Deepwater Horizon – Lessons learnt for national preparedness and response strategies based on findings from the disaster and remedial action taken

Environmental Panel of Experts "Consequences of pollution incidents"
Project group "Deepwater Horizon", September 2011

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1. Introduction

The independent Environmental Panel of Experts (Umweltexpertengruppe, UEG) "Consequences of pollution incidents", which provides consultation to the Central Command for Maritime Emergencies (Havariekommando, HK) in the area of environmental preparedness, was formed by the German Federal Ministry for the Environment (BMU), in part in response to a request from the Conference of North German Environmental Ministers. This panel of experts, comprising environmental specialists, works closely with environmental authorities and research institutes. Its tasks include the documentation of environmental preparedness and continued development of our understanding of the environmental consequences of incidents involving pollutants, assessment of knowledge for use in decision-making by the Central Command (HK), and being accessible to the HK with its knowledge in various disciplines.

Prompted by the BMU, as a consequence of the Deepwater Horizon (DWH) accident in the Gulf of Mexico the UEG formed a project group for the initial evaluation of the drilling platform disaster. The aim of the task force is to examine and evaluate the studies carried out during and following the disaster with respect to our national response and preparedness strategy. This report serves primarily to provide information to the appropriate institutions and bodies with competence in the areas of preparedness planning and response to oil spills.
It contains no analysis of error concerning the decisions taken (some of which were taken primarily to save time), nor any analysis of the detailed circumstances or technical shortcomings that combined to cause the accident.

Available publications on the Deepwater Horizon disaster were evaluated in terms of their subject matter and new findings. Besides evaluation of the effectiveness of the particular response strategies and consideration of the possible adverse effects on marine conservation assets, the need for further research & development activities was to be examined. Questions arising from the findings may be integrated into research plans proposed in the future.
The questions and findings emerging from this report can be taken into account, as appropriate, in national preparedness plans, monitoring programmes and response strategies after assessment by the responsible bodies.

2. Background

On 20 April 2010, on the exploration drilling platform Deepwater Horizon in the Gulf of Mexico, there was an uncontrolled release of gas followed by explosions. With failure of the blowout preventer (BOP), the platform began to burn. After unsuccessful attempts to extinguish the fire, the Deepwater Horizon platform sank on 22 April 2010. Eleven people lost their lives in the accident. Due to malfunction of the blowout preventer the crude oil in the deposit being explored flowed uncontrollably into the sea. After numerous attempts to seal the hole had failed, finally on 15 July 2010 the oil flow was stopped by the operation "Static Kill" after 86 days. According to official estimates, 780 million litres of crude oil flowed into the marine environment before the hole was sealed.

As a consequence of the Deepwater Horizon disaster and the resulting oil pollution, a multitude of monitoring and research programmes were initiated in the Gulf of Mexico by U.S. American authorities, by public institutes and non-governmental organizations (NGOs), by various universities, and by the companies involved. The investigations serve to secure evidence as well as to document the direct and indirect impacts of the accident. In addition to the case-specific observations, fundamental mechanistical dependencies and cause-and-effect relationships can be determined.

To explore the effectiveness of the response strategies that were employed, as well as their effects and impacts on the ecosystem and its possible damage, questions relating to the following issue areas arise:

- Basic process understanding
- Effectiveness of mechanical response strategies
- *In situ* burning and its impact
- Chemical oil control and ensuing processes
- Negative impacts for avifauna, fish and marine mammals
- Cleaning of oiled organisms
- Microbiological degradation processes
- Execution and conception of monitoring studies
- Information transfer and media communication

In evaluating the findings from the Deepwater Horizon disaster with respect to national strategies, the fundamental differences between the situation in the Gulf of Mexico in comparison with the German waters of the North and Baltic Seas need to be considered. Besides the differences in natural conditions such as temperature, the topographical differences between the two regions are to be considered. Due to the geological conditions, deep-water drilling in the North and Baltic Seas is not possible. Consideration of aspects and scenarios that cannot be applied to the conditions in the German seas will therefore be limited in the present report.

Regarding the accidental release of petroleum in Germany, in contrast to other European nations, the causes can essentially be limited to shipping disasters. There is only one drilling platform (Mittelplate A) in the German waters. It rests directly on the intertidal mudflat bottom, therefore it cannot be compared to conventional drilling platforms or drilling ships.

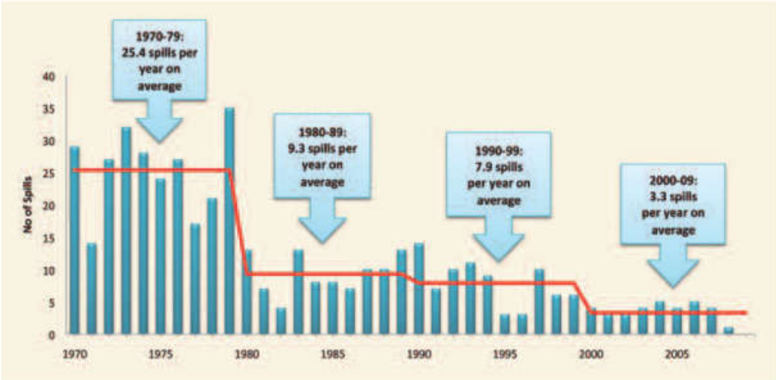


Figure 1: Number of large oil spills involving releases of over 700 tonnes of oil, per year between 1970 and 2009 worldwide (ITOPF 2010).

Despite increasingly stringent safety standards and decreasing numbers of oil accidents (Figure 1), as well as a drop in the amount of oil released by accidents (Figure 2), there is still a risk in Germany of the unintentional release of petroleum into the sensitive marine environment. Large amounts of petroleum are transported through German waters in the North and Baltic Seas. Crude oil tankers make up 20 per cent of the world's merchant fleet, but represent around 40 per cent of the total load capacity (Figure 3). Moreover, petroleum or crude oil is used as ships' fuel, so oil pollution is a risk with every ship disaster.

Due to the large amount of through traffic as well as the presence of important international harbours, the coastal region of the North and Baltic Seas is one of the marine traffic areas with the highest density in the world. For the Wadden Sea and adjacent marine areas, there is already a comprehensive catalogue of protection measures at the national and international levels to mitigate the impacts and hazards of shipping. Furthermore, the Wadden Sea of the German Bight (2002) and the Baltic Sea (except for the Russian part; 2005) have been designated by the International Maritime Organization (IMO) as Particularly Sensitive Sea Areas (PSSAs)[1], which calls for special protection by provisions of the IMO.[1]

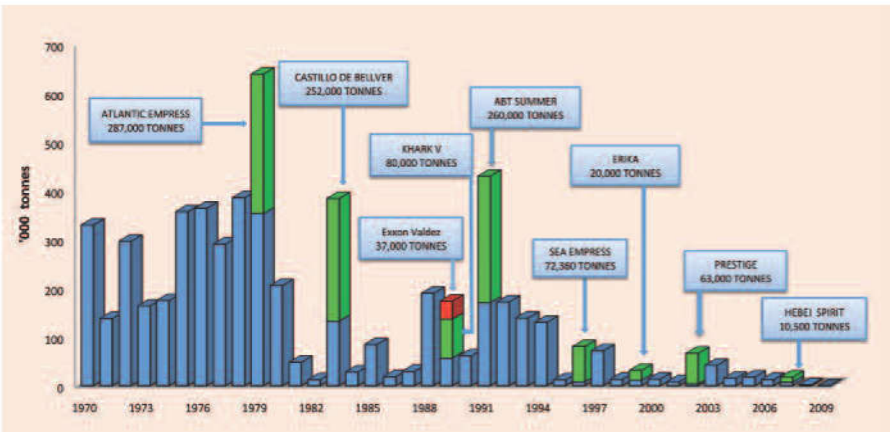
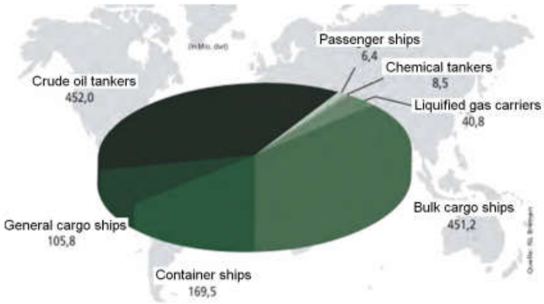


Figure 2: Amounts of oil released annually due to incidents from 1970 to 2009 (ITOPF 2010).

[1] The Wadden Sea and Baltic Sea are two of 13 PSSAs (Particularly Sensitive Sea Areas) designated worldwide.



Ship type	01.01.2008		01.01.2009		01.01.2010	
	number	in million dwt	number	in million dwt	number	in million dwt
Crude oil tankers	8693	399.8	9159	418.0	9740	452.0
Chemical tankers	1345	9.3	1347	9.4	1331	8.5
Liquified gas carriers	1318	30.2	1419	35.9	1489	40.8
Bulk cargo ships	7156	386.6	7481	414.4	7772	451.2
Container ships	4259	144.6	4639	161.9	4706	169.5
General cargo ships	17647	102.8	17949	106.9	17715	105.8
Passenger ships	4135	6.2	4161	6.8	4195	6.4
total	**44553**	**1079.5**	**46155**	**1153.3**	**46948**	**1234.2**

Figure 3: Amounts of oil released annually due to incidents from 1970 to 2009 (ITOPF 2010).

National scenarios currently being considered for the largest probable spill assume a maximum of 15,000 tonnes oil released. With the construction and operation of offshore wind parks additional risk-related questions could arise in the future (these aspects will not be considered initially by the task force). The current findings from the Deepwater Horizon disaster will be presented briefly in the following sections for the issue areas listed above. The evaluation of published findings from the investigations is limited to aspects that are relevant to the national preparedness and oil-spill response.

