IPIECA REPORT SERIES

VOLUME ONE

GUIDELINES ON BIOLOGICAL IMPACTS OF OIL POLLUTION

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PREFACE

This report is one of a new series commissioned by the International Petroleum Industry Environmental Conservation Association (IPIECA). The full series of reports will represent the IPIECA members' collective contribution to the global discussion on oil spill preparedness and response, initiated by major oil spill incidents during 1989/90.

In preparing these reports—which will represent a consensus of membership views—IPIECA has been guided by a set of principles which it would encourage every organization associated with the transportation of oil products at sea to consider when managing any operations related to the transportation, handling and storage of petroleum and petroleum products:

- It is of paramount importance to concentrate on preventing spills.
- Despite the best efforts of individual organizations, spills will continue to occur and will affect the local environment.
- Response to spills should seek to minimize the severity of the environmental damage and to hasten the recovery of any damaged ecosystem.
- The response should always seek to complement and make use of natural forces to the fullest extent practicable.

In practical terms, this requires that operating procedures for transportation, storage and handling of petroleum and petroleum products should stress the high priority managements give to preventative controls to avoid spillages. Recognizing the inevitability of future spills, management responsibilities should also give high priority to developing contingency plans that will ensure prompt response to mitigate the adverse effect of any spills. These plans should be sufficiently flexible to provide a response appropriate to the nature of the operation, the size of the spill, local geography and climate. The plans should be supported by established human resources, maintained to a high degree of readiness in terms of personnel and supporting equipment. Drills and exercises are required to train personnel in all spill management and mitigation techniques, and to provide the means of testing contingency plans which, for greatest effect, are carried out in conjunction with representatives from the public and private sectors.

The potential efficiencies of cooperative and joint venture arrangements between companies and contracted third parties for oil spill response should be recognized. Periodic reviews and assessments of such facilities are encouraged to ensure maintenance of capability and efficiency standards.

Close cooperation between industry and national administrations in contingency planning will ensure the maximum degree of coordination and understanding between industry and government plans. This cooperative effort should include endeavours to support administrations' environmental conservation measures in the areas of industry operations.

Accepting that the media and the public at large have a direct interest in the conduct of oil industry operations, particularly in relation to oil spills, it is important to work constructively with the media and directly with the public to allay their fears. Reassurance that response to incidents will be swift and thorough—within the anticipated limitations of any defined response capability—is also desirable.

It is important that clean-up measures are conducted using techniques, including those for waste disposal, which minimize ecological and public amenity damage. Expanded research is accepted as an important component of managements' contribution to oil spill response, especially in relation to prevention, containment and mitigation methods, including mechanical and chemical means.

INTRODUCTION

Oil spills continue to hit the headlines. The shock of the initial impact and mess of a spill generates legitimate public concern about various aspects of damage and recovery. However, anyone dealing with the aftermath of a spill can draw upon case history and experimental information which has been accumulating ever since the Torrey Canyon accident in 1967.

The aim of these guidelines is to summarize what this experience tells us about the short- and long-term biological effects of oil pollution. The guidelines are intended to help anyone facing questions about damage assessment, the prediction of possible long-term effects, or clean-up.

The scope is global, with examples from tropical, temperate and cold environments. The emphasis is marine, but some reference is made to other environments. Recommendations for further reading are given—these are books or review papers with their own detailed reference lists.

