Oil spill monitoring: analysis of similarities and differences in approaches and methodologies

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Abstract:

Monitoring of ecological impacts is generally set up in the wake of each major oil spill. However, the studies carried out in such a context differ between accidents. As a matter of fact, for similar coastlines and pollutants, it appears that the methods and the biological targets are not systematically identical from one spill to another. These differences can be explained by various parameters, such as the source and modalities of funding, the coordination structure, the extent of scientific knowledge, the local interest for a given environmental issue, the availability of research teams, the type of oil... Moreover, although a general agreement exists regarding the need for monitoring different communities and habitats, relevance and motivations underlying the choice of target species and/or methodologies do not seem to be much discussed. In order to identify similarities and differences, Cedre is carrying out a synthesis of the ecological impact assessment studies set up following six major oil spills. The objectives of the study are, on one hand, to compare the approaches and methodologies implemented in each case, and on the other hand, to inventory the targets in terms of habitats, communities, species... This work aims to identify some common approaches and strategies, which could be validated by the marine scientists’ community as efficient tools for assessing the ecological damage.

Keywords: Oil spill, ecological impact, monitoring.

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Introduction

Environmental impact assessment is generally set up is set up in the wake of each major oil spill. This ecological monitoring is however often implemented differently from one incident to another. Comparing what has been monitored in various incidents, it appears that for oil and shoreline presenting similarities on many aspects, target biota and methodologies are not systematically the same. Several reasons can explain these divergences: origin and modality of funding, the coordination structure, the general knowledge of the impacted area, the interest given for the biota, the research team availability, the objectives of the monitoring, or logically the nature of the oil spilled.

Even though there is a general agreement on the necessity to monitor a number of domains (the pelagic domain, the sub-tidal and/or tidal rocky and/or soft bottom benthic domains, and sometimes the supra-tidal domain), it seems that motivations and pertinence of target and/or methodologies choices is not much discussed. In order to identify similarities and differences addressing theses issues, we thus implemented a bibliographic analysis of oil spill monitoring publications (including unpublished reports) regarding 6 major spills, namely the Amoco Cadiz (CNEXO, 1981; NOAA-CNEXO, 1982), Exxon Valdez (Rice et al. (Eds), 1996), Aegean Sea (Ministerio de Medio Ambiente, 1996), Braer (Davies and Topping (Eds), 1997), Sea Empress (S.E.E.E.C, 1998) and Erika (M.A.T.E., 2001 ; Ifremer and Ineris, 2004) disasters (Table 1).
Table 1. Characteristics of the 6 analysed oil spills.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Amoco Cadiz</td>
<td>Exxon Valdez</td>
<td>Aegean Sea</td>
<td>Braer</td>
<td>Sea Empress</td>
<td>Erika</td>
</tr>
<tr>
<td>Situation</td>
<td>Northern Brittany, France</td>
<td>Prince William Sound, Alaska, USA</td>
<td>Galicia, Spain</td>
<td>Shetland Island, Scotland</td>
<td>Milford Haven, Wales</td>
<td>Bay of Biscay, France</td>
</tr>
<tr>
<td>Oil type</td>
<td>Arabian &amp; Iranian Light (light crude)</td>
<td>North Slope (light crude)</td>
<td>Brent Blend (light crude)</td>
<td>Norwegian Gullfaks (very light crude)</td>
<td>Forties Blend (light crude)</td>
<td>Bunker C (heavy fuel)</td>
</tr>
<tr>
<td>Cargo (tonnes)</td>
<td>227 000</td>
<td>180 000</td>
<td>80 000</td>
<td>84 500</td>
<td>130 824</td>
<td>31 000</td>
</tr>
<tr>
<td>Spill size (tonnes)</td>
<td>227 000</td>
<td>40 000</td>
<td>n.d.</td>
<td>84 500</td>
<td>73 000</td>
<td>19 000</td>
</tr>
<tr>
<td>Number of studies</td>
<td>56</td>
<td>78</td>
<td>13</td>
<td>27</td>
<td>69</td>
<td>42</td>
</tr>
</tbody>
</table>

Also, the objective of the study was to compare the principles and methodologies implemented to monitor the potentially affected domains (planktonic/benthic, subtidal/intertidal, supralittoral/terrestrial, birds and mammals…) and to inventory the targets in terms of habitats, species, etc.