For an initial detailed overview of the causes of the incident, the sequence of events, an analysis of errors and evaluation of the consequences, as well as preliminary recommendations on the implications, the following reports by US authorities are recommended:

- Macondo - The Gulf Oil Disaster, Chief Counsel's Report 2011, National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, 2011

- The National Incident Commander's Report: MC252 Deepwater Horizon, National Incident Command Deepwater Horizon Response, October 2010

- BP Deepwater Horizon Oil Spill - Incident Specific Preparedness Review (ISPR), Final Report, January 2011

- Deep Water - The Gulf Oil Disaster and the Future of Offshore Drilling, Report to the President, National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, January 2011

3. Process understanding

If petroleum or crude oil is introduced into the marine environment, for example by an accident, various processes of dissemination and degradation occur. External conditions such as temperature, wind and wave activity have a decisive influence on the processes. The basic processes and the occurrence of processes over time are schematically illustrated in Figures 4 and 5. Processes such as evaporation of the lighter and more volatile hydrocarbons primarily occur soon after the release of the oil. This increases the viscosity of the oil and reduces its dispersion and emulsification. With the loss of the light volatile components and the uptake of suspended particles the density of the oil gradually increases, allowing it to sink to the sea floor. Depending on the temperature and the available concentration of oil-consuming microorganisms, the degradation of the petroleum hydrocarbons occurs more or less rapidly. The degradation is strongly influenced by conditions such as oxygen availability and temperature, and under certain conditions it can require several decades.

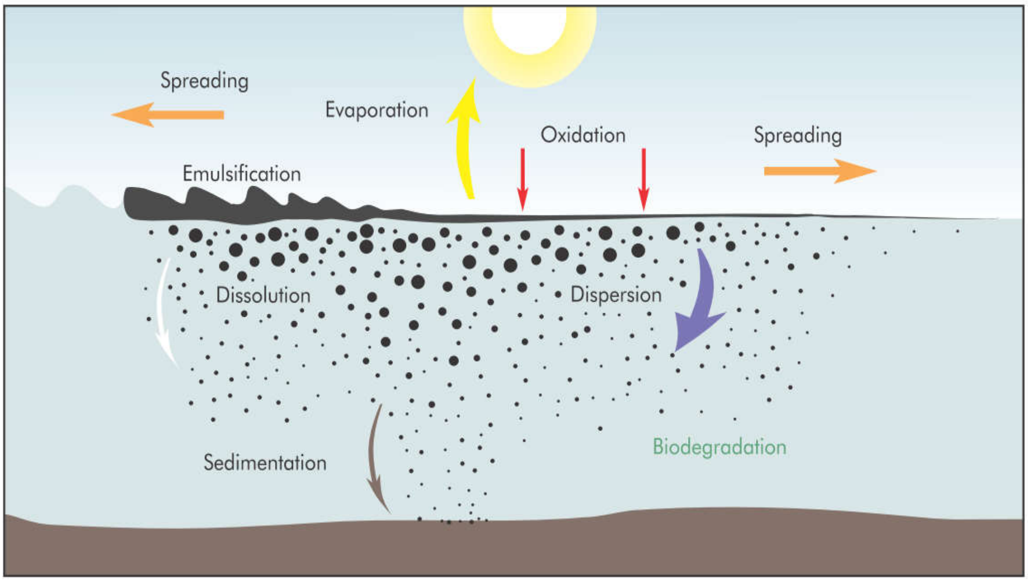


Figure 4: Processes occurring upon the release of oil to the marine environment (ITOPF 2002).

In contrast to most ship disasters, where the oil escapes into the water near the surface, the crude oil from the Deepwater Horizon leakage was released into the marine environment at a water depth of around 1,500 m. This kind of discharge and the depth of the water column above make it difficult to estimate the amount of oil remaining in the environment. The proportional estimates of dispersal and degradation of the oil are still being intensively discussed. It is estimated that around 17 per cent of the oil was caught directly at the blowout preventer, about 3-4 per cent was collected by mechanical response measures, 5-6 per cent of the oil was burned by *in situ* burning at the sea surface, 6-16 per cent was dispersed chemically and 12-20 per cent by natural processes, 18-32 per cent of the oil volume evaporated, and 13-39 per cent was deposited in the environment, either on the sea floor or on the coasts (see Figure 6).

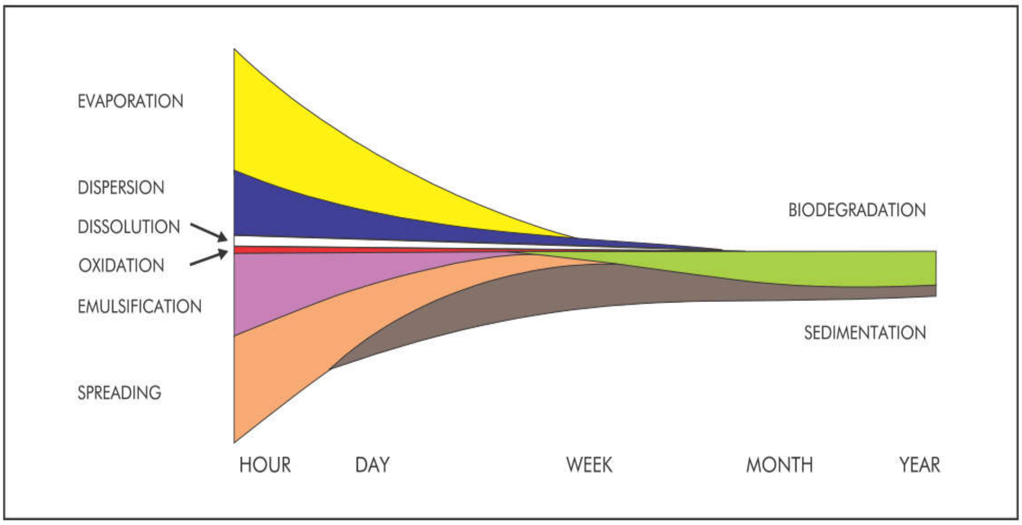


Figure 5: Illustration of the sequence of processes after an oil release (ITOPF 2002).

Many investigations presently underway are not yet completed, and so these initial estimates should be viewed with some uncertainty. For example, in November 2010, NOAA's estimate of the chemically dispersed oil was increased from 8% to 16%.
Because of its low density of around 0.88 kg/l, the crude oil rose up from the hole into the water column. Many of the processes mentioned above began with the upward flow of the oil. Only a fraction of the oil that originally escaped was able to reach the surface.
The Deepwater Horizon oil is relatively light, with a large proportion of volatile compounds. It also has a high proportion of n-alkanes, due to the fact that it is a paraffin-based oil. North Sea oil is somewhat comparable to this oil.

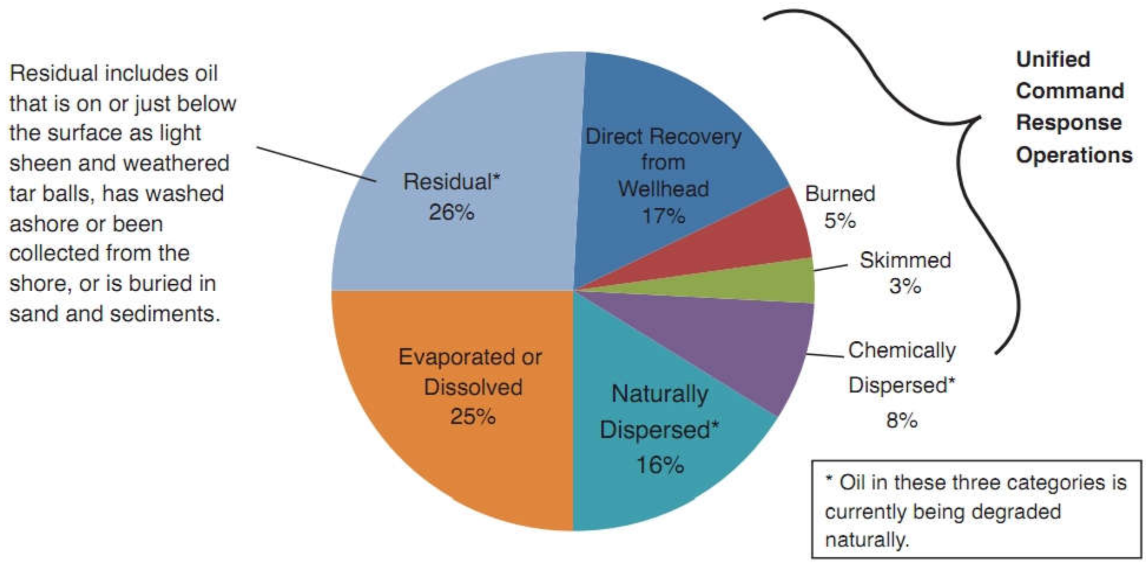


Figure 6: Estimates of the proportional distribution of oil released at Deepwater Horizon, August 2011 (NOAA 2010).

Several studies report the presence of extensive areas with oil plumes in the water column (Adcroft et al. 2011; Kujawinski et al. 2011). Researchers at the University of Georgia and other investigators (Thibodeaux et al. 2010) have reported on expeditions where oil layers were discovered on the sea floor. It should be noted, however, that oil also escapes at natural oil seeps in the Gulf of Mexico (Figure 7). According to estimates by NOAA, this source represents an annual volume of approx. 64,000 m³ of oil (OSAT2 2010). It is believed that, due to the natural oil seeps and the anthropogenic oil input in this area, the biological degradation of oil around the Deepwater Horizon was able to start more quickly.