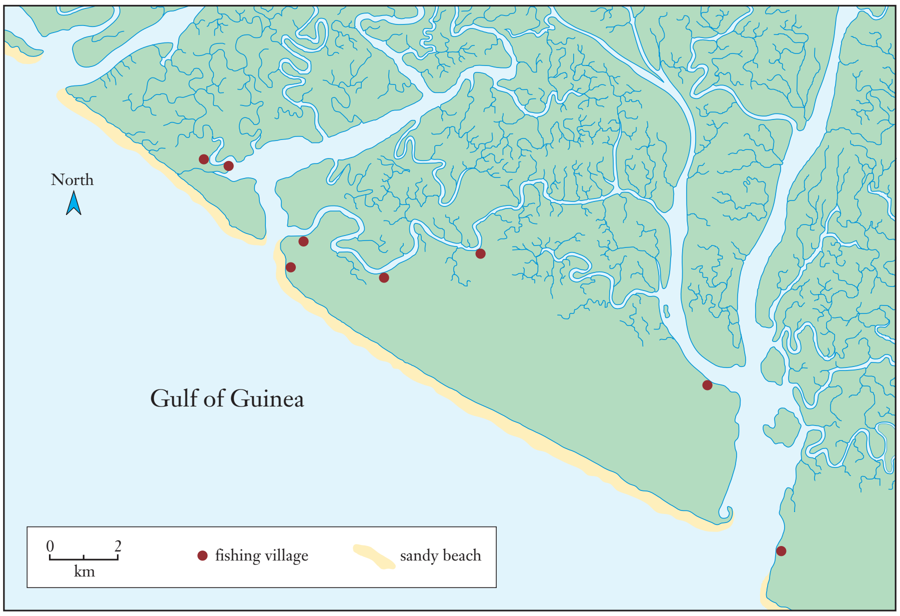
Jenifer M Baker

Jenifer M Baker

OIL POLLUTION DAMAGE AND BIOLOGICAL CONCERNS

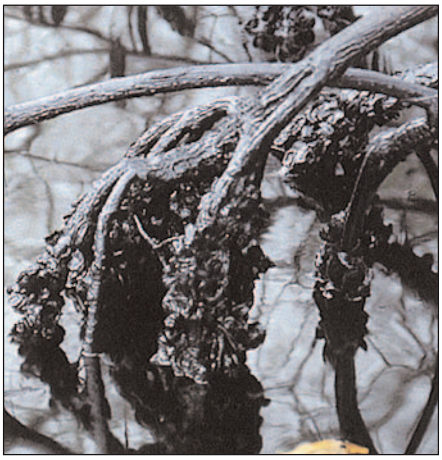
The initial impact can vary from minimal (e.g., following some open ocean spills) to the death of everything in a particular biological community. A mangrove swamp which has trapped crude oil, leading to death of the mangrove trees and associated fauna, can present a particularly bleak picture.

Right: A small part of the extensive mangrove swamps of the Niger Delta. The intricate sheltered creek systems can act as an oil trap, with potentially serious effects on the mangrove trees.



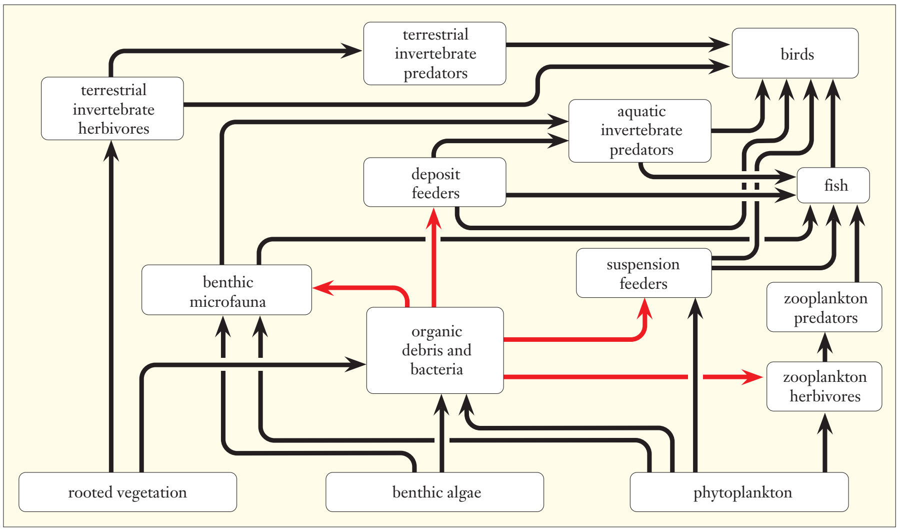
Recovery times following spills can vary from a few days to more than 10 years. There is no clear-cut correlation between size of spill and extent of damage, but a number of other factors are important in influencing degree of damage and recovery times.

