact to key stakeholders, e.g. government and the general public.
2. *Wider effects:* The need to apply an appropriate and effective method of investigating the impact on the wider marine environment and its resources.
3. *Best methods:* Impact assessment methodology needs to be considered that not only assesses the short-term impacts but also allows the prediction of potential long-term impacts.
4. *Efficient resource use:* The need to ensure effective use of resources during monitoring so that unnecessary procedures are avoided but that potentially useful ones are not overlooked.
5. *Mitigation effectiveness:* The need to provide an assessment of the effectiveness, or not, of spill response and clean-up activities, including the use of dispersants.
6. *Compensation/liability:* The need to provide monitoring and assessment input to the determination of compensation and/or liability issues as necessary.

There are aspects of already established national marine monitoring plans, such as the UK Clean Seas Environmental Monitoring Programme (CSEMP), which can be incorporated into post-incident monitoring. For example, the CSEMP refers to a manual detailing survey and sampling requirements (the 'Green Book' can be viewed at www.cefas.co.uk/publications/scientific-series/green-book) many of which will also be relevant for sampling during post-spill programmes (e.g. sampling methods for sampling sediments, water and biota). However, monitoring and impact assessment programmes in an emergency response context differ from those programmes that are designed with the aim of detecting long-term trends in physical, biological and chemicals variables. Some important differences are shown in Table 1.

This comparison demonstrates that although much of use can be transferred from existing programmes and used to assess post-incident impacts, there are some very significant differences between the purposes of each and, indeed, the circumstances under which they need to be conducted. Monitoring programmes for assessing post-incident impact may need to be applicable in a wide range of environments and take account of some very specific circumstances (e.g. analysis for a specific chemical for which routine methods may not exist, the sampling of very localised species and biological communities). As a result the programme design needs to be highly flexible to take account of a range of potential and opportunistic lines of evidence. These conditions serve to increase the need for guidelines and standardisation of those elements that can be standardised, and means that co-ordination is essential so as to ensure that resources are used effectively and that important lines of evidence are not overlooked.

4. Impact assessment

Definition. *Impact assessment is a process through which the consequences of an event (such as a marine spill) or process are assessed through the monitoring of key parameters and compared to a previous or 'normal' status. Impact assessment aims to establish the type, magnitude, and significance of any monitored changes and for them to be 'quantified' as far as possible.*

Types of impact as a result of a spill can be very varied and include both physical and chemical modes of action. When bulk oil comes ashore, smothering of animals in the intertidal and shallow subtidal areas is common. This may impact species of commercial fishery and conservation and/or ecological importance. In addition, filter-feeding bivalve molluscs can ingest oil droplets dispersed into the water column by turbulent wave activity and tidal currents (Law and Kelly, 2004). It is rare for significant

Table 1
A comparison between monitoring programmes designed to assess long-term trends (e.g. national marine monitoring programmes) and post-incident impacts and recovery.

	National monitoring programmes (e.g. CSEMP)	Post-incident monitoring and impact assessment programmes
Aim	To assess broad spatial and temporal trends in water quality and biological effects	To assess environmental changes caused by a specific incident (e.g. an oil or chemical spill) and subsequent recovery
Priorities	Long-term status of the marine environment	Short-term hazards to the public and commercial interests (e.g. fisheries and tourism) as well as long-term environmental damage
Timescale	Long-term trend	Immediate, short- and long-term impacts
Survey design	Set points on a broad scale	Localised dependent on incident type
Methodology	Set suite of chemical, biological and physical analyses	Potential for the inclusion of a wide range of methods dependent on incident type (e.g. chemical type and specific environment at risk)
Sample quality	Set sampling criteria	May also need to incorporate a range of opportunistic samples
Deployment	Planned months/years in advance	Needs to be deployed at very short notice (hours for initial sampling)
Assessment	Set assessment criteria	May need to consider a wide range of evidence to assess impact
Media profile	Low	Can be very high (spills are highly emotive, both locally and possibly nationally/internationally)