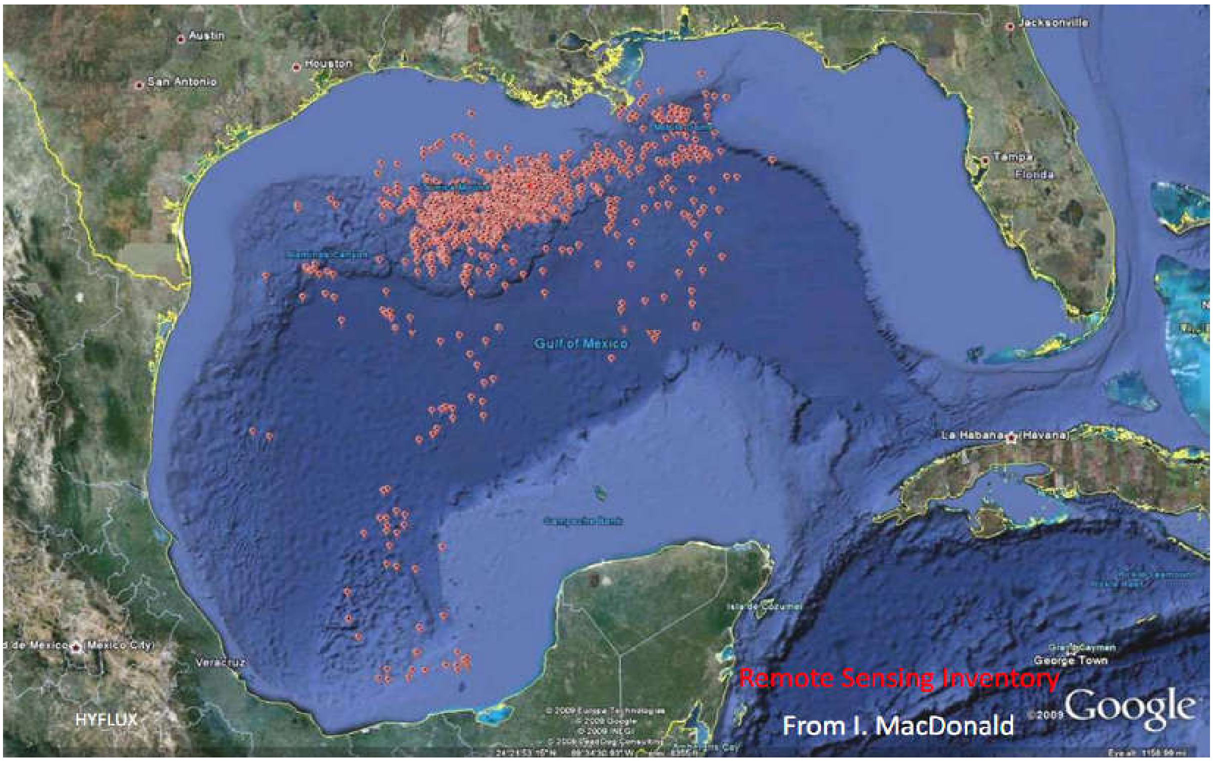


Figure 7: Natural oil seeps in the Gulf of Mexico (OSAT2 2010, MacDonald after Tunell 2010).

The average water temperatures in the North and Baltic Seas are considerably lower than those in the Gulf of Mexico. Because of the lower water temperatures it can be assumed that the degradation rate of oil released into the North and Baltic Seas would be lower. For example, at 10 °C lower temperatures the rate of degradation falls by a factor of 2 to 4. The transfer of volatile oil components into the atmosphere also occurs more slowly and is thus a less significant process at lower temperatures. Moreover, because of the shallower water depth in the North and Baltic Seas and because of the limited water exchange with surrounding marine regions (particularly in the Baltic Sea), the mass of water available for dispersion and evaporation processes is considerable smaller.

4. Mechanical response procedures

The response measures employed at and around the Deepwater Horizon spill location include a multitude of procedures for decreasing or stopping the flow of oil directly at the damaged drilling installation. These include attempts to manually close the blowout preventer, drilling relief holes, and various other operations with names like Top Kill, Junk Shot, Top Hat and Static Kill. In addition, in the area near the drill hole and at affected and potentially endangered coastal areas, further oil defence measures were employed (Figure 8): mechanical gathering of the oil, employment of booms and sand walls, *in situ* burning (ISB), and the use of chemical control agents (dispersants).

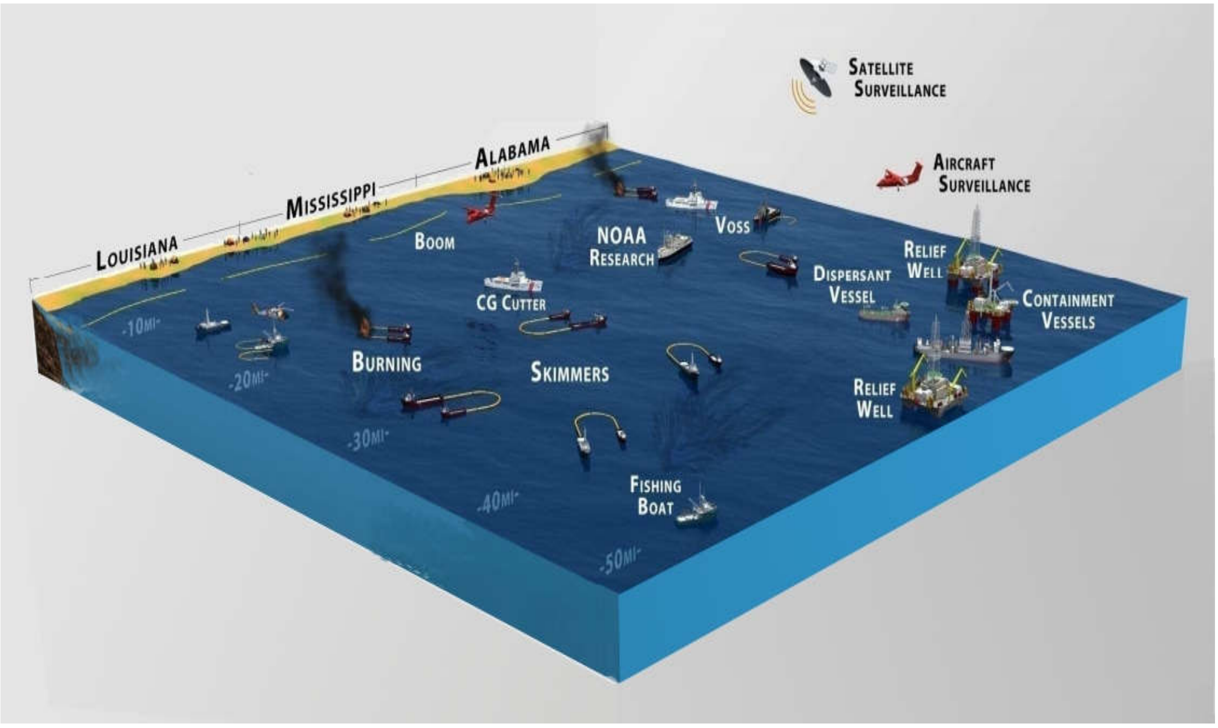


Figure 8: Schematic representation of the response measures carried out at and near the area of the Deepwater Horizon disaster (Picture source: cutout from the U.S. Government Handout Graphic, house.gov).

Successful employment of the various response measures depends strongly on the prevailing abiotic and meteorological conditions. Mechanical gathering or burning of the oil is only possible up to certain wave heights and wind speeds (Figure 9). Wind speed and wave height also limit the use of chemical agents. Also the weathering of the oil is a significant factor (cf. Figure 13).
Shoreline protection and the protection of sensitive areas have been described by American commissions as very successful for some areas. In the aftermath of the disaster, however, it was determined that there were also areas where the operations and effectiveness were deficient (ISPR 2011). Investigating commissions have also suggested that some of the sensitive areas and some areas especially deserving of protection were not considered, or were insufficiently considered, in the response plans.

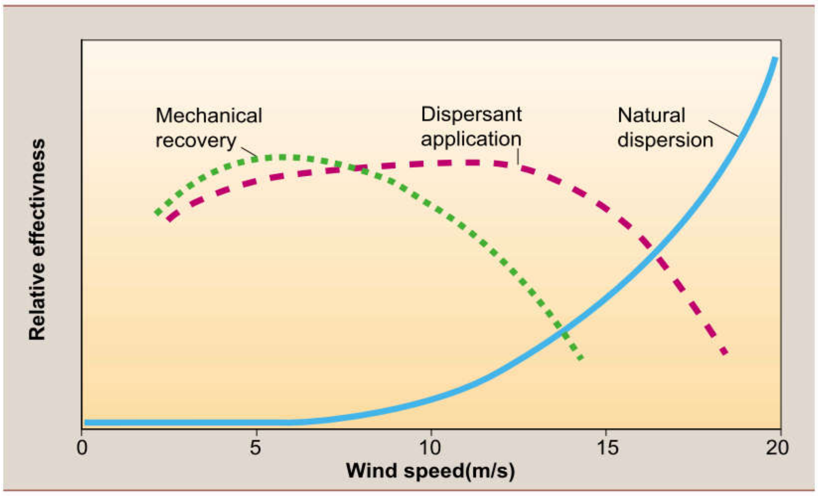


Figure 9: Effectiveness and implementation area of selected oil-control measures relative to wind speed (Picture source: Alun Lewis & Per Daling, Oil Spill Dispersants, SINTEF 2001).

Planning for the deployment areas for booms was carried out by NOAA under consideration of weather predictions and prognoses of the oil drift. Remote reconnaissance, using surveillance aircraft for example, was recognized as being an especially effective method for obtaining information on the extent of oil spread (ISP 2011). In addition to the mechanical effectiveness of the oil booms, the psychological importance of the luminous orange booms deployed near the coast was also reported (US NC 2011a) - and booms were deployed for this reason in some situations although their use was believed to be ineffective. Because of this, along with the fact that the coordination and deployment decisions were made at the local level, there were shortfalls in mechanical shoreline protection. The Unified Command Center was able to improve this situation in part by mediating among the various communities. Procurement of oil booms and oil recovery equipment was also carried out in part by the Unified Command Center, as was the establishment of national and international contacts with producers of the necessary response equipment (US Coast Guard 2010).

