ITOPF

PROMOTING EFFECTIVE SPILL RESPONSE

EFFECTS OF OIL POLLUTION ON THE MARINE ENVIRONMENT

TECHNICAL INFORMATION PAPER

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Introduction

Oil spills can seriously affect the marine environment both as a result of physical smothering and toxic effects. The severity of impact typically depends on the quantity and type of oil spilt, the ambient conditions and the sensitivity of the affected organisms and their habitats to the oil.

This paper describes the effects of ship-source oil spills and resultant clean-up activities on marine flora and fauna, and their habitats. Particular attention is devoted to discussing the complex interactions between oil and biological systems, which have been the subject of diverse studies over many years. Separate ITOPF papers consider the specific effects of oil on fisheries and mariculture and on wider human activity.

Overview

Oil spills can cause a wide range of impacts in the marine environment and are often portrayed by the media as 'environmental disasters' with dire consequences predicted for the survival of marine flora and fauna. In a major incident the short-term environmental impact can be severe, causing serious distress to ecosystems and to the people living near the contaminated coastline, affecting their livelihoods and impairing their quality of life (*Figure 1*). Images of oiled birds following a spill encourage the perception of widespread and permanent environmental damage with the inevitable loss of marine resources. Given the highly charged and emotional reaction usually associated with oil spills, it can be difficult to obtain a balanced view of the realities of spill effects and subsequent recovery.

The impacts of spills have been studied and documented in the scientific and technical literature over several decades. Consequently, the effects of oil pollution are sufficiently well understood to allow for broad indications of the scale and duration of damage for a given incident. A scientific appraisal of typical oil spill effects reveals that, while damage occurs and can be profound at the level of individual organisms, populations are more resilient. In time, natural recovery processes are capable of repairing damage and returning the system to its normal functions. The recovery process can be assisted by removal of the oil through well-conducted clean-up operations, and may sometimes be accelerated with carefully managed restoration measures. Long term damage has been recorded in a few instances. However, in most cases, even after the largest oil spills, the affected habitats and associated marine life can be expected to have broadly recovered within a few seasons.

Figure 1: Oil stranded on the shoreline adjacent to a fishing village.

Mechanisms for oil spill damage

Oil may impact an environment by one or more of the following mechanisms:

- physical smothering with an impact on physiological functions;
- chemical toxicity giving rise to lethal or sub-lethal effects or causing impairment of cellular functions;
- ecological changes, primarily the loss of key organisms from a community and the takeover of habitats by opportunistic species;
- indirect effects, such as the loss of habitat or shelter and the consequent elimination of ecologically important species.

The nature and duration of the effects of an oil spill depend on a wide range of factors. These include: the quantity and type of oil spilt; its behaviour in the marine environment; the location of the spill in terms of ambient conditions and physical characteristics; and the timing, especially in relation to the season and prevalent weather conditions. Other key factors are the biological composition of the affected environment, the ecological importance of the component species and their sensitivity to oil pollution. The selection of appropriate clean-up techniques and the effectiveness with which operations are conducted can also have a significant bearing on the effects of a spill.

The potential effects of a spill are also dependent upon the speed with which the pollutant is diluted or dissipated by natural processes. This determines the geographical extent of the affected area and whether or not sensitive environmental

