IPIECA REPORT SERIES

VOLUME FOUR

BIOLOGICAL IMPACTS OF OIL POLLUTION: MANGROVES

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International Petroleum Industry Environmental Conservation Association

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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; and
- 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, and 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

From the beginning of history, mangroves—the coastal forests of the tropics—have traditionally provided a variety of plant products, fish and shellfish for local communities. They also provide services such as coastal stabilization, and food chain support for near-shore fisheries. In recent decades there has been increased conversion for uses which do not sustain the mangrove habitat, such as large-scale fish culture ponds and industrial salt production, and there is concern about the resulting loss of mangroves. Nevertheless, all these uses—traditional and industrial—may be affected following oil spills and need to be considered during the contingency planning process.

This report provides information on the ecology and human use of mangroves, and on the fate and effects of oil. Mangrove forests are notorious oil traps, and oiled trees commonly die—so it is important for spill response plans to address habitat protection options. These, together with clean-up methods, are discussed with reference to case history experience and results from field experiments. In the longer term, rehabilitation may be desirable for oil-damaged mangrove areas, and there is information on how this can be achieved.

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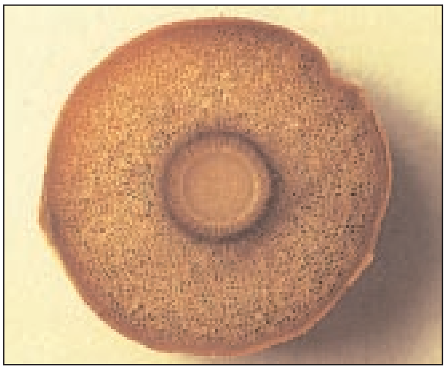
ECOLOGY OF MANGROVE FORESTS

The mangrove Sonneratia, *showing aerial 'breathing roots' (pneumatophores), Strait of Malacca, Indonesia.*

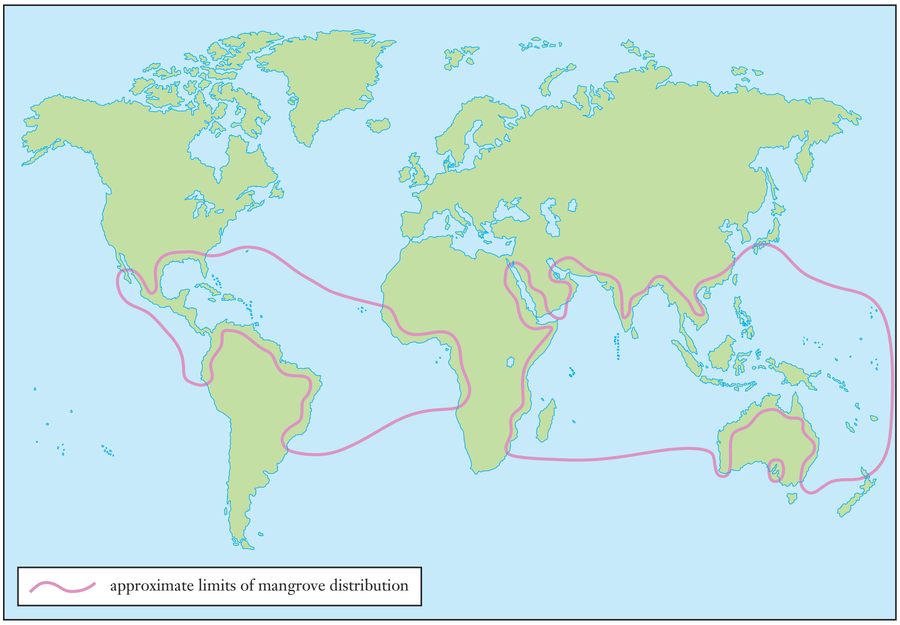
The term mangrove refers to salt-tolerant species of tree or shrub which grow on sheltered shores and in estuaries in the tropics and some sub-tropical regions.

There are about 60 species which occur exclusively in this habitat, and many non-exclusive species. Mangroves are outstandingly adapted to growing in sea water, which they desalinate by an ultrafiltration process. Mangrove roots typically grow in anaerobic sediment and receive oxygen through aerating tissue which communicates to the air through small pores (lenticels) on the aerial roots and trunks.

Mangroves may occur as narrow fringes on steeper shores and river banks, or as extensive forests on flat delta-land. Within any area of mangroves there may be zones or mosaics of different biological communities, depending upon many factors. These include height of sediment surface relative to tidal water movements, and salinity and nutrient supply (which in turn are influenced by freshwater inputs from the catchment area).



Cross-section of pneumatophore, showing spongy aerating tissue.