In total, 3,800 km of boom, 835 skimmers, 6,131 ships, and 123 aircraft (78 helicopters and 45 aircraft) were deployed. 47,000 people were involved in the mechanical oil recovery work. According to estimates, it is believed that workers were able to recover a total of 3 to 4 per cent of the oil by mechanical procedures. Based on these numbers and considering the amount of oil that reached the water surface and the coastal area, the use of a mechanical oil recovery strategy was considered to be a success. The ISPR report (2011), however, suggests that evaluation of the potential recovery capacity should not be related to the maximum pumping ability as it conventionally has been, but should include a consideration of the actual effectiveness.

The mechanical recovery equipment used is mostly produced in Europe, so it can be assumed that similar equipment was used in oil recovery at the Deepwater Horizon catastrophe as that which is used for national response in Germany. It would be advisable to compare the gear that was used with German equipment, with consideration of the respective experience.

Because special ships for pollution spill control would be deployed in German national response in addition to the mechanical equipment mentioned, it can be assumed that there would be a relatively higher effectiveness of the response. If necessary, increased effectiveness would be possible in Germany through the use of additional multi-purpose ships, contracts with tanker shipping companies, or by the deployment of private ships near the coastline. The feasibility of such measures should be appraised.

5. *In situ* burning and its consequences

In situ burning has been recognized for decades as a method to remove oil from the water surface (Figure 10). This response measure, like all other methods, can only be employed successfully under certain environmental conditions. The underlying technology has been tested and applied since 1967. Under the right conditions and with appropriate equipment it is estimated as an adequate oil pollution response method.

Figure 10: Controlled *in situ* burning in the Gulf of Mexico after containing the oil with a fire boom (Picture source: U.S. Navy, MCS Justin Stumberg).

The Federal On-Scene Coordinator (FOSC) for the Deepwater Horizon disaster brought this kind of response method into consideration at an early stage. However, the technique had never been used on such a large scale. In using this method, the potential danger to the population and to workers had to be considered. A specified concentration of airborne fine particulates (10 µm) of 150 $\mu g/m^3$ was not be exceeded.

In the Gulf of Mexico five different types of fire booms were employed. The total length of booms was around 7,000 m. A total of 411 *in situ* burns were carried out, of which 376 burned significant amounts of oil (Figure 11). Estimates of the amount of oil burned range from 30,000 to 40,000 m^3 (Allan 2011).

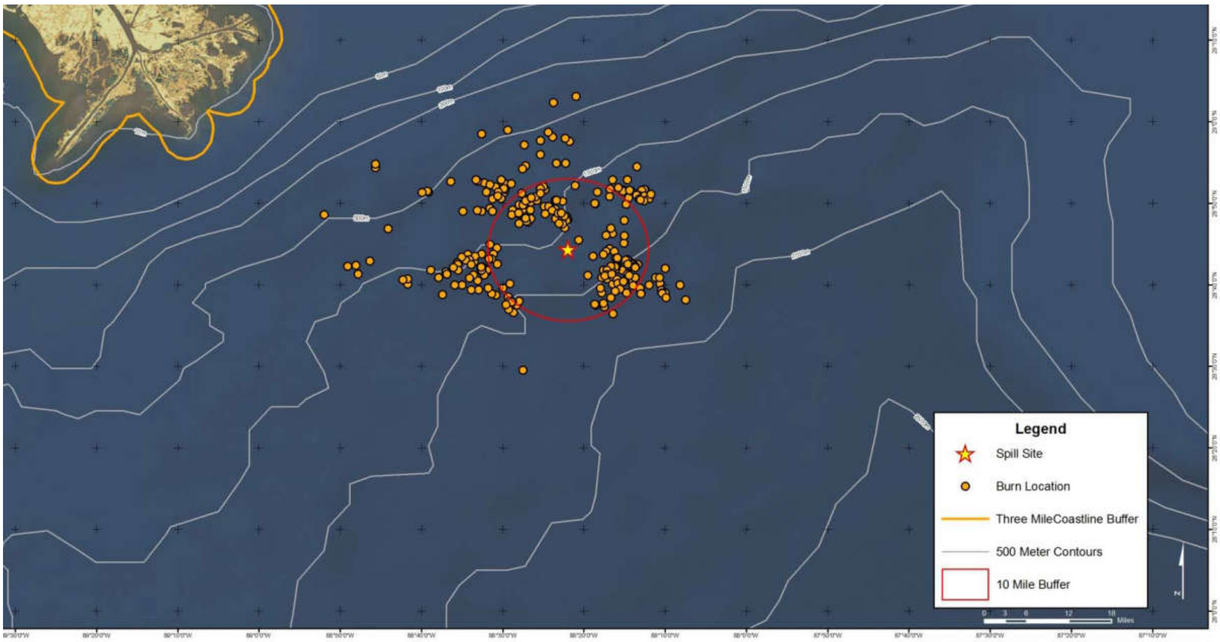


Figure 11: Positions around the Deepwater Horizon where *in situ* burning was carried out as an oil-control measure (Picture source: A. Allen, Spiltec, OSPR Workshop, Feb. 2011).

The use of *in situ* burning after the Deepwater Horizon disaster is rated as successful under the right conditions when carried out by trained personnel (ISPR 2011). However it should be generally noted, that *in situ* burning cannot and should not replace mechanical oil-recovery.

In the ISPR Report 2011, it was recommended that the National Response Team (NRT) require the Regional Response Teams (RRTs) to prepare and establish uniformous guidelines for carrying out *in situ* burning professionally, with the consideration for protecting the general health of the population. These guidelines should specify areas in which *in situ* burning cannot be used, and where it can be used without further consultations (e.g. in a certain distance from the coast). In addition to continuous maintenance of the necessary equipment, adequate training and drilling of personnel is required. Furthermore, it was determined that there is a need for additional research with respect to the evaluation of possible consequences and risks as well as a need for continuing development of the necessary equipment (ISPR 2010).

In Germany, according to the VPS Handbook, *in situ* burning can be considered on the water when a comparison of procedures indicates that local burning is the best solution for combating an oil spill and no other method proves to be less harmful to the environment.

This kind of response has never yet been employed in German waters. The Central Command for Maritime Emergencies maintains a 146 m long fire boom in Hamburg in case it needs to be used.

In situ burning in the German Bight is to be carried out with due caution. Because of the frequent presence of a west wind, toxic products of the burning process (gases and aerosols) would be transported toward the shorelines and coastal towns. Operational modeling of the air-pollution cloud is thus necessary before the potential use of on site burning.

6. Chemical oil control

In addition to mechanical methods of oil control after the Deepwater Horizon catastrophe, chemical response methods were employed as well. Based on the intended type of effect the chemical agents can be subdivided into different product groups. Some agents contract the oil phase on the water surface (oil herders), while others increase the viscosity of the oil (solidifiers), with benefits for the mechanical recovery. These kinds of chemical agents, as well as the agents for cleaning the coastlines and objects (shore-line cleaners) were not employed in the Deepwater Horizon incident. At the incidents spill site the so-called dispersants were used to facilitate the natural dispersion of the oil.

How dispersants work

Because of its low polarity, oil does not dissolve in water. With sufficient kinetic energy, however, it can disperse into the aqueous phase. The intensity of naturally occurring dispersion (see Figure 5) depends particularly on parameters like water temperature, wind intensity or wave height (Figure 9), salinity, and the type of oil.

Dispersants decrease the interfacial surface tension at the phase transition from oil to water. Small oil droplets can thus be broken out of an oil film much more easily. The dispersed oil is however not removed from the marine environment by the use of dispersants, rather it is distributed within the water phase in the form of fine oil droplets (Figure 12). By this the surface area of the exposed oil is increased by a huge factor, and thereby the accessibility to the microbial communities is enhanced. With the increased bioavailability the oil can be more easily populated by the ubiquitous occuring oil-consuming microorganisms that use the petroleum as an energy source. Under the right environmental conditions the dispersed oil can thus be degraded much more quickly.

When the oil no longer floats on the surface but is dispersed in the water, there is less danger for birds that are looking for food or a place to rest on the water become oiled, and the chance that oil will be washed up on the coastlines is reduced.

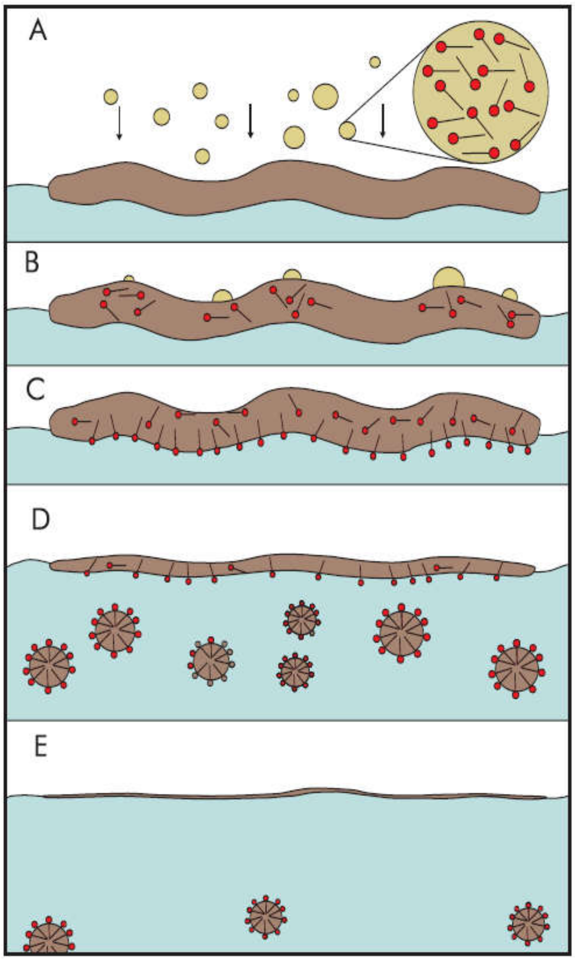


Figure 12: How dispersants work.
A) application of the dispersant in fine droplets; B) adsorption and transport of the active components into the oil film; C) reduction of interface tension by the surfactant; D) breakout of small droplets of oil by wave energy; E) dispersal of the oil droplets in the water to a depth of around 10 m (ITOPF 2010).