numbers of free-swimming fish to be impacted by oil spills, presumably because they avoid areas of contamination, although fish held in aquaculture can be both heavily contaminated and killed. This is not a topic currently well documented for chemical spills, although as some chemicals may be highly and rapidly toxic, the potential is certainly there. Temporary closure of fisheries may be necessary in order to protect human consumers from consumption of contaminated seafood, although the criteria for such closures vary from location to location. When imposing fishery closures, it is also important to think through the criteria for removing the restrictions. No areas on the globe are pristine, and there will always have been some level of pre-existing contamination before the spill. Some compounds (both chemicals and components of oils, such as low molecular weight polycyclic aromatic hydrocarbons (PAHs)) are water-soluble, and will also exert impacts and be accumulated from the dissolved phase, often causing taints in affected fish and shellfish (Davis et al., 2002). Also, some of the high molecular weight PAHs (such as some 5- and 6-ring compounds) can be metabolised in vertebrates to yield carcinogenic derivatives, and their toxic potential can be assessed using equivalency factors (Law et al., 2002). Recently, a means of summing acute toxicity potential for PAHs has also been proposed (Fisher et al., in preparation).

In the USA, the Department of the Interior's Natural Resource Damage Assessment and Restoration Programme aims to restore natural resources injured as a result of oil spills or releases of other hazardous substances into the environment. Damage assessments are the first step in this process and *are not done for the sake of science* (our italics). There are typically three components of injury assessments: spatial, temporal and degree of impact (Lehto, 2008). Mostly, this is conducted using field-based survey information, although modelling can also be used to reduce the scale of the effort needed to quantify injury (French-McCay, 2008). In high profile cases, such as the *Exxon Valdez*, scientists may be engaged in studies both in support of the NRDA itself and on behalf of the responsible party, and long-term studies may need to be undertaken in order to fully assess the impact of an incident (e.g., Culbertson et al., 2007; Laubier, 2006; Peterson et al., 2003). NRDA has also been applied in studies outside the USA, for instance, following the *Tasman Spirit* oil spill in Pakistan in 2003 (Alrai and Rizvi, 2005).

In summary, impact assessment in the context of marine spills will depend on the specifics of the spill and, in particular, on the nature of the environment in which it occurs. It is therefore impossible to prescribe exactly what elements need to be assessed, though pre-planning for appropriate monitoring will ensure the best approach. It is likely that common elements monitored to assess impact could include ecological community structure (abundance, diversity, etc.), sub-lethal biomarkers of effect in a range of species (e.g. enzyme levels, reproductive and behavioural parameters), contamination and/or tainting in commercial species, ecotoxicological assessments of contaminated water/sediment and measures of recovery and recruitment in the affected area. Indicators for ecological and chemical status are currently being developed as part of the European Water and Marine Strategy Framework Directives and it would also make sense for those conducting post-incident impact assessments to take account of these metrics as they become available.

5. Case studies

Within the UK, three incidents have required significant monitoring effort within the past 15 years. These involved the container ship *MSC Napoli* and the crude oil tankers *Braer* and *Sea Empress*. In the case of the two tanker oil spill incidents, a similar approach was taken to the organisation of the post-spill monitoring. In both instances, a committee was established to co-ordinate, assess and report on the results of the monitoring activities. Obviously, this took some time (a number of weeks in both cases), but some government agencies and universities began the work immediately (a) because samples taken immediately after the spill are extremely valuable (especially those from areas which will be impacted later) and (b) because their later involvement was inevitable. This latter consideration applied in particular to the government fisheries laboratories for Scotland and England/Wales, given their responsibilities for advising on fishery closures. Overall, the monitoring approach was developed, co-ordinated and funded through the controlling committees. The monitoring activity was intended, for both spills, to assess the impact on all species/habitats at risk – in the case of the *Sea Empress* spill, this resulted in more than 100 individual studies, including an assessment of possible impacts on bats roosting in sea caves (SEEEC, 1998). During the *Braer* spill, chemical oil dispersants were carried onto land by high winds, and this aspect was also included in the assessment (ESGOSS, 1994), so both yielded very wide-ranging studies.