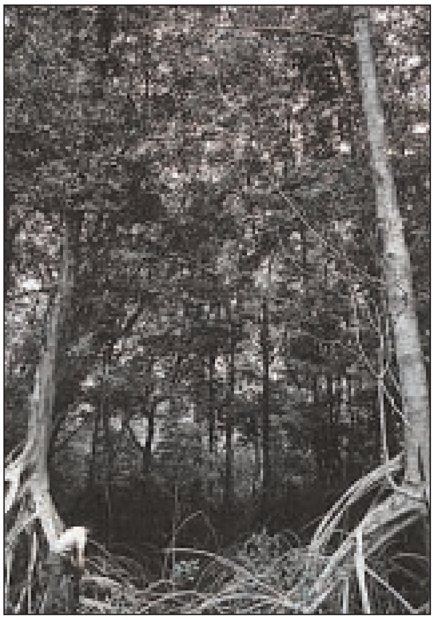
Map: global distribution of mangroves.

Mangrove forests in optimum conditions are one of the most productive ecosystems; for example a net primary productivity of 23.3 tonnes/ha/year and litter productivity of 10 tonnes/ha/year was measured for a 15-year-old stand of *Rhizophora* at Matang, Malaysia. The litter (such as fallen mangrove leaves) is broken down by bacteria, fungi and herbivores, and the resulting detritus supports food webs including large populations of invertebrates and fish. The calm waters in the forests are ideal breeding and nursery grounds for young fish and shrimps, while the aerial roots, lower trunks and mud surface usually support a varied fauna of oysters, snails, barnacles, crabs and other invertebrates. The upper part of the mangrove trees is an essentially terrestrial environment with a fauna of birds, mammals and insects.

Low-growing Avicennia, *Victoria, Australia.*

Mangroves are affected by the freshwater and nutrient supply which they receive from their catchment area, and on the other hand have a strong influence on the adjoining coastal waters and associated ecosystems such as coral reefs, seagrass beds and tidal marshes. For example, they trap and stabilize sediment which might otherwise limit the growth of corals.

The mangrove palm Nypa, *East Kalimantan, Indonesia. At this site it is growing with* Rhizophora.



Left: Tall red mangrove Rhizophora, *Niger Delta, Nigeria.*

A collection of mangrove molluscs from Kepala Jernih Island, Strait of Malacca, Indonesia.

Zonation of different mangrove species on a bank of the Bonny River, Niger Delta, Nigeria (infrared).

HUMAN USE OF MANGROVES

Aerial view of timber extraction plots bordering the San Juan River, Venezuela. Each plot of 20 x 300 m carries about 250 mature Rhizophora *and 20-30* Avicennia *trees.*

A plot after cutting. Some young seedlings can be seen between the fallen trunks, together with mangrove ferns.

Sustainable uses

The mangrove ecosystem has a utilitarian value based on both 'goods' (products) and 'services' of benefit to humans.

Products from mangrove trees include logs, fuelwood, charcoal, wood-chips, paper pulp, scaffold poles, piling and construction material, stakes for fish traps and fishing platforms, railway sleepers, wood for furniture making and carvings, material for roof thatching, bark for tannin, medicinal products, sugar, alcohol, acetic acid and dyes. Exploitation to obtain products for domestic use has occurred since the beginning of history. Modern exploitation has increased to industrial levels, and the application of proper forest management practices based on cutting cycles and specially designed tree-extraction systems has been necessary in order to maintain a sustainable yield.

In addition to plant products, the mangrove ecosystem can provide a sustainable yield of fish and shellfish if it is not over-exploited.

Services include:
- stabilization and protection of shorelines;
- filtering and trapping of water-borne pollutants;
- provision of nursery and feeding grounds for numerous species of finfish and prawns, and habitat for crabs and molluscs;
- provision of nesting sites for sea and shore birds; and
- provision of resources for tourism and recreation.

Traditional fishing (right) using a net in a mangrove creek, Niger Delta, Nigeria.

Fish trap (far right) on edge of mangroves, East Kalimantan, Indonesia.

Non-sustainable uses

Non-sustainable uses lead to loss of the mangrove habitat, and associated losses of shoreline, organic matter production and species dependent on the habitat and mangrove-based food chains. Mangrove forests may be felled for uses such as aquaculture ponds, salt pans, agricultural use including rice fields, airport and road construction, port and industrial development, resettlement and village development. Canalization and changes in drainage associated with these uses modify the natural water supply and may be detrimental to remaining mangroves.

Traditional aquaculture pond (tambak) in mangroves, East Kalimantan, Indonesia.

From the viewpoint of oil spill response, some of the above activities are vulnerable to oil and need to be considered along with the mangrove habitats. Aquaculture and the use of salt ponds might be particularly affected. Appropriate responses are also needed for port and harbour facilities and associated navigation channels.

Aquaculture ponds for fish and crustaceans (prawns and shrimps) have traditionally been excavated in mangrove areas in some parts of the world, notably south-east Asia and South America.

During recent decades, increased aquaculture of crustaceans has been an economic success worldwide, representing, nevertheless, a major problem for mangrove conservation. This is because of the large scale of habitat conversion, with associated changes in the natural tidal flow patterns and the generation of acid conditions (by oxidation of the disturbed sulphide-rich soils) which eventually affect the larvae. These problems can lead to a vicious cycle of mangrove clearing and abandonment called ‘shifting aquaculture’.