Right: This is all that remains of a mangrove forest which has been completely destroyed by oil.
Far right: Smothered with oil, these oysters clinging to the mangrove roots are dying.



THE IMPORTANCE OF COASTAL WETLANDS AND SHALLOWS

The *World Conservation Strategy* (IUCN/UNEP/WWF 1980) highlights the importance of the coastal wetlands and shallows into which oil slicks may drift. These areas '—especially estuaries and mangrove swamps—provide food and shelter for waterfowl and for fishes, crustaceans and molluscs utilized by an



Left: Food relationships in a typical estuary.

estimated two-thirds of the world's fisheries. Some are among the world's most lucrative fisheries, notably those for shrimp. Seagrass meadows also act as nurseries and nutrient suppliers for economically important fish species. Coral ecosystems are of more local, but nonetheless vital, significance—providing habitats for the fish on which many coastal communities in developing countries depend'.

Below left: Mangrove oysters in West Africa.
Below middle: Sea grass and kelp, Ireland.
Below right: A fish trap on the edge of Indonesian mangroves.

FACTORS INFLUENCING IMPACT AND RECOVERY

Above: Beach rye-grass growing in the presence of weathered, residual oil (Prince William Sound, Alaska)

Oil type

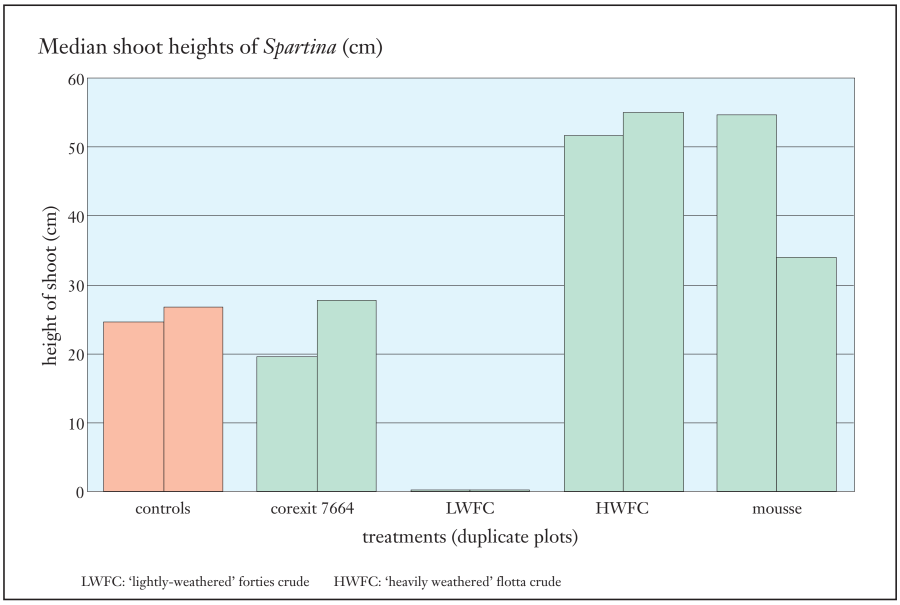
Both crude oils and products differ widely in toxicity. Experiments on plants and animals have shown that severe toxic effects are associated with compounds with low boiling points, particularly aromatics. The greatest toxic damage has been caused by spills of lighter oil, particularly when confined in a small area.

Spills of heavy oils, such as some crudes and Bunker C fuel oil, may blanket areas of shore and kill organisms mainly through smothering (which is a physical effect) rather than through acute toxic effects.

Oil toxicity is reduced as the oil weathers. Thus a crude oil spill which reaches a shore quickly will be more toxic to the shore life than if the slick has been weathering at sea for several days before stranding.

Oil from the Exxon Valdez spill in Alaska was relatively well weathered by the time it reached most shores. In the photo above, beach rye grass in Prince William Sound is recovering in the presence of residual oil, indicating its low toxicity. In some cases, such as the experiment detailed on the next page, weathered or heavy oils have even caused growth stimulation.

Right: The herbicidal effect of a light fuel oil spilt in a canal.