The fact that organisms living in the water are more exposed to the oil as a result of dispersion and spreading in the water body with the use of dispersants is however also a disadvantage. Because the organisms can be harmed by the toxic properties of the oil, the dispersants, and their combined effects. The degradation of oil by microorganisms also, as a rule, consumes oxygen, which can also lead to problems in the water.

Consequently the use of dispersants does not always lead to the desired enhancements for the whole biocoenosis. Before using dispersants it should be determined whether the product to be used is effective in the particular case and will facilitate dispersal of the oil. The use of dispersants is also problematic because, with the change in interface tension of the oil phase, mechanical oil recovery and removal methods are no longer effective. As with other oil control procedures, there are general requirements that need to be taken into account for the use of dispersants. In addition to considerations of wind speed and wave height (Figure 9), its effective use is only possible within a limited time window after the oil release[2]. There must be adequate opportunities for applying the dispersants within this time window by helicopter, ship or aircraft. An overview of the major advantages and disadvantages related to the use of dispersants is found in Table 1.

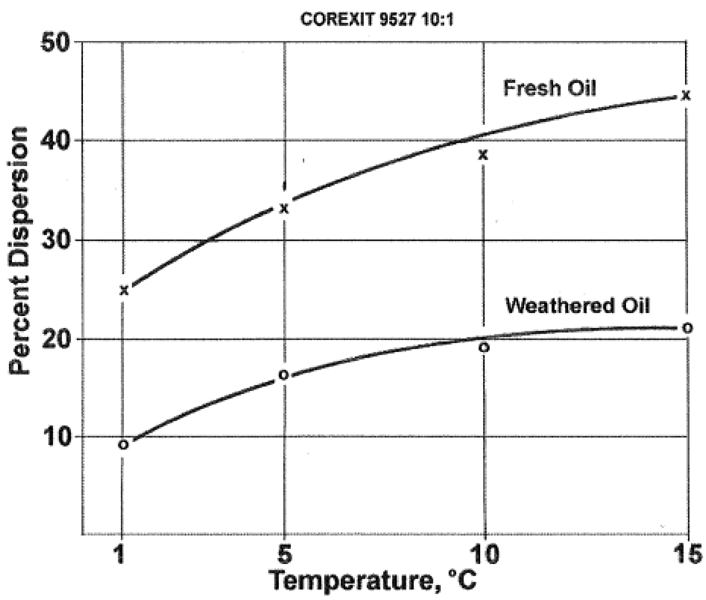


Figure 13: Influence of temperature on the effectiveness of the dispersant Corexit 9527 for fresh and weathered oil (Lehninen 1981 from IVL 2001).

[2] Crude oil consists of many different compounds. These are mostly hydrocarbon chains of various lengths. Depending on the molecule size and conditions, the shorter hydrocarbons volatilize, which results in an increase in viscosity of the oil and a decrease in the effectiveness of the dispersants (Figure 13).

Table 1: Advantages and disadvantages of dispersants.

Advantages of dispersants	Disadvantages of dispersants
Greater surface area of the oil → faster degradation Less oil on the water surface → fewer oiled birds → less oil on the coasts and beaches Oil distributed through the water column → lower concentrations → lower toxicity Relatively simple and effective application → wide operation range → large area capacity Less dependent on weather conditions → larger deployment spectrum Method with quickly visible results → media-effective	Oil is only surficially removed → it still remains in the environment → hazard for pelagic, demersal and benthic flora and fauna Dispersion of the oil into small droplets → booms and mechanical recovery methods become ineffective → in case of penetration into the sediments, degradation takes longer → increased oil exposure for organisms in the water Toxicity of dispersants and oil → direct and indirect effects, by single-substance toxicity and combined toxicity Limitations of the effective use → limited time window for an application → sufficient wave energy is necessary → specific products not appropriate for all oil types → use in freshwater is not intended

The positive effects associated with the use of dispersants needs to be weighed against the possible harmful effects for the ecosystem (Figure 14). Conditions such as wind direction, coastal development and conservation goals (sensitive coastal ecology, marine environment, fisheries, tourism, etc.) also need to be considered. A Net Environmental Benefits Analysis (NEBA) can be a useful tool for this kind of evaluation.

Because of the possible and sometimes significant ecological disadvantages, a general recommendation to use dispersants in an oil spill response cannot be given. By the same token, the use of dispersants cannot replace mechanical recovery measures.

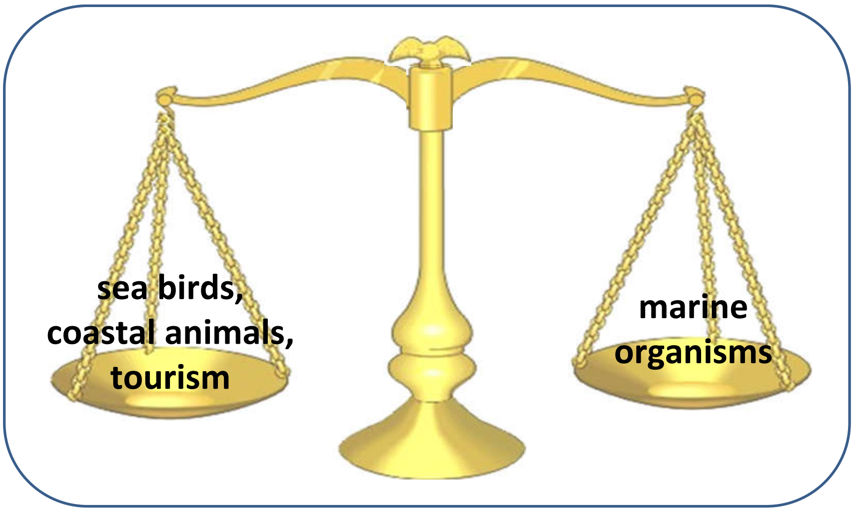


Figure 14: Interdependence of the conservation goals that may be involved in a decision to use dispersants (after Alun Lewis).

The situation in Germany

In cases of serious catastrophes and complex damage situations such as a large oil spill, the Central Command for Maritime Emergencies is responsible for incident management. This includes coordination of the operational units and the planning of the response strategies. For large-scale oil pollution in Germany the primary response strategy envisioned is mechanical recovery using specially designed ships and equipment. The use of dispersants by the Central Command is only possible in special cases, and then only when they could truly be effective and their use is ecologically rational.

With respect to potential use, the North Sea can be subdivided into three zones (Figure 15): Zone I – the use is problematical and generally not envisioned; Zone II – the use of dispersants is possible to a limited extent; and Zone III – the use is possible without quantitative restrictions.

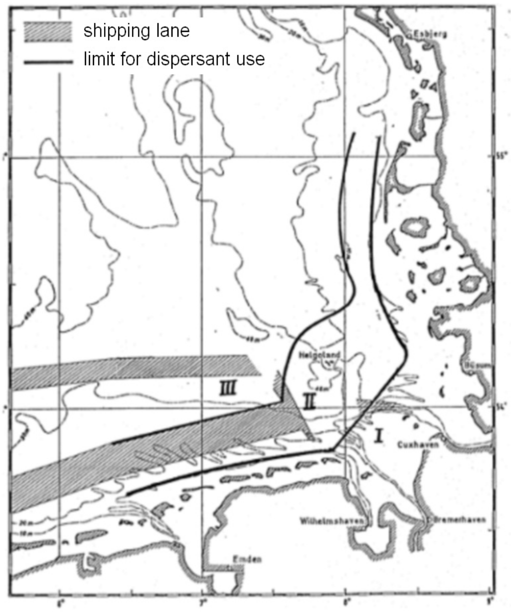


Figure 15:
Zonation of the North Sea (Federal Environment Agency - Umweltbundesamt Report 10204 216/05).

The use of dispersants is generally not intended in the Baltic Sea. The use is not appropriate because the Baltic Sea is a shallow inland sea with low water exchange, low wave energy, low salinity, low oxygen, and stratified water layers. For these reasons, the Helsinki Convention prohibits the use of dispersants here to combat spills.

Use of dispersants in the Deepwater Horizon incident

Dispersants were widely employed by BP for controlling the spilled oil caused by the Deepwater Horizon incident. The application of dispersants Corexit EC9500A and Corexit EC9527A to the water surface was carried out by using helicopters and aircrafts. 3,700 m^3 of dispersants were applied in this way. Additionally to the surface application, the dispersants were also applied underwater at a depth of 1,500 m. With the permission of the American Environmental Protection Agency (EPA) 2,900 m^3 of the dispersant Corexit EC9500 were injected directly into the oil flowing out under high pressure at the discharge location. It was the first time that dispersants were used underwater at such great depths in response to an oil spill.

In the course of deploying the dispersants, the EPA and the U.S. Coast Guard decided to limit the amount used daily to 15,000 gallons, approx. 57,000 litres (EPA & US CG 2010). Although the products being used are not among the most toxic products, they are also not the least toxic of available dispersants. The EPA halted the use by BP on short notice for testing and application of other dispersants with a lower toxicity than the products that were being used and which were also on the EPA list of permitted dispersants (EPA & US CG 2010). If it was not possible to use alternative dispersants, then this would have to be proven by BP. As a justification to continue using those dispersants that were already being used, BP stated that alternative products were either not available in sufficient quantities or that during breakdown persistent compounds would be produced that could have a toxic effect on the marine environment.