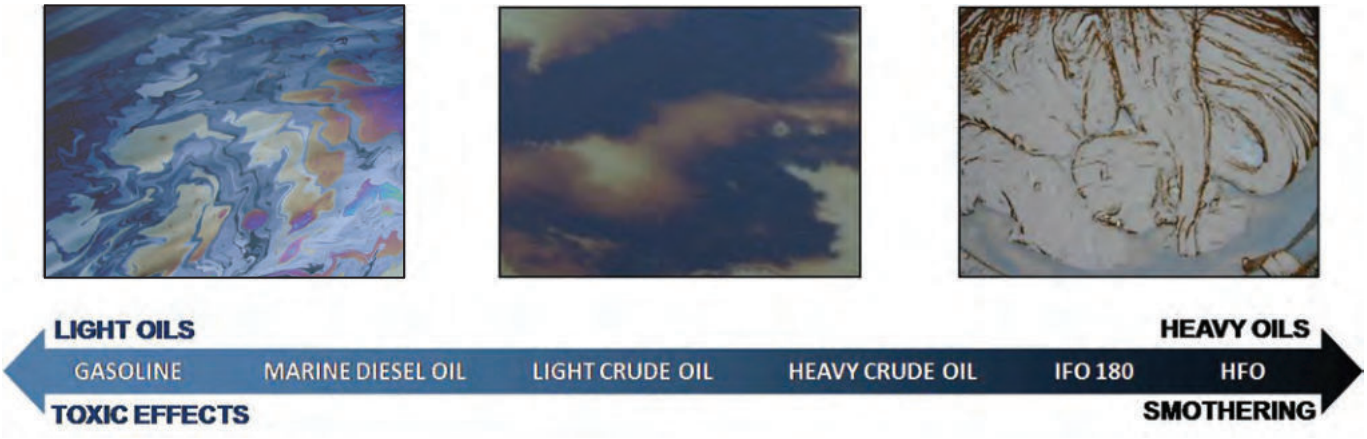

Figure 2: Typical effects on marine organisms range across a spectrum from toxicity (especially for light oils and oil products) to smothering (intermediate and heavy fuel oils (IFO and HFO) and weathered residues).

resources are exposed to elevated concentrations of oil, or its toxic components, for a significant period of time. Of similar importance is the extent to which organisms are vulnerable and sensitive to oil pollution. Vulnerable organisms are those which, because of their positioning in the marine environment, typically at the sea surface or the water's edge, are more likely to come into contact with oil. Sensitive organisms are those that would be acutely affected by exposure to oil or its component chemicals. Less sensitive organisms are more likely to withstand short-term exposure. In a number of countries, shorelines have been mapped and indices attributed to different habitats according to sensitivity. For example, the resultant maps or sensitivity atlases accord mangrove forests or saltmarshes a high index, while sandy beaches generally feature at a low index.

The characteristics of the spilt oil are important in determining the extent of any damage (*Figure 2*). A spill of a large quantity of highly persistent oil, such as a heavy fuel oil (HFO), has the potential to cause widespread damage in the intertidal zones of shorelines through smothering. However, toxic effects are less likely for HFO, or other highly viscous oil that has low water solubility, as the chemical components of the oil have a low biological availability. Oil incorporated within 'asphalt pavement' (a conglomerate of highly weathered oil and shingle) is similarly less bio-available, irrespective of its duration on the shoreline, although indirect damage may occur due to habitat modification.

In contrast, the chemical components of kerosene or other light oils have a higher biological availability and damage through toxicity is more likely. However, rapid dissipation, through evaporation and dispersion, means light oils may be less damaging overall, as long as sensitive resources are sufficiently distant from the spill location. On the other hand, effects can be expected to be greatest and longer lasting in situations where dilution is slowed, such as when the pollutant becomes trapped in muddy sediments or in enclosed areas, for example shallow lagoons with poor water exchange. At exposure levels lower than those sufficient to cause mortality, the presence of toxic components may lead to sub-lethal effects such as impaired feeding or reproduction.

The marine environment is highly complex and natural fluctuations in species composition, abundance and distribution over space and time are a fundamental feature of its normal functioning. Within this environment, marine animals and plants have varying degrees of natural resilience to changes within their habitats. The natural adaptations of organisms to environmental stress, combined with their breeding strategies, provide important mechanisms for coping with the daily and seasonal fluctuations in ambient conditions. This in-built resilience means that some plants and animals are able to withstand a certain level of contamination by oil. Nevertheless, spills are not the only anthropogenic pressure on marine habitats. Widespread over-exploitation of natural resources and chronic urban and industrial pollution also contribute significantly to the degree of variability within marine ecosystems. Against a background of high natural variability, more subtle damage inflicted by an oil spill, such as a downturn in breeding success, productivity or biodiversity, can be difficult to detect.

Recovery of the marine environment

The ability of the marine environment to recover from severe perturbations is a function of its complexity and resilience. Recovery from highly destructive natural phenomena, such as hurricanes and tsunamis, demonstrates how ecosystems can re-establish over time, even after severe disruptions with extensive mortality. While considerable debate exists over the definition of recovery and the point at which an ecosystem can be said to have recovered, there is broad acceptance that natural variability in ecosystems makes a return to the exact pre-spill conditions unlikely. Most definitions of recovery instead focus on the re-establishment of a community of flora and fauna that is characteristic of the habitat and functioning normally in terms of biodiversity and productivity.

