BAKER, J.M. — IMPACT OF OIL POLLUTION ON LIVING RESOURCES

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By Dr. J.M. Baker, Chairman
of the Working Group on Oil Pollution
of the IUCN Commission on Ecology
in cooperation with the World Wildlife Fund

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Contents

1. Introduction: Scope of The Report

Many thousands of papers on oil pollution and its effects are available in the scientific literature, as are several comprehensive reviews. This report is not intended to repeat previous work but presents aspects of particular concern to the World Wildlife Fund, the International Union for Conservation of Nature and Natural Resources, and related interests. It does not dwell at length on material available elsewhere, but gives references to appropriate reviews and papers.

Though accidental losses of oil at sea represent a relatively small proportion of total oil inputs to the environment, they are likely to be of most concern from the conservation point of view because the resulting slicks are particularly likely to coat birds, mammals, shore life and emergent vegetation. Emphasis is therefore given to this particular type of oil pollution, though without ignoring other sources.

Concerns may be expressed with regard to species, habitats or geographical areas. For ease of reference these three different but inevitably overlapping points of view have been covered in three different sections. All main plant and animal groups, all main habitats, and all major geographical areas have been dealt with in subsections with the aim of giving some reference material for any type of enquiry.

Particular sensitivities to oil pollution and clean-up operations are highlighted. The points raised for WWF/IUCN attention are based on informed opinion rather than derived through discussion of full background information in the report. In view of the wealth of information and discussion available elsewhere, it was felt that this pre-digested approach would be more useful to the WWF/IUCN, and would facilitate rapid response to particular incidents.

2. Oil Pollution and Clean-up Operations

National, international and industrial attempts to reduce oil pollution with the aim of preventing ecological damage should be encouraged as a first priority. Such attempts encompass improvements in areas as diverse as tanker construction and operations; shipping routes, navigational aids and pilotage procedures; terminal construction and operation; staff training; effluent treatment techniques; and regulatory controls at regional, national and international levels. Technical details are available in a number of publications, e.g., Wardley-Smith (1979) and UNEP (1982). Nevertheless, some oil pollution seems inevitable from the various sources outlined in Section 2.1.1., and clean-up capacity remains a necessity. A guide to the main intergovernmental and industry organisations concerned with various aspects of oil pollution in the marine environment (a total of 13 organisations) has been published by Witherby (1981).

2.1. Sources and Types of Oil Pollution

2.1.1. Estimates of inputs

Estimates of petroleum hydrocarbon inputs to the world's seas were reviewed by the Inter-Governmental Maritime Consultative Organisation (IMCO)—now the International Maritime Organisation (IMO)—and the US National Academy of Sciences in 1981 (IMCO, 1981) and their conclusions were as follows:

According to region, the relative importance of the various sources may differ from the overall world figures given above (see Section 5).

Sources of oil pollution are discussed in more detail in a number of publications, e.g., RCEP (1981) and IMCO (1981). It should be pointed out that most published discussions are concerned with the marine environment, but that some oil pollution of terrestrial and freshwater habitats also occurs through formation water discharges, blow-outs, pipeline breaks, storage tank leaks, road or rail accidents, and boat traffic on inland waterways.

2.1.2. Oil types and states

Crude oils from different fields may differ widely in physical, chemical and toxicological properties, as do refined products which range from gasoline to heavy fuel oil. Moreover according to source oil may reach the environment in different physical states, and this partly determines the types of organisms most threatened. Though accidental losses represent a relatively small proportion of the total oil inputs they are likely to be of the most concern to WWF/IUCN. This is because they usually produce coherent slicks which may coat birds, mammals, shore life and emergent vegetation. Normal operational pollution including that from land-based discharges usually comprises diluted dissolved and dispersed oil. In these physical states (which are also found under and round concentrated oil slicks) oil is likely to affect plankton, fish and benthic invertebrates. Some reaches the bottom sediments, where it may be retained with possible long-term chronic effects as it gradually breaks down.

Further information on oil types and states is given in Sections 2.3.2 and 2.3.4.

TABLE 1. *Inputs of petroleum hydrocarbons in the marine environment* (million metric tonnes per annum)

	Best estimate	Probable range	1973 estimate
Transportation	1.49	1.00–2.60	2.1
Tanker operation	0.71	0.44–1.45	
Drydocking	0.03	0.02–0.05	
Marine terminals	0.02	0.01–0.03	
Bilge and fuel oil	0.32	0.16–0.60	
Tanker accidents	0.39	0.35–0.43	
Non-tanker accidents	0.02	0.02–0.04	
Production platforms	0.05	0.04–0.07	0.08
Atmospheric	0.30	0.05–0.50	0.60
Municipal, industrial wastes, run-off	1.40	0.70–2.80	2.80
Natural seeps/erosion	0.30	0.03–2.60	0.60
Total	3.6	1.8–8.6	6.1

2.2. Fate of Oil

Physical and chemical changes in oil discharged into the sea are described in many publications, for example, the recent review by RCEP (1981) and are summarized in Fig. 1. Briefly, the oil is redistributed relatively quickly by the physical processes of spreading, evaporation, dispersion, solution, adsorption and sinking. Degradation occurs through chemical oxidation (especially under the influence of ultra-violet light) and by biological processes.

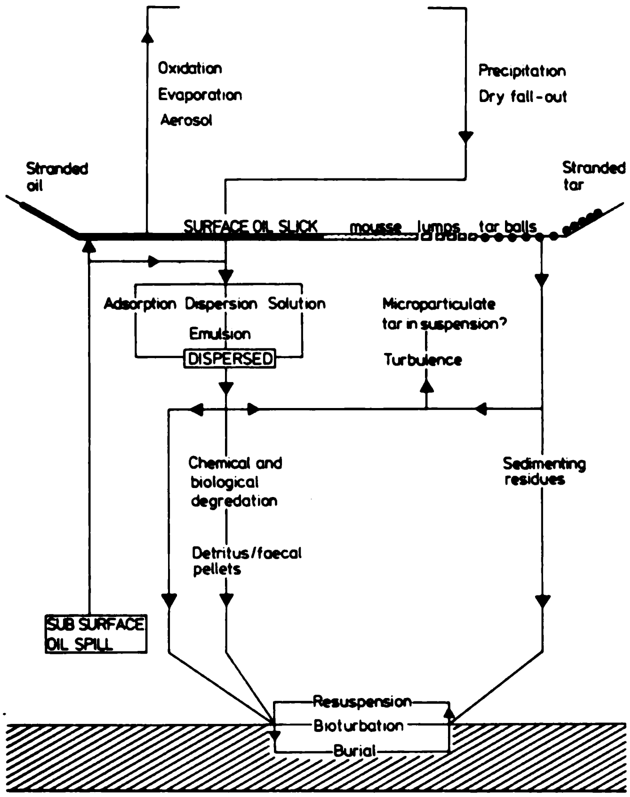

Fig. 1. A summary of the natural processes of dispersal and modification of oil in the marine environment (after Whittle *et al.* (1978), modified by Gunkel and Gassmann (1980)).

Processes likely to be of particular interest to WWF/IUCN include:

2.2.1. Mousse formation

Mousse is a water-in-oil emulsion which commonly forms at sea from crude oils. Water content can be as high as 80%, and the mousse usually proves relatively resistant to physical and chemical breakdown. Mousse formation means that the volume of pollutant increases, as does its intractability and its smothering capacity. Mousse has been the major pollutant after several well-known oil spills, e.g., the 'Torrey Canyon', the 'Metula' and the 'Amoco Cadiz'.

2.2.2. Adsorption and sedimentation

Hydrocarbons may adsorb onto particles (variously composed of clay, organic matter, plankton remains and living microbes). Such particles, sooner or later, sink to the bottom, where the rate of hydrocarbon degradation will depend not only on the hydrocarbon type but on the local physical and chemical conditions. There are several reports on enhanced hydrocarbon concentrations in the bottom sediments of estuaries and nearshore waters (see, for example, Dicks and Hartley, 1982), but little is known about the importance of sedimentation in deep waters.

2.2.3. Degradation

Crude oil is likely to contain thousands of different hydrocarbon and other compounds, with differing degradation rates. These rates may also vary according to temperature and oxygen concentration of the water, physical and chemical properties of the oil, relative extent of photochemical activity, and nutrients available to micro-organisms. A large number of different species of bacteria and fungi have been shown to be hydrocarbon degraders and under the right conditions even intractable products such as asphalt can be, at least partially, broken down. The toxicity of intermediate breakdown products is, however, largely unknown. There is consistent evidence that degradation rates are slow for petroleum hydrocarbons in poorly oxygenated sediments.

Detailed information of the degradation of oils is given by Malins (1981). Information of particular relevance to refinery effluents is available in CONCAWE (1979b).

2.3. Factors Influencing Extent of Damage

'Damage' to organisms may include (a) toxic effects leading to changes in metabolic functions such as photosynthesis of respiration; (b) physical smothering; and (c) tainting. Toxic effects and smothering may be lethal or sub-lethal (sub-lethal effects include reduced growth and reduced reproduction). Tainting in the sense of visible or tasteable contamination can lead to economic loss even if the health of the organisms involved (e.g., shellfish) is not directly affected. The concept of 'damage' also includes damage to the habitat as a whole, for example, oil may be retained in sediments for many years, exerting long-term effects on species composition and abundance.

'Recovery' may be defined as a return to the pre-pollution structure and functioning of the ecosystem or area covered, bearing in mind the range of natural fluctuations. The term is often used subjectively—inevitably so because quantitative pre-pollution data are frequently lacking.

Factors which influence the extent of damage are identified below and also mentioned as appropriate in the different species and habitat sections. More detailed information and references are available in Wardley-Smith (1983).

2.3.1. Volume of oil

It is hardly necessary to say that the greater the volume of oil discharged the greater the potential damage. In coastal areas or large lakes there is, however, a limit to the amount of light oil which will stick to a shore, and excess will run off and be carried elsewhere, perhaps to more distant shores, by the tide and the wind. Damage caused by light oil remaining on any particular shore is therefore more likely to be related to the toxicity of the oil, and to the type of biological community. If the oil is thick and viscous, for example heavily-weathered crude oil, heavy fuel oils, or mousses, then much larger amounts can stay on a shore, and the plants and animals may be smothered under a sticky blanket.

2.3.2. Type of oil

A variety of crude oil and oil products have been studied in various ways, and it is evident that both crude oils and products differ widely in toxicity. Toxicity does not vary consistently with oil properties, but in general, it appears that severe, toxic effects are associated with low boiling compounds and aromatics. With plants (which have been studied with herbicidal oils in mind) there is experimental evidence that toxicity increase along the series alkanes (paraffins)–cycloalkanes (naphthenes)–alkenes (olefins)–aromatics. Within each series of hydrocarbons the smaller molecules are usually more toxic than the larger.

These results are in general agreement with experiments on animals. Observations following oil spills suggest that the greatest short-term damage has been caused by lighter oil, particularly when confined in a small area, for example the diesel fuel from the 'Tampico Maru', the No. 2 fuel from the 'Florida', and the gasoline from the 'Dona Marika'. Severe immediate effects (in the case of the 'Dona Marika', reduction of the limpet population over about one mile of shore from 50 per m^2 to 1–10 per 100 m^2) do not appear to preclude good, if not complete, recovery over periods of time ranging from two to ten years.

Spills of heavy oils, such as 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.

Long-lived oils and oil incorporated into sediments (which sometimes includes more toxic lighter oils) may have longer-term chronic effects, and some concern has been expressed in particular over uptake of hydrocarbons including carcinogenic polycyclic aromatics. There is much evidence in the literature consistent with the generalisation that marine organisms exposed to petroleum hydrocarbons will rapidly accumulate those compounds in the tissues (see, for example, Section 3.5.1) but will gradually release most of the quantities taken up once the source of contamination has been removed.

2.3.3. Frequency of oiling

Estuarine and coastal waters near oil ports (Fig. 2) may suffer from comparatively large numbers of small spillages. Problems arise where many such spillages affect the same area, because in such a case the communities affected may never have a chance to recover properly.

The greatest frequency of oiling may be found near continuous discharges such as refinery effluents. Effluents which receive only primary treatment (gravity separation) commonly have oil contents between 5 and 25 parts of oil per million of water (ppm). In calm conditions thin oil films may rise to the water surface in the discharge area, and be left on the shore as the tide goes down.

2.3.4. State of oil

Any particular type of oil may have different effects according to whether it reaches living organisms as thin oil films, thick oil films, water-in-oil emulsions or oil-in-water emulsions. Oil films or water-in-oil emulsions (i.e., mousses) may coat organisms and have a directly toxic effect and/or a physically smothering effect. Oil-in-water emulsions may be formed from oil slicks, naturally or following the use of dispersants, and may be present in a variety of industrial and other effluents from land-based discharges. Such emulsions, which may disperse through large volumes of water, are more readily available to bacteria for degradation, but oil in this state is more likely to be ingested by plankton and a variety of animals which feed by filtering particles from the water.

2.3.5. Interactions affecting oil toxicity

The toxicity of oil may be altered through interactions with other compounds and this is of particular importance when considering effluents which contain low concentrations of oil and other compounds. Factors which may cause variations

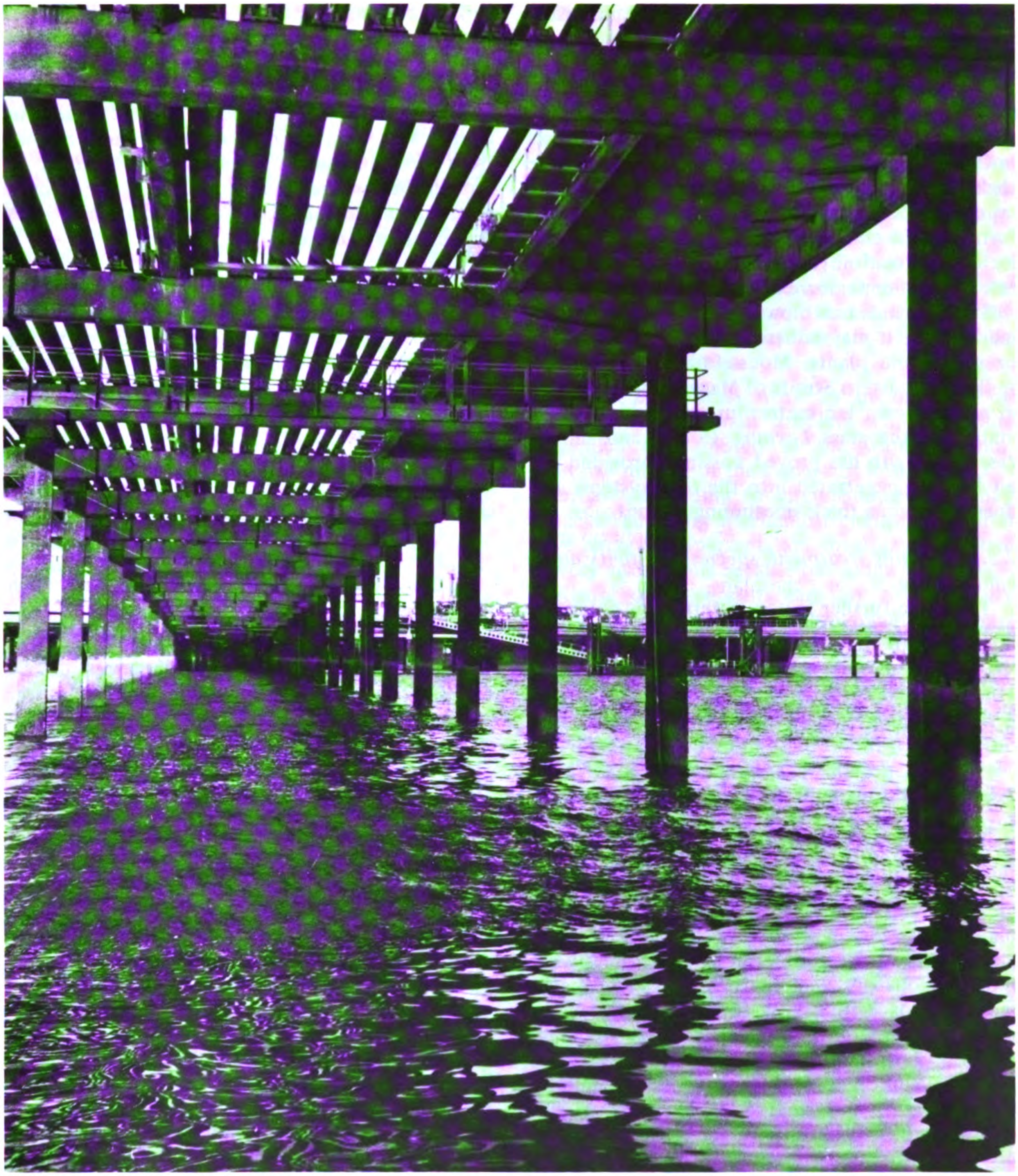

Fig. 2. Part of the oilport of Milford Haven, UK.

in toxicity of the oil by increasing or reducing the stress to particular organisms include salinity, pH, sulphides, phenols, ammonium compounds, suspended material, dispersants and temperature.

