*IPIECA REPORT SERIES*

*VOLUME THREE*

# BIOLOGICAL IMPACTS OF OIL POLLUTION: CORAL REEFS

IPIECA

IPIECA
REPORT
SERIES

VOLUME THREE

# BIOLOGICAL IMPACTS OF OIL POLLUTION: CORAL REEFS

IPIECA

International Petroleum Industry Environmental Conservation Association
5th Floor, 209–215 Blackfriars Road, London, SE1 8NL, United Kingdom
Telephone: +44 (0)20 7633 2388   Facsimile: +44 (0)20 7633 2389
E-mail: info@ipieca.org   Internet: www.ipieca.org



*This publication is printed on paper manufactured from fibre obtained from sustainably grown softwood forests and bleached without any damage to the environment.*

# CONTENTS



# 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

Coral reefs are the largest structures made by living things and exist as extremely productive ecosystems in tropical and sub-tropical areas of the world. Their location in nearshore waters means that there is a potential danger to corals from tanker accidents, refinery operations, oil exploration and production.

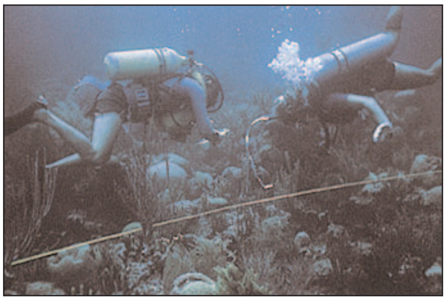
There are now a number of published scientific papers concerning the effects of oils on corals, but results are not entirely consistent. This report summarizes and interprets the findings, and provides background information on the structure and ecology of coral reefs.

Clean-up options and their implications are discussed in the light of the latest evidence from case histories and field experiments.

Anthony H. Knap

Bermuda Biological Station for Research, Inc.

# THE CORAL REEF ECOSYSTEM



*Above: Ecological survey work in progress.*

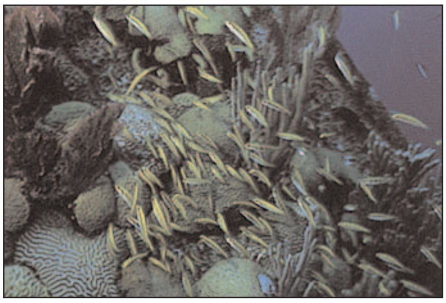
## Significance

Biological productivity per square metre of reef is usually 50 to 100 times more than in the surrounding oceanic waters. Coral reefs cover more than 600,000 $km^2$ and the longest of them, the Great Barrier Reef, extends for some 2000 km along the eastern coast of Australia. They are regarded as the most diverse and complex marine communities (a single reef may contain 3000 species), and play an important role in the geochemical mass balance of the oceans. It has been estimated that, annually, coral reefs are responsible for the deposition of half of the calcium brought to the oceans by rivers and (particularly important in the context of global climate change) more than 111 million tonnes of carbon per year.

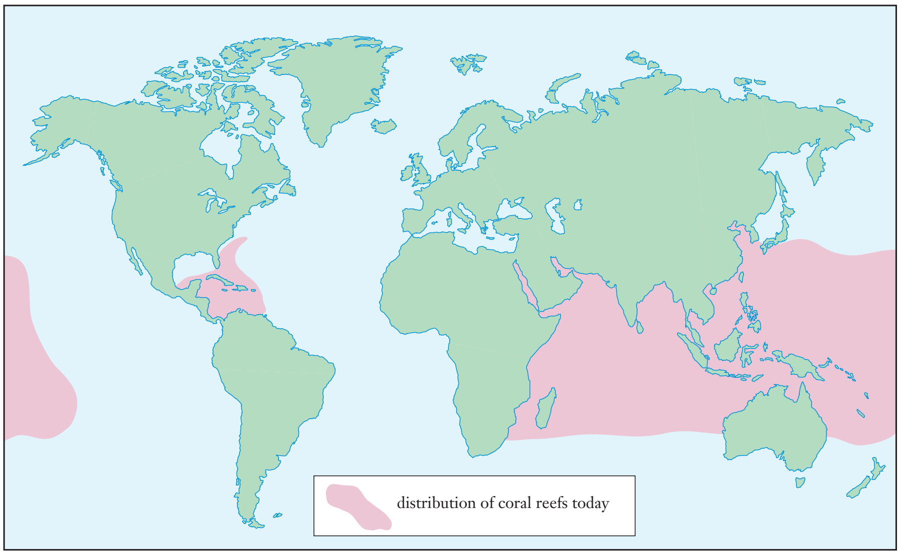
On a local scale, reef areas are an important fishery resource, are a barrier to coastal erosion, and their amenity value is often the basis of tourist economies.

## Distribution and types of reef

Coral reefs occur in warm tropical and sub-tropical seas where the average minimum water temperature is not less than 20 °C. There are basically three types: fringing reefs, barrier reefs and atolls. In atolls, the original land mass has subsided, producing an enclosed or semi-enclosed lagoon. Most reefs have a series of biological zones; an example of such a zonation is given opposite.