This principle can be illustrated by the experience of inappropriate clean-up operations following the loss of the tanker TORREY CANYON off the coast of England in 1967, in which the use of toxic cleaning agents on rocky shorelines led to considerable damage. Although the

detailed distribution of particular species present was altered and the effects of the perturbation could be traced over more than two decades, the overall functioning, biodiversity and productivity of the ecosystem was re-established within one to two years. Under the definition proposed above, the rocky shore community could be said to have recovered within the two year period. Nevertheless, the limitations of this definition can be recognised by considering the age distribution of the component organisms. Instead of the full range of ages prior to the incident, from juveniles to mature organisms, the newly recruited plants and animals fell within a narrow age range and consequently the community was, initially, less robust.

Similarly, if a mangrove stand is damaged, either by the effects of a spill or by natural phenomena, such as a tropical storm, in time, the affected area will be re-colonised by juvenile plants from adjacent areas. However, these replacement plants will all be of a similar age and will not provide the same full complement of environmental services until the trees reach maturity. These observations lead to a distinction between effects and damage, where, in some cases, less significant effects (in terms of the normal functioning of an ecosystem), may still be detected after an ecosystem has recovered from pollution damage.

Recovery mechanisms have evolved to deal with the pressures of predation and other causes of mortality. For example, one of the most important reproductive strategies for marine organisms is broadcast spawning, whereby vast numbers of eggs and larvae are released into the plankton and are widely distributed by currents. In most cases, only a few individuals in a million survive through to adulthood. This high fecundity gives rise to the over-production of young stages, thereby ensuring a considerable reservoir not only for the colonisation of new areas and recruitment into areas affected by the spill, but also for the replacement of individuals lost from the population. In contrast, long-lived species that do not reach sexual maturity for many years, and which produce few offspring, are likely to take longer to recover from the effects of a pollution incident.

In most cases recovery typically takes place within a few seasonal cycles and for most habitats within one to three years, mangroves being a notable exception, as shown in Table 1, below.

Habitat	Recovery period
Plankton	Weeks/months
Sand beaches	1 – 2 years
Exposed rocky shores	1 – 3 years
Sheltered rocky shores	1 – 5 years
Saltmarsh	3 – 5 years
Mangroves	10 years and greater

▲ *Table 1: Indicative recovery periods after oiling, for various habitats. The period is dependent on many factors including the amount and type of oil spilt. Recovery is defined here as the point at which the habitat is functioning normally.*

Marine environments

The following sections consider the different types of damage caused by ship-source oil spills in various environments.

Offshore and coastal waters

Most oils float on the sea surface and are spread over wide areas by waves, wind and currents. Some low viscosity oils may disperse naturally within the top few metres of the water column, particularly in the presence of breaking waves, where they are rapidly diluted. If the release of oil is continuous over time, concentrations of dispersed oil in the upper levels of the water column may be sustained close to the point of release. Notwithstanding this, the impact of spilt oil on species lower in the water column or on the sea bed is low, although damage may arise from sunken wrecks, spills of very heavy (or low °API)* oils or the tarry residues remaining after oil fires.

Plankton

The pelagic zones of seas and oceans support a myriad of simple planktonic organisms, comprising bacteria, plants (phytoplankton) and animals (zooplankton). These include the eggs and larvae of fish and invertebrates, including those which eventually settle on the sea bed or shoreline. Plankton naturally suffer extremely high levels of mortality, primarily through predation, but also through changes in environmental conditions and transport into regions where survival is unsustainable. In contrast, particularly favourable conditions with a plentiful supply of nutrients can lead to plankton blooms whereby populations dramatically increase, notably in spring in temperate climates. Once the input of nutrients subsides or the nutrients are consumed, populations collapse and the dead organisms biodegrade and fall to the sea bed. The ecosystem has evolved to respond to these extremes by copious production within short generation times. As a consequence, plankton typically display extremely patchy distribution both in space and time, ranking them among the most variable of all marine communities.

The sensitivity of planktonic organisms to exposure to oil has been well established and there would appear to be potential for far-reaching impacts. However, the typically massive over-production of young life stages provides a buffer for recruitment from adjacent areas not affected by the spill, sufficient to make up losses of eggs and larval stages, such that significant declines in adult populations following spills have not been observed.

Fish

Despite the susceptibility of juvenile stages of fish to relatively low concentrations of oil in the water column, adult fish are far more resilient and effects on wild stock levels have seldom been detected. Free-swimming fish are thought to actively avoid oil. In exceptional circumstances depletion of the year class for a particular species has been recorded but mass

** American Petroleum Institute gravity.*

Figure 3: Corralling oiled African penguins (Spheniscus demersus).