2.3.6. Topography, hydrography and climate

With some spillages, for example the 'Tampico Maru' and the 'Dona Marika', oils have been spilt and more or less confined in bays through various circumstances including currents, tides and prevailing wind direction.

Tidal range is important in determining the extent of intertidal contamination. Some refinery effluents are discharged into small bays or creeks where the hydrography does not favour rapid dispersal. These various conditions all help to produce localised effects of varying severity. Conversely, hydrographic conditions leading to good dilution and dispersal help minimise oil pollution effects and are an important consideration if the use of chemical dispersants is contemplated (see Section 2.4.3).

Climatic and weather conditions can influence the course of events following a spill by determining evaporation rates (wind and temperature), formation of emulsions (wind and waves), viscosity of stranded oil (temperature) and degradation rate of oil (temperature and sunlight).

Strong winds can blow oil above the high tide mark where it may adhere to cliff plants, lichens or sand dune plants. Mousse from the 'Metula' spill in the eastern Straits of Magellan in 1974 was in places blown ten metres into sand dunes dominated by the grass *Leymus*. In this and similar cases re-growth has proved possible, provided the oil has not penetrated into the root systems and does not form a thick smothering deposit.

2.3.7. Cleaning treatment, species sensitivity and habitat type

These are further factors determining extent of damage; these are dealt with elsewhere in the report.

More detailed information and references for all the factors mentioned above are available in Wardley-Smith (1983).

2.4. Oil Spill Clean-up

Methods available for oil spill clean-up are given below. It should be emphasised that a knowledge of the properties of the spilt oil and of local conditions are essential pre-requisites for planning a clean-up strategy—for example chemical dispersants are not effective on some of the more viscous oils and mousses, and in any case may be unacceptable in some shallow coastal waters because of insufficient capacity for rapid dilution. Local knowledge is best built into regional oilspill response plans, prepared and rehearsed *before* the event. Such plans should aim to resolve possible conflicts, for example, should dispersants be used on crude oil slicks in a seabird breeding area, in an effort to minimise bird casualties, *even if* the oil consequently dispersed into the water column kills fish eggs and larvae? Should a rocky shore in a tourist area be steam-cleaned *even if* this causes far more damage to shore life than not treating the shore at all?

Any oil spill response plan should recognise the fact that if large quantities of oil are spilt in coastal waters, some shore pollution is more or less inevitable.

The various methods available for oil spill clean-up may be listed as follows:

2.4.1. Natural clean-up

The 'do nothing' approach. A valid option in many cases, e.g., in some open sea areas remote from bird colonies; on exposed rocky shores; or on marshes where any form of clean-up would result in unacceptable physical disturbance such as trampling damage.

2.4.2. Mechanical

1. Containment and recovery from the water surface, e.g., using booms and skimmers, or sorbents and various collection devices. Limitations include sea state and current speeds.
2. Removal by pumping.
3. Use of heavy earth-moving equipment, e.g., on sandy beaches.
4. Use of custom-built beach-cleaning machines.
5. Hosing (high or low pressure) of beaches.
6. Hot water/steam treatment of beaches.
7. Use of cutting equipment (e.g., on marsh vegetation).
8. 'Disturbance' of sediments to release oil, e.g., using high pressure hosing or ploughing techniques.

2.4.3. Chemical

1. Dispersants. These may provide the only means of dealing with slicks in comparatively rough open sea conditions, and may also be used in nearshore waters and on the shore. However there are several limitations (see Section 2.4.8.2)
2. 'Herding' using surface-active agents.*
3. Gelling.*

2.4.4. Manual

1. Collection of tarballs.
2. Handspreading and collection of sorbents such as straw.
3. Cutting, e.g., oily seaweed.

2.4.5. Sinking

Sinking of slicks of relatively heavy oils, e.g., with sand. This should not be done where there is any likelihood that oil will reach vulnerable bottom areas such as shellfish beds.

2.4.6. Burning

Burning of floating or stranded oil is usually difficult because of rapid loss of volatiles; however this technique seems promising for polar

*Little used. Expensive, and ineffective if large amounts of oil are involved.

regions (for reasons outlined in Section 5.1) and air-droppable igniters for remote areas have been developed.

2.4.7. Enhanced biodegradation

Biodegradation of oil occurs naturally; oil-organisms are ubiquitous and rapidly multiply under suitable conditions. The degradation process requires oxygen and nutrients. Under some circumstances biodegradation may be enhanced through addition of micro-organisms and/or nutrients and oxygenation. Oxygenation is promoted by dispersal of the oil, which increases its surface area.

2.4.8. Uses and limitations

The uses and limitations of these various methods are described in a number of publications, a selection of which is given in the bibliography (see Section 2.4.9). For the purposes of this report, it is probably more useful to highlight the particular sensitivities of different species and habitats to different types of cleaning, and this is done as appropriate in Sections 3 and 4. The following general comments are concerned mainly with the two common clean-up approaches of physical removal and chemical dispersal. References are available in Wardley-Smith (1983).

2.4.8.1 Physical removal of oil and oily substrates, either on a large scale using bulldozers or on a small scale using buckets and spades, is commonly used on amenity sand and shingle areas. Such areas are not usually the richest of shores biologically, and physical removal appears to be acceptable from both the biological and amenity points of view. This method is not usually suitable, however, on rugged rocky shores or soft mud or saltmarsh substrates. Appropriate machinery cannot easily be manoeuvered along these types of shore, and removal of surface layers of sediment from mud flats and marshes would probably mean removal of many animals such as worms, and root systems of plants. This method is only likely to be justifiable in cases of thick smothering by potentially long-lived deposits which would prevent re-colonisation by plants and animals. In cases where lightly oiled saltmarshes have to be treated (e.g., for amenity reasons or because birds are threatened), the cutting and removal of oily stems and leaves (not the wholesale removal of the marsh surface) seems to be an acceptable treatment provided that heavy trampling damage can be avoided. However, from the point of view of vegetation recovery alone, it is probably best to leave the marsh alone.

The disposal of collected oil and oily debris is described by CONCAWE (1980b). Techniques may be classified into three groups, namely recovery of oil for reuse, stabilisation of the oily waste, and destruction or decomposition of the oil. Recovery techniques include gravity separation, emulsion breaking, and a variety of washing or extraction procedures. Oily waste can be stabilised through use in civil works or by a large range of landfill procedures. Destructive techniques include biological degradation or heat treatment (which may permit heat recovery). Biological degradation of oily refinery wastes through the technique of 'sludge farming' is described by CONCAWE (1980a).

2.4.8.2 Dispersants work by breaking up oil slicks into very small droplets which become suspended and diluted in the water column. Effective mixing of the dispersant into the slick is essential—according to circumstances this may be achieved using mechanical energy or natural wave energy. Dispersants are not usually effective on very viscous oils because of mixing problems.

Misuse of dispersants can give rise to many problems and the severe and sometimes long-lasting effects of products used to clear the 'Torrey Canyon' oil are often quoted. These early products were much more toxic than dispersants now available (some comparative figures are given by Norton and Franklin, 1980), but whatever the toxicity of a dispersant, its use on many sedimentary environments or in shallow water may cause problems by increasing the penetration in sediment or water column distribution of the oil. Misuses of dispersants during transport and handling can sometimes affect areas above high tide mark. Spillage of comparatively toxic products on cliffs during the 'Torrey Canyon' cleaning operations damaged several areas of cliff vegetation, and re-colonisation was slow. Spraying the shore and nearshore waters, indiscriminately or in windy conditions, can result in dispersant reaching lichens and other plants growing on cliffs, with little likelihood of dilution with adequate quantities of seawater.

2.4.9. Bibliography of clean-up techniques

CONCAWE (1980a) Sludge farming: a technique for the disposal of oily refinery wastes, *Report No. 3/80*, CONCAWE, Den Haag.

CONCAWE (1980b) Disposal techniques for spilt oil, *Report No. 9/80*, CONCAWE, Den Haag, 52 pp.

CONCAWE (1981a) Revised inland oil spill clean-up manual, *Report No. 7/81*, CONCAWE, Den Haag, 152 pp.

CONCAWE (1981b) A field guide to coastal oil spill control and clean-up techniques, *Report No. 9/81*, CONCAWE, Den Haag, 112 pp.

Environment Canada (1981a) Preliminary assessment of certain beach clean-up techniques, *Report No. EPS 4-EC-81-1*, Environmental Impact Control Directorate, February 1981, 57 pp.

Environment Canada (1981) Oil spill barriers and their use, *Report No. EPS-3-EC-81-5*, Environmental Impact Control Directorate, December 1981, 95 pp.

Environment Canada (1982) Canadian inland waters: coastal environments and the cleanup of oil spills, *Report No. EPS 3-EC-82-3*, Environmental Impact Control Directorate, July 1982, 33 pp.

Institute of Petroleum (1979) *Code of Practice for the Use of Oil Slick Dispersants*, Heyden & Son on behalf of the Institute of Petroleum, London, 34 pp.

International Maritime Organisation (1982) *IMO/UNEP Guidelines on Oil Spill Dispersant Application and Environmental Considerations*, IMO, London, 43 pp.

IPIECA (1980) *Application and Environmental Effects of Oil Spill Chemicals*, International Petroleum Industry Environmental Conservation Association, June 1980, 19 pp.

IPIECA (1980) *Oil Spill Chemicals: a bibliography on the nature, application, effects and testing of chemicals used against oil spilled in the marine environment*, International Petroleum Industry Environmental Conservation Association, June 1980, 83 pp.

ITOPF (International Tanker Owners Pollution Federation) publishes a series of technical information papers on various aspects of oil spill response and clean-up. Information from International Tanker Owners Pollution Federation Ltd., Staple Hall, 87–90 Houndsditch, London EC3A 7AX, UK.

Wardley-Smith, J. (ed.) (1983) *The Control of Oil Pollution* (revised edition), Graham and Trotman, London, 285 pp.

3. Effects of Oil Pollution and Clean-up: Animal and Plant Groups

3.1. Mammals

3.1.1. Information summary

Seals have been oiled on a number of occasions, for example, elephant seals and California sea lions following the Santa Barbara blow-out (Brownell, 1971; Geraci and Smith, 1977), and grey seals on Skomer Island (southwest Wales, UK) following an oil spill of undetermined origin in 1974 (Davis, 1974), and the 'Christos Bitas' accident in 1978 (Bourne, 1979). Effects on health and survival of adult seals appear to have been small but in the case of the Skomer seals some oiled pups died. In all these cases, however, it has been difficult to rigorously separate oiling effects from natural mortalities. A controlled experiment in Canada (Geraci and Smith, 1977) showed that up to 75 ml of ingested crude oil was not irreversibly harmful to ringed seals but that surface contact had a far greater effect, particularly on eyes.

Eleven otters are known to have been killed by the Bunker 'C' fuel oil spilt from the 'Esso Bernicia' in Sullom Voe, Shetland, UK, and a further 18 reported oiled but alive (Richardson, 1979). Attention has also been drawn to the vulnerability of sea otters in Canada (Ellis, 1979), and in California (Van Blaricom and Jameson, 1982).

Other animals at risk are manatees, whales and polar bears. There is so far little reliable information concerning oil pollution effects on manatees and whales, but results of an experimental study with four polar bears (Engelhardt, 1981) indicate long-term toxic effects and in some cases death following attempts to lick heavy oil deposits from fur.

In various places throughout the world, domestic animals (sheep, cattle and horses) graze on saltmarshes. The possibility of contamination of important grazing areas should be borne in mind. Additionally, sheep sometimes graze on seaweed dominated shores and following the 'Esso Bernicia' accident in Sullom Voe, Shetland, UK, 50 sheep were killed and the fleeces of over 2000 oiled (Richardson, 1979).

3.1.2. Points for WWF/IUCN consideration

1. There is no doubt that mammals using intertidal areas or the sea–air interface are at risk in spill areas; that some may die following oil contamination and ingestion, and that others may suffer a range of sub-lethal effects.

2. Local populations of some mammals, e.g., otters, could be significantly affected following bad spills.

3. It seems unnecesary to carry out further experimental oiling of mammals as a means of obtaining further information.

4. If mammals are considered a conservation priority at a particular site, then chemical dispersants should be used on slicks amenable to such treatment, in spite of the enhanced risk to water column or seabed organisms.

5. Cleaning methods (and cleaning success) for oiled mammals are less well researched than for birds.

3.2. Birds

3.2.1. Information summary

RCEP (1981) have summarised the mechanisms of oil pollution damage to birds as follows:

The most obvious effect "is to damage the plumage on which they depend for their insulation and waterproofing. The matting of the plumage by oil allows water to penetrate the air spaces between the feathers and the skin, with the result that the birds lose buoyancy and may sink and drown. Furthermore, having now no natural insulating layer of air, they rapidly lose heat. To counter this, there is an increased metabolism of food reserves in the body which, in heavily oiled birds, may amount to twice the normal rate and which may show a substantial increase even in lightly oiled birds. This increased metabolism is not balanced by a corresponding increase in the food intake. Indeed, a severely oiled bird is unable to hunt and catch its food; as a result, it rapidly becomes emaciated as well as cold and ill, and its chances of survival are small. Birds encountering freshly spilled oil may inhale fumes and by attempting to preen themselves may ingest significant amounts of toxic material; this may lead to respiratory and intestinal irritation and damage to organs such as the liver and kidneys. Stress and shock enhance the effects of exposure and poisoning. Birds exposed to more weathered oil are less likely to be poisoned but are vulnerable to the physical effects so long as the oil remains fluid enough to soak or adhere to feathers."

A wide variety of birds may be affected by pollution but species which spend much of their time on the sea surface are of course particularly at risk. For example, Bourne *et al.* (1967) estimated the loss of 30 000 seabirds in oil released in the 'Torrey Canyon' incident. A sample of 1233 birds killed in that incident included eight species of which 97% were guillemots and razorbills, many immature. Two spills in February 1979 between Nova Scotia and Newfoundland, Canada, caused reported losses of 1500 ducks and seabirds and an estimated total kill of more than 12 000 (Brown *et al.*, 1973). Some of the kill occurred more than 200 kilometres from the spill sites as the oil drifted on the sea. Species lost included oldsquaws, red-breasted mergansers, grebes, dovekies, murres, black guillemots, fulmars and common eider ducks (subspecies *borealis*).

Small discharges, often 'operational' rather than accidental, can be a serious problem in some areas. For example, in February 1969 an estimated 100–200 tons of oil in the Dutch Wadden Sea caused the death of probably about 40 000 birds, mainly eider ducks and common scoters (Swennen and Spaans, 1970). In January 1981, north-westerly gales drove many birds from their wintering grounds around the north of Scotland towards the Scandinavian coasts. Many were concentrated in the Skagerrak, and relatively small discharges from, perhaps, two ships resulted in the stranding of an estimated 30 000 oil-damaged birds, some of which were shown by leg rings to be immature birds from Orkney and Shetland (RCEP, 1981).

If an oil slick is discovered moving towards a concentration of birds, there is probably little that can be done to prevent heavy casualties unless the slick is amenable to dispersant treatment. Recent studies by Peakall *et al.* (1982) on the effects on herring gulls of Prudhoe Bay crude oil and oil-dispersant mixtures (Corexit 9527) indicate that the dispersant has only minimal effects on growth and organ weights and that the effects of an oil-dispersant emulsion are not much greater than those of the oil alone. Dispersion of oil into the water column would be expected to reduce markedly the exposure of seabirds to oil. The results, based on one oil and one dispersant, indicate that decreased exposure would more than compensate for the minor increase in adverse effects seen when dispersant is added to oil.

In exceptionally favourable conditions it may be possible to deflect or contain the approaching oil by deploying booms. Investigations have also been made into the possibilities of scaring birds from the path of the oil or of trapping them and holding them in captivity until their territority is clean.

RCEP (1981) came to the following conclusions concerning the treatment of oiled birds: "Effective cleaning methods exist and have been applied successfully to the treatment of birds such as swans, geese and some species of duck. While the same methods are effective on birds such as auks and divers, which are more at risk from floating oil, several factors militate against cleaning making a realistic contribution to their conservation. These species are more likely to be heavily oiled than swans or geese, they are generally in much poorer condition by the time they are rescued from the shore, their treatment requires more elaborate facilities and, because they are gregarious, the numbers affected in an oiling incident are generally such as to swamp the resources of bird cleaners. Only a very small proportion of oiled auks or diving seabirds can be rescued, rehabilitated and returned to the sea, even in the most favourable circumstances. The Royal Society for the Prevention of Cruelty to Animals which has had much experience in handling oiled birds, and the Royal Society for the Protection of Birds, acknowledge this and it is their policy that, in general, it is more humane to destroy oiled birds." Nevertheless, it should be recognized that, according to species and circumstances, the lives of individual birds can be saved, and that large numbers of people are concerned that they should be.

In summary, as a result of oil pollution individual birds are undoubtedly harmed, localised seabird colonies may be at risk, and species such as auks and divers that spend much time on the water and have low reproductive rates are especially vulnerable.

3.2.2. Points for WWF/IUCN consideration

1. Birds using the water–air interface are at risk in oil release areas. Most birds that come in contact with oil die.

2. Local populations and subspecies may be significantly reduced if oil occurs in areas where birds concentrate. It follows that the total populations of species with very local distributions may be at risk.