Beginning in November 2010, independent investigations reported the presence of extensive oil plumes in the general area around the Deepwater Horizon at a water depth of 1,000 to 1,300 metres (Hazen et al. 2010, Kujawinski et al. 2011, Thibodeaux et al. 2010, US NC 2011a). It is believed that the formation of these oil plumes was intensified by the underwater application of dispersants.

The effectiveness and impact of the underwater application of dispersants are of special interest for the investigations that were carried out. To learn more about where the Corexit finally ended up, Kujawinski et al. (2011) use the component DOSS (dioctyl sodium sulfosuccinate) as a tracer. DOSS decomposes very slowly in the sea. It was discovered in the oil plumes at a depth of 1,000 to 2,000 metres. DOSS is thus an appropriate tracer for the dispersants that were used: Corexit EC9500A and Corexit EC9527A. DOSS was not observed in the oil plumes in the water layers above 1,000 m. Two explanations for this behaviour can be proposed: 1. the dispersant was ineffective and diffused out of the oil plume, or 2) the dispersant was effective and was carried away with the splitting of small oil droplets (Kujawinski et al. 2011). The basic question still being discussed, to what extent the underwater application of dispersants after the Deepwater Horizon catastrophe led to a decrease in the amount of oil at the surface, has not been definitively answered (Figure 16). Likewise, no statement can presently be made about the long-term toxic effects[3] of the dispersants on the marine community.

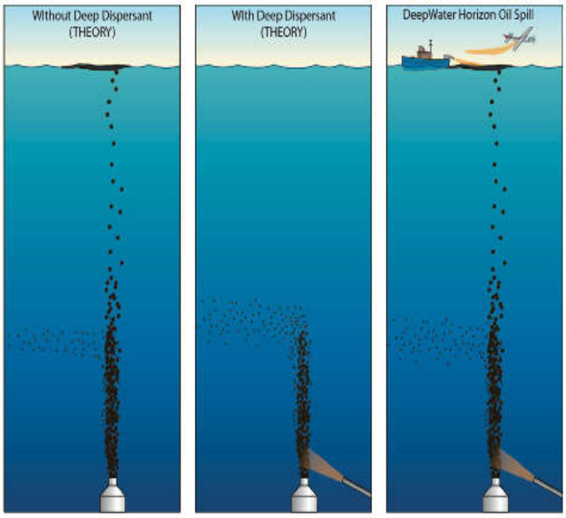


Figure 16:
Illustration of the question of effectiveness of dispersants used in the Deepwater Horizon disaster (Kujawinski et al. 2011).

The application of a total of 6,600 m^3 of Corexit represents one of the most extensive uses of dispersants ever. The underwater application was carried out to increase the dispersion of oil in the water column, so that lesser amounts of oil would reach the sea surface. According to initial estimates, the amount of oil dispersed by the application is 8-16 per cent (NOAA 2010, US NC 2011a).

Conclusions on the dispersant use

The Deepwater Horizon accident has initiated an intensive debate over the usage of dispersants. From Deepwater Horizon the presently incomplete findings of the effectiveness studies and the investigations of long-term effects should be used in future decision makings. For its possible use and successful application, an understanding of the data relating to the effectiveness and toxicity

[3] e.g. reproductive toxicity, effects at the population level, endocrine effects, immunotoxicity, etc.

of the dispersants is critical. If the information proves to be insufficient, special software such as that of EMSA can be used if necessary. Comprehensive contingency planning is essential for successful application of dispersants. Furthermore, the dispersants to be used and the necessary equipment for their application must be available on short notice. The response personnel should be sufficiently informed and appropriately well trained. For decisions about a possilble application, a contingency plan should be in effect, indicating sensitive areas and areas where a volume limitation is envisioned. In addition, procedures for a more effective determination of the form and thickness of the polluted layer should be further developed.

7. Impacts on fish, avifauna and marine mammals

Oil consists of a mixture of thousands of substances, most of which belong to the group of hydrocarbons. Oils from different sources are distinguished by their proportion of individual substances. These influence the particular physical, chemical and toxic properties. The initial composition of leaked oil can change in the environment through weathering (evaporation, dissolution, chemical and biochemical decomposition, see Figure 5); this can then result in changes in the oil's properties. In this way, for example, a highly volatile, low-viscous oil can alter to a more viscous oil with only a few volatile components. This more viscous oil has a stronger tendency to bind to surfaces upon contact and coats them permanently. This can be especially problematic for birds and mammals because it impairs their ability to regulate their body heat, which can result in death by hypothermia (Söding et al. 2010).
Aromatic hydrocarbons are of special toxicological significance. More volatile and water-soluble aromatics with 1 to 3 rings usually exhibit high acute toxicity, while higher condensed polycyclic aromatic hydrocarbons (PAHs) with 4 to 6 rings are often carcinogenic and persistent. Quantitatively, the most important hydrocarbons are the chain-forming saturated aliphatic compounds with 5 to 50 carbon atoms. They are, however, not very toxic and can be relatively easily decomposed by microorganisms.

Avifauna

No final report has yet been published on the total extent of oil pollution effects on birds during the Deepwater Horizon spill. However, the US Fish & Wildlife Service has published overview maps of birds impacted by the oil in the internet (US FWS 2011a, US FWS 2011b).
The detailed documentation of oiled birds is essential for the preparation of court cases that are being brought in order to make the organizations responsible for the spill accountable for the restoration of habitats and species that suffered damage. In addition, the data will be used to quantify the adverse effects to bird populations that are considered to be important by the US Fish and Wildlife Service, the Gulf states, and the general population. Finally, the data are needed to determine the extent of the impact of the oil spill on the bird populations in order to establish appropriate restoration procedures. The total costs charged to the polluter comprise the costs for

cleanup that was carried out, restoration efforts and other possible resulting costs. If the responsible parties are not prepared to pay for the damages that were caused, then court procedures will be initiated.

According to reports by the US Fish & Wildlife Service, no complete survey of the affected animals was carried out in the early days of the catastrophe. A survey system with integrated verification of the reports was developed after the first few days. The data are collected by authorized counters, but also by the general public who find birds and deliver them to rehabilitation centres. The species, location of the find, location conditions, condition of the bird and degree of oiling is registered. Before the data are put in a central database, they are evaluated to determine whether they are scientifically, legally, and qualitatively sufficient for the purposes mentioned above. This verification process takes about two weeks. Reports on the verified finds are produced daily.

The following information about the animals affected by the spill are taken from the Bird Impact Data reports of the US Fish & Wildlife Service of 20 April 2011 (US FWS 2011a). It is typical for oil spills that the number of birds recorded does not represent the total number of affected animals. A undetermined number of oiled animals cannot be recorded because bird carcasses can sink in the sea, drift away on currents, or simply are not found (for example, marine birds that die in inaccessible areas or carcasses are eaten by other animals).

Up to 20 April 2011 a total of 8,233 birds were collected on the coasts of the Gulf of Mexico, of which 53 per cent (4,389 individuals) were oiled. 37 per cent (3,046) of the birds were rescued alive, and of these 68 per cent were visibly oiled. Thus 25 per cent of all of the birds found were visibly oiled and still alive. Interestingly, the majority (62 per cent) of the dead birds found were not oiled externally. The extent of internal oiling in these animals has yet not been published. A further aspect is that a systematic search for victims of oil usually leads to increased finds of birds that died of natural causes.

In May 2011, the data on species composition of the affected birds were still considered by the US Fish & Wildlife Service to be tentative and incomplete. The spectrum of visibly oiled birds from the report of May 2011 includes around 75 species. Songbirds as well as birds of prey, sea and water birds were affected. The broad range of species included marine species such as the shearwater and gannet as well as coastal species such as pelicans, waders and egrets. The laughing gull *(Larus atricilla)*, at 45 per cent of all finds, was the species most frequently registered as oiled. Overall, gulls were most strongly affected (48%), followed by pelicans (13%), especially the brown pelican *(Pelecanus occidentalis)*, terns (12%) and gannets (11%), especially the northern gannet *(Morus bassanus)*. In the states of Mississippi, Louisiana, Florida and Alabama, only one species listed as endangered was affected by the spill: 49 individuals of the endangered subspecies of the interior least tern *(Sternula antillarum athalassos)* were registered as oil victims.

The extent to which the use of dispersants and other factors such as currents, water temperature, characteristics of the coastline, size and distribution of the bird populations had an influence on the number of oiled birds in the Gulf of Mexico has either not yet been resolved or not yet published.

Marine mammals

21 species of marine mammals occur in the Gulf of Mexico, six of which are classed as endangered under the Endangered Species Act. Marine mammals, fish and other marine animals were also registered by the US Fish & Wildlife Service during the survey and documentation of oiled birds. Here again it is stressed that the number of animals recovered does not represent the total number of affected animals. An indeterminate number of oiled organisms cannot be registered because the carcasses sink in the sea, are carried away by currents or simply are not found.

The data presented on the animals affected by the spill are taken from the reports of the US Fish & Wildlife Service of 20 April 2011 (US FWS 2011a). According to these a total of 13 marine mammals, including dolphins, were found alive. Of these, two animals exhibited visible traces of oil. After undergoing rehabilitation procedures, five animals were released again. The total number of mammals found dead along the Gulf States was 157. Only ten of these dead animals (around 10%) showed traces of oiling. 130 animals showed no visible outward signs of oiling, and the cause of death has not yet been determined for 17 animals.

Here also, the reports of the US Fish & Wildlife Service indicate that not all of the dead animals found, or injured animals that were caught could be directly related to the Deepwater Horizon catastrophe. Specific causes are usually established at a later time. One still incomplete part of the assessment is the clear determination of the causes of death among the animals in the impacted region.