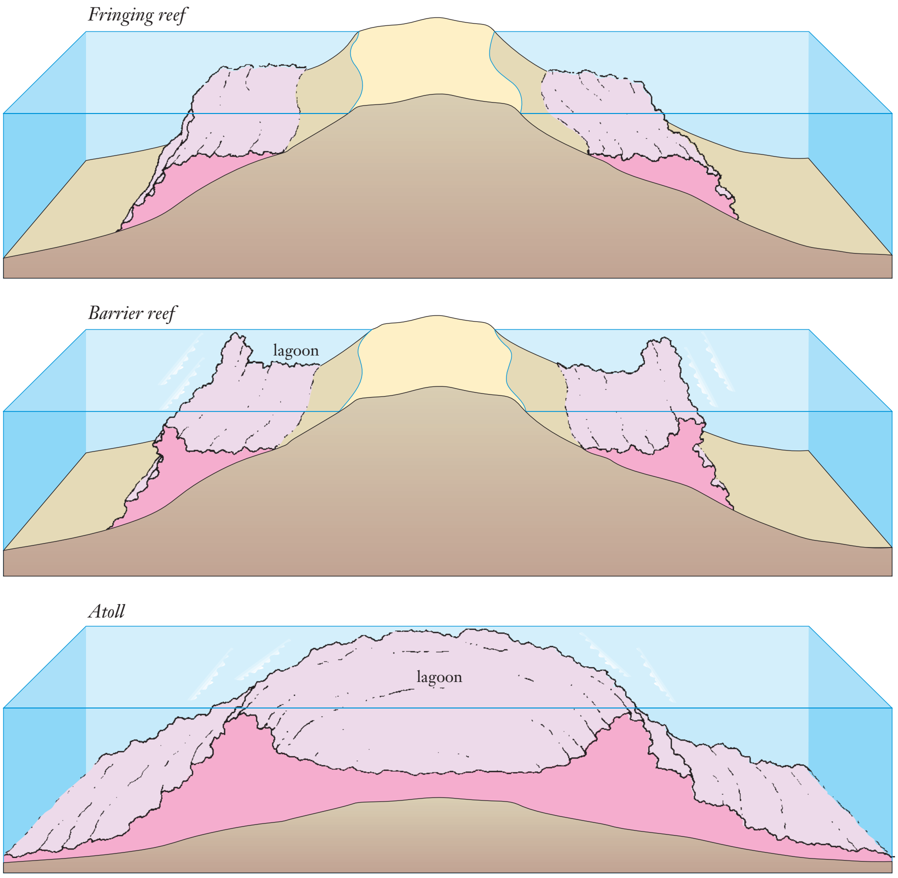


*Above: Coral reefs are the most diverse and complex marine communities.*




*Right: Coral reefs occur in warm tropical and sub-tropical seas: this map shows the global distribution of coral reefs today.*

Three types of coral reef



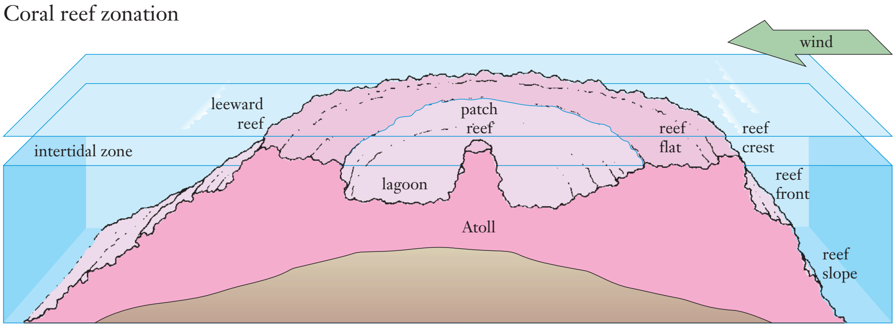

*Left: These diagrams show three types of coral reef (after Mann 1982).*

*Fringing reefs grow as a fringe to a land mass.*

*Barrier reefs occur further from the coast and have a lagoon between the reef and the land.*

*Atolls are isolated in deeper water and comprise a ring of coral with a central shallow lagoon.*

Coral reef zonation

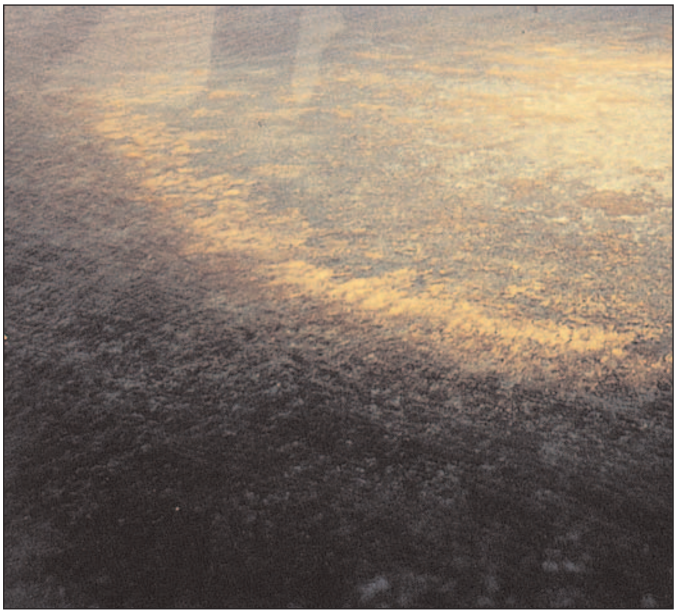



*Left: Zonation on a coral reef atoll in a location with a prevailing trade wind.*