Left: The effects of experimental oil and dispersant treatments (duplicate plots) on shoot heights of the common salt marsh grass Spartina anglica. The measurements shown were taken four months after treatment. 'Lightly weathered' Forties crude (topped until no dodecane remained) killed most of the grass shoots. 'Heavily weathered' Flotta crude (ex-refinery residue, n-C = 20+) stimulated growth. Mousse (from the Christos Bitas spill) produced variable results with some growth stimulation. Dilute Corexit 7664 dispersant did not affect the grass growth.

Oil loading

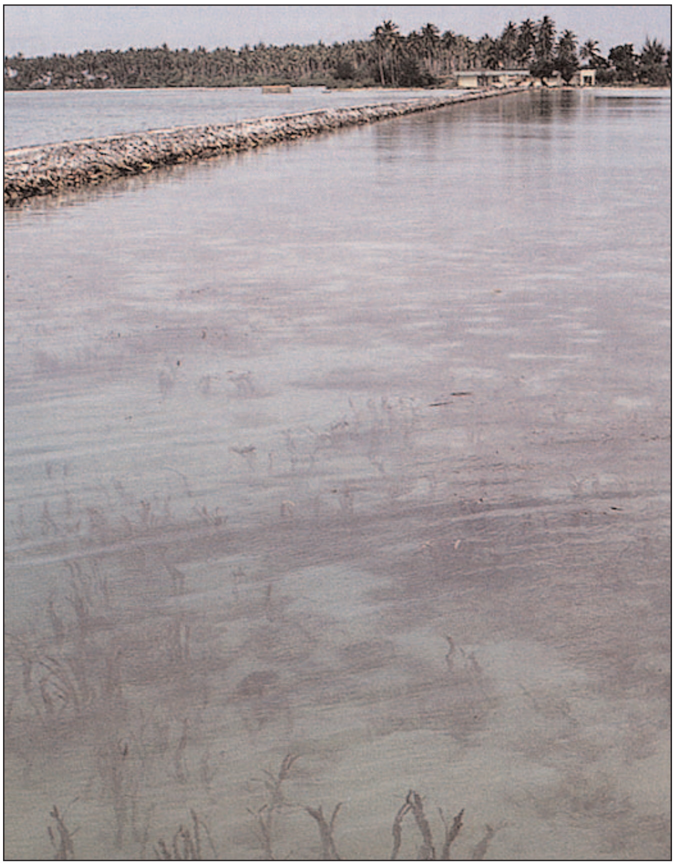
If oil loading is high, penetration into some sediments may be enhanced, and there is a greater likelihood of oil masses incorporating stones and gravel and hardening to form relatively persistent asphalt pavements. These are commonly 5–10 cm thick and 1–30 m wide; they persist longest on the upper shore where they can constitute a physical barrier which restricts recolonization, e.g., by plants such as grasses and shrubs. Following a spill, removal of bulk oil by clean-up teams can speed up recovery in some cases, by minimizing smothering effects and the chances of asphalt pavement formation.

The Metula and the Exxon Valdez oil spills provide an interesting comparison. Both were crude oil spills in cold water environments (the Straits of Magellan and Prince William Sound, respectively). In both cases large volumes of oil (particularly in the form of mousse) landed on a range of shore types. There was no clean-up in the case of the Metula, and a massive clean-up effort to remove bulk oil in the case of the Exxon Valdez. In the Straits of Magellan, mousse masses with sand, gravel and stones ('moussecrete') hardened into asphalt pavements, exceptionally up to 400 m wide. Subsequently these gradually eroded but remnants remain 16 years after the spill. In Prince William Sound and the Gulf of Alaska, asphalt pavement formation was largely averted.

Below: Oil masses, often incorporating stones and gravel, harden to form persistent asphalt pavement.

Geographical factors

In the open sea there is scope for oil slicks to disperse, and some large spills (e.g., the Argo Merchant and the Ekofisk Bravo blowout) have caused minimal ecological damage for this reason. Close to shore, damage is likely to be more pronounced in sheltered shallow water bays and inlets, where oil in the water may reach higher concentrations than in the open sea. This is also likely to be true of inland lakes and some riverine systems.



Above: Productive shallow sea, Java.