What domains are monitored?

Six recurrent domains, coherent in terms of functional role in the ecosystem and of scientific discipline, have been identified from the analysis of the impact studies: pelagic, both subtidal and tidal benthic, terrestrial, birds and marine mammals). Despite the many existing interactions between these domains, scientists are often specialized on one of them. Moreover, sampling methods and data treatment are eventually specific to each domain (eg planktonic vs. benthic studies).

The relative interest expressed towards each ecological domain is showed in figure 1. Following these 6 oil spills, 19 to 58% of the studies have focused on the tidal benthic domain which, eventually, is the oil natural landing and accumulation zone. Fewer studies have been implemented on this domain following the Exxon Valdez and Braer oil spills (19 and 26% respectively), especially because of the narrowness and/or inaccessibility of the shoreline.

The studies concerning the pelagic domain represent 0 to 23% of the total. This domain is especially studied when it is fished and/or farmed (eg Salmonids). In the Erika monitoring program, the pelagic domain has not been studied (no proposal), probably since routine monitoring programs concerning phytoplankton (teledetection) and fisheries stocks were running, and also because of the nature of the pollutant (a very viscous heavy fuel not subject to natural dispersion in the water column).
The subtidal benthic domain is investigated in 13 to 36% of the monitoring program studies, especially if the oil is light and highly naturally dispersible (Braer) and if marine resources are at risk (Aegean Sea). The potential impact on the supra-tidal/terrestrial domain is of special concern when it is widely polluted by oil aerosols or projections (0 to 15% of the studies, for the Braer and Erika respectively) and if botanists are available. For example, the lichen communities, which are systematically affected, are rarely monitored, due to the few scientific teams specialized on these organisms.

Regarding birds and mammals, the frequency of studies (0 to 15% and 0 to 29% respectively) increases with the importance of the local populations, heavy mortalities, and the interest given to these groups (mainly linked to the patrimonial status).

### Monitoring justifications

Depending on the domain, the most common justifications underlying the implementation of a given ecological monitoring rely, variably, upon: socio-economic and public health concerns, the functional role and/or the bio-indicating status of organisms, as well as their patrimonial value. Figure 2 shows the justifications, as expressed by the authors, of the various studies by domains.

![Figure 2: justifications given by the authors to investigate the domains.](image_url)

Being the primary production level of the trophic web, the plankton is largely (85%) monitored because of its functional role within the ecosystem.

Regarding pelagic fishes, studies are primarily justified by socio-economic concerns, hence the frequent commercial status of the species (76%) and the explicitly expressed public health motivations (23%).

Benthic studies, both in subtidal and tidal zones, are mainly justified by the fact that many species are sessile, unable to avoid the pollution, and thus stand as relevant indicators of environmental changes (33 to 36%).

Amongst the studies of subtidal fish, those targeting demersal species with high commercial value (23%) are clearly motivated by economic concerns.
Within the supratidal zone, the presence of species, communities or habitats of patrimonial interest is the most frequently expressed motivation for monitoring (29%). On the other hand, exposure by spray or splash of this terrestrial belt (Braer and Erika case) justifies 25% of the studies.

Regarding birds and mammals, their high vulnerability, due to tight relationships with the water to air interface, largely justify the monitoring.