Brine evaporation ponds required for salt crystallization are developed mainly by clearcutting mangroves on arid or semi-arid coasts, and significant areas have been destroyed in this way. In very dry regions, solar evaporation is sufficient to cause crystallization, but under more humid climatic conditions the brine has to be boiled over fires using mostly mangrove wood as fuel, which increases the pressure on the local mangrove resource.

The establishment and expansion of deep-water ports and associated waterways has led to direct loss of mangroves, and erosion. In particular, port facilities located upstream on tropical rivers can have a strong influence on downstream mangrove areas through the permanent dredging activities (and associated dumping of dredge spoil) required to maintain the navigation channels. Dredge spoil may physically smother mangroves, and there may also be an increase of acidity due to oxidation of the sulphide-rich sediment.

Dredge spoil dump, Niger Delta, Nigeria.

EXAMPLES OF MANGROVE USE FROM MALAYSIA

KEY

mangrove forests — international boundary

1. Sungai Merbok mangroves
2. Matang Forest Reserve and Kuala Gula bird sanctuary
3. Selangor mangroves/Pulau Ketam and Kapar Forest Reserve
4. Johore mangroves
5. Samunsam Wildlife Sanctuary
6. Sarawak Mangrove Forest Reserve
7. Rejang estuaries
8. Klias National Park
9. Mengkabong, Sulaiman and Abai Forest Reserves
10. Elopura and Sihyte Forest Reserves
11. Tawau Forest Reserve

Most mangrove forests in Malaysia are found along the meandering coastline of Sabah (350,342 hectares) followed by those in Sarawak (172,792 hectares) and in Peninsular Malaysia (123,482 hectares). Sustainable extraction of wood for charcoal and construction materials is a major and widespread activity. It is possible to maintain a sustainable yield with appropriate management; for example, in the Matang Mangrove Reserve an average felling cycle of 30 years is practised, and in Johore there is a 20-year cycle with a thinning cycle of about 10 years. Sustainable fisheries are also of major importance, with traditional equipment including gill nets, barrier nets, bag nets, cast nets, traps, hooks and lines. About 30 species of fish and 9 species of prawn have been obtained by using cast nets in the Kapar mangroves, which gives some idea of diversity.

Returning boat (immediately below) fully loaded with mangrove billets, Sepitang, Perak (by the Matang Reserve).

Dome-shaped kiln (below middle) with billets ready for loading.

Two rows of sheds (below right) housing several charcoal kilns accessible by boat. The sheds are thatched with Nypa *palm leaves—a mangrove product.*

In Peninsular Malaysia, the preponderance of mangrove forests along the west coast rather than the east is strongly reflected in the fisheries statistics as shown in

the table. They are in accordance with the belief that there is a positive correlation between mangroves and fisheries production.

An interesting fishery is that for jellyfish, which are routinely harvested in the Rejang estuaries of Sarawak between February and June each year. They are brined and processed for export markets in Japan and Taiwan. There are highly productive cockle culture sites on some mangrove foreshores in Peninsular Malaysia, and other sites have floating net cages for the culture of sea bass, grouper and snapper. The Pulau Ketam mangroves support well over 2000 of these floating net cages.

Landing (metric tonnes) of various fisheries products on the west and east coasts of Peninsular Malaysia.

	Prawns		Molluscs		Fish	
	West (a)	East (b)	West (a)	East (b)	West (a)	East (b)
1983	60,416	3584	5830	0	337,750	162,943
1984	50,984	6663	4332	0	292,426	127,233
1985	53,874	4193	2620	0	270,629	131,543
1987	62,174	4874	20,467*	0	417,221	235,829
1989	67,233	14,034	1529	0	361,426	250,227
1990	72,126	6961	4475	0	433,870	302,471
Average per year	61,135	6718	6542	0	301,558	201,708
b/a	< 11.0% >		< 0% >		< 67% >	

Note: * Probably inclusive of cultured cockles which were listed under a separate heading after 1987.
Data extracted from Annual Fisheries Statistics, Department of Fisheries, Kuala Lumpur.

Net cages for fish culture, Pulau Ketam.

The non-renewable conversion of mangrove swamps for aquaculture is within the limit of a total of 20 per cent of existing mangroves in a given district mentioned in national guidelines on the use of mangrove ecosystems. In 1990 a total of 1552 hectares of brackish water ponds were converted from mangrove swamps in Peninsular Malaysia for the culture of prawns and fish, and fattening of crabs. Other examples of uses which deplete the mangrove habitat are shown in the photographs below.

In contrast, many mangrove forests in Malaysia are wildlife reserves, as indicated on the map. Such areas conserve the natural mangrove habitats, and so contribute to the conservation of a number of threatened species such as the salt-water crocodile, milky stork and proboscis monkey.