Figure 4: Penguins benefit more than other bird species from cleaning. Here, rockhopper penguins (Eudyptes moseleyi) are rehabilitated.

mortalities are rare. Mortalities that have occurred have been associated with very high, localised concentrations of dispersed oil in the water column in storm conditions, with the release of substantial quantities of light oils into breaking surf along a shoreline, or with spills in rivers. The impact of oil spills on exploited fish stocks and cultivated marine products is considered in greater detail in the separate ITOPF paper on the Effects of Oil Pollution on Fisheries and Mariculture.

Seabirds

Seabirds are the most vulnerable open water creatures and in major incidents large numbers may perish. Sea ducks, auks and other species which raft together in flocks on the sea surface are particularly at risk. However, significant mortality in seabird populations can also arise from unrelated causes, such as storms or loss of a food source or habitat. Post-mortem studies may be required to identify the cause of death and whether this can be attributed to a particular incident.

Fouling of plumage is the most obvious effect of oil on birds. The plumage acts to trap warm air against the skin, providing both buoyancy and insulation. When oiled, the delicate structure of the protective layer of feathers and insulating down is disrupted, allowing seawater to come into direct contact with the skin, resulting in loss of body heat and the bird may ultimately succumb to hypothermia. In cold climates, a small oil spot on a bird's plumage may be sufficient to cause mortality. In many species, a layer of fat beneath the bird's skin acts both as a further insulating layer and as an energy reserve. This reserve may be rapidly consumed as the bird attempts to keep itself warm. A bird that is suffering from cold, exhaustion and a loss of buoyancy may drown. Furthermore, oiled plumage reduces the bird's ability to take off and fly in search of food or to escape predators.

Once oiled, a bird's natural instinct is to clean itself by preening which may spread the oil over otherwise clean areas of its body. Oil is very likely to be ingested which can have serious effects, such as congested lungs, intestinal or lung haemorrhages, pneumonia and liver and kidney damage. On return to the nest, oil can be transferred from a bird's plumage to that of its live young or to hatching eggs. Oil contamination of eggs can lead to eggshell thinning, the failure of the egg to hatch and developmental abnormalities.

There is no clear link between the quantity of oil spilt and the likely impact on seabirds. A small spill during the breeding season, or where large populations of seabirds have congregated, can prove more harmful than a larger spill at a different time of year or in another environment. Some species respond to colony depletion by laying more eggs, breeding more frequently or by younger birds joining the breeding group earlier. These processes can assist recovery, although recovery may take several years and also depends on food supply, habitat availability and other factors. While it is common for short and medium term losses to be recorded, the above recovery mechanisms may successfully prevent long-term impacts at a population level. However, in some circumstances there may be a risk that an oil spill could tip a marginal colony into permanent decline.

Cleaning and rehabilitation of oiled birds may be attempted, but for many species typically only a small fraction of treated birds survive the cleaning process. An even smaller proportion of those birds that are released tend to survive in the wild and breed successfully. Penguins are often an exception and are generally more resilient than many other species. When handled properly, the majority are likely to survive cleaning and rejoin breeding populations (*Figures 3 and 4*). Even for penguins it has been found that the breeding success of birds that have been cleaned is less than for those that escaped oiling altogether. Nevertheless, the development and promulgation of bird cleaning best practice is helping to improve outcomes.

Marine mammals and reptiles

Whales, dolphins and other cetaceans may be at risk from floating oil when surfacing to breathe or breach. Harm to nasal tissue and eyes from oil has been postulated. However, where mortalities have been recorded, necropsies have generally concluded death resulted from causes other

Figure 5: Oil can adversely affect the ability of mammals, such as this seal pup (Arctocephalus australis), to maintain vital physiological functions.

Figure 6: A juvenile hawksbill turtle (Eretmochelys imbricate) being cleaned (Image courtesy USCG).

than oil. While large tropical marine mammals, such as the herbivorous sirenians (manatees and dugongs), might also be expected to be vulnerable, reports of oil pollution damage to these animals are very rare. However, seals, otters and other marine mammals that haul-out or spend time onshore are more likely to encounter and suffer from the effects of oil. Species that rely on fur to regulate their body temperature are the most vulnerable to oil as the animals may die from hypothermia or overheating, depending on the season, if the fur becomes matted with oil (*Figure 5*).

Floating oil may be a threat to marine reptiles, such as turtles, marine iguanas and sea snakes. Turtles in particular are vulnerable during the nesting season. Loss of eggs and hatchlings may occur if oil strands on sand beaches or if nests are disrupted during clean-up operations. Adults can suffer mucus membrane inflammation increasing susceptibility to infection. However, there are many cases where oiled turtles have been successfully cleaned and returned to the sea (*Figure 6*). All species of sea turtle are endangered or threatened through human activities principally due to inadvertent fishing bycatch, deliberate targeting for food and shells and loss of habitat.