![Figure 3: proportion of commercial vs. not commercial species for each domain in oil spill monitoring](image)

Figure 3 shows that 18 to 68 % of the approaches, depending of the studied domain, focus on commercial species. Highest relative frequency (68 %) is noticed in the pelagic domain, which indeed includes many fished species. As well, subtidal benthic studies are often (60 %) targeted on organisms of commercial value, which happen to be flatfishes essentially. In the tidal zone, a third of the impact assessment studies is focused on commercial organisms, mainly invertebrates (eg molluses, crustaceans, …).

Concerning the supratidal domain, the low proportion of studies on commercial species can be explained by the prevalence of patrimonial issues (for example concerning rare and/or scarce vascular plants). Basically, the main studies on commercial species were here motivated by human health concerns, such as those implemented in the wake of the Braer oil spill, focused on sheeps and crops (Milne et al, 1997).

As expected, the main concerns about birds and mammals being their patrimonial value, no study was ever launched because of commercial issues (in terms of hunted resource).

**Which approach to what objectives?**

Within the 6 monitoring programs, we distinguished 3 main types of scientific approach, aiming at complementary objectives:

1. **Monitoring of the contamination**, involving hydrocarbon / PAHs concentration measurements within the environment and/or organisms,
2. **Monitoring of biological responses** at an individual scale, which are to be extrapolated at a species or population level, involving epidemiological surveys or the use of effects biomarkers,
3. **Systemic ecological monitoring** at the population and community scales.

The frequency distribution of each of these approach types, within the 6 monitoring programs, is showed on figure 4. Since many studies combine several approaches, the analysis is based on the number of approach implemented and not on the number of studies.
The distribution of the approaches appears to be similar in the oil spill monitoring programs of the Sea Empress, Erika and Exxon Valdez (figure 4). About 50% of the studies are approached at the ecological scale, versus 25% both at the biological and contamination scales. The Amoco Cadiz and Aegean Sea cases are relatively similar, but with 30 to 40% of studies at the biological scale. The Braer case is somewhat particular, because of a lesser implementation of ecological studies. This was mainly due to the rapid demonstration of the short-term, and relatively low, effect of the pollution on the benthic populations and communities (reference), which are generally the main targets regarding ecological monitoring. The proportion of studies of the biological responses at an individual level is quite the same than in other accidents, but contamination monitoring appears far more implemented (>50%), especially because of the importance of both professional fishing and farming of salmonids in the contaminated area.

What methods for contamination studies?

Several compounds can be measured in order to quantify the contamination of the organisms (figure 5). If surveys of total hydrocarbon levels only have been implemented following the Amoco Cadiz, Sea Empress and Exxon Valdez oil spills, studies focusing on groups of compounds (mostly PAHs and/or aliphatics) are set up in each case of oil spill, sometimes in completion of total hydrocarbons measurements. According to many authors, PAHs are preferable to total hydrocarbons dosage, because of the persistence and long-term effects of this fraction. The toxicity of PAHs such as benzo(a)pyrene is, indeed, largely documented. Moreover, PAHs such as Pyrene/Fluoranthene analysis allow fingerprinting of the contamination sources. Aliphatics such as steranes and terpanes are also considered as a relevant target by authors, in order to identify the origin of contamination (Porte et al., 2000). Aliphatics analysis is justified by their tendency to accumulate within the tissues, fingerprinting property, and resistance to degradation of the heavy molecules allowing long-term studies.
However, if hydrocarbon level measurements within marine biota are frequently implemented, biological detoxication activity directly influences the bioaccumulation of the oil in the tissues. As a result, hydrocarbon levels may not reflect accurately the real contamination of marine organisms. Hence, two types of markers are generally proposed to complete this approach: chemical markers such as trace metals characteristic of certain oils (heavy fuels), and biomarkers. Note that, during this study, examples of trace metals monitorings (nickel and vanadium) are to be found in the case of the *Erika* only, because of high concentrations of those compounds in the fuel spilled (Amiard et al, 2004; Chiffioleau et al, 2004).