*Reef slope: area of deep corals.*
*Reef front: drops steeply to a depth of 5–15 m.*
*Reef flat: area of stony corals, soft corals and coralline algae.*
*Patch reefs: rise from the lagoon floor and consist of stony corals and soft corals.*

## Structure and function

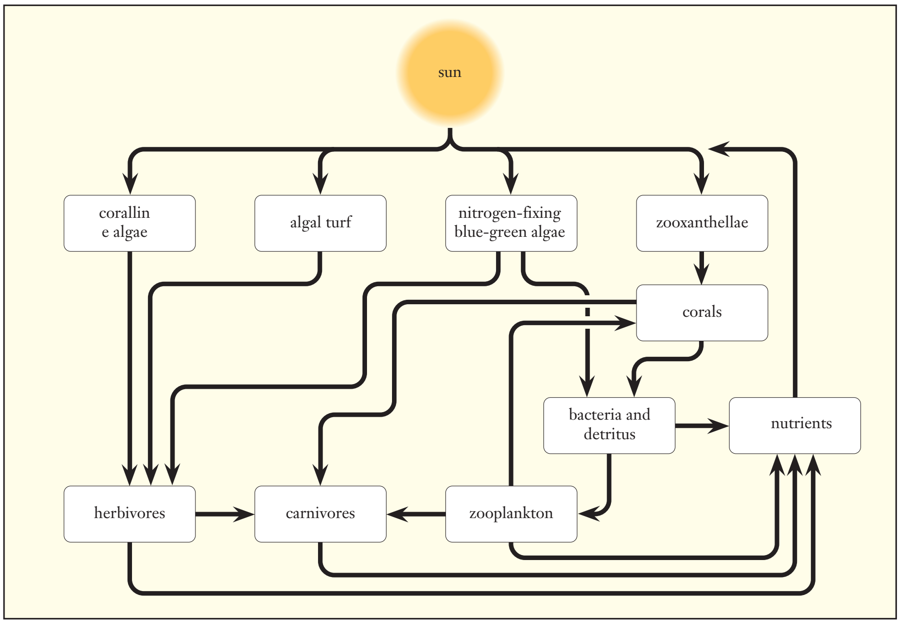
The stony reef-building corals provide shelter and substratum for a wide variety of organisms, and with their calcium carbonate skeletons help form the physical basis of the reef. This underlying structure consists partly of corals which remain *in situ*, but mostly of corals that have been broken down into sand and silt and then re-consolidated into calcite rock by many microbial and chemical processes. Over the reef grow hard, lime-encrusted coralline algae, which flourish in areas of wave action and give some protection against storms. In addition to the stony corals, the reef fauna include soft corals—which do not have solid skeletons of calcium carbonate.



*Above: an aerial view of a barrier reef off the coast of Puerto Rico. The yellowish region is the shallow crest, composed of the reef-building elkhorn coral.*

*Above right: brain coral, an example of a stony reef builder.*

The stony corals possess a symbiotic relationship with microscopic algae (zooxanthellae). Through photosynthesis (the use of light and nutrients) these algae trap energy and provide food which helps the coral to build its skeleton. In turn, the coral provides a place within its tissues for the algae to live, and provides the plant cells with vital nutrients in the form of animal waste products. This relationship provides a nutritive and perhaps competitive advantage for corals, but obviously limits their growth to areas where they can receive enough light (i.e. shallow, clear waters). A minority of coral species do not contain zooxanthellae—these colonize caves and deep water.




*Right: A simplified diagram of how a reef ecosystem works, with the zooxanthellae interacting with the coral, the coralline algae which cement the structure, and the filamentous blue-green algae (cyanobacteria) providing much of the nitrogen fixation. The algae are eaten by the herbivores which in turn are a food source for the carnivores, as are the zooplankton. The cycles are completed by the release of nutrients back into the system.*

## Threats to coral reefs

Serious damage to corals may result from a variety of human activities, including:

- oil pollution;
- sedimentation produced by deforestation, soil erosion, dredging and drilling activities;
- heated effluents from power plants;
- sewage and nutrient pollution;
- the use of dynamite as a method of catching fish;
- collection for the aquarium and souvenir trades;
- anchor damage from recreational boating.