Shallow inshore waters

Damage in shallow waters is most often caused by oil becoming mixed into the water column by strong wave action or by the inappropriate use of dispersants too close to the shore. In many circumstances the dilution capacity, for example due to tidal flushing, is sufficient to keep concentrations of oil in the water below harmful levels. On the other hand, where light refined products or light crude oils have become dispersed into shallow water leading to high concentrations of the toxic components of oil, mortality of bottom-dwelling (benthic) animals and those living in the sediment has occurred.

Seagrass

Different species of seagrass are found in temperate and tropical waters. They support a highly diverse and productive ecosystem, sheltering many other organisms. Beds of seagrass reduce water currents, thereby increasing sedimentation, while the root structures stabilise the seabed, protecting coastal zones from erosion. Floating oil is most likely to pass over seagrass beds with no ill effects. However, if oil or its toxic components become mixed into these shallow inshore waters at sufficiently high concentrations, seagrass and associated organisms may be impacted. Clean-up operations in the vicinity of seagrass should be undertaken with care, as the plants can be torn or pulled out by vessel propellers and boom anchors.

Corals

Coral reefs provide an extremely rich and diverse marine ecosystem, are highly productive and offer coastal protection to otherwise exposed shorelines. Corals are highly sensitive organisms that can take a long time to recover from oiling. Dispersed oil presents the greatest risk of damage to coral reefs. This risk is highest where increased turbulence from breaking waves encourages natural dispersion of spilt oil and where dispersants are used. In addition to the coral themselves, the communities which the habitat supports are also sensitive to oil. Consequently, dispersants should not be used in the vicinity of coral reefs. On rare occasions, coral reefs may dry out at spring tides, presenting a risk of smothering from floating oil.

Vessel groundings present a more prevalent source of damage to coral reefs than oil pollution. Other anthropogenic impacts can also induce stress in corals, for example, overfishing or destructive fishing practices, nutrient pollution and increased sedimentation due to deforestation and coastal construction projects.

Shorelines

Shorelines are exposed to the effects of oil more than any other part of the marine environment. However, much of the flora and fauna on the shore are inherently resilient, since they must be able to tolerate the tidal cycle as well as periodic exposure to pounding waves, drying winds, extremes of temperature, variations in salinity through rainfall and other severe stresses. This tolerance also gives many

shoreline organisms the ability to withstand and recover from spill effects.

Rocky and sandy shores

Exposure to the scouring effects of wave action and tidal currents means that rocky and sandy shores are the most resilient to the effects of a spill (*Figure 7*). This scouring also usually enables natural and rapid self cleaning to take place. A typical example of an impact on rocky shores in temperate climates is the temporary loss of the common limpet (*Patella vulgata*), a keystone species of marine snail. 'Keystone' species are plants or animals that exert a controlling influence on the ecosystem that is disproportionate to their biomass, and their removal is likely to lead to a dramatic change to that ecosystem. Limpets grazing on micro-algae on rock surfaces limit algal growth and settlement of other fauna. Their loss typically leads to a rapid growth of opportunistic green algae (*Figure 7 inset*). Over time this algal growth is displaced by other algal species and as space becomes available for limpets to re-colonise the rock surface, the ecological balance is gradually restored. On tropical and sub-tropical sandy shores, ghost crabs (*Ocypode sp.*) occupy a similar environmental niche as limpets and high mortality rates are a common feature of shoreline oiling. Despite this, within weeks of shorelines becoming clean, the crabs often re-colonise the beaches in similar numbers as before.

Soft sediment shores

Fine sands and mud are found in areas sheltered from wave action, including estuaries, and tend to be highly biologically productive (*Figure 8*). They often support large populations of migrating birds and indigenous sediment dwelling invertebrates, including bivalves, and are also nursery areas for some species.

While fine sediments are not as readily impacted as other substrates, oil can become incorporated through flocculation with sediment stirred up by storm activity or penetration through worm burrows and open plant stems. Pollutants that do penetrate fine sediments can persist for many years, increasing the likelihood of longer-term effects.