**Use of biomarkers**

Many different biomarkers are used in order to identify exposure levels or effects of hydrocarbons on organisms (figure 6).

![Figure 6: number of studies involving the use of biomarkers.](image)

Among identified biomarkers, the most used in oil spill monitoring are (i) the induction of detoxication enzymes, such as EROD\(^1\) activity (catalysed by P450 cytochromes), (ii) the PAHs degradation products (ie metabolites), and (iii) the genotoxic effects as recommended by the OSPAR Commission (JAMP, 1998a). Note that each of these biomarkers is more or less directly related with the metabolic processes of detoxication, whether it be the PAHs degradation activity in itself, or its by-products (metabolites, deleterious effects…). Exposure to PAH induces a detoxication process, increasing EROD activity involving P450 cytochromes, thus resulting in the production of PAHs metabolites. PAHs metabolites are considered particularly interesting, since they provide information both on contamination intensity and potential toxicity. Indeed, many of the PAH metabolites are ultimately more toxic than the hydrocarbon in its original form. For example, some by-products possess the ability to form adducts with biological macromolecules, such as DNA or proteins. Most notably, genotoxicity biomarkers such as the arising of DNA adducts or broken DNA strains are considered as efficient biomarkers of adverse effects.

Note that, because of natural fluctuations (e.g. EROD activity level, dependant of the reproductive cycle), the studies involving biomarkers are often implemented on species which biology and physiology are well documented, mainly commercial species of fish and shellfish.

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\(^1\) (Ethoxy Resorufin O-Deethylase)
Other less specific biomarkers, such as immunotoxicity, enzymes or biochemical products, have been used in particular cases. Metal binding proteins, such as metallothioneins, are specifically used for metal-rich fuel spills (figure 6).

Beside the use of biomarkers, the individual biological response is also monitored through diverse alterations of the physiology, morphology, immune system, and/or blood pathologies (table 2).

<table>
<thead>
<tr>
<th>Effects</th>
<th>Amoco Cadiz</th>
<th>Aegean Sea</th>
<th>Braer</th>
<th>Sea Empress</th>
<th>Erika</th>
<th>Exxon Valdez</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochemical alteration</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae</td>
<td>benthic fish, invertebrates, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physiological alterations</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, pelagic fish, pelagic fish</td>
<td>bivalves, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immune system alterations</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, echinoderms</td>
<td>bivalves, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood pathologies</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, echinoderms</td>
<td>bivalves, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Histopathology</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, echinoderms</td>
<td>bivalves, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organ lesions</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, echinoderms</td>
<td>bivalves, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morphological alterations</td>
<td>bivalves</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, echinoderms</td>
<td>bivalves, algae</td>
</tr>
<tr>
<td></td>
<td>benthic fish</td>
<td>benthic fish</td>
<td>bivalves, algae</td>
<td>Mammals, birds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Foraminifers</td>
<td>benthic fish</td>
<td></td>
<td></td>
<td>bivalves, algae, echinoderms</td>
<td>bivalves, algae</td>
</tr>
</tbody>
</table>

Table 2: sub-lethal effects, and target group, monitored at the biological scale. (benthic in pale grey, pelagic in medium grey, birds and mammals in dark grey)

Two tendencies emerge from the analysis of the oil spill monitoring programme:
- Use of Biomarker appears more and more frequent in oil spill monitoring and its diversity increases with the development of new methods (figure 6).
- An increase of coupled contamination/biomarkers and other biological responses studies appears in Europe recent spills.

**Experimental toxicity assessment**

Two types of experimental studies have been identified:
- studies of the biological responses to a certain dose of contaminant (dose/effect studies)
- bioassays which corresponds to the evaluation of the toxicity of environmental components (sediment, sea water) through the responses of an organism or biological model exposed to it.