Fish and other wildlife

Reports on the extent of the impacts on affected fish species and the communities in the water column are not presently available. Experience from past oil spills in the Gulf of Mexico, however, does not suggest the probability of long-term damage to the fish stocks. Following the Deepwater Horizon catastrophe large areas around the spill area and on the coasts were closed to fishing. This primarily impacted fishing areas for shrimp, groupers and red snapper (Söding et al. 2010). A large proportion of the animals collected and documented in the course of the US Fish & Wildlife Service investigations concern sea turtles. Four species of these endangered or threatened sea turtles live in the Gulf of Mexico. For one species (Kemp's ridley turtle), in fact, the only nesting area in the world is in the western Gulf. According to the report of 20 April 2011 (US FWS 2011a) a total of 536 living and 613 dead turtles were collected. Of the living turtles caught, 456 showed visible signs of oil. The number of dead turtles that were oiled was only 18 animals (approx. 3%). 517 of the turtles that were found dead showed no visible oil traces. After rehabilitation measures, 469 turtles were released again. In order to protect the sea turtle nests from possible oil damage on the shores of the affected areas, a total of 278 nests were transported to safety. 14,676 turtle hatchlings could thus be released again.

Cleaning of oiled birds and other animals

Rehabilitation stations were operated in Mississippi, Louisiana, Florida and Alabama. Of the 3,046 living birds caught until April 2011, a total of 1,252 individuals were released from the stations. That equates to approx. 41 per cent of the living birds caught. The proportion of the released birds that were direct victims of the oil pollution is still unclear. Detailed information about rescue measures and their results are likewise not available.

8. Microbiological degradation processes

The monitoring carried out after the catastrophe as well as several accompanying process studies were very detailed and extensive in respect to the description of the microbiological components. The first publications (Hazen et al., 2010; Camili et al., 2010; Hamdan & Fulmer, 2011) appeared as early as 2010 and 2011 to highlight the importance of this trophic level in the degradation of the oil. Nevertheless, it is evident that, due to the complexity of the damage process, a conclusive assessment can presently not be made. The massive use of the dispersant Corexit EC9500A itself very probably led to a change in the microbial community involved in the breakdown of the oil. Based on sediment samples, Hamdan & Fulmer (2011) were able to show that Corexit very specifically affects particular bacterial populations. In general, the genus Vibrio is positively affected with respect to its growth rate. But because the genus includes many pathogenic species (*V. cholerae*, *V. vulnificus*, *V. parahaemolyticus*), resolution of the question whether the use of dispersants in the warm surface waters of the Gulf might be promoting the growth of pathogens is urgent. This possibility is borne out by a recently published metagenome study by Widger et al. (2011) in which a massive increase of *V. cholerae*-related DNA sequences was verified in the US coastal waters of the Gulf of Mexico following the oil spill.

Which effects the use of Corexit and of the presence of the oil in the cold, deep water of the Gulf will have is currently unknown. Hazen et al. (2010) were able to state the presence of finely distributed oil in deep water, which led to an intensified growth of oil-degrading γ–Proteobakteria and to a faster oil degradation than expected. Nevertheless, Samantha Joye (University of Georgia), who recently carried out a diving expedition to the area, described the deep-sea floor near the discharge location as a "graveyard" covered with a thick layer of brown slime.

It will take years before it is possible to make a conclusive judgement on the ecosystem impacts of the oil spill and the dispersants extensively applied in response to the spill. In the Gulf of Mexico, the Deepwater Horizon spill caused one of the most extensive oil pollution catastrophes in history. By expanding the use of dispersants into the underwater realm, and at unprecedented volumes, a field experiment was initiated whose consequences for nature and the environment remain uncertain for the time being.

9. Monitoring studies

After the Deepwater Horizon disaster numerous investigations were undertaken by universities, public authorities, non-governmental organizations and private bodies. These serve to ascertain the negative impacts of the oil catastrophe and can be useful in court hearings (see Chapter 7). The investigations encompass all potentially affected aspects of the marine biocoenosis (cf. Figure 17).

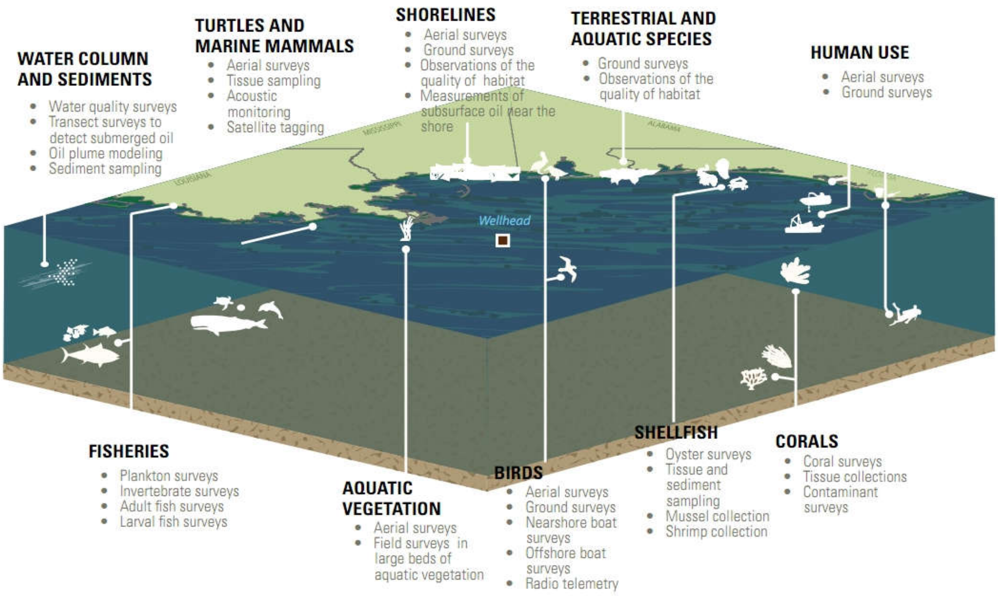


Figure 17: Investigations initiated on various aspects of the marine biocoenosis after the loss of the Deepwater Horizon (US NC 2011a).

An overview of the monitoring programmes can be found on the internet page "GeoPlatform – Gulf Response"[4] of the National Oceanic and Atmospheric Administration (NOAA).
In the report to the president of the United States it was established that, directly after the spill, many independent scientists were willing to carry out investigations related to monitoring that would complement those of the government. Due to uncertainties about the financing, however, the start of research activities was delayed (US NC 2011a).

In general, the type, range and depth of a monitoring programme depends on the goals of the monitoring. These can also change significantly during the course of a spill. In the following paragraphs the considerations for designing the appropriate monitoring programmes in Germany are outlined.

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[4] http://www.geoplatform.gov/gulfresponse/

Initial investigations

At the beginning and during the discharge phase, primary questions involve the amount and kind of oil as well as its extent, projected transport and final destination. Whenever it appears necessary or reasonable, monitoring should be complemented and supported by modeling studies. Valuable measurements may thus be applied in a significantly more focused and effective manner (BSH, FZG).

Remote sensing methods

Remote sensing operations carried out by aircraft or helicopters are the most useful method for obtaining rapid and extensive overviews. The necessary equipment is available and ready for use in Germany (German Navy, Central Command for Maritime Emergencies) and its neighbouring countries.

Chemical monitoring studies

The material-specific properties of the oil can be obtained mainly from the polluter of the pollution. Nevertheless, the spilled oil should still be carefully characterized using GC and GC/MS methods.

At the beginning of the investigation very rapid quantitative or semi-quantitative methods are important to assess the amount of contamination of the water and the coasts. Fluorescence spectroscopic methods are appropriate for this. Both spot-sampling with analyses in the laboratory and continuous *in situ* methods with appropriate sensors are feasible. The latter permit a rapid semi-quantitative overview of larger water bodies and, in contrast to remote sensing techniques, can also verify the presence of oil at greater water depths.

The longer the time period and the farther away the study area is from the discharge and incident location, the more important it is to have qualitative proof that the pollution originates from the original spill and not from another source.

Quantitative results can initially be obtained with factor comparison methods (UV-VIS-F) to estimate the total amounts of oil. Through the course of the weathering of the oil (by evaporation, solution and degradation) the analysis of specific components using GC-MS becomes more important.

The following goals are at the forefront:

1. Qualitative and quantitative determination of toxic components (particularly aromatic hydrocarbons: alkylated and non-alkylated aromatics), in order to determine and evaluate the toxic contamination of water, sediment and biota
2. Verification of the identity of the oil by pattern comparison with the primary spill oil
3. Determination of the spatial extent of the environmental contamination – important for damage assessment and documentation as well as compensation claims
4. Observation and documentation of changes through time (weathering and degradation of the oil, recovery of the ecosystem)

Some of the analyses can be carried out by state and federal environmental laboratories and also by commercial laboratories. In Germany, the Federal Maritime and Hydrographic Agency (BSH) has the highest experience in these kinds of investigations, and that institution should therefore have a leading role.

Biological investigations

The floral and faunal research can basically be divided into three different areas of study:

1. Physical pollution such as contamination and adverse effects to feathers or gills
2. Absorption and accumulation of oil, oil derivatives and detergents, and assessment of possible toxic effects
3. Consideration of secondary and adverse effects at the population level, as well as on the entire biocoenosis

Conclusions concerning monitoring studies

In the event of a spill in national waters, the presence of a preformulated plan increases the certainty of response action and the response speed. The available time for evaluating the initial situation is limited.

A monitoring plan should be part of preparedness planning for a catastrophe. The Environmental Panel of Experts (UEG) should be involved in its preparation and, if appropriate, should also coordinate it. Preliminary work on this has already been done on the initiative of the UEG.

10. Transfer of information

Public information in the USA was disseminated through several media. Besides the traditional media a significant amount of information transfer was handled through the internet. This can create obstacles when a flood of information sources is available and the desired information is difficult to find. It is thus important to create official portals that provide reliable, clearly presented and well structured documentation, information and data. In the case of the Deepwater Horizon the official data from various public agencies was presented on a central web site (http://www.geoplatform.gov/gulfresponse). The geoinformation model provided here with its ability to link various levels of information is a very good solution.