The *MSC Napoli* incident did not have such a large impact, largely because the hazardous substances aboard the vessel were handled in such an effective manner that none were lost into the sea (Law, 2008). No committee was established to oversee monitoring activities in this instance, however, the Department for Environment, Food and Rural Affairs agreed to fund relevant studies and asked Cefas (Centre for Environment, Fisheries and Aquaculture Science) to develop and co-ordinate an effective programme. As in earlier cases, government bodies had already expanded their current monitoring activities so as to provide information with which to assess the impact of the incident. For example, the Environment Agency expanded its bathing water monitoring programme (undertaken under the EU Bathing Waters Directive) to include screening analyses for chemicals carried aboard the vessel; Cefas undertook sediment sampling at a number of locations around Lyme Bay and stored them frozen as a baseline in case the need arose to determine concentrations of spilled chemicals at a later date. Incidents such as the *MSC Napoli* benefit from the use of ongoing risk assessment practices which inform the impact assessment. An important example in this case was the bioassay-based assessment of hold water toxicity (Kirby et al., 2008) that provided an important monitor of cargo-derived contaminant risk during the incident. Sampling and analysis were not initiated until several weeks into the incident but could have been established faster as a result of pre-considered monitoring plans. In each case, the monitoring approach was developed by experienced scientists, but without the benefit of established guidelines. A full report of the monitoring undertaken and an assessment of impact are given elsewhere (Law, 2008).

6. Conclusions and discussion

This paper has considered the status of post-incident monitoring and impact assessment in the context of relative importance to other considerations during an oil or chemical spill incident. The benefits of a well-planned and pre-considered monitoring programme are clear for reasons that range from scientific quality to cost-effectiveness and public protection. Furthermore, although the scientific literature is full of studies that have conducted post-incident monitoring and impact assessment (especially following notable incidents) they are rarely of a fully integrated nature nor do they often have high quality pre-incident data for their comparisons. The effectiveness of any monitoring or impact assessment will depend on a range of things but the need for routinely collected samples to establish pre-incident baselines and the need to consider extended, long-term post-incident monitoring are important issues that have been raised in studies following the *Sea Empress* (Batten et al., 1998) and the *Prestige* (Laffon et al., 2006) spills. It is therefore surprising that the production of monitoring guidelines and the organisation and integration of monitoring for accidental spills have not generally been afforded a higher priority.

It is against the background described in this paper and others (Kirby and Law, 2009; Kerambrun et al., 2006) that initiatives to establish better logistical organisation of post-spill monitoring are recommended. One such approach is currently being developed in the United Kingdom under a government-funded project called PREMIAM (Pollution Response in Emergencies: Marine Impact Assessment and Monitoring) (see www.premiam.org for further information). The PREMIAM project is supported by a range of government stakeholders responsible for water quality, spill response, food safety, human health, coastal resources and conservation and aims to deliver two fundamental aspects that are key to the provision of high quality post-incident monitoring (i) an agreed set of guidelines and (ii) the formation, co-ordination and maintenance of a network of service providers to be mobilised in the event of an incident. Agreed guidelines for post-incident monitoring are considered essential so that the appropriate techniques are used, there is a scientifically robust approach so as to promote integration of the various interested parties. Every incident is unique and therefore any monitoring programme will have to have some elements that are bespoke. However, guidelines would provide benefits in developing a framework for best practice for a range of essential post-incident monitoring activities including; monitoring programme development, survey design, collection, transport and storage of samples (water, sediments and biota), for which biological and chemical analysis techniques are available and their purposes, ecological and ecotoxicological assessment techniques, statistical treatment of data and presentation of the outputs are in the most appropriate ways for the intended audience. Just as critical as the guidelines to successful monitoring is the identification and organisation of a range of service providers, both scientific and technical, that can be mobilised at short notice to initiate the programme. Those that are considered essential include: scientific and analytical suppliers (analytical chemists, ecologists, ecotoxicologists, etc.), providers of survey platforms and samplers (for offshore, nearshore and coastal environments and for commercial species), modelling, sample storage and transport and local experts.

Initiatives such as PREMIAM will help to establish a more effective approach to post-incident monitoring. However, once guidelines are established and networks are in place to ensure that the procedures can be conducted within appropriate timeframes, budgets and scientific quality there needs to be continued vigilance on the part of the responsible organisations to ensure that it is maintained. The occurrence of marine incidents requiring post-incident monitoring can be frequent but high profile incidents (especially affecting a specific nation) can also be spaced by years and it is this that can result in complacency, loss of expertise and readiness. The responsible authorities, and other relevant stakeholders, need to ensure that practices are also in place to maintain that capability. In doing this they should refer to other sectors of the response family, such as search and rescue and spill treatment and clean-up, whose capability is maintained by involvement in regular exercises and by the use of cross-boundary agreements where an incident affects more than one nation.