Since the Amoco Cadiz grounding, dose/effect studies have been implemented after each analysed oil spills, though to different targets and methodologies (table 3). In these experimental studies, the biological model is often determined, on the one hand by the commodity of laboratory keeping, especially the breeding techniques, and in the other hand, the possibility to easily observe and quantify biological responses. The most frequently used target species are benthic invertebrates which biology is fairly documented. One of the widely recognised ecotoxicological approaches is the study of ontogenic development of early stages of bivalves and echinoderms (Erika). Allowing to identify a toxic impact on embryos, larvae or juveniles, this approach gives predictive information on potential mid- or long-term impact on population demographic structures. Beside invertebrates, this type of study is also implemented for commercial pelagic fish (Exxon Valdez). Regarding the adult stage, experimental studies are mainly physiological approaches on commercial bivalves. The effect to oil exposure of mussel energy balance through scope for growth has, in particular, been largely implemented following the Aegean Sea and Erika oil spills. Concerning pelagic fish, a unique experimental study on the avoiding behaviour of salmonids has been identified after the Sea Empress oil spill.
Due to a limited exposition, shoreline terrestrial vegetation is rarely investigated from an experimental point of view. Anyway, two dose/effects studies have been implemented on tidal and terrestrial plants after the *Braer* and *Erika* oil spills. However, if dose/effect experimental designs allow to identify in lethal or sub-lethal effects of oil exposure, extrapolation to the environment of the results remains unreliable without field validation in terms of hydrocarbons bio-availability, biota vulnerability and/or a parallel *in situ* dose/effect approach.

### Table 3: experimental approaches and corresponding biological targets (benthic in pale grey, pelagic in medium grey, flora in dark grey).

<table>
<thead>
<tr>
<th>Approach</th>
<th>Method</th>
<th><em>Amoco Cadiz</em></th>
<th><em>Aegean Sea</em></th>
<th><em>Braer</em></th>
<th><em>Sea Empress</em></th>
<th><em>Erika</em></th>
<th><em>Exxon Valdez</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dose / effect studies</strong></td>
<td>Ontogeny physiology / survival</td>
<td>larvae bivalves</td>
<td>terrestrial flora</td>
<td>embryos/larvae echinoderms</td>
<td>embryos/larvae saltmarsh flora</td>
<td>saltmarsh flora</td>
<td></td>
</tr>
<tr>
<td>Histopathology / biochemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sand seabed flora</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethology (avoiding))</td>
<td></td>
<td></td>
<td></td>
<td>pelagic fish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bioassays</strong></td>
<td>Ontogeny and/or physiology / growth / survival</td>
<td>Amphipoda Polychaeta</td>
<td></td>
<td>embryos/larvae of bivalves Copepoda macroalgae</td>
<td>Copepoda</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Histopathology / Ethology / survival</td>
<td></td>
<td></td>
<td></td>
<td>microalgae</td>
<td>terrestrial fauna</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There is a frequent implementation of bioassay toxicity studies in the *Exxon Valdez, Sea Empress, Erika* and monitoring programmes, mainly on well documented and recommended (JAMP, 1998b) biological models such as amphipods, copepods, polychets and unicellular algae. Regarding the wide range of bioassays, the ICES *Working Group on Biological Effects of Contaminants* (WGBEC) listed the different techniques (Hylland, 2000) and emphasised the need for methods to monitor effects of contaminants in pelagic ecosystems. Even though standardised, biological targets of bioassays should be adapted to the specificity of a given oil spill, using for example local species, widely distributed and/or of commercial interest.

**Ecological approaches**

The third type of impact assessment approach addresses a higher biological organisation level, namely the populations and communities. The aim of ecological studies is to identify a potential loss and/or degradation within complex ecosystems or its components, through the fluctuations of descriptive parameters related to environmental factors including pollution. The ecological approach includes several methods, depending on the target of the study (eg populations, zoological or functional groups, communities).
Figure 7: frequency distribution of ecological approaches in the different oil spills, according to studied domain (left), and scientific skills (right).