3. No available spill response measures are likely to significantly reduce overall seabird casualties, though dispersants may be useful in some circumstances, as may bird-scarers.

4. If birds are considered a conservation priority at a particular site, then chemical dispersants should be used on slicks amenable to such treatment, in spite of the enhanced risk to water column or seabed organisms.

5. In general, it is more humane to destroy badly-oiled birds than to attempt cleaning and rehabilitation. On an individual basis, some birds can and should be saved.

3.3. Reptiles and Amphibians

No information concerning deleterious effects of oils on reptiles has been found, but the following possibilities exist.

3.3.1. Turtles

Oil on the shore between the sea and laying areas could coat adult turtles moving up the shore, possibly to the detriment of their eggs which might get oily while being laid. The young which, after hatching, go down the shore to the sea, might also be oiled and suffer.

Witham (1978) reports the death of two small green turtles, one of which was found with tar in its mouth and the other found covered with oil. He also points out that young sea turtles are so infrequently seen after leaving their natal beach that the period is called the 'lost year' and that young turtles dying as a result of oil spills would probably also be seen only infrequently (regardless of how serious the problem really is).

3.3.2. Others

Crocodiles, alligators, frogs and toads may all be at risk, mainly in freshwater habitats but occasionally (e.g., with some crocodiles) in estuaries or nearshore waters.

3.4. Fish

3.4.1. Information summary

RCEP (1981) concluded that the surfaces of most fish are coated with mucous to which oil does not readily adhere although dispersants tend to destroy this protection. Gross oil pollution may clog fish gills and so cause asphyxiation; however, the main concerns are that adult fish or young fish congregating in shallow water might be harmed by toxic oil constituents dispersed in the water column. Light oils such as gasoline which are highly toxic have been known to cause substantial fish kills when spilled in restricted inshore localities (GESAMP, 1977).

There is no definitive evidence which suggests that oil pollution has significant effects on adult fish populations in the open sea; this does not mean that effects do not exist. Reed (1981) concludes that sampling problems result in such large confidence limits on field survey estimates that mortality below an order of magnitude greater than normal would be virtually impossible to detect. Reed describes computer modelling as an alternative approach and describes an example from the Georges Bank. This indicates that a thirty-day spring blowout releasing 5000 tons of oil per day would cause a maximum reduction of about 1400 tonnes of cod, distributed over five years. The validity of computer models has, however, been questioned (White, 1983, pers. comm.) because of inadequacies in basic data.

Malins and Hodgins (1981) concluded that "there is ample evidence that fish exposed to petroleum in sediments, water or through the diet accumulate hydrocarbons in tissues and body fluids. The tissues are purged of these hydrocarbons when the fish are no longer exposed." However, some of the metabolic products may remain in the tissues for prolonged periods. Laboratory studies have shown that the accumulation of hydrocarbons and the metabolites in fish causes a number of deleterious changes that can affect survival; however, many of these changes were induced at relatively high concentrations that probably would not be encountered in the marine environment.

Fish eggs and larvae are relatively immobile. Immediately underneath oil slicks there are likely to be heavy mortalities which may be exacerbated by the use of dispersants. Chronic sublethal effects have been extensively studied, and it is clear that under laboratory conditions chronic exposure to relatively low levels of petroleum hydrocarbons (0.1–1 ppm) can have marked effects on the proportions of eggs that hatch and the subsequent growth of the larvae. Developmental abnormalities have also been noted. According to the limited data available, such concentrations are likely to be maintained only in confined areas such as industrialised estuaries or close to the outfalls of industrial discharges into the sea. Thus the above effects are most likely to be of significance (i.e., significance additional to the usual high *natural* mortalities of fish eggs and larvae) for species with very restricted distributions.

Apart from direct effects on fish, oil pollution may affect fishing operations by fouling equipment such as nets and fish traps. This is likely to cause particular local hardship in shallow water subsistence fishing areas such as the Niger Delta or the shallow coastal waters of South-east Asia.

3.4.2. Points for WWF/IUCN consideration

1. Some spills, particularly of light products, may cause substantial fish kills in restricted waters such as rivers, lakes or shallow sea areas.

TABLE 2

Concentration of Unresolved Complex Mixture (UCM) hydrocarbons found in mussels from various locations

Location details	UCM ($\mu g\ g^{-1}$ dry weight)	Reference
North Sea oil-production platform	52 77 60 46	Rowland and Volkman (1982)
Oil refinery outfall	600–1200	Smith and Burns (1978)
Various US Mussel Watch stations	3–298	Farrington (1978)
Pristine area in north-east Gulf of Alaska	17.6	Wise *et al.* (1980)
Oil seep, Coal Oil Point, Santa Barbara	88	Wise *et al.* (1980)
Oil seep, Goleta Point, South California	ca. 120	Risebrough *et al.* (1980)
Areas near high urban populations (e.g., Monterey, Humboldt Bay, San Francisco Bay)	ca. 20–40	Risebrough *et al.* (1980)
Cape Cod Canal, Mass. following spill of No. 2 fuel oil	27–199	Farrington *et al.* (1982)

2. Under laboratory conditions, chronic exposure to low levels of petroleum hydrocarbons can significantly affect egg hatching and larval development.

3. If fish breeding grounds or concentrations of larvae in shallow water are considered a conservation priority, then chemical dispersants should not be used on slicks (as they may increase hydrocarbon concentrations in the water column).

4. There is no definitive evidence which suggests that oil pollution has significant effects on adult fish populations in the open sea; however, definitive evidence is very difficult to obtain because of field sampling problems and the difficulty of separating pollution effects from the effects of fishing.

3.5. Invertebrates

3.5.1. Information summary

The main groups for which information is available are marine molluscs, crustaceans, 'worms'—mainly polychaetes, echinoderms, corals, zooplankton, and a variety of freshwater invertebrates.

Molluscs include grazers, e.g., limpets, chitons and winkles; carnivores, e.g., whelks; filter feeders, e.g., mussels, cockles, oysters, clams and scallops; and deposit feeders, e.g., *Scrobicularia*. In the intertidal zone and in shallower water any of these types may be killed either by smothering, following gross oil contamination, or through toxic effects. Filter feeders and deposit feeders are also particularly likely to ingest and accumulate dispersed or sedimented oil. Table 2, from Rowland and Volkman (1982) summarizes some recent data on concentrations of unresolved complex mixture (UCM) pollutant hydrocarbons in mussels (filter feeders).

Such tainting may affect many species of commercial importance but, following the cessation of pollution, it is usual for hydrocarbons in the tissues to be reduced to low levels within 30 days (RCEP, 1981). However, release times are different for different hydrocarbons and organisms. (This comment applies to other groups of organisms, e.g., fish, as well as molluscs). For example, Anderson and Neff (1974) worked on discharges of hydrocarbons from oysters which had been exposed to 400 ppm dispersed No. 2 fuel oil (light gas-oil) for eight hours. At the end of the exposure the oysters had accumulated 312 ppm oil hydrocarbons in their tissues. When the oysters were returned to clean seawater, more than 90% of the *n*-alkanes were discharged in 24 hours; the aromatic components, however, were released much more slowly. After 672 hours (28 days) small amounts of mono-, di- and trimethylnaphthalenes remained in the oyster tissues.

RCEP (1981) has summarized information on crustaceans as follows:

"Crustaceans that are mobile, such as lobsters and crabs, generally inhabit the sub-tidal zone and are not as subject to direct contact with oil as are the inter-tidal molluscs and the attached Crustacea, like barnacles. However, heavy mortalities have been observed during large spillages where the oil has become dispersed in the water column in shallow waters. There are reports of sub-lethal effects; for example, crude oil in sea water at a concentration of 0.9 ppm was observed to depress the appetite and alertness of adult lobsters and thus interfere with feeding (GESAMP, 1977). As is the case with other marine organisms, eggs and larvae are particularly sensitive to oil in the water and the lethal threshold for lobster larvae appears to range between 2 ppm and 30 ppm. ... Fresh oil, or oil that has been treated with dispersants, can cause high mortality among sedentary crustaceans, notably barnacles which inhabit the intertidal zone; weathered oil is much less damaging unless it is sufficiently thick to smother the animals. On the other hand, an oceanic goosebarnacle, *Lepas fascicularis,* which attaches itself to floating debris, readily accepts tarballs as a substratum."

Worms living in intertidal sediments may be killed in large numbers if fresh oil penetrates the substratum. Levell (1976) experimented with crude oil and dispersant on a lugworm (*Arenicola*) bed and found that cast production was reduced by both pollutants (applied singly or as mixtures). Reductions in cast density in the month following pollution were 25–50%, with some recovery subsequently. Successive pollutions had more severe effects. There is also evidence both from experiments (e.g., Grassle *et al.*, 1981) and field surveys (e.g., Armstrong *et al.*, 1979) that subtidal species may be affected following accumulation of hydrocarbons in bottom sediments.

Echinoderms, including sea-urchins and starfish, are nearly all sensitive indicators of clean water; they may be killed in large numbers by toxic oil (RCEP, 1981).

Information on corals is given in Section 4.3.

There has been much laboratory work to determine the toxicity of oil to zooplankton but effects in the open sea are difficult to investigate. See also Section 4.1.

References for work on freshwater invertebrates are detailed in FBA (1978). Both lethal and sub-lethal effects have been reported for a range of species including chironomids. Less information is available than for marine invertebrates.

There are few studies concerned with recovery of invertebrate populations over long periods of time, but Southward and Southward (1978) found that 'Torrey Canyon' effects could still be detected on rocky shores ten years after the spill, and some spills have resulted in contaminated bottom sediments which constitute a chronic source of pollution (a recent example is the 'Tsesis' spill, Boehm *et al.*, 1982).

3.5.2. Points for WWF/IUCN consideration

1. Fresh oil can cause heavy mortalities of invertebrates.

2. Long-term (10+ years) effects on populations are indicated, in some cases.

3. In some cases, invertebrate mortalities may have an indirect effect on other species. For example, intertidal mud flats rich in worms and crustaceans often form important bird and fish feeding grounds. They could be rendered useless for this purpose following a large spill of fresh oil. Subtidal invertebrates form a major portion of the diet of many commercial fish species.

3.6. Vascular Plants

3.6.1. Information summary

The vascular plants most commonly affected by oil pollution are saltmarsh and mangrove species (see Sections 4.6 and 4.7), but terrestrial and freshwater species are also at risk in some areas.

Oil pollution can kill plants and inhibit growth by various mechanisms: (1) by acting as a physical barrier and preventing gas exchange; (2) by being directly toxic; (3) by affecting soil properties; and (4) by affecting the abilities of other plants to grow and compete.

Photosynthesis may be reduced by oil pollution, possibly because some oil films limit carbon dioxide entry. Riedhart (1961) has shown that if the carbon dioxide content is increased round an oil-treated leaf, the inhibition of photosynthesis disappears. Light intensity reduction may also be a cause of decreased photosynthetic rates though in many cases plants have been found growing through very dark-coloured oil. The inhibition of photosynthesis may cause a reduction in sugars and the dissolved solid content of plants. Work has been carried out on this as oil-based pesticides are used in the fruit industry (Calpouzos, 1966).

Oil may also limit plant oxygen supply, although evidence for this is conflicting; for example, Brown and Reid (1951) found that oxygen can diffuse through some oil films. In many wetland plants, the root system depends on the shoots for most of the oxygen supply. For example, soil around *Spartina* roots is enriched with oxygen diffusing from the roots which in turn has come down from the shoots. When the stomata are blocked by oil, the oxygen content of the roots and the rhizosphere fall (Baker, 1979). The reducing conditions which result may be deleterious to the plants. Mangrove roots obtain their oxygen from pneumatophores (aerial roots) which are susceptible to oil coatings.

Land plants tend to have oleophyllic surfaces, which may explain the observation of Nelson-Smith (1968) that land plants seemed more readily affected by 'Torrey Canyon' oil than algae (which are probably protected by their mucilagenous outer layers). Any dispersant designed to penetrate easily into oils is likely to penetrate easily into plants. Most workers believe oil travels primarily through the intercellular spaces, rather than along vascular tissue. Hutchinson and Hellebust (1974) review some of the literature. Cell walls are normally considered saturated with water, so they should inhibit passage of oil (Young, 1935). However, once inside the cell walls, the oil meets the phospholipid cell membranes in which it will easily dissolve. It can thus affect flow of ions and disrupt osmotic control. Hutchinson and Hellebust (1974) observed that oil caused a loss of turgor in *Carex* species resulting in the collapse of plants.

Seed germination and seedling growth are very susceptible to oil pollution (McCown and Deneke, 1972) and this, of course, affects the future population. For example, Getter *et al.* (1981) found a decrease in seedling density in oiled mangrove swamps compared with unoiled mangrove swamps.

Oil affects many properties of soil which in turn affect plant growth. This is discussed in the section on terrestrial habitats (4.9). Plants roots will grow through oil in soil but there is a reduction of side branches. They produce side branches as soon as they grow through to the other side of the oiled layer.

Certain species of plant are more susceptible to oil pollution than others. Plants with rhizomes or other underground storage organs tend to be more resistant than annuals and shallow-rooted plants. Members of the Umbelliferae and conifers are resistant to injury by the lighter oils. These oils are therefore used as weedkillers on crops such as carrots or conifer seedlings (Lachman, 1944). With most species, seedlings are very susceptible compared with mature plants.

The effects of the 'Amoco Cadiz' oil spill on the seagrass *Zostera marina* were studied by Jacobs (1982). He gives data on changes in shoot density, length of internodes and biomass production, and concluded that the effects were short-term and local (evidenced by blackened leaves). Baker *et al.* (1982) are using field experiments to study the effects of oil and dispersants on the intertidal seagrass *Zostera noltii*; a preliminary conclusion is that oil/dispersant mixtures are particularly damaging.

Clean-up methods are dealt with as appropriate in Sections 4.6–4.9.

3.6.2. Points for WWF/IUCN consideration

1. Vascular plants may be damaged or killed by light toxic penetrating oils or by smothering layers of heavy oils.
2. Many vascular plants will recover from oil pollution provided the underground parts are not damaged.
3. Wetland plants with root systems depending upon oxygen diffusion from aerial parts are likely to be particularly susceptible to oil clogging.
4. There is a need for further information on seagrasses, particularly tropical species.

3.7. Algae

3.7.1. Information summary

O'Brien and Dixon (1976) have written a comprehensive review on the effects of oil and oil components on algae. The more important points are summarized here and recent developments presented for the different groups of algae.

Macrophytic algae. Oil does not always stick to macrophytic algae (seaweeds) because of the mucilagenous coating (Straughan, 1971); however, dispersants may penetrate this coating. When oil does stick the fronds can be seriously overweight and subject to breakage by the waves (Nelson-Smith, 1973) though algae with annual basal growth can generally recover. Algae in rock pools and high up on the intertidal zone are particularly susceptible (Smith, 1968). In general, intertidal areas denuded of algae and animals following severe oil and dispersant pollution are readily repopulated by algae once the pollutants have been substantially removed. The algal cover then remains high for a long time due to the slow recovery of grazing animals (Bellamy *et al.*, 1967). Diving studies following the 'Torrey Canyon' showed heavy mortality of red algae in areas where dispersants had been applied intertidally (Potts *et al.*, 1967). Red algae were effective indicators of damage, because they changed in colour upon exposure to relatively low dispersant doses (Drew *et al.*, 1967). Field experiments with a modern dispersant have indicated that chronic exposure to dilute dispersant may cause partial disintegration of some red algae (Baker *et al.*, 1980).

Many algae are of economic importance either directly as food (e.g., *Porphyra* in Japan and elsewhere) or for products such as agar. Algal culture for these purposes is particularly important in Japan and South-east Asia. Oiled or tainted algae lose their commercial value (Numata, 1982, pers. comm., has cited cases in Tokyo Bay).

Phytoplankton. Laboratory studies (e.g., Gordon and Prouse, 1973) have indicated that low concentrations of oil may inhibit photosynthesis and depress growth, or with some oils photosynthesis may be stimulated. Field studies are more difficult; O'Brien and Dixon (1976) state:

"Field studies concerning the effects of accidental spills on phytoplankton populations have yielded no observations particularly incriminating to oils or oil residues. Conclusions from such studies have to be considered tentative because of problems involved in differentiating between the effects of many environmental factors, each of which could have influenced the results observed. ... It is possible that high reproductive rates of phytoplankton counteract short-term reductions in numbers caused by oil (Straughan and Abbott, 1971) but the refractory nature of many petroleum-derived compounds could have long-term implications especially in polluted environments."

The presence of oil may affect the balance of organisms present but this is difficult to measure as the populations of organisms change throughout the season. A microcosm experiment reported by Vargo *et al.* (1982) showed that low levels of No. 2 fuel oil could increase phytoplankton abundance—reduced predation pressure and altered herbivore feeding behaviour were postulated as mechanisms to account for this.

Dispersants used in clean-up can have more damaging effects on phytoplankton than oil. Heldal *et al.* (1978) found that the majority of oil dispersants they tested were more toxic to two green algae than to the brown shrimp. (The brown shrimp is used for the UK dispersant licensing toxicity test.)