On the shore itself there is a range of possibilities concerning the fate and effects of oil. These are bound up with two important variables: the energy level of the shore (degree of exposure to wave energy), and substratum type. On exposed rocky shores, effects on shore life tend to be minimal and recovery rates rapid because oil does not stick easily to such shores. Even if some does, it is likely to be quickly cleaned off by vigorous wave action. With increasing shelter of rocky shores, the likelihood of oil persisting increases, as does the algal biomass with its capacity to trap oil. The most sheltered shores tend to be sedimentary, with mud flats, marshes, and (in the tropics) mangroves. Such vegetated areas have a high biological productivity but are also the worst oil traps, and are therefore of particular concern following spills.

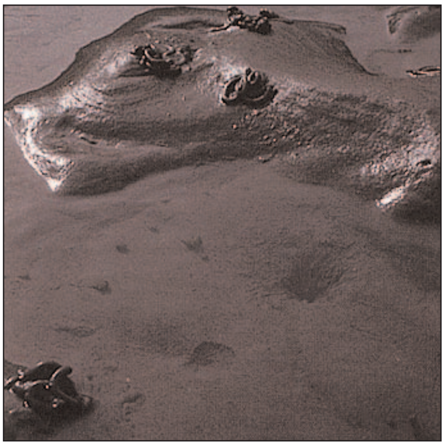
The general relationship between shore energy levels and biological recovery times is shown in the figure on the next page, which draws upon a number of reports in the scientific literature. Recovery times tend to be longer for more sheltered areas because of oil persistence, but the correlation is not always straightforward because other variables (such as oil type) are also involved.

If oil penetrates into the substratum, residence times are likely to be increased. The extent to which this can happen varies with substratum type. Shores over a range of energy levels with freely draining sand, gravel or stones are porous, and oil penetrates relatively easily. If it then becomes adsorbed onto the large surface area of the sub-surface grains, and weathers *in situ* to become more viscous, it may remain in the sediment for many years. In contrast, oil does not readily penetrate into firm waterlogged fine sand or mud—it tends to wash off with subsequent tidal

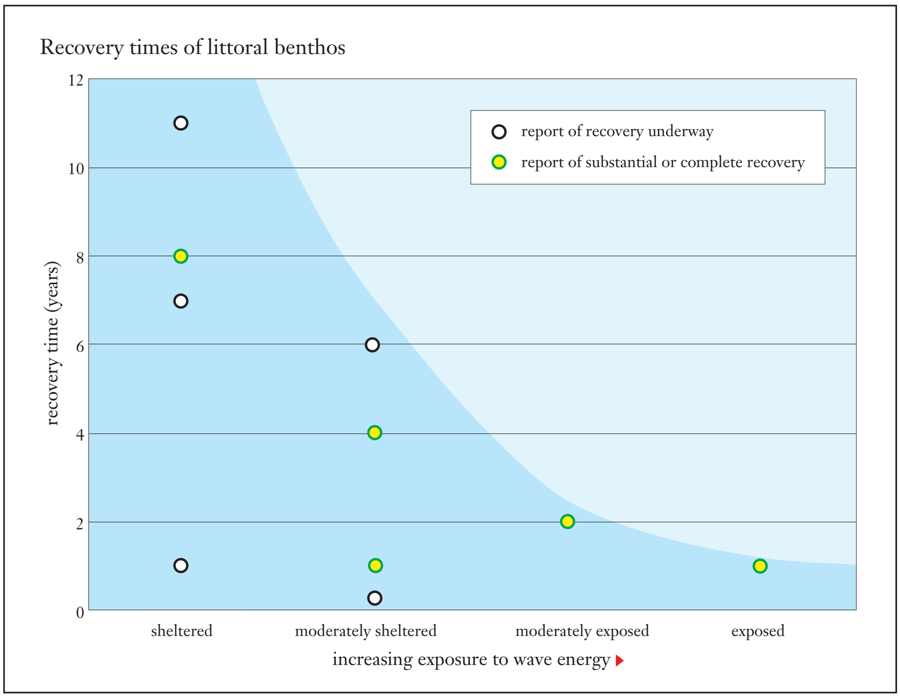
Right: Riverine forest, Amazonia.