Prawn ponds (below left), Jugra, Selangor.

Village re-settlement (below middle), Awat-Awat, Sarawak.

Early stage in reclamation for industrial estates and coastal highway (immediately below), Batu Maung, Penang.

CONSERVATION

Objectives and how they may be achieved

There are many different conservation objectives, and priorities will be different in different places. Some examples are:

- maintenance of 'reservoirs' for natural restocking of adjacent exploited areas;
- protection of breeding and feeding areas important for fisheries;
- protection of shorelines from erosion; and
- preservation of rare and endangered species.

Depending upon the specific objectives for any area, mangrove conservation can be achieved by management on a sustainable basis, or by creating protected areas. According to the report on *Global Status of Mangrove Ecosystem*s (IUCN 1983) 18 countries have established mangrove reserves to safeguard the habitat and associated species—in all, less than one per cent of the total mangrove area of the world.

All conservation efforts require efficient legislation to control activities that might adversely affect the ecosystem. Several countries, notably in the ASEAN region, have established national mangrove committees (NATMANCOM) to provide the necessary input for adequate mangrove management. For example, the Malaysian NATMANCOM recommended that not more than 20 per cent of existing mangroves in a given district should be cleared for pond construction, and that there should be a 100-metre buffer zone along the coast between the pond site and the mean high-water level of the sea.

Other countries, such as some in Latin America, have developed special policies on coastal marine protected areas.

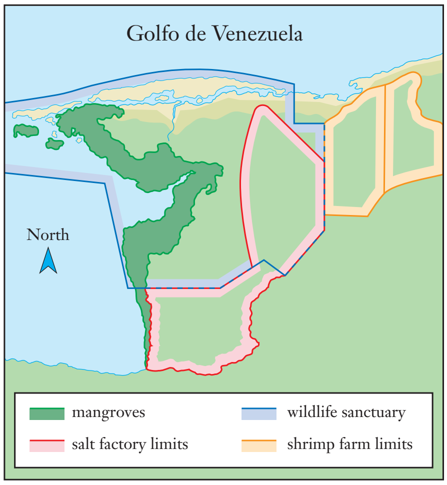
Mangroves help to stabilize intertidal sediments such as this shellfish-rich shore in Hong Kong (below left) and this muddy bank in the Niger Delta (below middle) where the mangroves are also a source of fuel wood.

This mangrove-fringed lagoon (below right) in Curaçao, Netherlands Antilles, is a haven for wildlife.

CONSERVATION AND DEVELOPMENT ISSUES: EXAMPLES FROM VENEZUELA

In Venezuela, a recent presidential decree regulates the protection of mangroves and associated ecosystems in the context of watersheds, prohibiting specific activities such as dredging, land filling and use of biocides, but excluding areas with forest management or subsistence activities of indigenous people. Below are some examples of measures taken to harmonize conservation and development .

- *Shrimp farm development.* Proposals to initiate extensive shrimp farm developments have been controlled by the government through requirements for appropriate siting of ponds, monitoring water quality, controlling discharges into the surroundings and the strict sanitary control of seed stocks.
- *Industrial salt production.* Proposals to convert the 5000 hectares of mangroves of Los Olivitos Swamp to large-scale salt production were countered by a multi-use proposal from the government, and public demands for environmental impact assessments. One particular area of concern for any salt development is the discharge of hypersaline water, which in shallow waters can have far-reaching biological consequences.
- *Port development.* The problems of dredging and dredge spoil dumping were taken into account by an oil company which manages the important pipeline terminal of Caripito, about 100 km upstream on the densely mangrove-bordered San Juan River in the north-eastern region of Venezuela. Navigation channels had to be deepened for larger ships. Following an environmental impact assessment, it was possible to recommend minimal-impact disposal sites for spoil behind the riverine mangrove fringe, where mangroves would not be affected.

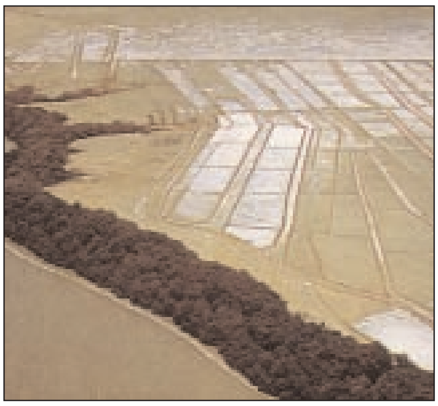


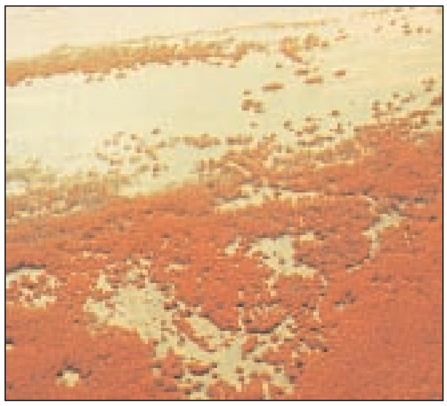
Multi-use proposal for Los Olivitos Swamp, showing limits for different uses.