Blue-green algae often increase in numbers after oil pollution (Griffiths, 1972; Reish, 1971). Blue-green algae are structurally similar to bacteria and are often associated with polluted waters with high organic content.

Periphyton i.e. algae growing on substrates and suspended particles, can be more susceptible to oil pollution than phytoplankton. Oil particles become attached to the substrate and suspended particles, so the algae are in contact with the oil, including insoluble fractions (Hellebust *et al.*, 1975).

Lichens. A lichen is a symbiotic association of an alga and a fungus. Lichens above high tide level were killed after the 'Torrey Canyon' and most of the damage was done by the oil dispersants, not the oil itself (Ranwell, 1968). Lichens form a significant part of the vegetation in tundra regions, and here they are also susceptible to oil pollution (McCown *et al.*, 1972).

3.7.2. Points for WWF/IUCN consideration

1. Following oil clearance, many algal communities recover well from spills, and in the intertidal zone it is common to have a phase of increased algal abundance due to reduction of grazing molluscs.

2. Dispersants may increase damage to algae by penetrating their protective mucilagenous coating. Sub-tidal red algae may be damaged by dispersants in the water column.

3. Low concentrations of oil have been shown to affect phytoplankton in the laboratory, but sampling problems mean that it is difficult to adequately study possible effects in the sea.

4. Effects of Oil Pollution and Clean-up: Habitats

4.1. The Open Sea

4.1.1. Information summary

Two incidents in which oil stayed at sea and, for the most part, was left to disperse through natural processes, are the 'Argo Merchant' tanker accident and the Ekofisk 'Bravo' blowout. The former involved heavy fuel oil off the north-east coast of the USA; the latter was of crude oil in the North Sea. Information on the 'Argo Merchant' is available in NOAA (1977), MacLeod *et al.* (1978), Kuhnhold (1978) and Morson (1978), and on the Ekofisk blowout in Audunson (1978), Grahl-Nielsen (1978) Johnson *et al.* (1978), Addy *et al.* (1978) and Whittle *et al.* (1978).

In the case of the 'Argo Merchant', fouled zooplankton, moribund fish eggs and a relatively high percentage of oiled birds were observed near the spill site. Kuhnhold (1978) concluded, however, that abundance studies in benthic and pelagic communities including commercial fish species did not suggest an overall major adverse impact. NOAA (1977) concluded that the outcome of the spill was fortunate in that (1) the density of the oil was low enough to prevent wholesale sinking and subsequent contamination of the bottom, and (2) the spill occurred in the winter, when biological activity, productivity and fishing activities were relatively low. Following the Ekofisk blowout, there was some evidence that fish picked up Ekofisk oil via the digestive tract. However, the concentrations of analysed hydrocarbons in the liver and muscle tissues of fish caught in the Ekofisk area soon after the oil flow was stopped, and again some two months later, were within the range experienced in the past from samples caught in the open seas around the UK (Whittle *et al.*, 1978). Changes in the fauna of the bottom sediments could not be specifically attributed to the blowout (Addy *et al.*, 1978).

4.1.2. Points for WWF/IUCN consideration

1. The 'do-nothing' option is commonly applied to spills in the open sea. In other words, slicks are kept under surveillance but there is little or no clean-up response unless the oil drifts towards sensitive areas such as bird concentrations or coastal shallows.

2. Oil slicks left to drift at sea eventually diminish and break up through natural processes. Some oil reaches the seabed (see Section 4.2).

3. Effects on plankton, fish eggs and birds have been reported. These effects have not been considered serious in the best-documented large spills that occurred offshore, in contrast to large spills (e.g., the 'Amoco Cadiz') that occurred close to the shore.

4. Relatively numerous, small undocumented spills at sea are of concern from the point of view of bird deaths (see Section 3.2).

4.2. The Seabed

4.2.1. Information summary

Oil may reach the seabed from effluents, slicks or oiled shores. Both naturally or chemically dispersed oil may be absorbed onto particulate matter and sink to the seabed, or in cases of severe intertidal contamination there may be 'creep' to sub-tidal areas.

Some effects of spills on conspicuous species on sub-tidal rock and sand were reported for shallow areas following the 'Torrey Canyon' (Smith, 1968) and 'Amoco Cadiz' (Cabioch *et al.*, 1980) spills. In the case of the 'Torrey Canyon', deaths of a variety of crustaceans, molluscs, echinoderms and algae could be attributed mainly to the widespread use of types of dispersant which are no longer licensed for oil spill clearance. In the case of the 'Amoco Cadiz , the spill mainly affected the fauna on fine sediments, notably the populations of *Ampelisca* (a crustacean).

Field experiments (Baker *et al.*, 1980) have provided further information on the probable effects of a severe spill and modern dispersant cleaning on sub-tidal kelp forest communities, and indicate that prolonged exposure to dilute dispersant may cause degeneration of some species of red algae. An interim conclusion from the Baffin Island Oil Spill (BIOS) project (Blackall and Sergy, 1983) is that 'the short-term impacts on the subtidal benthos associated with the nearshore use of dispersants are more serious than those associated with the onshore movement of oil slicks and the subsequent leaching of oil off the shoreline'.

In offshore oilfields, most long-term studies have used the relatively immobile macrobenthic community as an indicator of the overall biological health of the area. In some cases effects have been observed, in others not. The first area to be monitored in this way was the Ekofisk Oilfield (Dicks, 1976) in the North Sea, where grab-sampling surveys have been carried out since 1973. By 1977, it was possible to map an area of effects around the installations and describe in some detail the impact on the community in terms of species composition and abundance (Addy *et al.*, 1978), but it has not so far been possible to separate the effects of oil pollution from other factors. For example, physical disturbance of sediment was implicated and a slight increase in silt content close to the installations may have been caused by discharge of drilling mud or redistribution of sediment resulting from pipe burying or anchorage. Further work is necessary to distinguish between and assess the scale of these different influences and define the particular agent(s) responsible. Such information is vital for the assessement of the need, or otherwise, for remedial action and the form which such action might take.

4.2.2. Points for WWF/IUCN consideration

1. Oil reaches the seabed through the mechanisms of sedimentation and 'creep', and is retained in the sediments.
2. Ecological changes have been observed around some offshore installations but not others; the role of sediment-bound oil in causing these changes is not yet clear.
3. Prolonged application of dispersants in shallow nearshore waters may affect seabed organisms.

4.3. Coral Reefs

4.3.1. Information summary

Two recent reviews of oil pollution effects on coral reefs are available, namely Ray (1981) and Loya and Rinkevich (1980). There have been few detailed quantitative field studies, and laboratory studies are difficult to compare because of the wide range of techniques used.

Oil has been implicated in a recolonisation failure in the Gulf of Eilat. Following a 90% mortality to the shallow corals due to unusually low tides in 1970, recolonisation of two areas was studied, (1) a reef exposed to large inputs of oil located 3 km south of an oil terminal from which numerous spills occurred, and (2) a reef 5 km south of the terminal. Recolonisation was normal on the reference reef but there was a failure of opportunistic species such as *Stylophora pistillata* to recolonise the oiled reef. This reef is probably the most badly-oiled area of corals reported in the literature. Only counting those spills large enough to 'blacken' the reef, 95 spills occurred from 1971–1973. with frequency ranging from one to seven per month. In addition to the oil input, there was also phosphate eutrophication of the shallow lagoon due to nearby fertilizer plants (which makes definitive conclusions regarding cause and effect relationships rather difficult). However, Loya (1975) inferred that oil may damage the reproductive system of corals, interfere with larvae production, or reduce larvae viability and inhibit their normal settling, and Rinkevich and Loya (1979) have confirmed oil effects on reproduction in laboratory experiments.

Two field experiments are of particular interest. Kinsey (1973) floated crude oil above coral and found no toxicity effects or abnormal behaviour patterns. In contrast, Johannes *et al.* (1972) found that oiled corals which were partially exposed to air were damaged.

Laboratory experiments reviewed by Ray (1981) and Loya and Rinkevich (1980) indicate a range of possible responses to oil, including abnormal mouth-opening and feeding behaviour, mucus secretion, decreased growth rates and increased tissue death rates. Ray (1981) has described mucus secretion as the single most important defense mechanism because the mucus tends to either repel or trap the oil contacting the surface. However, mucus-consuming fish, such as the butterfly fish *Chaetodon* spp., could become contamined as a result. Chronic (three-month) exposures of *Manicina areolata* to water-accommodated fractions of No. 2 fuel oil led to atrophy of mucus-secreting cells and other pathological responses (Peters *et al.*, 1981).

4.3.2. Points for WWF/IUCN consideration

1. Severe damage is most likely in the case of upper-reef corals in shallow water, especially if oil slicks coat the corals during extreme low tides.
2. Dispersant use in shallow lagoon water might increase adverse effects, but more information is needed (some field experimental work addressing this problem is in progress at present).
3. Mechanical damage to reefs could be caused by the activities of clean-up gangs. It may be best, therefore, to select natural (unassisted) recovery as the remedy on badly-oiled reefs.
4. If slicks are sighted near coral reefs, the priority should be treatment while they are still in deep water. Diversion away from shallow reef and lagoon areas, or erection of temporary barriers to keep slicks from contacting the reefs, are possible responses in some cases but are unlikely to be practicable if the spill is large.

4.4. Intertidal Rocks

4.4.1. Information summary

This section considers the effects of oil and dispersants on shores with bedrock outcrops, including mixtures of such outcrops and derived boulders and stones. Such shores may be found from the most exposed headlands to the most sheltered inner recesses of fjords, and support different types of communities depending upon exposure grade.

With an exposed limpet/barnacle-dominated shore such as is common in north-west Europe, some oils and/or dispersants can cause substantial limpet detachment (Dicks, 1973). Although many detached limpets are capable of recovery in the laboratory, they usually do not get a chance in real life because of predation by gulls. This was particularly striking after the 'Dona Marika' accident (Blackman *et al.* 1973), when the affected area was well-defined by the flocks of gulls circling the bay and picking up limpets as they dropped off the rocks. Limpets graze algae which are relatively resistant to oil and dispersant pollution, and when the limpets have gone there is an invasion of the green alga *Enteromorpha* followed by brown alga such as *Fucus* spp. The extensive algal growth in turn tends to smother and prevent the settlement of barnacles and other species.

Gastropod molluscs such as winkles (*Littorina* spp.) top shells (*Gibbula* spp.) and dog whelks (*Nucella* spp.) commonly retract into their shells under the influence of oils and dispersants and are then liable to be washed away by tidal action. Recolonisation of shores by adults has been observed (Baker, 1976). Crapp (1971) deduced that animals were washed into the sub-littoral zone and eventually crawled back into the littoral.

Unlike many temperate shores, the upper part of the intertidal zone of tropical rocky shores is often dominated by oysters. Barnacles, winkles, limpets, coralline algae and the brown alga *Sargassum* also occur (Stephenson and Stephenson, 1972; Malley *et al.*, 1978). Little is known about oil pollution effects on such shores.

Surface features likely to enhance oil retention include cracks, gullies, pools, spaces under boulders, pitting of the rock surface, encrusting of the rock surface by organisms such as barnacles and mussels, and organic activity (e.g., rock-boring shell-fish). Transfer of pollution to nearshore waters, or re-distribution of shore pollution, may occur through run-off of liquid oil. Remobilisation of tarry deposits may occur in hot weather.

Natural clean-up of even heavy oils is usually effective on the more exposed rocky shores. With light products on any rocky shore, the substrate penetration problems of other intertidal habitats do not apply, and removal through evaporation and tidal flushing is relatively rapid. Mechanical clean-up methods by high-pressure hosing, hot water or stream treatments generally increase run-off and oil levels in nearshore waters, and are likely to lead to short-term loss of most organisms with a possible 'recovery' time of 5–15 years. Dispersants increase run-off and subsequent high levels of oil in nearshore water columns. Also there is the possibility of enhanced tainting of filter-feeding shellfish. The cutting and collection of oiled seaweed (e.g., *Ascophyllum* beds on sheltered rocky shores) removes a habitat and food supply used by many molluscs and crustaceans, and locally reduces the detritus supply. The careless turning over of stones removes niches and may subject sessile organisms to intolerable light and heat. All clean-up methods are likely to cause disturbance to wildlife, including birds nesting on cliffs above the shore, and seals with pups on rock platforms, at or near some rocky shore sites at certain times of year.

4.4.2. Points for WWF/IUCN consideration

1. The worst recorded effects of light oils and products on rocky shores are loss of most organisms in the spill area through toxic effects, followed by an algal-dominated phase prior to complete 'recovery' possibly 5–15 years. The worst effects of heavier oils and mousse are the smothering of organisms and long-term retention of tarry deposits inhibiting recolonisation.
2. Natural clean-up is usually effective on exposed rocky shores.
3. Hosing and dispersant treatments are likely to increase short-term run-off and lead to relatively high oil concentrations in nearshore waters. There is also the possibility of penetration into sediments around rocks.
4. All clean-up methods are likely to involve some physical disturbance which may be an important consideration in some cases (e.g., if birds or seals are breeding nearby).

4.5. Mud and Sand Flats

4.5.1. Information summary

It has become clear (see for example, reports in *J. Fish Res. Board Canada, 35* (5), 1978) that in several cases oil has penetrated soft intertidal sediments in areas sheltered from wave action. This oil has apparently remained there for many years, and in some cases has been gradually leaching out, constituting a long-term source of chronic pollution. In higher energy beaches, oil may become buried through sand movements, but is also more likely to be eroded through the same mechanism (as happened at some sites following the 'Metula' accident (see Guzman and Campodonico, 1981)). From the ecological point of view, greatest concern has been expressed about sheltered sediments, (a) because they are more likely to retain oil, and (b) because they often have a rich fauna, with a great variety of polychaete worms, bivalves and crustaceans. Such animals may be killed in large numbers if toxic oil penetrates the sediments, and penetration is, of course, more likely if the sediments are perforated with burrows. Faunistically rich intertidal flats often form important bird and fish feeding grounds and could be rendered useless for this purpose following a large spill of fresh oil.

Recent field experimental work (see, for example, Little *et al.*, 1981; Abbiss *et al.*, 1981) has been aimed at answering the question: would modern dispersant use at the time of spilt oil coming ashore reduce penetration and retention of oil in sediments? Preliminary findings indicate that:

1. On the waterlogged flats investigated oil did not penetrate the sediment, regardless of whether dispersants were used or not.
2. On the well-drained fine sand flats investigated, there was some marginal evidence that dispersant alone could reduce lugworm cast production, and evidence that some dispersant treatments enhanced penetration of oil into sediments, where it was retained at greater concentrations than untreated oil.
3. Variability of behaviour and effects of oil and dispersed oil at any particular intertidal sedimentary site was observed and is attributed to local variations in factors such as degree of surface rippling, draining time of sediments, behaviour of the water table and sediment particle size.
4. None of the experiments carried out indicate that dispersant application is likely to be a useful cleaning method for relatively sheltered intertidal sediments.

4.5.2. Points for WWF/IUCN consideration

1. Penetration, retention and ecological effects of oil can be a long-term problem in some intertidal sediments.
2. There is no easy way of cleaning such sediments, so diversion of oil into areas which are more easily cleaned or where oil might be less persistent, should be a priority following a spill.

4.6. Saltmarshes

4.6.1. Information summary

Saltmarshes often act as oil traps both because they are relatively sheltered from wave action and because the vegetation offers a large absorptive surface area. Effects of single spills, successive spills and refinery effluent discharges on marsh vegetation have been reviewed by Baker (1979). Briefly, marsh plants show a wide range of susceptibility to typical crude oils, ranging from annuals such as *Salicornia* spp., which are killed by one oiling, to *Oenanthe lachenalii* which withstands 12 experimental successive monthly applications of fresh Kuwait crude oil. *Spartina*, a dominant genus in temperate areas, can survive single oil spillages well but does not tolerate chronic pollution. Experimental evidence suggests that oil interferes with the normal oxygen diffusion process down the plants into the roots. Competitive advantages are gained by tolerant species following oiling. This was particularly striking in an upper salt marsh community studied by Baker (1971), where the susceptible *Juncus maritimus* was replaced by *Oenanthe* and by *Agrostis stolonifera*. Different crude oils and products vary considerably in their toxicity. Light aromatics appear to be the greatest contributor to acute toxicity. Some heavy or weathered oils stimulate the growth of salt marsh plants. Serious damage may be caused either by heavy spills of fresh oil (which is partly absorbed by the plants and has a phytotoxic effect) or by very thick layers of weathered oil or mousse (which smother the plants).

Several experiments with dispersants have been carried out; none have indicated that dispersants are an effective way of cleaning oil from marshes. Stripping the marsh surface has been used as a cleaning technique after some spills but may lead to erosion problems. A 'worst case' example is the Ile Grande marsh in Brittany, oiled following the 'Amoco Cadiz' spill. Vandermeulen *et al.* (1981) have described the massive clean-up of the heavily oiled marsh, during which much of the surface sediment was removed to a depth of about 50 cm. As a result, the marsh is undergoing increased erosion and invasion of sand from offshore stocks. Residual oil, left behind from the clean-up, is being trapped under sandbars from where it may be released in the future. Krebs and Tanner (1981) have proposed a stripping and propagation technique for areas where extensive damage has already been caused by oil alone. Oiled substrate stripping is certainly a radical clean-up approach, with attendant dangers as demonstrated at Ile Grande; however, successful propagation (notably of *Spartina*) would help stabilize sediments and start the recovery process.