Saltmarshes

The upper fringe of soft sediment shores is often dominated by saltmarsh vegetation comprising woody perennials, succulent annuals and grasses. Saltmarshes are usually associated with temperate climates but occur throughout the world, from sub-polar regions to the tropics. On tropical shores, saltmarshes are often associated with mangroves, occupying the upper and lower intertidal zones respectively. Species composition is determined to a large extent by salinity. For example, in low salinity or brackish waters found in the upper reaches of estuaries, marsh vegetation gives way to reed beds. Plant detritus carried away from marshes also contributes to food webs in estuaries and nearshore waters. Many saltmarshes have been attributed special conservation status under the Ramsar Convention on Wetlands of International Importance, due to their importance as habitats for birds, especially migratory species.

Figure 7: Rocky shorelines are commonly exposed to wind and waves and may rapidly self-clean. Biota including limpets may be affected by oil. Significant mortality may result in the subsequent abundance of opportunistic flora (algae and seaweed) that would otherwise be kept under control through grazing. Over time, species re-establish and equilibrium will be restored.

Figure 8: Soft sediments are often found along sheltered, less dynamic shorelines and are usually highly biologically productive. Leaving an oiled marsh to clean naturally should be considered, as clean-up operations have the potential to extend and aggravate the damage. Oil penetrating into the substrate, as shown in the cross-section sample, can remain for years.

The impact of an oil spill on saltmarshes depends on the time of year relative to periods of plant growth. Temperate or cold region marshes are dormant during winter months, while in the Mediterranean growth is slow during high summer temperatures. A single event is unlikely to cause more than temporary effects but longer term damage, possibly over several years, can be inflicted by repeated, chronic oiling or by aggressive clean-up activity, such as trampling, the use of heavy equipment or removal of contaminated substrate. Cleaning of a saltmarsh is difficult without risking additional damage and so it is frequently recommended to leave marshes to clean naturally. However, if burning or cutting vegetation is to be contemplated, this is best done after the vegetation has died back. In general, as long as the roots or bulbs of the plants are not harmed by serious oiling or excessive compaction during the clean-up, seasonal re-growth may be expected to follow.

Mangroves

Mangroves are salt-tolerant trees and shrubs growing at the margins of sheltered tropical and sub-tropical waters. Mangrove stands provide a valuable habitat for crabs, oysters and other invertebrates as well as important nursery areas for fish and shrimp. In addition, the complex root structure traps and stabilises sediment, thus reducing erosion of coastlines and minimising deposition of terrestrial sediments on adjacent seagrass beds and coral reefs.

Their location means that mangroves are highly vulnerable to oil spills. Mangroves are also considered to be extremely sensitive to contamination by oil, dependent to a large extent on the substrate in which the mangroves are growing. Mangroves typically grow in dense muddy anaerobic sediments and rely on oxygen supplied through small pores (lenticels) on aerial roots (*Figure 9*). Heavy oil inundation of the root systems may block this oxygen supply and may cause the mangroves to die. However, in open aerated sediments, which allow relatively free water exchange, the root systems draw oxygen from seawater and so have a higher tolerance to smothering by oil. In the second mechanism, the toxic components of oil, notably in light refined products, interfere with the plants' systems for maintaining the salt balance, thereby affecting their ability to tolerate salt water. Experience has indicated that loss of mangroves due to heavy oil smothering appears to be less likely than mortality due to inundation with lighter products, including some cleaning agents, which can result in localised loss of tree cover.

Organisms living within the mangrove ecosystem can be impacted both by direct effects of the oil and also the longer term loss of habitat. Natural recovery of the complex mangrove ecosystem can take a long time and reinstatement measures may have real potential to accelerate the recovery process in such habitats.

Long term damage

An effective clean-up operation usually includes removal of bulk oil contamination, reducing the geographical extent and duration of pollution damage, and allowing natural recovery to commence. However, aggressive clean-up methods can

Figure 9: Mangroves are highly vulnerable to oil. Coating of stilt roots or pneumatophores (breathing structures growing vertically through the substrate) can cause blockage of the lenticels (pores) preventing the exchange of gases and leading to asphyxiation.

cause additional damage and natural cleaning processes may be preferable. Over time, several factors reduce the toxicity of oil so that the contaminated substrate can support new growth (*Figure 10*). For example, oil can be flushed away by rain and tides and as the oil weathers the volatile fractions evaporate, leaving less toxic residual oil.