Existing small-scale salt production (below left) in the southern part of Los Olivitos.

Pipeline (below middle) carrying dredge spoil through mangrove fringe, San Juan River.

Los Olivitos Swamp (below right), aerial (infrared) view.





FATE AND EFFECTS OF OIL

This shows the oil-killed Rhizophora *zone in the Kepala Jernih transect.*

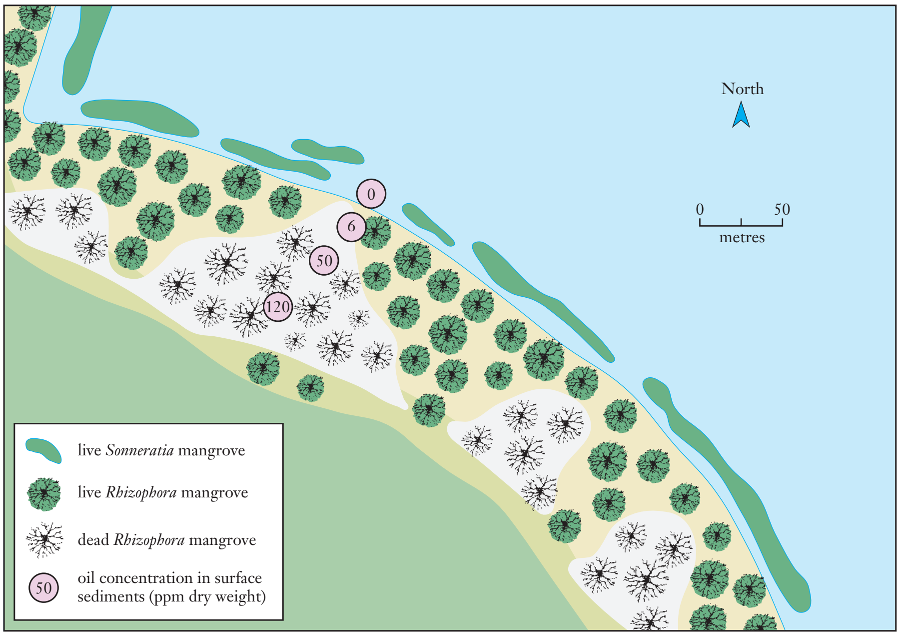
Oil slicks enter mangrove forests when the tide is high, and are deposited on the aerial roots and sediment surface as the tide recedes. This process commonly leads to a patchy distribution of the oil and its effects, because different places within the forests are at different tidal heights. It can be very difficult to assess the extent and distribution of oiling in a dense forest shortly after a spill, because oil on the ground can be invisible from the air if hidden by a closed forest canopy, and invisible from the sea if the seaward fringe has escaped contamination because of its lower tidal height. Aerial survey can be used for assessment at a later stage if the oil kills the mangroves, when the dead areas are easily visible because of defoliation.

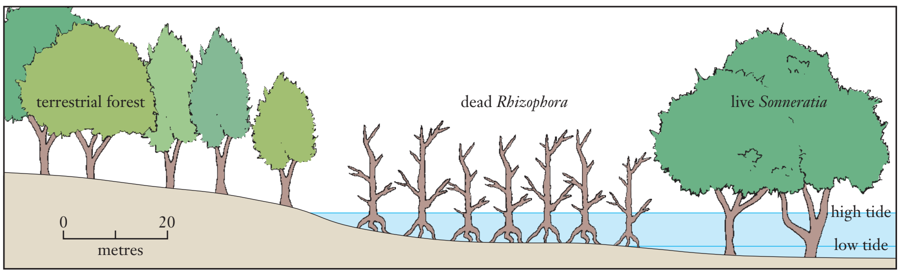
Mangroves can be killed by heavy or viscous oil that covers the trees' breathing pores thereby asphyxiating the subsurface roots which depend on the pores for oxygen.

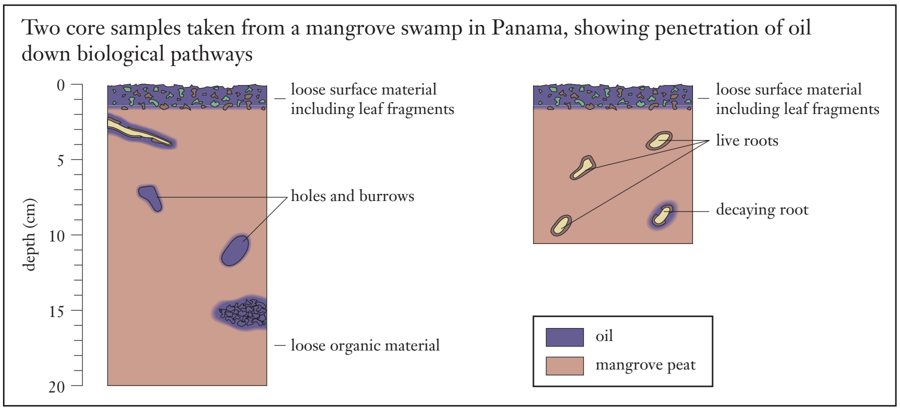
Survey results from the Strait of Malacca, Indonesia, illustrating patchiness of oil effects.