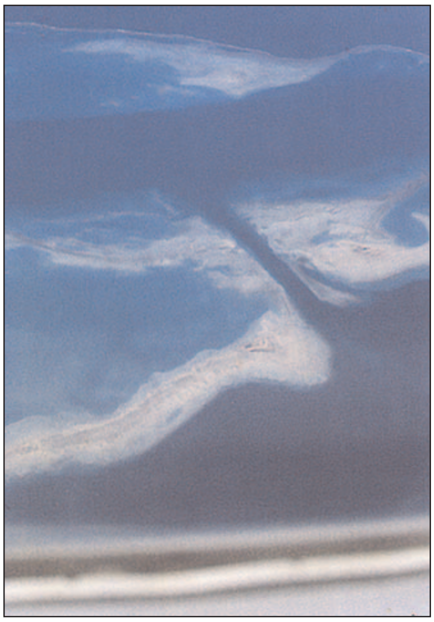
Major natural disturbances, such as hurricanes, also have an effect on coral reefs. Recently, studies on global warming and other climate changes have revealed additional threats. Increasingly warm temperatures have resulted in 'coral bleaching' events, when corals release the algae from their tissue. During and following such events, corals may suffer tissue damage, in which case they would be more susceptible to the effects of an oil spill.

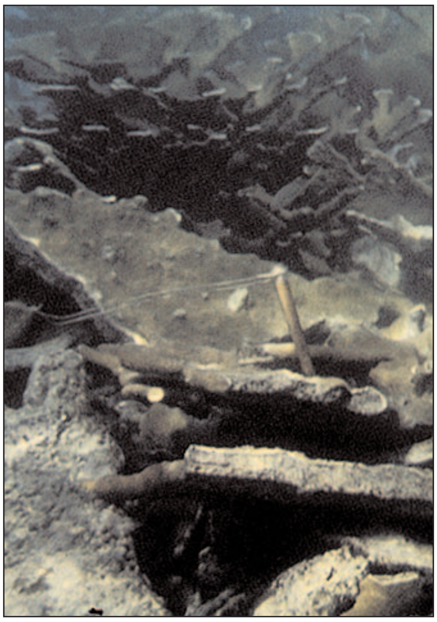
Research has shown that reefs can regenerate, but we still do not have a good understanding of the mechanisms or the time scale involved.

*Below left: This aerial view of a patch reef in the Red Sea shows mechanical damage in the form of a man-made channel.*

*Below centre: Large fronds of elkhorn coral broken during the passage of a tropical storm.*

*Below: Mechanical damage to a wide area of reef in the Florida Keys, caused by the grounding of a large freighter. Abundant sediment and rubble has resulted, which can lead to turbidity and thus be harmful for corals. The rubble can be mobilized in storms and cause additional mechanical damage. The structure of the reef may be cracked, leading to the loss of large pieces during storms.*





# EFFECTS OF OIL POLLUTION ON CORALS

## How oil comes into contact with corals

Oil can come into contact with corals in a number of ways. Oil is less dense than water so generally it floats over the reefs (though there is some dispersion and dissolution into the water column, as described later). However, some reef areas are exposed to the air during low tides as well as during exceptionally low tides due to lunar cycles. This situation, coupled with an oil spill, can cause direct contact of oil with the corals and result in smothering. Another mechanism involves waves breaking on the reefs and shoreline, creating droplets of oil that are distributed into the water column and come into contact with the corals. As corals secrete mucus, especially when stressed, the droplets can stick to them easily (but may subsequently be shed with the mucus). In some areas with high dust loadings and/or high particle content of the water column, oil can combine with mineral particles and sink, and these oily particles may affect the corals. The whole process of weathering (including evaporation and effect of sunlight) can also cause oil to sink and come into contact with deeper corals. Crude oil in some production areas may flow over the shore and continue underwater, smothering shallow reefs.

Oil components can dissolve in water to some extent, which exposes the corals to potentially toxic compounds. Generally, the concentrations of dissolved compounds decrease rapidly from the surface to the bottom. The use of chemical oil dispersants can increase the dispersion of the oil into the water, thus increasing the potential for contact with the corals. This has implications for spill response, considered later.

*Below: These photographs show the effects of exposure to oil on brain coral. A healthy coral is shown immediately below; the centre picture shows a coral after exposure to oil, with oil sticking to mucus. Compared with the healthy coral, the polyps (coral animals) are retracted, as the detail on the far right indicates.*

*Left: Coral reefs and tankers do not mix.*

## Laboratory studies

Most studies of the effects of oil on corals have been conducted in the laboratory. However, many of these studies are difficult to relate to actual field conditions as the concentration and type of oil under laboratory conditions were different. Some were conducted under static testing where additional stress could be induced by microbial activity, oxygen depletion and the accumulation of possibly toxic waste products. The wide range of effects on corals resulting from exposure to oil in the laboratory includes decrease in growth, decrease in reproductive and colonization capacity, negative effects on feeding and behaviour, and alteration of secretory activity of mucous cells. In a multidisciplinary study in Bermuda using a flow-through dosing system, effects on the major reef-building coral after exposure to oil at 20 parts per million for 24 hours included tissue rupture, polyp retraction and tissue swelling. However, after a few days in clean water the corals recovered.