As the marine environment has such a strong capacity for natural recovery, the impact of an oil spill is usually localised and transitory and there are few documented examples of long term damage. However, under certain specific circumstances, damage may be persistent and impairment of an ecosystem longer-lasting than might typically be expected. The circumstances that tend to lead to acute long term damage are associated with the persistence of oil, particularly where oil has become trapped within the sediment and is protected from normal weathering processes. Examples include sheltered habitats, such as marshes, shingle shorelines and nearshore waters, especially when an oil spill coincides with storm conditions. A storm surge inundating a marsh, with the associated turbulent conditions, is likely to bring fine sediments into suspension and into contact with naturally dispersed oil. Once the storm abates, the oil incorporated within the sediment settles to the marsh floor. Similar circumstances result in oil being incorporated into fine sediments and settling in nearshore waters. In both situations, anaerobic conditions slow any degradation of the oil. On shingle shorelines, the weathering of the mixture of oil and shingle can result in the formation of an asphalt pavement, which may persist for some time. Oil products that are more dense than seawater, such as very heavy oils or fire residues, fall to the seabed where they can remain undisturbed for indeterminate periods and may result in localised smothering of benthic organisms.

Post-spill studies

Research into the effects of oil pollution has followed almost every major incident since the loss of TORREY CANYON. As a result, a very substantial body of knowledge now exists on the likely environmental effects of a spill. Given this level of knowledge it is therefore neither necessary nor appropriate to consider post-spill studies after every spill. However, in order to determine the specific extent, nature and duration of the impact arising from the particular circumstances of an incident, post–spill studies may sometimes be necessary. Since the effects of oil pollution are, for the most part, well understood and predictable, it is important that studies focus on quantification of conspicuous damage rather than attempting to investigate a wide array of hypothetical impacts. The variability exhibited by the marine environment means that the study of an extensive range of potential impacts are very likely to lead to inconclusive results.

The techniques available for chemical analysis of pollutants are continually evolving. Concentrations of the potentially toxic components of oil can now be measured down to levels of parts per trillion (ppt, ng/kg, 1 x 10^{-12}). One of the most important objectives of damage assessment studies is to establish both a pathway for the observed damage and the qualitative identification of the particular oil contaminant responsible, particularly in chronically polluted environments. This is usually done by Gas Chromatography linked to Mass Spectrometry (GC-MS) analysis.

Figure 10a: Intrusive clean-up of the marsh has caused additional damage over and above that caused by the oil.

Figure 10b: The cleaned marsh after seven weeks with signs of new growth apparent.

Figure 10c: After 22 months, the marsh has full ground cover, albeit with opportunistic species.

Figure 10d: After three years, the marsh has returned to full species diversity.

▲ *Figure 10: Natural recovery of a damaged marsh.*

Biomarkers are routinely used to screen animals for exposure to the polycyclic aromatic hydrocarbons (PAH) found in crude oil and oil products. For example, measurement of EROD (Ethoxyresorufin-O-deethylase) activity detects enzyme levels in liver tissue, involved both in the metabolism and elimination of toxins and also in the development of cancerous tumours. This technique is sufficiently sensitive to indicate exposure to PAH without detectable body burden and so can provide an early warning of potential damage. However, changes in the levels of activity of this enzyme are also indicative of other causes of stress, such as the presence of other similar toxic materials unrelated to oil. Activity levels also reflect the age and reproductive status of the animal, as well as changes in temperature. It is important, therefore, that such studies take account of these potentially confusing factors.

Studies may be prioritised according to a number of factors. Firstly, the baseline against which effects are to be established: whether by reference to pre-spill data, where this exists; by comparison with equivalent species, communities or ecosystems at reference sites outside the affected area; or by monitoring the recovery of a feature of conspicuous damage, such as the mortality of seabirds or shell fish. Plankton provides a poor subject for investigation. Although both laboratory and field studies have demonstrated mortality and sub-lethal effects upon exposure to oil, variability of the plankton is so high that comparisons between pre- and post-spill situations are likely to be unreliable. Other factors to be considered include the geographical extent of the affected area, the degree of contamination and related levels of exposure (concentration and duration) and the importance of the affected resource, i.e. its rarity or ecological function. Finally, the practical feasibility of conducting the studies should be considered. Feasibility may relate to financial support or simply the practicality of accessing study sites or the risk of disruption to the site during the period of study. Further guidance on designing and conducting post-spill studies can be found in the separate paper on Sampling and Monitoring of Marine Oil Spills.