Left: Natural cleaning on a rocky shore of moderate exposure. The time interval between the two photographs is four years.

immersions. However, the picture may be very different on sheltered sand and mud shores with high biological productivity. Oil pathways are provided by the burrows of worms, molluscs and crustaceans, and the stems and root systems of marsh plants. Under normal conditions, these pathways allow the penetration of oxygen into sediments that would otherwise be anaerobic. A possible problem following oiling is that there is sub-surface penetration of the oil, followed by death of the organisms that normally maintain the pathways. The pathways then collapse, e.g., burrows become filled in with sediment from the top if they are not actively maintained. Thus oil can be trapped in anaerobic sediment, where its degradation rate will be very low, and organisms trying to recolonize may encounter toxic hydrocarbons. In these conditions, oil-tolerant opportunistic species are favoured.



Top: Lugworm burrows and casts.
Above: Oil penetration down a marsh grass stem.



Left: Biological recovery depends on exposure to wave energy—but other variables, such as oil type, are also involved.

Climate, weather and season

High temperatures and wind speeds increase evaporation, which leads to a decrease in toxicity of oil remaining on the water. Temperature affects the viscosity of the oil (and so the ease with which it can be dispersed, and with which it can penetrate into sediments). Temperature, together with oxygen and nutrients supply, determines the rate of microbial degradation which is the ultimate fate of oil in the environment.

According to season, vulnerable groups of birds or mammals may be congregated (perhaps with young ones) at breeding colonies, and fish may be spawning in shallow nearshore waters. Winter months may see large groups of migratory waders feeding in estuaries. Winter oiling of a salt marsh can affect over-wintering seeds and reduce germination in the spring. Marked reduction of flowering can occur if plants are oiled when the flower buds are developing; even though there may be good vegetative recovery, there is loss of seed production for that year.

Biological factors

Different species have different sensitivities. For example, many algae (seaweeds) are quite tolerant, possibly because of their mucilage coatings and the frequency of tidal washings. In contrast, mangrove trees are very sensitive. Comments on the main groups of plants and animals are given below.

Group	Comments
Mammals	It has been rare for whales, dolphins, seals and sea lions to be affected following a spill. Sea otters are more vulnerable both because of their way of life, and their fur structure.
Birds	Birds using the water-air interface are at risk, particularly auks and divers. Badly oiled birds usually die. Treatment requires specialist expertise and the right facilities—amateur attempts can distress the birds even more. Recovery of populations depends either on the existence of a reservoir of young non-breeding adults from which breeding colonies can be replenished (e.g., guillemots) or a high reproductive rate (e.g., ducks). There is no evidence so far that any oil spill has permanently damaged a seabird population, but the populations of species with very local distributions could be at risk in exceptional circumstances.

Fish	Eggs and larvae in shallow bays may suffer heavy mortalities under slicks, particularly if dispersants are used. Adult fish tend to swim away from oil. There is no evidence so far that any oil spill has significantly affected adult fish populations in the open sea. Even when many larvae have been killed, this has not been subsequently detected in adult populations, possibly because the survivors had a competitive advantage (more food, and less vulnerable to predators). Adult fish in fish farm pens may be killed, or at least made unmarketable because of tainting.
Invertebrates	Invertebrates include shellfish (both molluscs and crustaceans), worms of various kinds, sea urchins and corals. All these groups may suffer heavy casualties if coated with fresh crude oil. In contrast, it is quite common to see barnacles, winkles and limpets living on rocks in the presence of residual weathered oil.
Planktonic organisms	Serious effects on plankton have not been observed in the open sea. This is probably because high reproductive rates and immigration from outside the affected area counteract short-term reductions in numbers caused by the oil.
Larger algae	Oil does not always stick to the larger algae because of their mucilaginous coating. When oil does stick to dry fronds on the shore, they can become overweight and subject to breakage by the waves. Intertidal areas denuded of algae are usually readily re-populated once the oil has been substantially removed. Many algae are of economic importance either directly as food, or for products such as agar. Algae cultured for this purpose lose their commercial value if tainted.
Marsh plants	Some species of plant are more susceptible to oil than others. Perennials with robust underground stems and rootstocks tend to be more resistant than annuals and shallow rooted plants. If, however, perennials such as the grass *Spartina* are killed, the first plants to recolonize the area are likely to be annuals such as the glasswort (*Salicornia*) This is because such annuals produce large numbers of tidally dispersed seeds.
Mangroves	The term 'mangrove' applies to several species of tree and bush. They have a variety of forms of aerial 'breathing root' which adapts them for living in fine, poorly oxygenated mud. They are very sensitive to oil, partly because oil films on the breathing roots inhibit the supply of oxygen to the underground root systems.