## Field studies

Field reports on the biological impact of oil pollution in reef areas range from the mass mortality of fishes and invertebrates to no apparent effect. However, only a few reports deal with corals specifically, and a number of the results are ambiguous.

One long-term study of corals in the Gulf of Eilat, Red Sea, has shown that a steady, chronic discharge of oil onto a coral reef area from oil terminal operations causes effects which include decreased colonization, decreased coral viability, coral mortality, damage to the reproductive system and many other changes. It appears that these chronic events are more detrimental to corals than one-time oil exposures even though the one-time exposure is more visible, and chronic oil pollution can make corals more susceptible to natural phenomena. For example, data on the re-colonization of a coral reef after a very low tide in the Gulf of Eilat showed that after 10 years the corals re-established well in a relatively clean environment but those corals on a chronically oil-polluted reef did not. The study suggested that the presence of oil may affect coral settlement and/or development of coral larvae.

*Right: This table shows a summary of published information concerning oil effects on coral reefs (field studies).*

| Spill | Amount and type | Reported effect |
|---|---|---|
| 1968: Witwater spill,Galeta Island, Panama | 20,000 barrels diesel oil and Bunker C | Harmful effects on meiofauna, mangroves, fiddler crabs; elimination of algae; reef corals least affected |
| 1970: Pipeline break, Tarut Bay, Saudi Arabia | 100,000 barrels of Arabian light crude oil | Mortalities among crabs, bivalves, gastropods, fish; mangrove trees less affected; no detrimental effects on corals and other fauna; good subsequent recovery |
| 1971: M/V Solar Trader, Florida Keys | 520 tonnes fuel and lubricating oils | Numerous dead lobsters and clams; survey 8 months later reported large algal growth on corals |
| 1974: Sygma, east coast of Australia | 400 tonnes of heavy fuel oil | 13 km beaches affected, no reported effect on marine life |
| 1975: MV Lindenbank, Fanning Atoll, Pacific Ocean | 10,000 tonnes copra, palm oil, coconut oil | Mortalities in fish, crustacea and molluscs; later, extensive growth of the algae *Enteromorpha* and *Ulva*; reported complete recovery of coralline algae community after 11 months |
| 1969–79, Oil terminals, Gulf of Eilat, Red Sea | Many small scale chronic spills | Decrease in coral and fish diversity; lack of colonization by hermatypic corals in reef areas chronically polluted by oil; damage to reproductive systems of corals |
| 1982–84: Studies on one species of coral in Bermuda | 20–50 ppm exposure in field chambers (Arabian light crude oil) | No long-term effects on coral growth or behaviour in the field |
| Oil refinery, Aruba, Caribbean | 60 years chronic oil discharge, including spills and clean-up | Spatial structure of the reef deteriorated, living coral cover was low, fewer juveniles present downcurrent |
| 1985: Arabian Gulf Study | Coral reef exposed to Arabian light crude oil films floating above corals (0.10mm/5 days) | No visible effects during a one-year observation period; growth was not affected during the one-year follow-up |
| 1984–86: TROPICS experiment, Atlantic coast of Panama | 20–50 ppm exposure North Slope crude oil for 24 hours | Minor effects on seagrasses and corals; major effects on mangroves |
| 1986–91: Galeta oil spill, Panama | 50,000 barrels crude oil | Coral coverage significantly declined on the reef affected by the oil; corals to 6 m depth were affected after two years; long-term assessment still underway in 1992 |

*Left: Slicks coming from an oil-killed mangrove area, one and a half years after the spill.*

A study of a reef area downstream of a major oil refinery on the Caribbean island of Aruba has also shown a decreased viability of the reef over time, with deterioration of the spatial structure of the reef, low coral cover and fewer juveniles present. The results of chronic oil pollution in this study, including spills and clean-ups over a 60-year period, were seen over a distance of 10–15 km downcurrent of the refinery.

In a review of the effects of oil spills on corals by the US National Research Council, little damage was recorded from acute spills to the corals themselves, although associated organisms of the coral reefs, such as crustacea and sea urchins, were killed. A more recent field experiment in the Arabian Gulf concluded that no long-term effects were recorded when the corals were exposed to a floating crude oil film of 0.10 mm for five days. Work in a lagoonal reef system on the Atlantic coast of Panama showed that shallow corals (0–0.5 m) were slightly affected by a 24-hour exposure to fresh oil; but deep corals were not affected by oil exposure.

*Below: An oiled reef in Panama.*

However, the most recent study of an oil spill on corals in Panama has shown substantial coral damage caused by an oil spill, which included damage to corals living at 3–6 m depth. Branching corals appeared more susceptible than the massive corals, and recovery has been slow. This was the first major oil spill in a coral reef area where considerable baseline information was present prior to the spill. The results, which are inconsistent with those of other studies discussed above, may be due to the size of the spill and the fact that much of the oil was distributed into the mangrove sediments. These sediments are now slowly releasing the oil, and coral viability may be depressed due to continual slow leaching of oil. Thus, in this scenario, an acute oil spill can become a long-term chronic contamination problem.