Restoration, reinstatement and remediation

Restoration, also known as reinstatement or remediation, is the process by which measures are taken to restore the damaged environment to conditions where it is functioning normally more quickly than might be expected from natural recovery processes alone. The terms are often used interchangeably in the context of environmental damage. However, in comparing environmental law in the United States and European Union with the international regime of the 1992 Civil Liability and Fund Conventions (CLC & FC), the interpretation of the terms can be different. Guidance provided by the 1992 Fund Claims Manual** indicates that within the international regime, **reinstatement** measures should have a realistic chance of significantly accelerating natural recovery without adverse consequences for other natural or economic resources. The measures should also be in proportion to the extent and duration of the damage and

*** http://www.iopcfund.org/publications.htm*

the benefits likely to be achieved. Damage is considered as the impairment of the marine environment, where impairment in this context can be described as the abnormal functioning or absence of organisms within a biological community, caused by the spill.

The US regulations promulgated under the 1990 Oil Pollution Act (OPA '90) also acknowledge natural recovery as a key mechanism for **restoration** but introduce two concepts: primary and compensatory restoration. Compensatory restoration is intended to compensate for environmental services 'lost' during the period that the environment is undergoing recovery, whereas primary restoration refers to actions taken to restore or accelerate recovery and is equivalent to reinstatement under the international regime. The 2004 EU Environmental Liability Directive (ELD) also includes these concepts in terms of **remediation**. However, the international regime does not recognise the concept of compensatory restoration or remediation.

Figure 11: An area of mangrove, created from planting individual seedlings in a grid pattern.

Following a clean-up operation, further active steps may be justified to restore damaged resources and encourage natural recovery, especially in circumstances where recovery would otherwise be relatively slow. An example of such an approach following an oil spill would be the replanting of saltmarsh or mangrove plants (*Figure 11*). Once the new growth has become established other forms of biological life return and the potential for erosion of the area is minimised.

Designing meaningful reinstatement strategies for fauna is a much greater challenge. Damaged habitats may be protected and recovery of ecosystems may be enhanced, for example, by restricting access and human activity, by placing controls on fishing to reduce competition for a limited food source, as is the case with sand eels and puffins, or by closing beaches used by turtles during the nesting season. In some cases, protection of a natural breeding population at a nearby, un-oiled site may be warranted, for example by predator control, to provide a reservoir from which re-colonisation of the damaged areas can occur. However, many complex biological, ecological and environmental factors are likely to govern the ability of adjacent populations to re-colonise a polluted area.

In reality, the complexity of the marine environment means that there are limits to the extent to which ecological damage can be repaired artificially. In most cases natural recovery is likely to be relatively rapid and will only rarely be outpaced by reinstatement measures.

Key points

- A wide range of highly complex ecosystems exist within the marine environment and substantial fluctuations in abundance and diversity occur as a feature of their normal functioning.
- The marine environment has a strong capacity for natural recovery from severe perturbations caused by natural phenomena as well as oil spills.
- The key mechanisms for environmental damage from oil spills are smothering and toxicity but the severity of the damage depends very much on the type of oil spilt and how quickly it dissipates relative to the location of resources sensitive to oil pollution.
- The most vulnerable organisms are those found on the sea surface or shorelines.
- Saltmarshes and mangroves are the most sensitive shoreline habitats.
- Seabirds are particularly at risk. Some species, and penguins in particular, respond well to cleaning, however, others may not survive for long when released back into the wild after cleaning or may have difficulty breeding successfully.
- Although short-term impacts can be severe, lasting damage is unusual even following the largest incidents. Where observed, long term damage has been restricted to geographically discrete areas where conditions have permitted accumulations of oil to persist.
- Effective planning and execution of response operations both mitigate damage and provide the first step to recovery by the removal of oil.
- Well designed reinstatement measures may sometimes enhance natural recovery processes.

TECHNICAL INFORMATION PAPERS

1 Aerial Observation of Marine Oil Spills
2 Fate of Marine Oil Spills
3 Use of Booms in Oil Pollution Response
4 Use of Dispersants to Treat Oil Spills
5 Use of Skimmers in Oil Pollution Response
6 Recognition of Oil on Shorelines
7 Clean-up of Oil from Shorelines
8 Use of Sorbent Materials in Oil Spill Response
9 Disposal of Oil and Debris
10 Leadership, Command & Management of Oil Spills
11 Effects of Oil Pollution on Fisheries and Mariculture
12 Effects of Oil Pollution on Social and Economic Activities
13 Effects of Oil Pollution on the Environment
14 Sampling and Monitoring of Marine Oil Spills
15 Preparation and Submission of Claims from Oil Pollution
16 Contingency Planning for Marine Oil Spills
17 Response to Marine Chemical Incidents

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