Acknowledgement

The PREMIAM project is funded by the Department for Environment, Food and Rural Affairs under contract ME5407.

References

Alrai, I.S., Rizvi, S.H.N., 2005. Natural resource damage assessment programme for Tasman Spirit oil spill in Pakistan. In: Conference Proceedings, International Oil Spill Conference, Miami Beach, FL, USA, May 15–19, 2005, pp. 10577–10580.

Anderson, A.G., 2002. The media politics of oil spills. Spill Science & Technology Bulletin 7, 7–15.

Batten, S.D., Allen, R.J.S., Wotton, C.O.M., 1998. The effects of the Sea Empress oil spill on the plankton of the southern Irish Sea. Marine Pollution Bulletin 36, 764–774.

Bolognesi, C., Perrone, E., Roggieri, P., Sciutto, A., 2006. Bioindicators in monitoring long term genotoxic impact of oil spill: Haven case study. Marine Environmental Research 62, S287–S291.

Burgherr, P., 2007. In-depth analysis of accidental oil spills from tankers in the context of global spill trends from all sources. Journal of Hazardous Materials 140, 245–256.

Culbertson, J.B., Valiela, I., Peacock, E.E., Reddy, C.M., Carter, A., van der Kruik, R., 2007. Long-term effects of petroleum residues on fiddler crabs in salt marshes. Marine Pollution Bulletin 54, 955–962.

Culbertson, J.B., Valiela, I., Pickart, M., Peacock, E.E., Reddy, C.M., 2008a. Long-term consequences of residual petroleum on salt marsh grass. Journal of Applied Ecology 45, 1284–1292.

Culbertson, J.B., Valiela, I., Olsen, Y.S., Reddy, C.M., 2008b. Effect of field exposure to 38-year-old residual petroleum hydrocarbons on growth, condition index, and filtration rate of the ribbed mussel, *Geukensia demissa*. Environmental Pollution 154, 312–319.

Davis, H.K., Moffat, C.F., Shepherd, N.J., 2002. Experimental tainting of marine fish by three chemically dispersed petroleum products, with comparisons to the *Braer* oil spill. Spill Science & Technology Bulletin 7, 257–278.

de la Huz, R., Lastra, M., Junoy, J., Castellanos, C., Viéitez, J.M., 2005. Biological impacts of oil pollution and cleaning in the intertidal zone of exposed sandy beaches: preliminary study of the "Prestige" oil spill. Estuarine, Coastal and Shelf Science 65, 19–29.

Donaldson, J.F.D., 1999. Review of Salvage and Intervention and their Command and Control. The Stationery Office, London. 104 pp., ISBN: 9780101419321.

Dyrynda, E.A., Law, R.J., Dyrynda, P.E.J., Kelly, C.A., Pipe, R.K., Graham, K.L., Ratcliffe, N.A., 1997. Modulations in cell-mediated immunity of the mussel, *Mytilus edulis*, following the 'Sea Empress' oil spill. Journal of the Marine Biological Association of the UK 77, 281–284.

Dyrynda, E.A., Law, R.J., Dyrynda, P.E.J., Kelly, C.A., Pipe, R.K., Ratcliffe, N.A., 2000. Changes in immune parameters of natural mussel, *Mytilus edulis*, populations following a major oil spill ('Sea Empress', Wales, UK). Marine Ecology Progress Series 206, 155–170.

Endresen, Ø., Behrens, H.L., Brynestad, S., Andersen, A.B., Skjong, R., 2004. Challenges in global ballast water management. Marine Pollution Bulletin 48, 615–623.

ESGOSS, 1994. The Environmental Impact of the Wreck of the Braer. The Scottish Office, Edinburgh. ISBN: 0 7480 0900 0.

Eyring, V., Isaksen, I.S., Berntsen, T., Collins, W.J., Corbett, J.J., Endresen, O., Grainger, R.G., Moldanova, J., Schlager, H., Stevenson, D.S., in press. Transport impacts on atmosphere and climate: shipping. Atmospheric Environment.

Fernley, P.W., Moore, M.N., Lowe, D.M., Donkin, P., Evans, S., 2000. Impact of the *Sea Empress* oil spill on lysosomal stability in mussel blood cells. Marine Pollution Bulletin 50, 451–455.