Above: Barnacles and limpets are the dominant invertebrates on many rocky shores. If they are killed following a spill, recovery of the community depends upon the settlement of young stages of these species out of the plankton. Settlement and subsequent growth depends on adequate reduction in the volume and the toxicity of shore oil residues.

Above: Dying Avicennia mangrove with oil covered pneumatophores (breathing roots). Below: Part of pneumatophore system, with horizontal underground root and vertical aerial roots.

Above: A section of salt marsh from Wales. A layer of heavy fuel oil has, over a period of 14 years, been buried under new sediment. Marsh vegetation has recovered well, with sea rush plants growing through the oil layer. To clean or not to clean?

Clean-up and rehabilitation efforts

Clean-up efforts can decrease or increase damage. Sometimes there has to be a trade-off between different biological concerns.

The physical removal of oil from the water surface decreases overall damage, by reducing the threat to birds, mammals, and shorelines. The physical removal of thick bulk oil, or 'loose' oil, from shorelines can also decrease damage, by removing the threat to wildlife, by reducing the likelihood of oil floating off and threatening other areas, and by averting the formation of asphalt pavements.

The removal of residual oil, e.g., stains, weathered crusts, or oil absorbed in sediments, is more controversial. From the biological point of view, there seems little point in disturbing the shore to remove such residues *if biological recovery is progressing*. It might be justifiable if absorbed oil is hindering recovery.

Consideration of biological trade-offs most often arises if use of dispersants is being contemplated. Dispersants may break up a floating slick and so reduce the threat to birds and mammals, but the dispersed oil enters the water column. In deep, open waters it is rapidly diluted, but in shallow waters it may increase the threat to plankton, fish eggs and larvae. For this reason dispersant use may be prohibited from some areas at certain times of year.

Rehabilitation can speed up recovery in some cases, notably marshes and mangroves. In both cases there are examples of successful transplant programmes, undertaken after removal of bulk oil or when oil toxicity had been lost through natural weathering.

Right: Mangrove rehabilitation programme.

WHAT IS RECOVERY?

Biological recovery, in the context of getting back to 'normal' after an oil spill, can mean different things to different people. The most recent definition, based upon Clark's rationale, is:

> *Recovery is marked by the re-establishment of a healthy biological community in which the plants and animals characteristic of that community are present and are functioning normally.*

There are two important points about this definition. First, the re-established healthy community may not have exactly the same composition or age structure as that which was present before the damage. Second, it is impossible to say whether an ecosystem that has recovered from an oil spill is the same as, or different from, that which would have persisted in the absence of the spill. Both these points arise from the fact that ecosystems are naturally in a constant state of flux.

Left: The two photographs are both of healthy natural mangrove forest dominated by the same species. That on the left has many young trees, probably in the age range 5–15 years. That on the right has mainly very large trees (some over 30 m tall). The age is difficult to estimate, but for the argument let us say 100 years. A bad crude oil spill is likely to kill all the trees, irrespective of age. In both cases the recovery process is likely to begin after a year or so, when degradation of oil in the sediments has reached the point at which new seedling establishment is not inhibited by lingering toxicity. The young forest structure could then be re-established in around 15 years, but the old forest structure would take 100 years. The recovery time in the latter case would be 100 years if the definition of recovery required a return to the previous age structure, but might be 5–15 years if the definition given above is used.