4.6.2. Points for WWF/IUCN consideration

1. Salt marshes are sheltered oil traps.
2. The main reasons for concern about oil pollution of marshes are:

(a) coastal erosion—loss of vegetation through oil damage or unsuitable cleaning techniques can lead to de-stabilisation of sediments.

(b) conservation interests—salt marshes are often used as breeding grounds by wildfowl and waders.

(c) economic interests—in many parts of the world salt marshes are important grazing areas mainly for sheep but also for cattle and horses.

3. Most marsh vegetation can recover well from light coatings of fresh crude oils, or from spills of weathered oil provided these are not smotheringly thick.

4. Serious damage may be caused by heavy spills of fresh crude, or very thick layers of weathered oil or mousse.

5. Marsh cleaning methods (burning, cutting or dispersant treatment) do not appear in most cases to decrease the damage done by oil pollution, and often increase it. However, drastic treatment may be needed for thickly coated marshes in order to remove oil that may otherwise remain for many decades.

6. If sediment stripping is used as a drastic clean-up treatment then a replanting scheme is probably necessary to help stabilise sediments.

4.7. Mangrove Swamps

4.7.1. Information summary

The term mangrove refers to approximately 70 species of tree or bush which occur on sheltered shores and in estuaries or nearshore waters in the tropics and some sub-tropical regions. Comprehensive reviews of mangrove ecology are already available, e.g., Macnae (1968), Lugo and Snedaker (1974), Chapman (1977), and the IUCN Commission on Ecology report on the global status of mangrove ecosystems (1982).

The following are features which may make mangrove swamps vulnerable to oil pollution (Fig. 3). Mangroves are outstandingly adapted to growing in seawater, which they desalinate by an ultrafiltration process (Scholander, 1968). Mangrove roots typically grow in anaerobic mud and receive oxygen through aerating tissue which communicates to the air through small pores (lenticels) on the stilt roots or special 'breathing' roots (pneumatophores). Thus oil deposits on aerial roots may reduce oxygen diffusion to the underground root system. Oil in the sediments may possibly damage root systems and so interfere with the ultrafiltration process.

Fig. 3. Dead mangroves (*Sonneratia*) in oil-contaminated sediments, Indonesia.

TABLE 3

Incident	Effects	References
Spill of 37 000 barrels of Venezuelan crude oil from the Zoe Colocotroni'.	*Rhizophora mangle* and *Avicennia nitida* defoliated and died during the three years following the spill. Mangrove prop root invertebrates were reduced. By 1977 the oil was highly weathered even in the most heavily oiled areas and some recolonisation was observed.	Nadeau and Bergquist (1977); Page *et al.* (1979)
Spill of 54 000 barrels of crude from the 'Showa Maru', Singapore Strait, 1975.	Dead mangroves were found in bays on two islands; they were associated with low numbers of invertebrates and petroleum hydrocarbon residues in sediments. (However, these residues could not be attributed specifically to the 'Showa Maru' on the basis of chemical analyses.)	Baker *et al.* (1981)
Comparison of five oil spill sites in the Gulf of Mexico and the Carribean Sea.	The responses of the oiled mangrove communities at the various sites were similar and included defoliation and mortality of trees, mortality of seedlings and leaf deformation. However, differences in the physical environment (e.g., topography, exposure to wave action) greatly influence the distribution and persistence of oil.	Getter *et al.* (1981)
Funiwa 5 blowout, Nigeria. Up to ca. 146 000 barrels released. An unknown amount reached the Niger Delta.	Immediate effects noted by Baker: defoliation of some *Rhizophora* seedlings, death of crabs and winkles. Large trees not defoliated at this stage. Effects after 14 months noted by Gilfillan and Teas: mangroves killed over 836 acres (=1.45% of total area surveyed from air), recovery of flora and fauna starting.	Lasday *et al.* (1981)

Reports in the literature of oil pollution damage to mangroves include the following, given in Table 3.

A summary of other incidents is given by Lewis (in press).

The Funiwa blowout has affected a greater area of mangroves than other incidents reported to date. This incident provides evidence that mangroves may die slowly, i.e., the final extent of impact may not be obvious immediately after a spill.

The physical removal of oil is probably an inappropriate procedure in mangrove swamps where the aerial root systems would be very vulnerable to physical damage. The aerial spraying of offshore floating slicks with dispersant concentrate would minimize the possibility of oil being stranded in mangrove swamps, and could be the best option in some cases, but dispersed oil would enter the water column where its effects are unknown, as is the effect of dispersant sprays unintentionally blown on to the various mangrove species. Slicks sprayed in main creeks used as boat routes by local people may result in dispersed oil reaching further into the swamps and eventually sinking into the sediments, again with unknown long-term effects. Flushing the swamp surface and aerial root systems using low pressure hosing could be a clean-up option in some areas.

4.7.2. Points for WWF/IUCN consideration

1. The acute short-term effects of oil in mangrove swamps are likely to be high mortalities of invertebrates, defoliation of mangroves and death of seedlings.
2. In the longer term, trees in the most affected areas are likely to die. Such trees may be large and old which means that recovery times to prespill conditions will be very long.
3. Superficial oil is likely to weather comparatively quickly, but little is known about oil penetration and fate deeper in the sediments.
4. A number of cases of both mangrove and invertebrate re-colonisation have been reported.
5. Mangrove swamps are probably the most difficult type of habitat to clean, and spill response should concentrate on trying to prevent oil entering such areas in the first place.

4.8. Freshwater Habitats

4.8.1. Information summary

A preliminary desk study and bibliography has been compiled by the UK Freshwater Biological Association (FBA, 1978), and good documentation of several incidents is available from the USA. Pollution sources identified include pipelines

(Fig. 4), tanker accidents, domestic and industrial heating oil accidents, outboard motors, surface run-off, municipal and industrial effluents.

Some examples of spill studies are summarised in Table 4.

On a larger scale, oil production and exploration are taking place in freshwater habitats including the Amazon Basin, the Niger Basin and the Caspian Sea (which ranges from freshwater to high-salinity areas). Lakes Tanganyika and Malawi are now arousing interest. Further details are given in Section 5.

4.8.2. Points for WWF/IUCN consideration

1. Oil production and exploration, with attendant physical disturbance and pollution risks, is taking place in freshwater areas of conservation importance, e.g., the Amazon Basin and ancient inland seas/lakes.

2. Spills of light oils can cause large mortalities of organisms in streams and rivers, but at least partial recovery has been reported in several cases.

3. Spills (especially of heavier oils) in ponds and lakes with no or restricted throughflow are likely to present much greater problems in terms of persistence of the pollutant and slow recovery rates.

4. Relatively little information is available on clean-up methods and their effects. Booms and sorbents are likely to be useful for small spills. Dispersants are likely to increase effects in the water column (but their use may nevertheless be justified if birds, such as ducks, are considered a conservation priority). It should be noted that most dispersants work better in seawater than in freshwater, though experimental work is being conducted on formulations for low salinities.

Fig. 4. Fuel oil pipeline crossing a freshwater reedswamp, UK.

4.9. Terrestrial Habitats

4.9.1. Information summary

Relatively little has been documented about oil pollution in terrestrial habitats (partly because there are fewer cases of such pollution), and those cases that are reported often say virtually nothing about the effect on the vegetation. The tundra regions of Alaska and the Delta region of the Niger are examples of areas where oil production is developing and where terrestrial habitats may, and have been, affected. There are also other incidental cases reported throughout the world (see, for example, Fig. 5). In some, more damage than necessary has been caused because of inadequate

TABLE 4

Incident	Effects	References
5000 gallon gasoline spill, Grace Coolidge Creek, S. Dakota, Nov. 1969.	A survey immediately after the accident indicated that the majority of aquatic invertebrates were killed for at least two miles downstream. In May 1970 gasoline residues were still present under rocks, no stonefly nymphs were present, and mayfly nymphs and caddis-fly larvae were severely reduced. Diptera, especially the chironomid *Orthocladius*, persisted. In October 1970 recovery was nearly complete.	Bugbee and Walter (1973)
7000 gallon diesel fuel spill, Boone Creek, S. Carolina, 1972.	Stations downstream from the spill generally had reduced numbers and types of organisms. Larvae of Diptera and nymphs of mayflies and stoneflies were the most sensitive macroinvertebrates. About 90% of the standing crop of fish were killed. Partial recovery was noted by September 1972.	Schultz and Tebo (1975)
3800 litre fuel oil spill, Mill River, Massachusetts, 1972.	Effects in two marshes were studied. Seven of 18 plant species eliminated in the first year after pollution were annuals; all 23 unaffected species were rhizomatous perennials. Annuals reinvaded in 1974–5.	Burk (1977)
Experimental spills of crude oil and dispersant	Short-term results indicated that the oil/dispersant mixture affected zooplankton, phytoplankton, bacteria, fungi and dissolved oxygen to a greater degree than oil alone.	Scott *et al.* (1979)

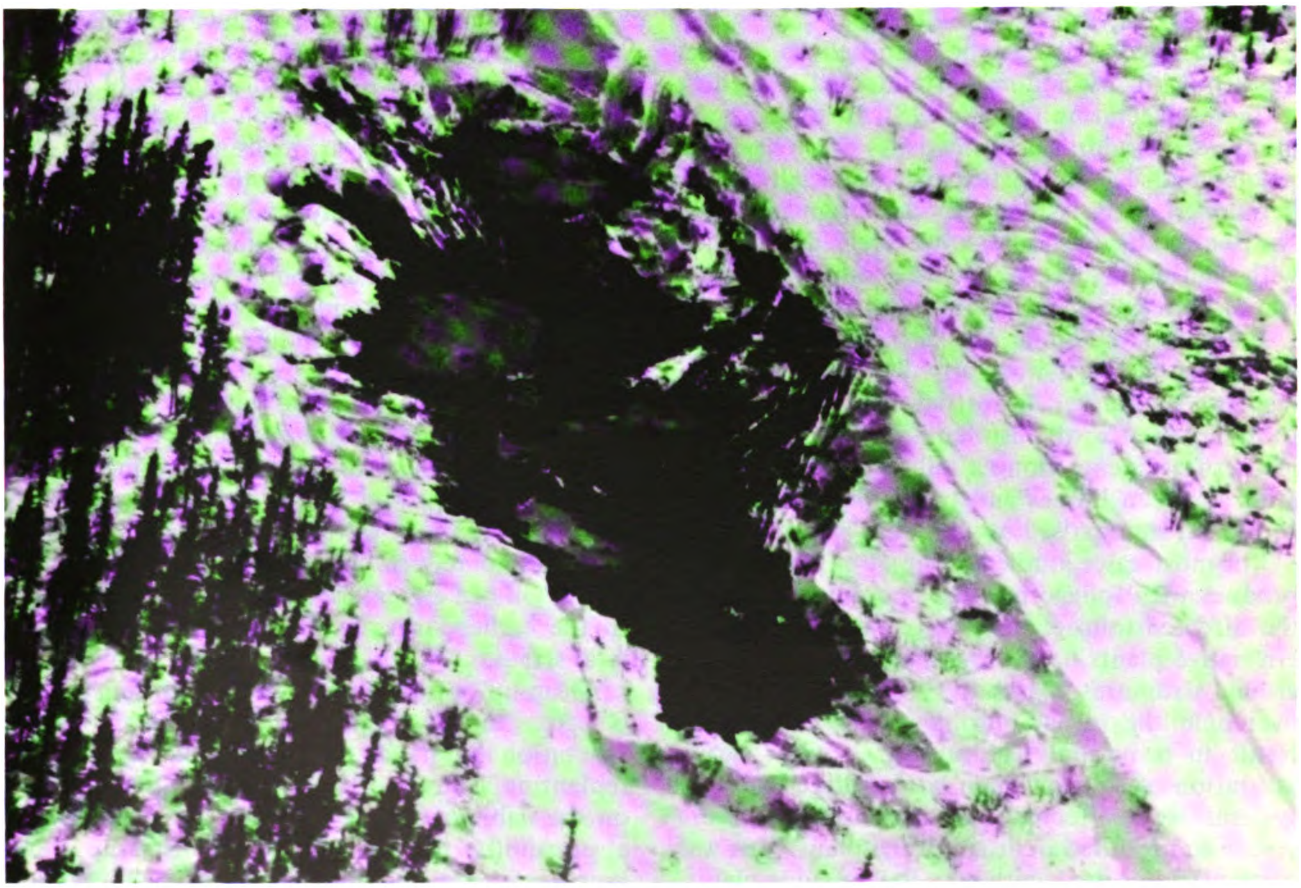

Fig. 5. Terrestrial pollution following a pipe-line leak, Canada. (Photo: E. P. S., Environment Canada.)

precautions. For example, at the Meredosia Oil Terminal, the Illinois River flooded a tank farm in April 1979 and the hydrostatic pressure lifted some of the diesel tanks and toppled them. The oil spread over the floodwaters in this area of corn farmland. Tanos (1981) suggested some of the ways this could have been prevented, including moving oil from the lighter tanks to the big tanks before the flood reached its highest level.

Spilt oil may penetrate to the water table, with the risk in some areas of polluting drinking-water sources. The protection of ground water is described by CONCAWE (1979a). Duhme (1982, pers. comm.) has pointed out that the decision for the site of the new Munich Airport was influenced by the assumption that the water table should be relatively close to the surface to facilitate clean-up techniques in the case of an accident (an alternative assumption being that there should be the deepest-possible absorbing layer between the water table and the possible spill source.

Petroleum affects soil properties and microbial populations (Odu, 1972). Bacterial numbers increase, including aerobic nitrogen-fixing bacteria. Eventually the nitrogen content of the soil increases. Odu (1977) reported that by the third year after an oil blowout on Nigerian agricultural land and secondary forest, vigorous growth of plants was observed.

Oil-polluted soil can be returned to normal more quickly by adding nutrients and ploughing to increase aeration (Odu, 1978). In tundra communities the addition of nutrients alone has been recommended as soil disturbance, especially of the permafrost area, is likely to cause rapid erosion. Nutrient addition should, however, be approached with caution if there is any likelihood of enriched run-off entering oligotrophic communities.

Before the 800-mile Alaska pipeline was built, experimental work was carried out to study the response of Alaskan terrestrial plant communities to the presence of petroleum and a survey was made of accidents along a military pipeline operating between Haines and Fairbanks. McCown *et al.* (1972) summarised observations as follows:

"In most cases studied, contact of a petroleum product with foliage resulted in eventual death of the affected foliage. However, since many northern native plants have developed extensive underground structures, regrowth from root-stocks may overcome the initial burning of the foliage and result in a natural restoration. ...(with) heavy saturation of soils or when both foliage and root systems were affected, damage was much more severe and resulted in death of the plant. This was particularly evident with very low growing plants, e.g., mosses and lichens...

Observations of actual refined fuel spills from pipelines in interior Alaska indicated that these products are potentially more destructive than crude oil. Depending on the site and degree of contamination, refined fuel spills remain in the subsurface layers of soil for years. In drier sites a heavy organic mat covering the soil surface can act as a barrier for subsequent natural revegetation and restoration.... North-facing slopes showed both greater initial damage and slower recovery rates than comparable south-facing slopes. In heavily petroleum-saturated sites, all vegetation was killed ... and in particularly cold areas, little revegetation was occurring after 15 years. This long term damage was in part due to the presence of the dead, dry organic mat which both retained the fuel in subsurface layers and prevented germination of seeds (a result of both the hydrophobic dry surface and the lack of a mineral soil surface). In contrast, low lying areas which acted as drainage channels showed considerable recovery, especially when on relatively warm exposures.

The observation that immediate damage during the season of the spill can be relatively low may allow appropriate measures to be employed to reduce the resultant damage in subsequent years. Such practices as washing the affected foliar and ground surfaces and stimulating the plant–soil system through fertilization (Schwendinger, 1968) may be helpful. In more severe situations, burning may serve the dual purpose of removal of surface contamination and stimulation of natural vegetation processes. However, realising that both contaminated arctic and subarctic systems remain thermally and physically stable and that man's attempts at clean-up may upset this stability, treatment beyond the general removal of petroleum accumulations and the prevention of water system contamination should be utilized with much caution."

Only a small amount of work so far has been carried out in Nigeria on the effect of oil pollution on vegetation; Kinako (1981) did some experiments which showed that the short-term effects of oil pollution on a Nigerian grass herb community was to reduce species numbers and productivity. Oil had a greater effect when it was applied to the earlier stages in seral succession than the later stages.

Clean-up options include doing nothing (which is often the best option), burning, removal of vegetation by hand, or mechanical removal and replanting. The type of action to be used depends on the habitat. Odu (1977) considered burning as a possibility in the Ogoni area, Nigeria. Here, however, the land was used for shifting cultivation and fire forms part of the management system.

Elsewhere, experiments have shown that in many cases fire destroys the vegetation and recolonisation takes a long time; indeed, toxic by-products may be left (Vandermeulen and Ross, 1977).