Fisher, T.T., Law, R.J., Rumney, H.S., Kirby, M.F., Kelly, C., in preparation. Towards a scheme of toxic equivalency factors for the acute toxicity of PAH in sediment.

French McCay, D.P., Whittier, N., Ward, M., Santos, C., 2006. Spill hazard evaluation for chemicals shipped in bulk using modelling. Environmental Modelling & Software 21, 156–169.

French-McCay, D., 2008. Modeling as a scientific tool in NRDA for oil and chemical spills. In: Conference Proceedings, International Oil Spill Conference, Savannah, GA, USA, May 4–8, 2008, pp. 1147–1151.

Garcia Negro, M.C., Villasante, S., Carballo Penela, A., Rodriguez, G.R., 2008. Estimating the economic impact of the Prestige oil spill on the Death Coast (NW Spain) fisheries. Marine Policy 33, 8–23.

Garza-Gil, M.D., Prada-Blanco, A., Vazquez-Rodriguez, M.X., 2006. Estimating the short-term economic damages from the Prestige oil spill in the Galician fisheries and tourism. Ecological Economics 58, 842–849.

GESAMP, 2002. The revised GESAMP hazard evaluation procedure for chemical substances carried by ships. GESAMP Reports and Studies No. 64, Publication Number 463/02, 137 pp.

Guterman, L., 2009. *Exxon Valdez* turns 20. Science 323, 1558–1559.

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

HASREP, 2005. Response to harmful substances spilt at sea. Project co-funded by the European commission under the community framework for co-operation in the field of accidental or deliberate marine pollution. Prepared by The Alliance of Maritime Regional Influences in Europe (AMRIE), Centre de Documentation, de Recherche et d'Expérimentations sur les Pollutions Accidentelles des eaux, (CEDRE) and TNO Built Environment and Geosciences, The Netherlands.

Homan, A.C., Steiner, T., 2008. OPA 90's impact at reducing oil spills. Marine Policy 32, 711–718.