In each of the analysed monitoring programs, the potential alteration of the ecosystems is studied through the impact on community structures (figure 7). These studies often concern the benthic domain, especially soft bottom substrates. This approach, which relies upon synthetic descriptors (abundance, biomass and specific richness, diversity / equitability and biotic indices) is largely used in benthic ecology, to describe the health state of communities, after organic matter enrichment in particular (Pearson and Rosenberg, 1978 ; Hily and Glémarec, 1990). Due to the multiplicity of sources for natural fluctuations, pre-spill data are essential to identify the oil effects.

Commercial fish and sometimes shellfish are studied through demographic approaches at the population level. Common halieutic and population dynamic methods are implemented to identify the potential impact. Thus, pre-spill data are generally available through stock and fisheries management long term series. Beside those two main approaches, ecological studies focus on mortality counting (especially birds and mammals), behavioural modifications (ethology), cartography (setting up and comparison of distribution maps), and ecophysiological studies monitoring the evolution of synthetic parameters of population health, including physiological condition indices, growth, etc…

Reference baseline data availability

Availability of reference baseline data is a recurrent problem in oil spill impact assessment. Thus, in order to avoid this difficulty, post-oil spill ecological studies are often implemented on documented taxons and stations, previously monitored for various reasons not necessarily related to oil spill concerns. Moreover, in order to improve the somewhat incomplete figure provided by pre-spill data, many studies include control stations selected outside polluted areas. According to figure 8, recourse to spatial comparison between polluted and unpolluted sites (control) is frequently implemented for the 6 analysed oil spill monitoring programs. Despite an unsuitability to document accurately the pre-spill situation, such control sites surveys provide valuable information about the fluctuations as well as their sources outside the spill area (eg chronic pollution, natural cycles).

Whenever coupled, both kind of reference data (temporal and spatial) are reported to provide efficient and complementary results as regards to the identification of the effects attributable to the oil spill. Moreover, an ecosystem being dynamic, punctual information is less relevant than time series which gives an idea of the long term tendencies of the system (eg chronic decline of a given population, not related with the pollution).
Discussion

This discussion consists of a synthesis on recurrent reflections and remarks from the analysed literature. Whatever the surveyed domain is, measurements of descriptive data about contamination by hydrocarbons, in parallel with the monitoring of biological responses, is necessary to demonstrate their relationship. In this regard, beside the quantitative approach, the interest of a qualitative description of the various compounds of the pollutant is often emphasized. Indeed, this qualitative approach allows in particular the identification of the oil source (fingerprinting methods). This demarche is particularly interesting since chronic pollution sources are generally present in spill polluted areas.

Pelagos

Pelagial communities are spatially and temporally highly variable. Consequently, knowledge regarding their natural fluctuations depends on the availability of time series pre-spill data, condition rarely fulfilled in the oil spill monitoring programmes herein analysed. Moreover, this variability requires a high frequency sampling strategy, implemented rapidly after the spill, making difficult to precisely investigate this domain. As a matter of fact, in 5 of the 6 analysed spills, plankton monitoring only represents 1 to 8% of the surveys (Exxon Valdez and Amoco Cadiz respectively) while fish are commonly studied. The Aegean Sea case is particular, with 20% of the surveys on plankton. The availability of pre-spill data (4 years) and running programmes on water quality, explain this attention.

Regarding nekton, the impact assessment requires a solid knowledge of seasonal and annual natural fluctuations of population parameters. In most of the cases, studied pelagic fish are commercial species which stocks are fairly surveyed (fishing, demographic and population dynamic data).

Benthos

Sedimentary bottoms constitute a natural receptacle for hydrocarbons, through coating, sedimentation, adsorption on particulate matter, dissolution, infiltration. Being a relatively stable contaminant trap, it is less difficult to detect alterations in the benthic domain than in the water column. The benthic environment is, thus, considered as a good integrator and indicator of oil impacts.