Patches of oil-killed mangroves (right), Pemping Island. The figures are oil concentrations in the surface sediments (ppm dry weight).

Transect through mangroves (below right), Kepala Jernih Island. These results were obtained two years after the Showa Maru *spill, but chemical analysis of oil from the sediments indicated more than one source.*







Oil, especially fresh light oil, can penetrate into mangrove sediments and damage cell membranes in the root systems. These two core sections show penetration of oil down biological pathways.

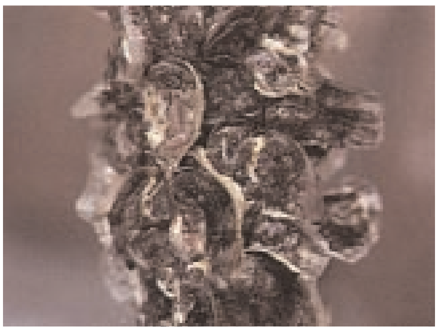
Mangroves can also be killed through the toxicity of substances in the oil, especially lower molecular weight aromatic compounds, which damage cell membranes in the subsurface roots. This in turn impairs the normal salt exclusion process, and the resulting influx of salt is a source of stress to the plants.

The organisms among and on the mangrove trees are affected in two ways. First, there may be heavy mortalities as a direct result of the oil. For example, oil may penetrate burrows in the sediments, killing crabs and worms, or coat molluscs on the sediment surface and aerial roots. Second, dead trees rot quickly, leading to loss of habitat for organisms living in the branches and canopy of the trees, and in the aerial root systems. Large falling trees or branches can also be a hazard for rehabilitation workers.

Over time several factors reduce the toxicity of oil that has been deposited in mangrove forests. The amount of oil in the soil is reduced by rain and tides. In addition the oil weathers, a process in which some of the more toxic volatile fractions evaporate, and chemical changes such as oxidation make the residual oil less toxic. Eventually the soil can support mangrove growth once more, with the time-scale involved varying according to local conditions such as the amount of water circulation in the immediate area. Oil degradation can be rapid in the tropics and there are instances of natural seedling establishment and growth in oiled soil within a year of a spill. These processes can be slower if oil degradation is inhibited because of anaerobic soil conditions. Another possibility is that high tannin concentrations in some mangrove peat may inhibit oil-degrading bacteria.

Heavy fuel oil (below left) on sediment surface and in seaward zone of Avicennia, *United Arab Emirates. The mangrove pneumatophores are oiled and the trees are wilting. In this case the oil is sticking to the surface of the sediment and is not being lifted off by the incoming tide.*

These oysters (below middle) in the Niger Delta, Nigeria, will lose their habitat if the mangrove trees are killed. The epiphytic orchid (immediately below) in Panama is at risk because it is growing on an oil-killed mangrove tree which is breaking up.



OIL SPILL RESPONSE

It is generally agreed that mangroves are particularly sensitive to oil and that they are priority areas for protection. The main protection options are:

- mechanical recovery offshore from the mangroves;
- dispersal (using oil spill dispersants) offshore; and
- booming of mangrove shorelines and inlets.

Of these, it is the dispersal option which gives rise to the most debate. Experimental evidence concerning the effects of dispersed oil compared with untreated oil on mangroves is available, and is a useful input to contingency planning.

The evidence points to the conclusion that mangrove trees tolerate dispersed oil better than untreated oil. If the objective is to protect the trees, the habitat they provide, and some wildlife species (notably water birds), then chemical dispersal

Mangrove protection and clean-up: a summary of field experimental results.

Experiment	Findings
Malaysia, Lai and Feng (1985)	Untreated crude oil was more toxic than dispersed crude to mangrove saplings. Untreated oil in the upper sediments required a longer time to weather and depurate than chemically dispersed oil.
Turkey Point, Florida, Teas *et al.* (1987)	Mangroves treated with pre-dispersed light crude oil (simulating a well-dispersed slick moving inshore) showed no greater mortality than was found in untreated plots. High-pressure sea-water washes applied to the mangroves the day after oiling with non-dispersed oil were ineffective in reversing oil toxicity, as were post-oiling washes containing a non-ionic water-based dispersant.
TROPICS experiment, Panama, Ballou *et al.* (1989)	Fresh untreated oil had severe long-term effects on survival of mangroves and associated fauna. Oil which was chemically dispersed just offshore had minor effects on the mangroves but affected corals. (This experiment is described in more detail in the IPIECA report *Biological Impacts of Oil Pollution: Coral Reefs*.)