Huijer, K., 2005. Trends in oil spills from tanker ships 1995–2005. In: Paper presented at the 28th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Calgary, Canada, June 7–9, 2005.
Kerambrun, L., Laruelle, F., Calvez, I., 2006. Determining the priorities for post-spill studies. In: Conference Proceedings, Interspill, London, March 21–23, 2006, 8 pp.
Kingston, P.F., 2002. Long-term environmental impact of oil spills. Spill Science & Technology Bulletin 7, 53–61.
Kirby, M.F., Neall, P., Tylor, T., 1999. EROD activity in flatfish from the area of the *Sea Empress* oil spill. Chemosphere 38, 2929–2949.
Kirby, M.F., Devoy, B., Law, R.J., Ward, A., Aldridge, J., 2008. The use of a bioassay based approach to the hazard/risk assessment of cargo derived toxicity during shipping accidents: a case study – the MSC Napoli. Marine Pollution Bulletin 56, 781–786.
Kirby, M.F., Law, R.J., 2008. Oil spill treatment products approval: the UK approach and potential application to the Gulf region. Marine Pollution Bulletin 56, 1243–1247.
Kirby, M.F., Law, R.J., 2009. Pollution Response in Emergencies – Marine Impact Assessment and Monitoring (PREMIAM). In: Conference Proceedings, Interspill, Marseille, May 12–14, 2009.
Koh, C., Tan, F., 2008. Dispersant effectiveness testing on chemical floaters and its environmental concerns. In: Conference Proceedings, International Oil Spill Conference, Savannah, GA, USA, May 4–8, pp. 811–815.
Laffon, B., Rabade, T., Pasaro, E., Mendez, J., 2006. Monitoring of the impact of Prestige oil spill on *Mytilus galloprovincialis* from Galician coast. Environment International 32, 342–348.
Laubier, L., 2006. Compensating ecological damage: a personal experience. Oceanis 32, 279–296.
Law, R. (Compiler), 2008. Environmental monitoring conducted in Lyme Bay following the grounding of *MSC Napoli* in January 2007, with an assessment of impact. Science Series, Aquatic Environment Monitoring Report, Cefas, Lowestoft, 61, 36 pp.
Law, R.J., Campbell, J.A., 1998. The effects of oil and chemical spillages at sea. The Journal of the Chartered Institution of Water and Environmental Management 12, 245–249.
Law, R.J., Kelly, C., 2004. The impact of the "*Sea Empress*" oil spill. Aquatic Living Resources 17, 389–394.
Law, R.J., Kelly, C.A., Baker, K.L., Langford, K.H., Bartlett, T., 2002. Polycyclic aromatic hydrocarbons in sediments, mussels and crustacea around a former gasworks site in Shoreham-by-Sea, UK. Marine Pollution Bulletin 44, 903–911.
Law, R.J., Kelly, C.A., Matthiessen, P., Aldridge, J., 2003. The loss of the chemical tanker Ievoli Sun in the English Channel, October 2000. Marine Pollution Bulletin 46, 254–257.
Lehto, J., 2008. Where response meets natural resource damage assessment (NRDA). In: Conference Proceedings, International Oil Spill Conference, Savannah, GA, USA, May 4–8, 2008, pp. 1153–1158.
Leschine, T.M., 2002. Oil spills and the social amplification and attenuation of risk. Spill Science & Technology Bulletin 7, 63–73.
Lessard, R.R., DeMarco, G., 2000. The significance of oil spill dispersants. Spill Science & Technology Bulletin 6, 59–68.
Lunel, T., Elliot, A., 1998. The incident and clean-up. Fate of oil and impact of the response. In: Edwards, R., Sime, H. (Eds.), The Sea Empress Oil Spill. Proceedings of the International Conference held in Cardiff, February 11–13, 1998. The Chartered Institution of Water and Environmental Management. Terence Dalton Publishers, 507 pp. (Chapter 2).
Morales-Caselles, C., Kalman, J., Riba, I., DelValls, T.A., 2007. Comparing sediment quality in Spanish littoral areas affected by acute (Prestige, 2002) and chronic (Bay of Algeciras) oil spills. Environmental Pollution 146, 233–240.
Page, D.S., Boehm, P.D., Douglas, G.S., Bence, A.E., 1995. Identification of hydrocarbon sources in the benthic sediments of Prince William Sound and the Gulf of Alaska following the Exxon Valdez oil spill. In: Wells, P.G., Butler, J.N., Hughes, J.S. (Eds.), Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters, ASTM STP #1219. American Society for Testing and Materials, Philadelphia, pp. 41–83.
Peacock, E.E., Hampson, G.R., Nelson, R.K., Xu, L., Frysinger, G.S., Gaines, R.B., Farrington, J.W., Tripp, B.W., Reddy, C.M., 2007. The 1974 spill of the Bouchard 65 oil barge: Petroleum hydrocarbons persist in Winsor Cove salt marsh sediments. Marine Pollution Bulletin 54, 214–225.
Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E., Irons, D.B., 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302, 2082–2086.
Purnell, K., 2009. Are HNS spills more dangerous than oil spills? In: Conference Proceedings, Interspill, Marseille, May 12–14, 2009.
Reddy, C.M., Eglinton, T.I., Hounshell, A., White, H.K., Xu, L., Gaines, R.B., Frysinger, G.S., 2002. The West Falmouth oil spill after thirty years: the persistence of petroleum hydrocarbons in marsh sediments. Environmental Science and Technology 36, 4754–4760.
Sánchez, F., Velasco, F., Cartes, J.E., Olaso, I., Preciado, I., Fanelli, E., Serrano, A., Gutierrez-Zabala, J.L., 2006. Monitoring the Prestige oil spill impacts on some key species of the Northern Iberian shelf. Marine Pollution Bulletin 53, 332–349.
SEEEC, 1998. The Environmental Impact of the *Sea Empress* Oil Spill. The Stationery Office, London. ISBN: 0 11 702156 3.
Smith, H.D., 1995. The environmental management of shipping. Marine Policy 19, 503–508.
Wells, P.G., Hofer, T., Nauke, M., 1999. Evaluating the hazards of harmful substances carried by ships: the role of GESAMP and its EHS working group. The Science of the Total Environment 237, 329–350.
White, H.K., Xu, L., Lima, A.L.C., Eglinton, T.I., Reddy, C.M., 2005. Abundance, composition and vertical transport of PAHs in marsh sediments. Environmental Science and Technology 39, 8273–8280.
Woolgar, L., 2008. Assessing the increasing risk of marine oil pollution spills in China. In: Conference Proceedings, International Oil Spill Conference, Savannah, GA, USA, May 4–8, 2008, pp. 711–715.