Benthic studies are generally implemented in the shallow water coastal and tidal zones. On soft bottoms, sampling relies classically on tools such as unitary surface standardised grabs or corers depending on the targeted community (meiofauna, macrofauna, megafauna). On the tidal zone, sampling is done within unitary surface quadrates along altitudinal transects. If sampling tools and strategies are diverse, there are two necessary conditions to be fulfilled: the collect of volumes and replicates satisfactory to the significance of the samples, and methodology coherence both through survey duration and between stations.

The emblematic fauna
Birds and mammals have been distinguished because of their high vulnerability to floating oil pollutions. Moreover, they are highly emblematic, often patrimonial and very much covered by the media as the first and sometimes main victims of the spills. The methods used to assess the oil spill impact on these species are diverse (ethology, biometry, population dynamic, autopsies…) but generally in coherence with those implemented to survey the populations before the spill. As a matter of fact, the availability of time series pre-spill data for marine birds and mammals is required to definitely assess the impact degree of an oil spill.

Scales
In absence of human perturbations, the structure of a given ecosystem reaches a dynamic equilibrium showing natural fluctuations in response to environmental changes at multiple scales. Consequently, in order to identify the effects of an accidental perturbation, sampling frequency has to be defined in function of the biology of the targeted species and/or communities. Thus, in principle, survey and acquisition of data should be implemented at temporal scale coherent with:
- the scale of the potential ecological damages, i.e. with the biological responses to be monitored (e.g. short term acute toxicity, long term sublethal effects…)
- the oil characteristics (chemical composition, weathering behaviour such as tendencies to natural dispersion or emulsification, remanence…)
- and the environmental variability.

From the spatial scale of a survey depends the significance of the results in term of global impact sustained by the environment. The determination of such an essential aspect of an oil spill monitoring programme is not systematic. The spatial extent of monitoring could, indeed, vary according to particularities of a given pollution. Thus, according to the type of oil (light crude vs. heavy fuel, etc…), its weathering behaviour, the weather conditions during the spill, the area and the types of habitats contaminated are different (e.g. contamination of the water column? impact limited to the tidal rocky shores? contamination of estuaries? monitoring the supratidal zone?…) and should be considered for the spatial delimitation of the monitoring programme. Moreover and as for the temporal variability, many populations show high spatial natural fluctuations, due to a heterogeneous distribution on a variable scale according to the groups (meio-, micro-, macro- and megafauna for example). Thus, the spatial scale of the studies should ideally allows to obtain results for areas representatives of:
- the studied habitat (nature of substrate, physical, chemical and biological environmental characteristics) within the contaminated area
- the degree of pollution of this habitat
- the biological target (population, species, community…)

Reference data
Comparison between pre- and post- spill situations allows in theory to assess the extent of damages induced by the pollution, as well as to record the degradation dynamic and the time needed for the environment to restore. Logically, the quality of the pre-spill data in terms of comparability with the post-spill results needs to be examined in terms of sampling and treatment methods, sampling seasonality, etc… When time series baseline data exist, this approach is efficient, but implicates sampling strategies adapted to the target group. In order to demonstrate an impact, sampling initiation and frequency have indeed to be coherent with the biological response temporal scale which in particular depends on the generation time and life cycle of the target. Regarding this aspect, plankton, bacteria and foraminifers monitoring for example should be implemented extremely shortly after a spill. In this respect, monitoring environmental parameters (hydro-climatic and edaphic factors) is ideally very interesting in order to isolate the pollution effects from the natural fluctuations and/or chronic pollution. The acquisition of many data allows to run multivariate analysis to discriminate the spill effects from others influences.
Comparison between polluted and control stations is commonly implemented, especially when no pre-spill data are available. In order to obtain relevant results, control sites have to be as much similar as possible to the contaminated sites in terms of environmental factors, including background pollution.

**Bibliography**