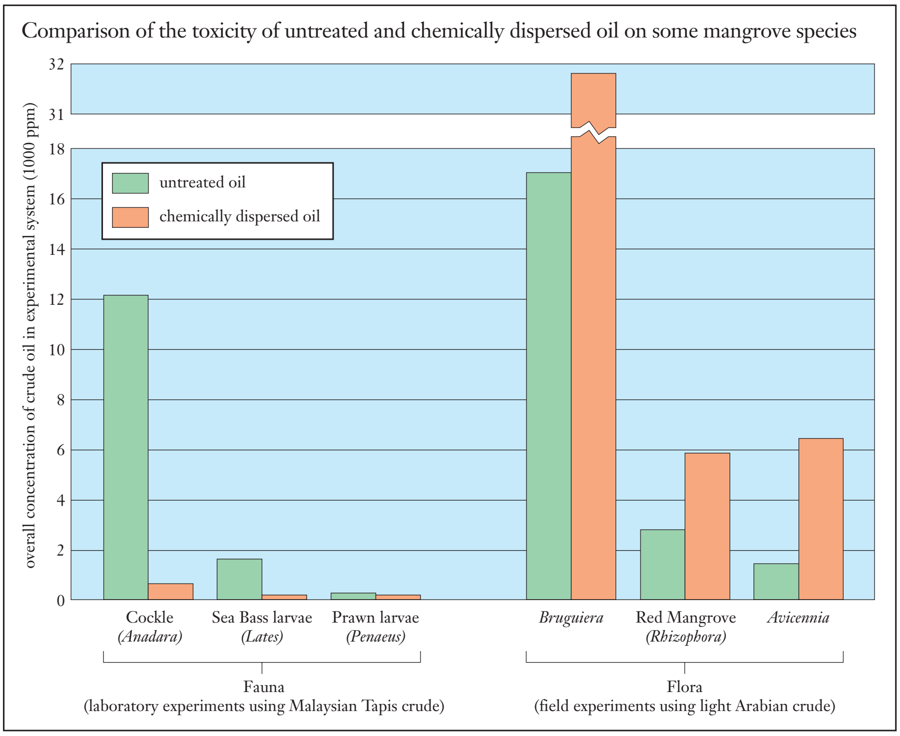
offshore can be an effective measure under certain conditions (if the type of oil is dispersable and weather and sea conditions allow dispersant application). However, the possible effects on organisms in the water column need to be considered, and the advantages and disadvantages of offshore chemical dispersal weighed up as part of the contingency planning process. This subject is discussed more fully in the IPIECA report *Dispersants and their Role in Oil Spill Response*.

If oil enters mangroves, the main clean-up options are:

- booming and skimming of oil on the water surface in mangrove creeks;
- pumping of bulk oil from the sediment surface, depressions and channels;
- water flushing of free oil from sediment surface and mangroves, into areas where it may be collected; and
- use of absorbent materials, with subsequent collection and disposal.

There have recently been some promising experimental results using a newly developed chemical shoreline cleaner on trees oiled with heavy oil that covered the lenticels. The cleaner reduces oil adhesion with minimal dispersion.

Difficulties are that some mangrove forests are virtually impenetrable, and heavy clean-up operations may cause physical damage. Moreover, if a large spill of relatively fresh light crude oil enters a forest, sediment penetration and toxic damage can occur very quickly, so that it is unrealistic to expect a clean-up operation to save many trees.



Comparison of the toxicity of untreated oil and chemically dispersed oil on some mangrove species. The histograms show LC_{50} values—the oil concentrations that kill 50 per cent of the test organisms (in the case of the fauna, after 96 hours; in the case of the mangrove saplings, after 30 days). The lower the LC_{50} value, the lower the tolerance. The results indicate that:

- *chemically dispersed oil is less toxic to mangrove saplings than untreated oil, probably because it is less likely to stick to the pneumatophores and sediment surface;*
- *chemically dispersed oil is more toxic to the fauna species tested than untreated oil, probably because they are more in contact with it through the water column; and that*
- *there are considerable differences in tolerance between different species. (Experiments carried out at Universiti Sains Malaysia.)*

REHABILITATION OF OIL-DAMAGED MANGROVES

When mangroves have been killed by oil there is often a great interest in rehabilitation of the forests based on a desire both to re-establish the important mangrove ecosystems and to restore the appearance of the shoreline by replacing the unsightly dead blackened trees with live green ones. Positive steps can be taken to achieve this, though it is probably inevitable that rehabilitation schemes will have to focus on one or a few key species of tree—restoration of the full complexity of the mangrove ecosystem will depend upon subsequent natural processes.