Removal of oil by removing oil-covered vegetation is often a good method; it is not a very efficient way of removing oil, but revegetation usually occurs quickly (Vandermeulen and Ross, 1977). Mechanical removal of vegetation usually damages the habitat so that revegetation is slow (Vandermeulen *et al.*, 1981). Replanting may be used to hasten the recovery process.

4.9.2. Points for WWF/IUCN consideration

1. In temperate and tropical countries, agricultural land can often eventually be re-used after an oil spill. Addition of fertilisers and ploughing speeds up the recovery process, but fertilisers should be used with caution if there is a danger of nutrient-enriched run-off entering oligotrophic communities.

2. If a natural habitat is affected, plants may be growing well again after three years, but the community may be at an earlier seral stage.

3. In the Arctic, recovery is much slower and in some situations takes more than 15 years; during this time there is the possibility of erosion.

4. Clean-up activities can often do much damage and reduce the chances of successful revegetation; burning can kill the vegetation and leave toxic by-products; mechanical clean-up can destroy soil structure and cause erosion.

5. The Oil Industry in Different Regions of The World

This section summarises information on oil industry activities in different parts of the world, and considers problems on a regional basis. Considerable differences occur between regions, and some of these are illustrated in Fig. 6 (oil production and reserves), Fig. 7 (refining capacity and oil consumption) and Fig. 8 (main oil movements by sea). Detailed maps showing the locations of the world's oilfields are available in B.P. (1977). In recent years there has been a great expansion in exploration and production offshore – this continuing activity embraces every continent and a range of conditions from shallow tropical seas to ice-bound polar waters (Fig. 9).

5.1. Polar Regions

A considerable amount of information is available from the United States and Canadian arctic oilfields, and this is of relevance to other polar regions. Drilling is normally from drillships in open water and artificial islands in the landfast ice zone. During 1982 the first caisson-stabilised artificial island was under construction; if it is successful, the next step may be year-round drilling from larger islands in moving pack ice. Larger islands could provide harbours for ice-breaking tankers.

Pollution could result from a blowout, tanker accident, ruptured pipeline or storage tank. Owens and Robilliard (1981) point out that stranded oil is likely to persist longer in the Arctic because of reduced thermal and mechanical (wave) energy levels, and that the hostile conditions may limit operational response.

Possible oil spill countermeasures in landfast sea ice have been described by Allen and Nelson (1981). One of the most promising techniques is burning (Fig. 10) because (in contrast to other regions) crude oil achieves a relatively thick equilibrium layer on polar waters or ice, and the lighter, more inflammable components are retained while the oil is entrained in ice. Air droppable igniters for remote areas have been described by Meikle (1981).

Priority is given to the concept of total containment of a major spill at or near its source. This would be much more difficult to achieve in breaking ice than in the landfast ice illustrated. In the case of a blowout, the possibility of relief-well drilling depends on the damage done to the drilling equipment by the incident and the time and difficulty of replacement. A stand-by drillship in open water can quickly replace a damaged one. Replacing a drill rig on an artificial island in ice might take much longer.

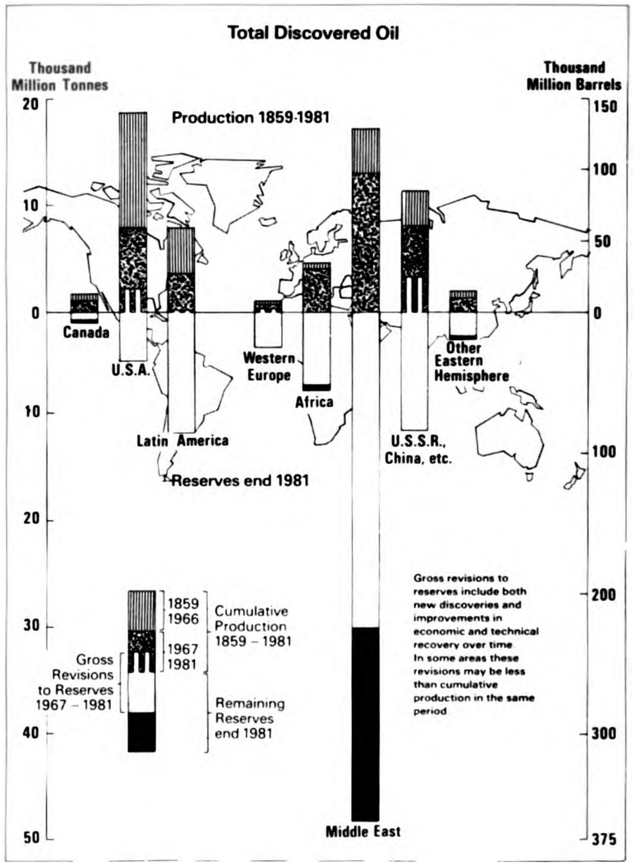

Fig. 6. World oil production and reserves. Reproduced from the B.P. Statistical Review of World Energy 1981.

The Arctic Marine Oil Spill Program (AMOP) reports annually, through a technical seminar, on many aspects of oil spills and countermeasures, including the 'do-nothing' approach for shorelines. The fifth report was published in 1982 (AMOP, 1982).

Maps are available for all Canada's coasts and some inland waters showing distribution of birds at risk from oil at all seasons. Brown *et al.* (1975) and supplements give much detail for the north-east Atlantic and adjacent arctic waters. Regions of importance to birds and mammals are presented in the Canadian Wildlife Service publication 'Arctic Ecology' map series which includes

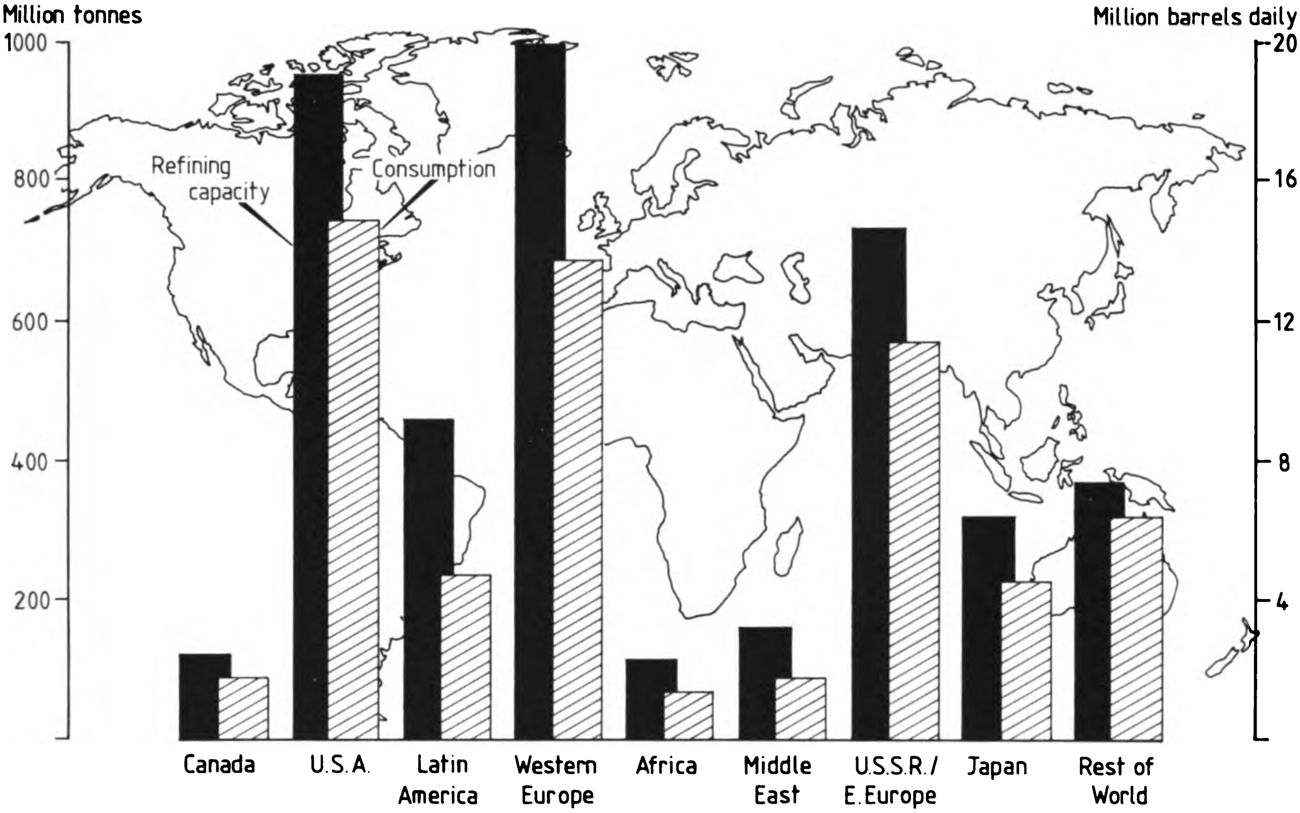

Fig. 7. World refining capacity and oil consumption 1981. Re-drawn from the B.P. Statistical Review of World Energy 1981.


Fig. 8. Main oil movements by sea 1981. Re-drawn from the B.P. Statistical Review of World Energy 1981.

34 1:1,000,000 map sheets of Arctic Canada and 324 pages of text (second edition, 1972).

The Alaskan coast has been mapped using the Environmental Sensitivity Index of Gundlach and Hayes (Gundlach and Hayes, 1982), and an oil spill response considerations manual including a biological resource inventory, prepared for the Alaskan Beaufort Sea coast (Morson *et al.*, 1982). Birds and mammals (particularly seabirds, seals and polar bears) are at risk from polar oil spills

Fig. 9. Main areas of offshore activity 1981 (after King, 1981).

1. Sverdrup Basin
2. Beaufort Sea
3. Bering Sea
4. Lower Cook Inlet
5. Baltimore Canyon
6. S. California
7. Blake Plateau
8. N. Gulf of Mexico
9. S. Florida
10. Campeche
11. Venezuela
12. Trinidad
13. Amazon
14. Campos
15. W. Chile
16. Malvinas Basin
17. Baffin Island
18. Labrador Shelf
19. Newfoundland
20. Georges Bank
21. Barents Sea
22. North Sea
23. W. Shetland
24. Porcupine
25. Bay of Biscay
26. E. Spain
27. Gulf of Cadiz
28. Sicily
29. Malta
30. Sierra Leone
31. Ivory Coast
32. Nigeria
33. Cameroun
34. Gabon
35. Congo
36. Angola
37. S. Africa
38. English Channel
39. Prinos
40. Nile Delta
41. Gulf of Suez
42. Persian Gulf
43. Bombay High
44. Seychelles
45. S. Yemen
46. Tanzania
47. Gulf of Thailand
48. Natuna Is.
49. Java Sea
50. N.W. Shelf
51. Exmouth Plateau
52. Gippsland
53. New Zealand
54. Bohai Gulf
55. Beibu Gulf
56. S. China Sea
57. Palawan
58. Sarawak
59. Malacca Strait
60. Gulf of Carpentaria
61. Fiji

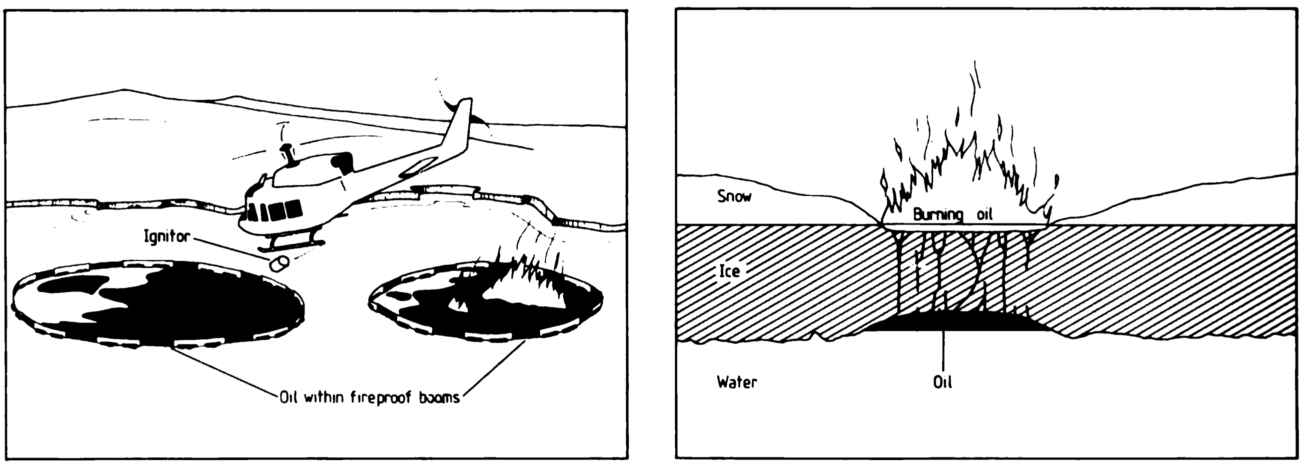

Fig. 10. Use of burning as a spill countermeasure on landfast sea ice (after Allen and Nelson, 1981).

(see preceding sections on birds and mammals). Information on tundra vegetation is given in the 'terrestrial habitats' section.

The effects of year-round open ice-breaker tracks (if they come) on marine and other wildlife are not known and little-discussed in the literature, though it has been speculated that whales could become trapped in them.

5.2. North America

On the North American mainland a relatively high proportion of oil has already been extracted (see Fig. 6), thus making tar sand and oil shale extraction relatively attractive. The Canadian tar sand extraction began commercially in 1967 and now produces about 200 000 barrels of 'synthetic' crude a day from two plants. Production by open pit mining destroys a limited amount of wildlife habitat and processing involves a lot of water and alkali. The water, alkali and some oil are held for a time in 25 square kilometres of settling ponds, some up to 50 metres deep. Because they are open in early spring and late autumn when nearby water bodies are ice-covered, the ponds are attractive to migrant aquatic birds which pass in hundreds of thousands. Diversion of the birds is difficult though much effort has gone into trying, so there have been losses. There is a potential for failure of retaining dykes which, if it occurred, could release contaminated water into a major tributary of the Mackenzie River system and cause ecological change there. Oil shale extraction is in pilot plant study in the US. Production would likely involve waste water problems similar to Canada's.

Offshore work in the Atlantic, Pacific and Gulf of Mexico has potential for ecological impacts from blowouts and spills. In the Gulf of Mexico tropical hurricanes interfere with exploration and production. In the north-east Atlantic icebergs complicate exploration drilling and will increase production costs. Drilling in the Atlantic from anchored drilling platforms or dynamically-positioned drillships in hundreds of metres of water uses very advanced technology. Production methods have not yet been tried.

Information on Canadian maps is given in Section 5.1. In the US, the Interior Department's Fish and Wildlife Service has produced the Atlantic Coast ecological inventory, a comprehensive series of maps of natural resources intended as a planning tool for governments and industry. A similar inventory of Pacific Coast resources is underway.

5.3. Central America and the Caribbean

In the 20th century Central America and the Caribbean has been one of the world's main oil production areas, second only to the Middle East. It should remain so for the foreseeable future with some 10% of the world's 'proven' oil reserves. Oil consumption for the area as a whole in 1980 was ca. 75% of production, making it a net exporter of oil, most of which has been sent by sea to the eastern USA and Europe. Much of the production of oil has been onshore, especially in Venezuela (notably in the Maracaibo Basin), Trinidad and Mexico, but recent and massive oil finds off the Mexican coast in the Bay of Campeche and off Trinidad have resulted in considerable offshore development. Oil inputs to the sea have mainly been from shipping (mostly tankers), natural seepages and urban and industrial inputs, although urban and industrial development has been relatively small. Precise figures for oil inputs in this area are not readily available.

A change in both absolute and relative sizes of the various inputs may be postulated in the light of extensive offshore developments in some areas. This increases the risks of pipeline spills and blowouts (e.g., Ixtoc I, one of the world's largest spills at ca. 140×10^6 galls, Fig. 11.) as well as chronic inputs such as production water. Shipping action has also increased, partly from exporting the increasing production from the area and partly from passage of ships carrying Alaskan oil to the eastern USA via the Panama Canal. Currently ca. 4.7 million barrels of oil a day pass through the Caribbean. A rapid development of large-scale industrial concentrations along the coasts of Mexico, Venezuela, Colombia and some of the Greater Antilles Islands, especially Puerto Rico, also indicates the likelihood of increased chronic inputs. The environmental aspects of chronic discharges from offshore exploration and production and coastal industrial developments deserve future attention.

The special characteristics of Caribbean marine resources in relation to oil pollution are as follows. Extensive coral, mangrove and seagrass areas occur, all of which are sensitive to spills and chronic discharges. Much of the sea area is relatively shallow and supports large fisheries which are important components of many of the island economies. Mangroves and seagrasses form nursery and feeding grounds for several commercial species and many of the eastern islands rely heavily on tourism, mostly in relation to beaches and marine recreation. All such resources are particularly sensitive to spills and their clean-up as well as chronic discharges. Oil spill contingency plans or response arrangements (such as the Clean Caribbean Cooperative already in existence) need to pay particular attention to these sensitive areas.