AN EXAMPLE OF A SENSITIVE INLAND AREA: THE AFRICAN GREAT LAKES

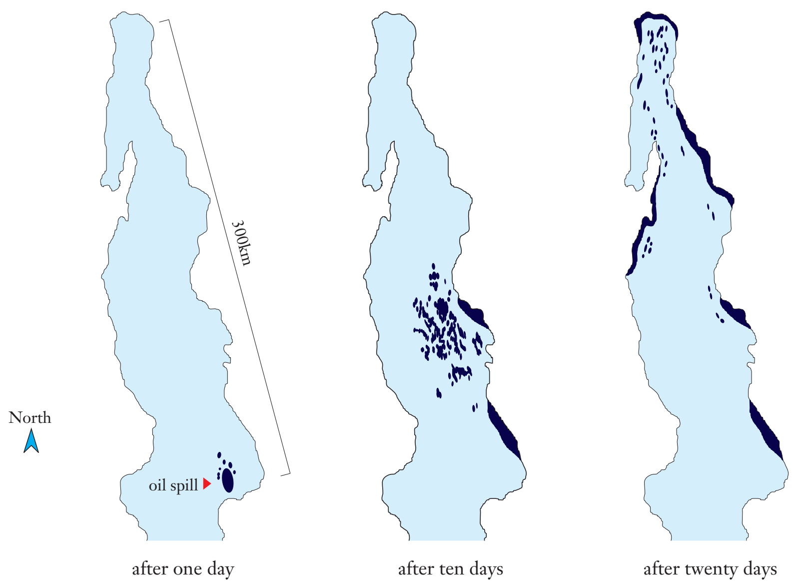
Topographical, human and ecological factors combine to make potential oil pollution of particular concern in some freshwater and terrestrial environments. For example, with respect to the African Great Lakes (an area where there is oil exploration interest):

Below: The African Great Lakes support numerous lakeside communities and unique biological species.

- the lakes, being land-locked, have less scope for natural dispersal and dilution of oil than the open sea;
- numerous lakeside communities depend directly upon the lakes for their water supply, and for their livelihood from fishing;
- lakes such as Tanganyika and Malawi are ancient and have evolved unique biological communities; there are hundreds of species of fish and other creatures which are found nowhere else in the world.

Right: Speculative scenario of the effects of a 30,000-tonne oil spill on Lake Tanganyika over 20 days during June to August, the period of southerly winds.

Speculative Lake Tanganyika scenario, June–August (period of southerly winds), after a 30,000-tonne spill of crude oil



ACKNOWLEDGEMENTS AND FURTHER READING

Acknowledgements

Working on projects for the oil industry in many parts of the world has provided an invaluable background to this review, and I would like to thank the many companies who have made this possible. In particular, recent work for Exxon has provided specific material for the review—this work was carried out jointly with R. B. Clark, P. F. Kingston and R. H. Jenkins. I am indebted to these colleagues for numerous productive discussions. M. Wilson and J. H. Oldham made invaluable contributions to a succession of marsh projects. Insights into the African Great Lakes developed through a project with the International Association of Theoretical and Applied Limnology; and into mangroves through working with H. J. Teas. The food relationships diagram on page 5 is based upon information given by J. Green in *The Biology of Estuarine Animals* (Sidgwick & Jackson, London, 1968).

Further reading

Baker, J. M., Clark, R. B., Kingston, P. F. and Jenkins, R. H. (1990). Natural Recovery of Cold Water Marine Environments after an Oil Spill. Paper presented at the 13th AMOP Seminar, Edmonton, June 1990. 111 pp. Can be obtained from Institute of Offshore Engineering, Heriot-Watt University, Edinburgh EH14 4AS, Scotland.

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The International Petroleum Industry Environmental Conservation Association (IPIECA) is comprised of oil and gas companies and associations from around the world. Founded in 1974 following the establishment of the United Nations Environment Programme (UNEP), IPIECA provides one of the industry's principal channels of communication with the United Nations. IPIECA is the single global association representing both the upstream and downstream oil and gas industry on key global environmental and social issues including: oil spill preparedness and response; global climate change; health; fuel quality; biodiversity; social responsibility; and sustainability reporting.

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