An analysis in the USA indicated that the absence of a public crisis communication plan clearly hampered information management, direct information transfer and effective crisis communication management during the organization of the response (ISPR 2011).

With regard to the preparedness for a pollution incident in German coastal waters, the question needs to be considered whether, in addition to the advance creation of investigation plans and monitoring schemes, plans could also be developed and made ready for the transfer of

information to the general public. In an actual response case, the press relations, for example, could be concentrated in the Central Command for Maritime Emergencies, where an appropriate plan of action already exists. Updated information on the state of the spill could be released through the internet site of the Central Command. In the preparation of information, a well-structured organization of the data is important, both for the general public and for concerned parties. The necessity of having an information platform already in place before an accident occurs should also be considered. A broad public could thus be informed of the extensive preliminary activities that are required for the investigations and overall preparedness.
The fully developed plan for monitoring in the case of pollution incidents could be presented, possibly together with the findings for the routine monitoring prior to an incident. A connection to the expanded German Marine Monitoring Programme (BLMP+, presently undergoing an organizational transition), would be a practical step. The Contingency Planning for Pollution Control (Vorsorgeplanung Schadstoffunfallbekämpfung, VPS), which already includes, for example, data from biological studies, presents a basis for a presentation platform. This is, however, not presently open to the public but used for informing public authorities involved in pollution incident response.

11. Summary

The findings reported here represent the current state of knowledge. Many of the investigative programmes, some designed for the long term, are not yet completed. Although initial publications and some final reports are now available, assessment of the real ecological magnitude will not be possible for several years. Many aspects and findings are still being hotly debated by specialists.
A direct projection of the experiences and knowledge obtained in the Gulf of Mexico onto the North and Baltic Seas is not fully possible, in part because the water bodies are different in their topography and natural conditions, but also because of the different regulatory backgrounds of the seaboard countries. However, indications for reviewing and optimizing the present procedures and preparations for a possible accident do emerge.
Due to the heavy ship traffic as well as the presence of oil platforms operated by other countries, there are risks for a major oil spill in the German territorial waters of the North and Baltic Seas. Despite the constant tightening of safety standards, the possibility of accidents cannot be completely eliminated. For an effective spill response, therefore, comprehensive contingency planning is necessary. If the planning just begins after an accident has happened, valuable time may be lost or poor decisions can be made.
During the spill response after the Deepwater Horizon event it became evident that the existing regional contingency planning in the USA was sufficient for minor incidents, but that strategic planning at the national level and realistic worst-case scenarios are lacking. In part, the qualitatively very different contingency plans contained obvious procedural gaps. The preparedness and response strategies for large quantities of oil need to be coordinated throughout the respective region. For Germany this has already been implemented through

bilateral, trilateral and multilateral agreements (Bonn Agreement, Helsinki Convention, DenGerNeth, SweDenGer, etc., see Figure 18).
Furthermore, the Deepwater Horizon incident has once more illustrated the importance of a clear regulation of hierarchies, competences and responsibilities. Assessment reports indicate that e.g. communication between operation units and local authorities needs to be improved. In Germany, responsibilities and competences have been regulated since the establishment of the Central Command for Maritime Emergencies (HK) and the Maritime Emergency Reporting and Assessment Centre (MERAC, German: MLZ, Maritime Lagezentrum).
It has also become apparent that, for public acceptance, reliable and channelled information of the press and the general public is vital. This includes proper handling of the media and a coordinated transfer of information. Information policies during such an accident should thus observe the basic rules of medial communications (for example, "one voice", "no salami-slice strategy", etc.). A basic strategic approach or suitable information portal could possibly be established as part of the national contingency strategy.

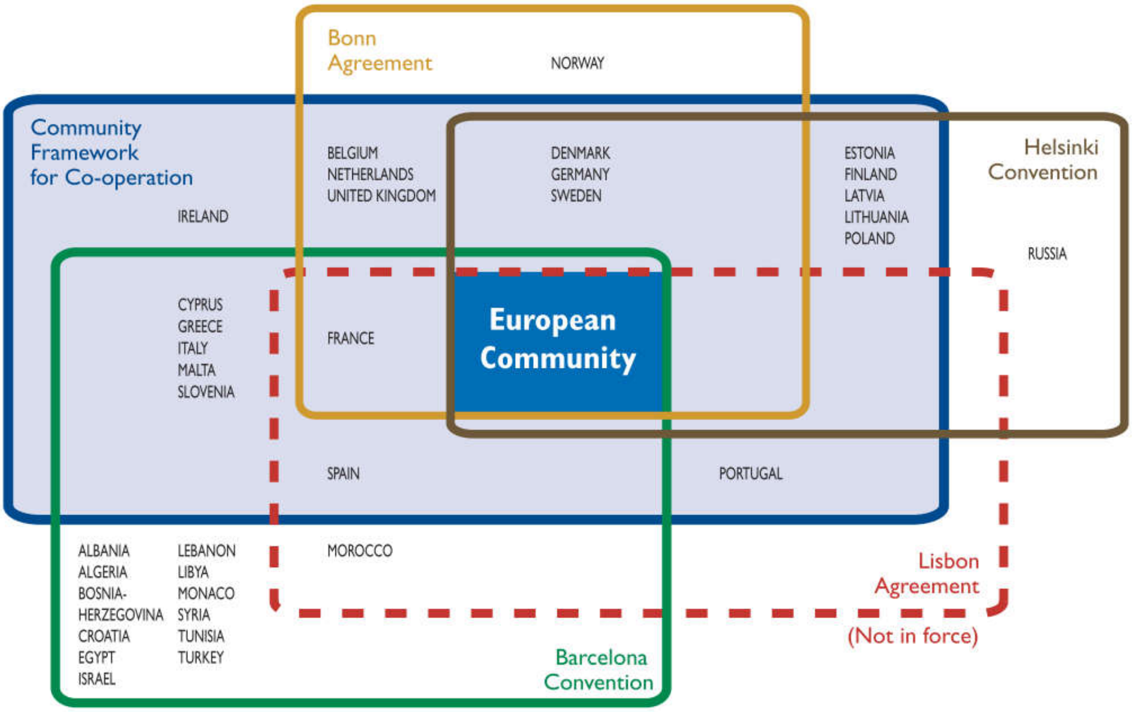

Figure 18: International agreements and conventions for protection of the seas (EMSA 2004).

In the case of the Deepwater Horizon incident the mechanical response measures can basically be rated as successful, even though the protection of some areas worthy of protection has been judged as inadequate. The use of *in situ* burning is assessed as effective under the right conditions. However, to assess the consequences of the *in situ* burning and judge the use of dispersants, a further need of research is required.

The catastrophic oil pollution caused by the collapse of the Deepwater Horizon rig has led to an ongoing debate on contingency and response strategies. These, along with the results of the various investigations, should be used for a validation and, if need be, development of national strategies. Independently of the Deepwater Horizon disaster, there is a constant need to integrate new scientific knowledge and new developments into preparedness and response plans as a continuous process. Room for improvement is recognized in the USA in the areas of crisis management, distribution of funds for the investigations, and implementation of clean-up measures in the aftermath. The question whether inadequacies exist in these areas in Germany should also be examined.

In order to ascertain the impacts of a spill, information on the situation before the pollution must be available. Such a database can only be obtained by regular monitoring studies. It should be examined whether potential monitoring schemes can be integrated into the contingency planning. This is presently being prepared in the UEG, and includes coordination with further national monitoring programmes.

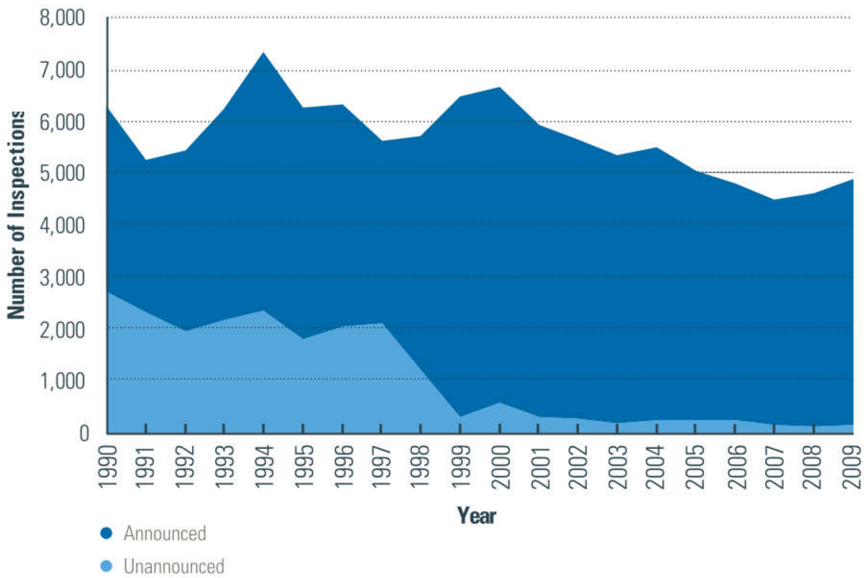

Figure 19: Number of announced and unannounced inspections on drilling platforms in the Gulf of Mexico from 1990 to 2009 (US NC 2011a).

Figure 19 shows the trend of announced and unannounced inspections in the Gulf of Mexico. Although the total number of inspections carried out does not change much over time, the number of unannounced inspections dropped significantly since 1999. Regulatory standards, professional inspection and, if necessary, significant penalties for non-compliance are crucial for operational safety. If an accident occurs the only recourse is to try to improve the situation and limit damage. Recovery of just 10 per cent of the oil released from an oil spill is considered to be a success. The key to marine protection, therefore, lies in preventing accidents by implementing a comprehensive safety strategy in spite of routines, time pressures and financial expense.

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13. Annexes

Annex 1: North Sea: Platforms, pipelines, cables, sediment dredging, mariculture (BSH 2012).