Recent initiatives on the part of the United Nations Environment Programme and the International Union for the Conservation of Nature and Natural Resources, in conjunction with Caribbean governments, have been aimed at preparing a conservation strategy to protect and manage the outstanding biological resources of the area. In addition to the environmental concerns already noted, many species of international conservation importance occur, including mammals (e.g., manatees) and turtles.

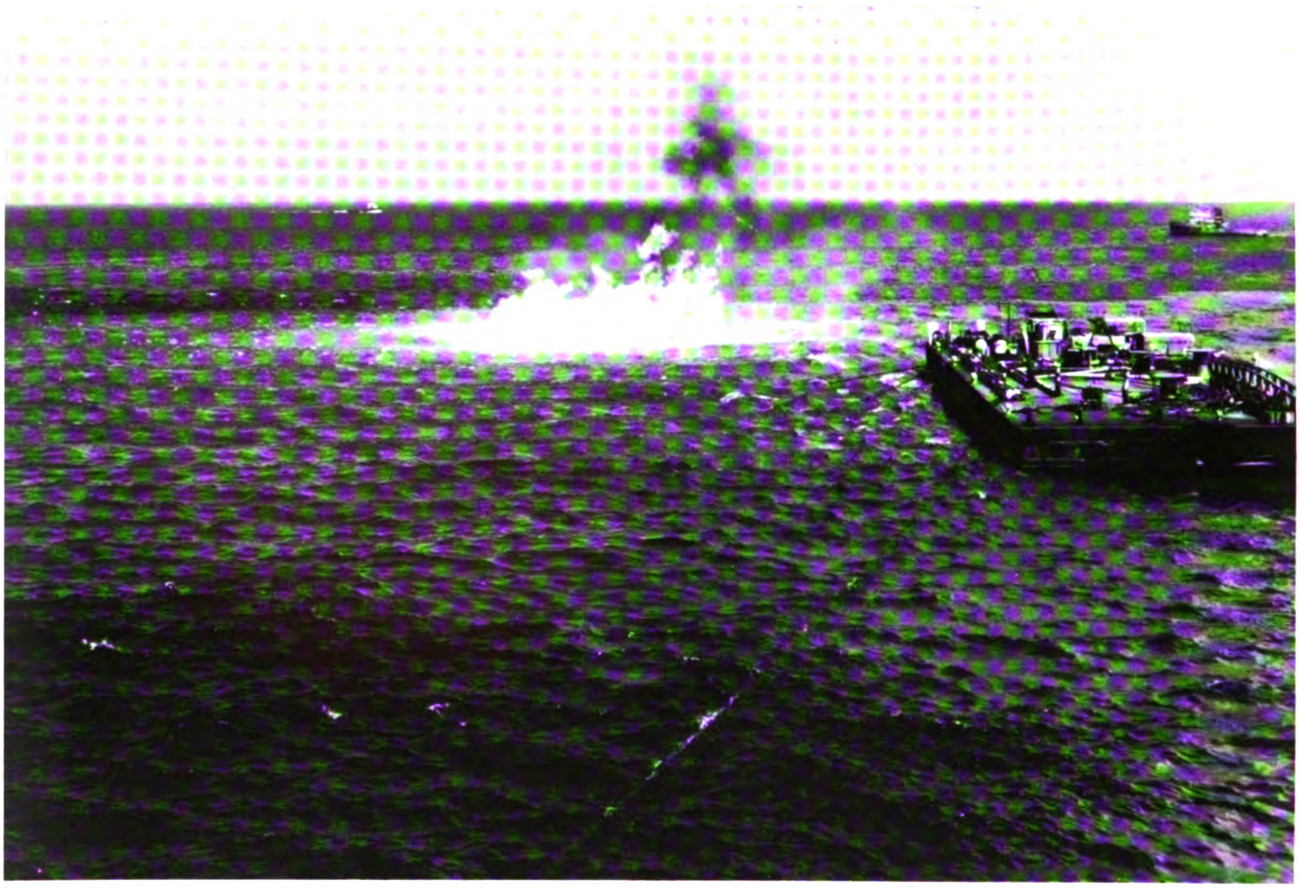

Fig. 11. The Ixtoc I blowout, Gulf of Campeche, Mexico. (Photo: E.P.S., Environment Canada.)

5.4. South America

In Brazil, offshore reserves are being developed in the Campos Basin and exploration contracts have been signed for areas in the mouth of the Amazon. In the Amazon Basin itself, oil was discovered in 1955 (the Nova Olinda well, south of Manaus) but production could not be maintained at this site. There are producing oil wells in the Upper Amazon Basin, both in Peru and Colombia.

In the southern part of South America, producing oil wells are concentrated (1) in the Magellanes Basin (Chile and Argentina) including parts of Patagonia, the eastern Straits of Magellan and Tierra del Fuego, (2) in the San Jorge Basin (Argentina), and (3) along the eastern foot of the Andes (Bolivia and Argentina). Exploration interests now extend into the Malvinas Basin.

Apart from crude oil, Brazil has extensive deposits of oil shale in the southern states of São Paulo and Parana.

If oil production should increase in the Amazon Basin, IUCN should give high priority to the control of possible ecological effects. Potential disruption through the cutting of roads and pipeline routes is probably at least as important as possible effects of spills and chronic discharges.

In the south, seabirds (notably penguins) and inshore fisheries are at risk from operations in the Magellanes Basin.

5.5. Europe, USSR and the Mediterranean

Western Europe is a net importer of oil. The states bordering the south-eastern Mediterranean have comparatively limited oil consumption and some, such as Libya, are major exporters. In the USSR, production and consumption of oil more or less balance.

5.5.1. Europe

Western Europe is the world's second largest consumer of oil and despite the discovery and development of numerous oilfields in the North Sea, still imports large quantities of oil. Exploration is being carried out in a number of areas, as well as the North Sea. Most promising are the Porcupine Basin (west of Ireland), west of the Shetlands and off central and northern Norway, although the depth of water and weather conditions present technical problems in these areas. A sizeable gas-condensate discovery has been made in the Bay of Biscay and several gas fields are being developed in the Gulf of Cadiz.

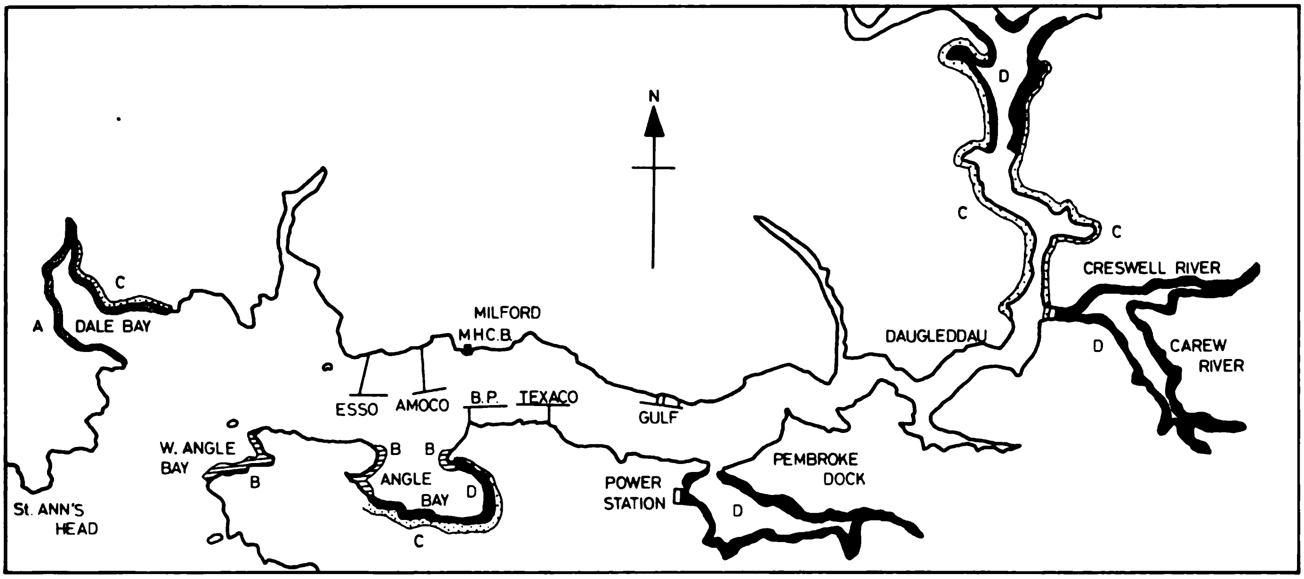

Fig. 12. Port of Milford Haven, UK. Anti Oil Pollution Plan.
Key: Areas in which dispersant may not be used without prior consultation.
Area 'A' Consult Warden Dale Fort Field Centre.
Area 'B' Consult Oil Pollution Research Unit or Warden Orielton Field Centre.
Area 'C' Consult District Inspector of Fisheries.
Area 'D' Consult Nature Conservancy Council.

The offshore activity carries the risk of large accidental spillages of oil to the marine environment as well as the chronic inputs of oil through routine operations and discharges. The sea lanes around north-western Europe are some of the busiest in the world and there have been a number of large oil spills resulting from tanker accidents, e.g., 'Torrey Canyon', 'Amoco Cadiz'. Similar accidents may be expected in the future. In addition there are large inputs of oil from urban, industrial and refinery sources.

In addition to the offshore activity there are numerous, but generally small, onshore fields in Western Europe, notably in the UK, France, the Netherlands, West Germany, Austria, Italy and Yugoslavia. Exploration onshore is continuing, including in areas of nature conservation importance, e.g., in the New Forest, England.

The overland pipeline routes for the transportation of crude oil and products may pass through environmentally sensitive areas. However, a recent review of European pipeline spillages between 1975 and 1979 (CONCAWE, 1980c) indicated that 70% involved only very small volumes and only five out of 78 spillages required extended clean-up effort.

At particular risk from large spills are shallow-water fish nursery areas, shellfish beds and breeding or feeding concentrations of seabirds. There are a number of oil spill contingency plans both at the regional and national levels which often incorporate consultation with local academic institutions for advice on clean-up and assessment of effects. For example, Milford Haven is one of Europe's largest oil ports and in addition to sites of marine biological and ornithological interest, contains small but potentially sensitive fisheries for fin- and shellfish. Fig. 12 illustrates the sensitive areas and arrangements for consultation before shore clean-up. The plan forms part of an efficient management of the port which helps to minimise ecological effects (Dicks and Hartley, 1982).

5.5.2. USSR

The USSR is largely self-sufficient in oil with production balancing consumption. The majority of production is onshore, the major areas being the Volga–Ural Province and the West Siberian Basin, although there is offshore production in the Caspian Sea where further exploration is being carried out. The control of possible ecological effects in the Caspian should receive high priority because (1) there is a large proportion of endemic species, and (2) there is a wide range of faunal assemblages resulting from local variations in salinity. The large onshore production of oil may cause serious pollution of rivers and lakes.

5.5.3. Mediterranean Sea

The Mediterranean is surrounded to the north by industrialised Europe and to the south and east by less-industrialised nations. There is widespread exploration for oil, particularly off western Spain, Tunisia and Libya, Sicily, Egypt, and the Adriatic and Ionian Seas. Commercial quantities of oil have been found in a number of areas, in particular Libya and Sicily, and production has commenced off western Spain, Tunisia and Greece.

The northern Mediterranean already receives a large pollution load from industrial and urban sources, and concern has been expressed about the effects of this particularly in view of the enclosed nature of the Sea. However, as has been pointed out by Clark (1979), much of this concern has been on the basis of conjecture and where studies have been carried out, although polpution damage has been demonstrated, the situations were not beyond recovery.

An international 'Mediterranean Action Plan' was adopted in 1975 and in 1978 the Barcelona Convention (the convention for the protection of the Mediterranean Sea against pollution) was adopted. Some progress towards the objectives of the Convention has been reported (e.g., *Mar. Pollut. Bull.*, *12*, 35–36).

5.6. Africa

There are onshore oilfields in all of the North African countries, numerous fields along the east and west coasts of the Gulf of Suez, and several recent discoveries offshore in the Gulf (see Section 5.7). Nigeria is an important producer, with oilfields both onshore and offshore in the Niger Delta region. Much of the onshore production is in mangrove areas. Recent discoveries have been made off the Ivory Coast, Benin, Cameroun, Gabon, the Congo Republic, Angola and South Africa, and the Tanzanian government is developing the Songo–Songo gas field (partly onshore and partly offshore). There is exploration around the Seychelles.

The results of core sampling and seismic surveys have led to oil industry interest in Lakes Tanganyika and Malawi in the East African Rift Valley. Possible developments in these deep ancient lakes should be followed closely by IUCN in view of the high proportions of endemic species including fish 'species flocks' of very close-related yet distinct species (Moss, 1980). Mangroves are particularly at risk in the Niger Delta from spills, chronic discharges and physical disturbance such as pipeline laying.

The UNEP Regional Seas Programme includes West and Central Africa, East Africa and the Red Sea and Gulf of Aden, and oil pollution control measures are being pursued through this Programme. Increasing public awareness and government concern is in evidence.

5.7. The Middle East and India

5.7.1. The Middle East

The Middle East is currently the world's largest oil production area (ca. 30%) and is likely to remain so with an estimated 55% of the world's 'proven' oil reserves (approximately five times more than the nearest rival, Latin America, with 10.6%). The majority of new exploration and production is offshore, and one of the fastest-developing areas with enormous production potential is in the Gulf of Suez in the Northern Red Sea. The great majority of Middle East oil is transported by pipeline and/or ship to other parts of the world.

Oil consumption and refining in the Middle East is considerably less than production (total consumption is ca. 9% of production) but is currently growing rapidly with urban and industrial development programmes.

These factors mean that the potential for oil pollution is different from the world average (see Baker and Dicks, 1982). Table 5 gives a summary of the main differences for the Gulf, and a similar pattern must be expected for the Red Sea.

At present, the great majority of oil entering the sea in the Gulf is as surface slicks, and for the foreseeable future tanker spills, tanker washings, pipeline breaks and offshore blowouts are the most likely sources of oil pollution. However, the

TABLE 5

Estimated inputs of oil to the marine environment (as a percentage of total), Gulf vs. rest of the world

	Gulf		World
	1977 (Neumann, 1979)	1979 (Golob, 1980)	(Cowell, 1978)
1. Tanker and ship traffic (spills and routine discharges)	86	58	23
2. Offshore production and natural seepages*	14	22	14
3. Refining, industrial and urban	<0.12	20	63

*Only minor unspecified contribution.

current urbanisation, industrialisation and offshore production programmes throughout the Middle East indicate an increase in chronic discharges (effluents and offshore production water discharges) and suggest that in the future more attention should be directed to their environmental effects.

The enclosed nature of the main receiving bodies (the Red Sea and the Gulf) in conjunction with little water exchange with the Indian Ocean (as a result of evaporative losses) considerably reduces dispersion potential for pollutants compared with the open ocean and many coastal regions. Golob (1980) estimates ca. 3.1% of the total world oil input to occur in the Gulf, but in view of the confined nature of the water body this represents an input of some 47 times more per unit area than the world average.

International spill response plans are in preparation for the Gulf (e.g., Kuwait Action Plan) and individual countries and operating companies hold varying stocks of spill clean-up equipment. The biological effects of clean-up should be borne in mind when considering the overall effects of spills. The limited capacity for dispersion in many parts of the Gulf and the Red Sea suggests that caution should be used when cleaning up with disperant chemicals.

Habitats which are common and at risk from both spills and chronic discharges in the Red Sea and the Gulf are primarily coral reefs and sediment communities, notably seagrass beds and mangrove swamps (see Fig. 13). Fishing for finfish and crustaceans is also important locally and some species of international conservation importance (e.g., turtles) are present in some areas. General summaries of habitats and organisms at risk from spills and chronic discharges are given in Baker and Dicks (1982).