*Right: An injured head of coral (the main reef-building species in this part of Panama), four and a half years after the spill.*

*Far right: Larval settlement plates for colonization studies.*

## Factors influencing impact and recovery

There are many factors that influence the effect of an oil spill on any ecosystem, and it is not surprising that there are conflicting reports of effects on coral reefs. Some of the most obvious factors are:

- the amount and type of oil spilled;
- the degree of weathering of the oil prior to contact with corals;
- the frequency of the contamination;
- the presence of other stress factors, such as high sedimentation;
- physical factors such as storms, rainfall and currents—the state of the tide during the initial contamination is very important;
- the nature of the clean-up operation;
- the type of coral; and
- seasonal factors, e.g. coral spawning.

*Right: Many corals spawn only once or twice a year, timed by lunar cycles. Eggs or larvae are released into the surface waters, where they are particularly vulnerable to oil. The pink stripe in this picture consists of the larvae of soft corals near Bermuda. They have floated to the surface and been swept into a band by convergence currents.*

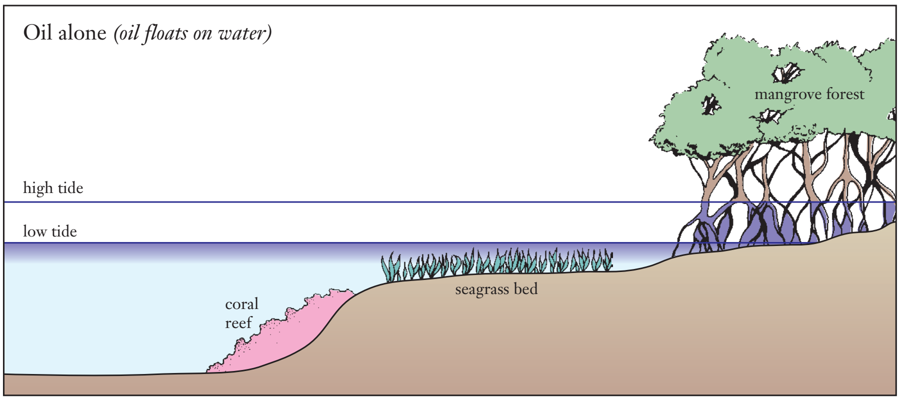
# CLEAN-UP CONSIDERATIONS

## Mechanical clean-up

One of the important considerations in the clean-up of coral reefs is that navigation in these areas can be difficult. On fringing reefs, little can really be done other than natural clean-up. In more quiescent lagoonal areas, booms and skimmers can be used, although in many parts of the world, navigation in these areas is usually carried out visually. Considering mechanical clean-up of an oil spill on the water outside of a normal navigation channel, the proximity of corals to the surface coupled with floating oil could present major problems for normal vessel operation.

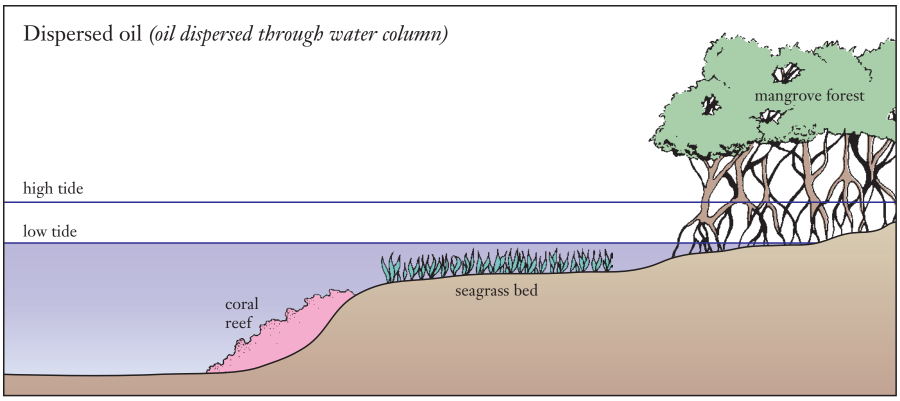
## Dispersants and the TROPICS experiment

In lagoonal situations the use of dispersants could be attractive, especially if mangroves or other sensitive areas such as a bird sanctuary were being threatened. The TROPICS experiment carried out for the American Petroleum Institute in