It is obvious that regeneration either by natural recruitment or by artificial replanting immediately after an oil spill would be unlikely to restore the forest: whatever there was about the oil that killed the trees would almost certainly still be present to kill or inhibit the growth of natural recruitment or planted mangroves. An example of post-spill toxicity was demonstrated at the Refineria Panama spill of crude oil in 1986 where groups of red mangrove propagules were planted at sites at which the mangroves had been killed by oil. (The term 'propagule' in this case refers to seedlings growing out of fruits; they start doing this while the fruits are still attached to the trees, and are the normal, tidally-dispersed propagating organs of the red mangrove.) Those propagules planted three months and six months post-spill all died; however, some of the propagules planted nine months post-spill and larger fractions of those planted later survived.

Red mangrove seedlings about one year after planting as propagules in an oil-killed mangrove area. The photograph was taken eight years after the spill. The effectiveness of the hand planting shows that the previous lack of regeneration was not because of toxicity of the residual oil, but because propagules were not reaching the area. St Croix, US Virgin Islands.

Mangrove propagules blocked from tidal dispersal by a fallen oil-killed mangrove tree trunk, Niger Delta, Nigeria.

The time that must elapse after an oil spill for the soil to become sufficiently non-toxic for natural propagules or replanted mangroves to survive depends on factors such as the kind of oil spilled, the type of soil, local tidal flushing and rainfall. That mangroves are able to grow does not require that all oil has been eliminated from the soil. Mangroves can become established and apparently grow normally at oil spill sites where there is residual weathered oil, as indicated by the disturbed soil giving off an odour of crude oil and an oil sheen appearing on the water surface. Such evidence of past oil spills may persist in mangrove soils for more than a decade.

Natural regeneration of oil-killed mangrove forest can be expected to occur, but the process may be slow as a consequence of residual oil toxicity or because propagules (or seeds) of mangroves, which are ordinarily dispersed by tidal waters,

Red mangrove propagules (below left) collected from un-oiled forest.

Mangrove nursery (below).

Taking nursery-grown seedlings by boat to be planted.

may be unable to reach the sites affected by oil because of barriers of fallen branches, aerial roots and trunks of the killed mangrove forest. In some cases regeneration may be slow because there are not enough live trees locally to provide an adequate seed supply.

One approach to restoring an oil-killed mangrove forest as soon as possible after the oil spill was used at the site of the Refineria Panama spill. Cylinders of oiled mangrove soil were removed by use of post hole diggers and nursery-grown seedlings planted in the holes or the holes filled with upland soil and propagules planted. In either case the developing roots of the seedling plants were protected from residual oil in the soil by a buffer of non-oiled soil in which the roots of a seedling could grow while the toxicity of oil in the soil continued to decrease through weathering and tidal and rainfall washing.

Making a planting hole (right) in oil-killed mangroves with a post hole digger.

The cylinder of mangrove substratum (peat) removed by a post hole digger, and a planted mangrove seedling (far right).

Mangrove seedlings planted in holes filled with upland soil.

As an aid in restoring a mangrove forest as rapidly as possible, it is useful to set up a nursery where mangroves can be grown in order to have plants ready to plant out in the field when the oil toxicity has attenuated. Both planting of nursery-grown mangrove seedlings with their packets of upland soil and planting propagules in upland soil within the oiled mangrove forest proved successful in Panama, where in excess of 75 hectares of oil-killed mangrove forest was replanted. More than 86,000 nursery-grown mangrove seedlings and propagules were used for the restoration. At two years post-spill, when the first natural regeneration was beginning to appear in the form of newly rooted propagules, planted nursery seedlings were already about one metre tall. Survival of planted mangroves was typically greater than 90 per cent.

Mangroves from the nursery about 18 months after planting.

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Further reading

Ballou, T. G. *et al*. (1989). Effects of untreated and chemically dispersed oil on tropical marine communities: a long-term field experiment. *Proceedings 1989 Oil Spill Conference*, API Publication No. 4479, American Petroleum Institute, Washington, DC, 447-454.

IPIECA (1992). *Biological Impacts of Oil Pollution: Coral Reefs.* IPIECA Report No. 3, International Petroleum Industry Environmental Conservation Association, London.

IPIECA (1993). *Dispersants and their Role in Oil Spill Response*. IPIECA Report No. 5, International Petroleum Industry Environmental Conservation Association, London.

IUCN (1983). *Global Status of Mangrove Ecosystems*. Commission on Ecology Paper No. 3, reprinted from *The Environmentalist* 3, Supplement No. 3. 88 pages. International Union for the Conservation of Nature and Natural Resources, Gland, Switzerland.

Lai, H. C. and Feng, M. C. (1985). Field and laboratory studies on the toxicity of oils to mangroves. *Proceedings 1985 Oil Spill Conference*, API Publication No. 4385, American Petroleum Institute, Washington, DC, 539-546.

Teas, H. J. *et al*. (1987). Effects of south Louisiana crude oil and dispersants on *Rhizophora* mangroves. *Marine Pollution Bulletin* 18, 122-124.

Teas, H. J. *et al*. (1989). Mangrove restoration after the 1986 Refineria Panama oil spill. *Proceedings 1989 Oil Spill Conference*, API Publication No. 4479, American Petroleum Institute, Washington, DC, 433-437.

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