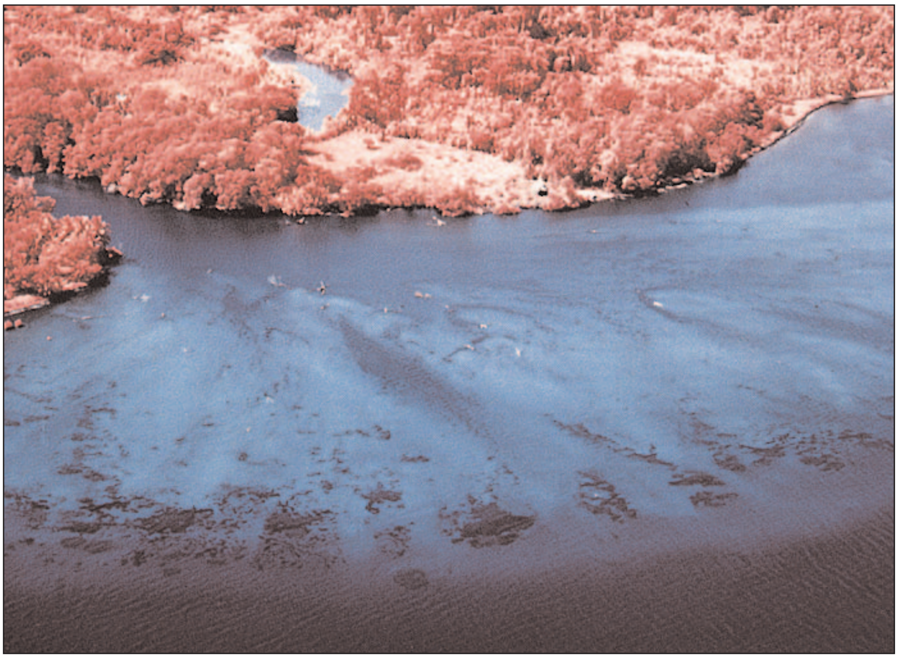

*Left: In most cases corals are associated with other sensitive areas such as seagrasses and mangroves. In this context, it is important to weigh up the advantages and disadvantages of different types of spill response for the different biological communities. A study in Panama, known as the TROPICS experiment, was undertaken to investigate this.*

*Where the oil is floating, the spill will affect surface corals, seagrasses and mangroves.*



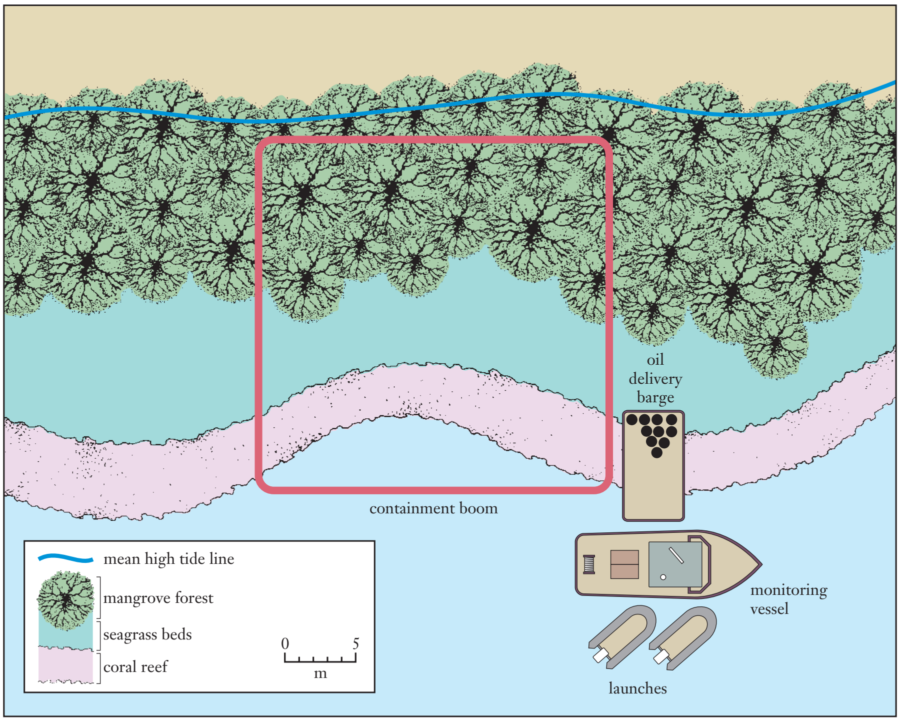

*Where the oil is dispersed through the water column, the mangrove community may be protected but seagrasses and deeper corals will be affected.*

*Right: An aerial view (infra-red) showing the association of mangroves and fringing reef.*

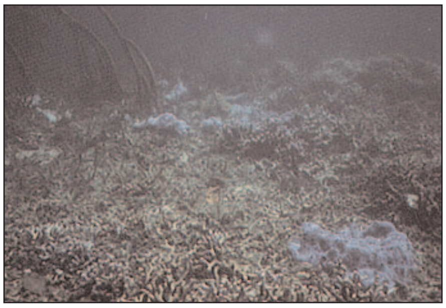


Panama illustrates a scenario where oil dispersants in areas with reasonable current speed could be used to protect a mangrove system. The experiment was a multi-disciplinary study to investigate the effects of untreated crude oil and crude oil treated with a chemical dispersant on tropical ecosystems containing mangroves, seagrasses and corals. This study simulated the 'worst case' exposure level for dispersed oil and a moderate exposure level for oil only.

*Right: A plan of the TROPICS experiment.*



Three sites were selected in Panama in 1000-$m^2$ sections. Booms were deployed around the sites and crude oil only was delivered to one site, oil and chemical dispersant was applied to the second, while the third remained as a control. Pollutants were applied evenly over a 24-hour period and the sites were monitored for two years after the spill. Assessments were made over time of the distribution and extent of contamination by hydrocarbons and the short- and long-term effects on survival, abundance and growth of the dominant flora and fauna of each habitat.



*Above: A shallow reef community following dispersed oil treatment. White patches are recently killed sponges. Many corals and other invertebrates were also affected.*

The whole, fresh, untreated oil had severe long-term effects on survival of mangroves and associated fauna, and relatively minor effects on seagrasses, corals and associated organisms. Chemically dispersed oil caused decline in the abundance of corals, sea urchins and other reef organisms, reduced coral growth in one species, and had minor or no effects on seagrasses and mangroves.
The results in the study point to the trade-offs in habitat survival that different decisions could make to inter-tidal and sub-tidal habitats. If one were to take no action in a spill, the mangroves and some inter-tidal organisms would suffer; however, in most environments the corals would remain healthy. Using dispersants nearshore can expose sub-tidal organisms to far more oil, and result in more coral and seagrass damage. However, the mangroves are likely to be less affected. The last conclusion of this study was that dispersants may provide a benefit if used in deep waters or areas with rapid dispersal, as the effects on organisms from this study were dose-related. Such information is an important input to decision making about dispersant use; for example, on the coral island of Bermuda the use of dispersants is limited to lagoonal areas of at least 10 m depth.

*Left: TROPICS experimental site with oil being released.*

# ACKNOWLEDGEMENTS AND FURTHER READING


## Acknowledgements

The author has spent the past 20 years involved in oil-spill research. Much of the funding for this work has been provided by grants from the oil industry as a whole. Specifically, the author would like to acknowledge support from the American Petroleum Institute, British Petroleum International, the government of Bermuda, Esso Bermuda, Exxon and the Mobil Oil Corporation for major funding. Dr Clay Cook provided helpful discussion during this review, and photographs were kindly loaned by Drs J. N. Butler, B. D. Keller, C. Hansen, H. Guzman and R. E. Dodge. The map showing global distribution of corals is based upon information given in Barnes, R. D. (1987) *Invertebrate Zoology* (fifth edition), Saunders College Publishing.


## 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 Number 4479, American Petroleum Institute, Washington D.C., 447–454.

Dubinsky, Z. (1990) *Coral Reefs*, Elsevier Scientific Publishing Co., 550 pp.

Jackson, J., *et al.* (1989) Ecological effects of a major oil spill on Panamanian coastal marine communities. *Science*, *243*, 37–44.

Knap, A. H., *et al*. (1985) The effects of chemically and physically dispersed oil on the brain coral *Diplonia shigosa (Dana)*—a summary review. *Proceedings 1985 Oil Spill Conference*, API Publication Number 4385, American Petroleum Institute, Washington D.C., 547–551.

LeGore, S. *et al.* (1989) Effect of chemically dispersed oil on Arabian Gulf corals: a field experiment. *Proceedings 1989 Oil Spill Conference*, API Publication Number 4479, American Petroleum Institute, Washington D.C., pp 375–380.

Loya, Y. and Rinkevich, B. (1980) Effects of oil on coral reef communities. *Marine Ecology Progress Series*, 3, 167–180.

Mann, K. H. (1982) *Ecology of Coastal Waters—A Systems Approach*, Chapter 6: Coral Reefs, 160–182, University of California Press, Berkeley and Los Angeles.

National Research Council (1985) *Oil in the Sea: Inputs, Fates and Effects*, National Academy Press, Washington D. C., 449–59.

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.

**Company Members**

Amerada Hess

BG Group

BHP Billiton

BP

Chevron

CNOOC

ConocoPhillips

EnCana

ENI

ExxonMobil

Hunt Oil

Hydro

Kuwait Petroleum Corporation

Mærsk Olie og Gas

Marathon Oil

Nexen

NOC Libya

Petroleum Development of Oman

Petronas

Petrotrin

PTTEP

Repsol

Saudi Aramco

Shell

Statoil

TNK-BP

Total

Woodside Energy

**Association Members**

American Petroleum Institute (API)

Australian Institute of Petroleum (AIP)

Canadian Association of Petroleum Producers (CAPP)

Canadian Petroleum Products Institute (CPPI)

CONCAWE

European Petroleum Industry Association (EUROPIA)

Institut Français du Pétrole (IFP)

International Association of Oil & Gas Producers (OGP)

Petroleum Association of Japan (PAJ)

Regional Association of Oil and Natural Gas Companies in Latin America and the Caribbean (ARPEL)

Regional Clean Sea Organisation (RECSO)

South African Petroleum Industry Association (SAPIA)

World Petroleum Congress (WPC)

IPIECA

International Petroleum Industry Environmental Conservation Association
5th Floor, 209–215 Blackfriars Road, London, SE1 8NL, United Kingdom
Telephone: +44 (0)20 7633 2388   Facsimile: +44 (0)20 7633 2389
E-mail: info@ipieca.org   Internet: www.ipieca.org