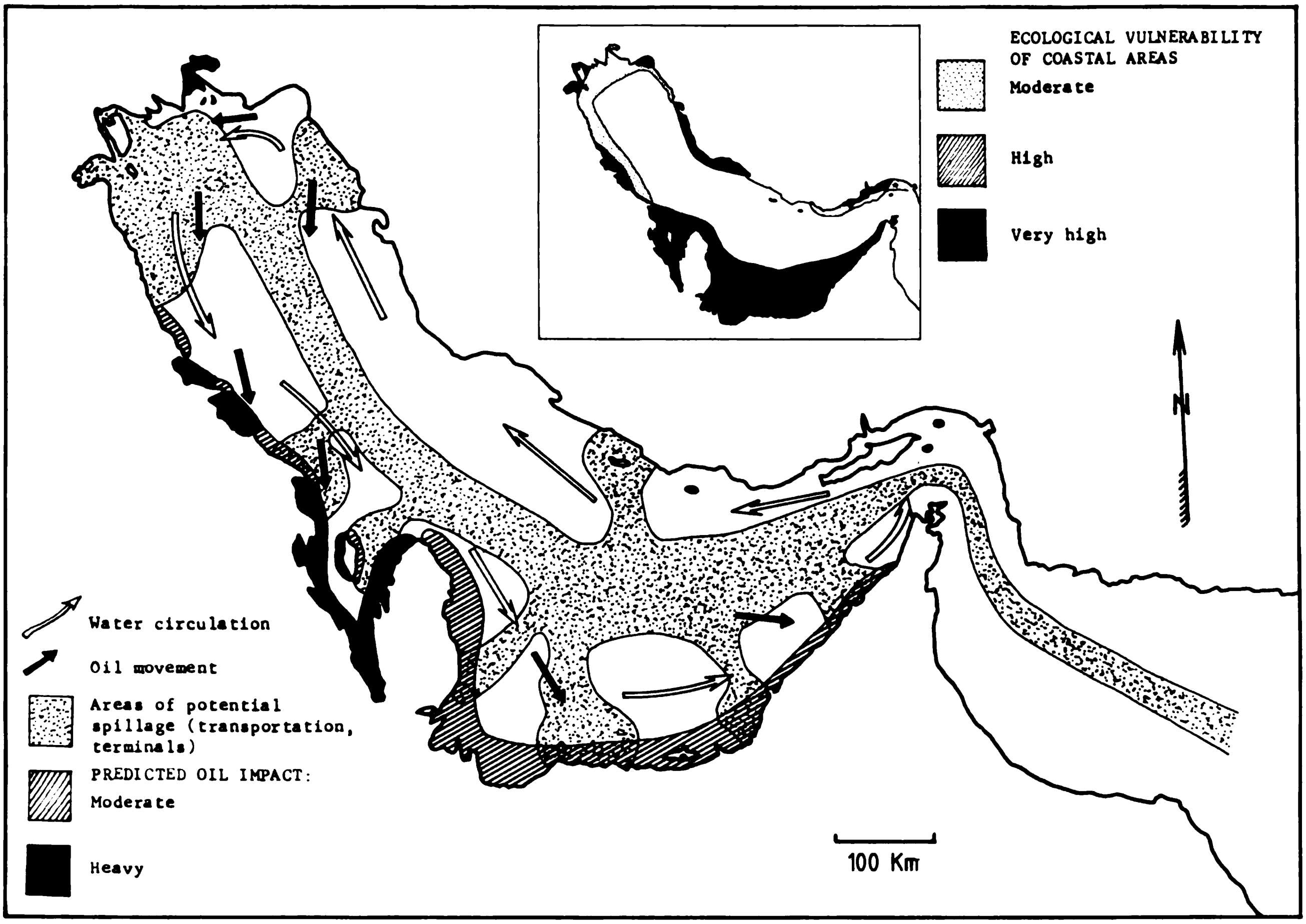

Fig. 13. The potential for oil pollution: predicted sources, circulation patterns and shoreline impact areas in the Gulf. Ecological vulnerability of coastal areas is shown in the inset. Vulnerability was defined on the basis of habitat sensitivity, shallow water depth, high temperature and salinity, and poor circulation. Adapted from Neumann (1979).

Although quoted figures are concerned with marine habitats, it should be remembered that some oil pollution of terrestrial and freshwater habitats also occurs through blowouts, pipeline breaks, storage tank leaks, road or rail accidents, boat traffic on inland waterways and by general industrial discharges.

5.7.2. India

India, as a net importer of oil and in world terms a relatively small producer, might be expected to conform more closely to the world pattern of oil inputs to the sea as summarised in the table above. However, the proximity of the major oil tanker routes from Middle Eastern production areas past the west coast of India and Sri Lanka suggests a relatively higher likelihood of spills from tankers and tanker washings (see, for example, Sen Gupta and Kureisky, 1981). In addition, offshore oil production (started in 1978) in the north-western seas is in the process of rapid expansion and currently produces more than one-third of the total Indian oil. Risks from pipeline spills, blowouts and production water discharges may thus be expected to increase.

Marine habitats at risk include mangrove swamps, coral reefs and seagrass beds. Wider conservation interests in the Northern Indian Ocean include resident and migratory birds, turtles and mammals (especially cetaceans) and much interest is focussed on oceanic islands.

5.8. South-east Asia and China

The area of South-east Asia and China is a region of diverse development with widely different oil-related activities. Countries such as Japan consume large quantities of oil (about 8% of the world's output) but produce exceptionally little (in 1980, Japan had only one offshore oilfield and several small onshore fields producing about 0.015% of world output). On the other hand, a large amount of production occurs amongst the islands of Indonesia. China is a net exporter of oil.

The islands of Indonesia, Malaysia, Japan and the Philippines are near to some of the busiest shipping routes of the world. Here, tanker traffic operates from the Middle East and Far East carrying oil mainly to Japan and to the west coast of North America. Much of this tanker traffic is through narrow straits and amongst small islands.

Almost all of the countries within this region have programmes of exploration for oil and gas underway, with China considered to be a likely high producer in the future. Exploration and production inevitably carries the risk of blowouts and other sources of spillage, whilst increased export of crude oil and products will involve more tanker traffic. Thus, the risk of serious pollution, already high in Indonesia, will be increased.

Two major ecosystems are noted here as particularly sensitive: mangroves and coral reefs. Both occupy extensive areas of the coastlines in this region. The shallow coastal waters are of particular importance for fisheries.

5.9. Australia and New Zealand

Australia and New Zealand produce small amounts of oil but are net consumers. Both have programmes of exploration underway. Much past exploration in Australia has been carried out to the north-west of the continent and has resulted in extensive gas finds but not oil. The main producing and present oil exploration area in Australia is in the region of the Bass Strait and Tasmania. In New Zealand, the main production (of gas and condensate) derives from the Maui Field off the south-west coast of North Island. Neither Australia nor New Zealand is on main tanker routes.

It seems likely that oil production and associated exploration and production facilities will increase slightly in future years with associated increases in tanker traffic. However, in Australia the Great Barrier Reef is viewed as a potentially oil-rich zone. In 1979, the Australian government placed an indefinite ban on drilling in this area of high conservation interest, much of which would be very susceptible to damage by oil pollution. Areas of mangroves are also present in north-eastern Australia. There are doubtless other areas of high scientific and conservation interest such as the marine national parks off the coast of northern New Zealand, but information on such areas is widely dispersed.

6. Conclusions

6.1.

The groups of organisms most likely to be severely affected following oil spills are those at the water/air interface, namely birds, mammals and emergent vegetation. Local populations of birds and mammals may be significantly reduced, and badly oiled vegetation may die and take a long time to recover. Mangroves are of particular concern in this respect.

6.2.

Conclusions concerning relative vulnerability of different types of shoreline, and recommended clean-up approaches, have been summarised by Gundlach and Hayes (1978) in a vulnerability index. A modification of this index is given in Table 6. It should be emphasised that in some cases clean up operations are a necessary response to factors not dealt with in this ranking of shore-

TABLE 6

Summary of proposed environmental classification in order of increasing vulnerability to oil spill damage (modified from Gundlach and Hayes, 1978).

Vulnerability index	Shoreline type	Comments
1	Exposed rocky headlands	Wave reflection keeps most of the oil offshore. Clean-up frequently unnecessary.
2	Eroding wave-cut platforms	Wave-swept. Most oil removed by natural processes within weeks.
3	Fine-grained sand beaches	Oil does not usually penetrate far into the sediment, facilitating mechanical removal if necessary. Otherwise, oil may persist several months. (Recent evidence suggests that water table movements in sediments are a factor affecting degree of penetration.)
4	Coarse-grained sand beaches	Oil may sink and/or be buried rapidly making clean-up difficult. Under moderate to high energy conditions, oil will be removed naturally within months from most of the beachface.
5	Exposed, compacted tidal flats	Most oil will not adhere to, nor penetrate into the compacted tidal flat. Clean-up is usually unnecessary, except to prevent the oil from going elsewhere.
6	Mixed sand and gravel beaches	Oil may undergo rapid penetration and burial. Under moderate to low energy conditions, oil may persist for years.
7	Gravel beaches	Same as above. Clean-up should concentrate on high-tide swash area. A solid asphalt pavement may form under heavy oil accumulations.
8	Sheltered rocky coasts	Areas of reduced wave action. Oil may persist for many years. Clean-up is not recommended unless oil concentration is very heavy.
9	Sheltered tidal flats	Areas of low wave energy and high biological productivity. Clean-up is not recommended unless oil accumulation is very heavy. These areas should receive priority protection by using booms or oil sorbent materials.
10	Saltmarshes and mangroves	Most productive of aquatic environments. Oil may persist for years. Cleaning of saltmarshes by burning, cutting or stripping should be undertaken only if heavily oiled. Mangroves should not be altered. Protection of these environments by booms or sorbent material should receive first priority.

line types. For example, a shore may have to be cleaned quickly because it is used by birds, seals or tourists, in spite of the prediction for that shore that oil will be removed naturally within weeks or months (see Section 2.4).

6.3.

Habitats not included in 6.2 include the open sea, the seabed, coral reefs, seagrass beds, lagoons and embayments with restricted circulation, freshwater habitats and terrestrial habitats. Vulnerability classifications along the lines of Gundlach and Hayes shoreline system would be useful for these different areas.

6.4.

There is little evidence of subtle long-term effects of oil pollution; however, it has to be pointed out that there are enormous difficulties in distinguishing subtle long-term effects of oil or any other pollution in field conditions. This is because of 'background noise', i.e., natural fluctuations and trends against which pollution-induced fluctuations and trends may be lost.

6.5.

Clean-up is often difficult and expensive and may cause further damage. The foremost priority should therefore be encouragement of national, international and industrial attempts to reduce oil pollution with the aim of preventing ecological damage. Such attempts encompass improvements in areas as diverse as tanker construction and operation, shipping routes, navigational aids and pilotage procedures, terminal construction and operation, staff training, effluent treatment techniques, and regulatory controls at regional, national and international levels. WWF/IUCN does not have specific expertise in these subjects so should aim to promote progress by supporting existing programmes, e.g., ratification of IMO Conventions and the Regional Seas Programme of UNEP.

6.6.

Some oil pollution is nevertheless inevitable from the various sources outlined in Section 2.1, and response plans and clean-up capacity remain a necessity. Essential features of national and regional plans are identification and mapping of vulnerable areas and consideration 'before the event' of (1) priorities for protection, (2) the appropriate course of action if oil is spilled (e.g., protect using temporary barriers, treat with dispersants, remove using physical methods, leave to weather naturally), and (3) available resources (e.g., aircraft) for surveillance and treatment.

Pollution control plans need to be backed up with statutory controls and appropriately severe penalties for non-complicance.

6.7.

More needs to be known about the relative effectiveness and ecological effects of different clean-up techniques, and more experimental use could be made of oil spills when they occur for this type of investigation.

7. Summary of Priorities for WWF/IUCN Support

The specific ecological expertise of the WWF/IUCN can usefully complement the predominantly technical and legal expertise available elsewhere (see, for example, the 13 organisations including UNEP, IMO and several industry organisations described in the guide published by Witherby (1981)). For example, the WWF/IUCN should be able to respond quickly to requests for post-spill advice on vulnerable species or habitats. Apart from these unpredictable incidents, priority support should be given to:

1. National and regional ecological impact assessments and contingency plans, particularly in the tropics.

2. Practical projects concerned with the protection, clean-up and restoration of sensitive habitats, in particular:
   - Mangroves
   - Seagrass beds
   - Coral reefs
   - Freshwater habitats

3. A review of oil pollution effects and associated disturbances on the seabed, (including coral reefs and seagrass beds) with the aim of producing a vulnerability classification along the lines of that already available for intertidal areas.

4. Surveillance of possible oil industry developments in the Amazon Basin and in ancient lakes such as Tanganyika and Malawi.

8. References

Abbiss, T. P., Little, D., Baker, J. M. and Tibbetts, P. J. C. (1981) The fate and effects of dispersant-treated compared with untreated crude oil, with particular reference to sheltered intertidal sediments. Part II. *Proc. of the Fourth Arctic Marine Oilspill Program Technical Seminar, Edmonton, 16–18 June 1981*, pp. 401–443.

Addy, J. M., Levell, D. and Hartley, J. P. (1978) Biological monitoring of sediments in the Ekofisk oilfield. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 514–539.

Allen, A. A. and Nelson, W. G. (1981) Oil spill countermeasures in landfast sea ice. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Atlanta, 2–5 March 1981*, API/EPA/USCG, pp. 297–304.

AMOP (1982) *Proc. of the Fifth Arctic Marine Oilspill Program Technical Seminar, Edmonton, 15–17 June 1982*, Environmental Emergency Branch, Environmental Protection Service, 618 pp.

Anderson, J. W., and Neff, J. M. (1974) Accumulation and release of petroleum hydrocarbons by edible marine animals. *Proc. of the International Symposium: Recent Advances in the Assessment of Health Effects of Environmental Pollution, Paris, June 1974.*

Armstrong, H. W., Fucik, K., Anderson, K. W. and Neff, J. M. (1979) Effects of oilfield brine effluent on sediment and benthic organisms in Trinity Bay, Texas, *Marine Environ. Res.*, *2*, pp. 55–69.

Audunson, T. (1978) The fate and weathering of surface oil from the 'Bravo' blowout. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 445–475.

Baker, J. M. (1971) Studies on saltmarsh communities. In E. B. Cowell (ed.) *The Ecological Effects of Oil Pollution on Littoral Communities*, Applied Science Publishers, Barking, pp. 16–101.

Baker, J. M. (1976) Ecological changes in Milford Haven during its history as an oil port. In J. M. Baker (ed.) *Marine Ecology and Oil Pollution*, Applied Science Publishers, Barking, pp. 55–66.

Baker, J. M. (1979) Responses of saltmarsh vegetation to oil spills and refinery effluents. In R. L. Jeffries and A. J. Davy (eds.) *Ecological Processes in Coastal Environments*, Blackwell Scientific Publications, Oxford and London, pp. 529–542.

Baker, J. M., Crothers, J. H., Mullett, J. A. J. and Wilson, C. M. (1980) Ecological effects of dispersed and non-dispersed crude oil: a progress report. In *Proc. of the Institute of Petroleum Conference on Petroleum Development and the Environment, London, 20–21 November 1979*, Heyden & Son Ltd., London, pp. 85–100.

Baker, J. M., Suryowinoto, M., Brooks, P. and Rowland, S. J. (1981) Tropical marine ecosystems and the oil industry; with a description of a post-oil-spill survey in Indonesian mangroves. In *Proc. of the PETROMAR 80 Conference on Petroleum and the Marine Environment*, Graham and Trotman, London, pp. 679–701.

Baker, J. M. and Dicks, B. (1982) The effects, monitoring and control of pollution from the Gulf States oil industry. IUCN paper prepared for Expert Meeting of the Gulf Co-ordinating Council to Review Environmental Issues, 16 pp.

Baker, J. M., Crothers, J. H., Little, D. I., Oldham, J. H. and Wilson, C. M. (in press) Comparison of the fate and ecological effects of dispersed and non-dispersed oil in a variety of intertidal habitats.

Bellamy, D. J., Clarke, P. H., John, D. M., Jones, D., Whittick, A. and Darke, T. (1967) Effects of pollution from the 'Torrey Canyon' on littoral and sub-littoral ecosystems, *Nature* (London), *216*, pp. 1170–1173.

Blackall, P. J. and Sergy, G. A. (1983) The BIOS Project —an update. In *Proc. of the 1983 Oil Spill Conference, San Antonio, Texas, 28 Feb.–3 March 1983*, API/EPA/USCG, pp. 451–455.

Blackman, R. A. A., Baker, J. M., Jelly, J. and Reynard, S. (1973) The 'Dona Marika' oil spill, *Marine Pollution Bull.*, *4* (12), pp. 181–183.

Boehm, P. D., Barak, J. E., Fiest, D. L. and Elskus, A. A. (1982) A chemical investigation of the transport and fate of petroleum hydrocarbons in littoral and benthic environments: the 'Tsesis' oil spill, *Marine Environ. Res.*, *6*, pp. 157–188.

Bourne, W. R. P., Parrack, J. D. and Potts, G. R. (1967) Birds killed in the 'Torrey Canyon' disaster, *Nature* (London), *215*, pp. 1123–1125.

Bourne, W. R. P. (1979) The 'Christos Bitas' affair, *Marine Pollution Bull.*, *10* (5).

B. P. (1977) *Our Industry Petroleum*, British Petroleum Co. Ltd., London, 600 pp.

B. P. (1981) *BP Statistical Review of the World Oil Industry*, British Pet. Co. Ltd., London.

Brown, R. G. B., Gillespie, D. I., Loche, A. R., Pearce, P. A. and Watson, G. H. (1973) Bird mortality from oil slicks off Eastern Canada, February–April, 1970, *Canadian Field Naturalist*, *87*, pp. 225–234.

Brown, R. G. B., Nettleship, D. M., Germain, P., Tull, C. E. and Davis, T. (1975) *Atlas of Eastern Canadian Seabirds*, Canadian Wildlife Service, Environment Canada, Ottawa, 220 pp.

Brown, S. O. and Reid, B. L. (1951) Report on experiments to test the diffusion of oxygen through a surface layer of oil. Texas A. and M. Res. Found., Project 9, 5 pp. (mimeo).

Brownell, R. L. (1971) Whales, dolphins and oil pollution. In D. Straughan (ed.) *Biological and Oceanographic Survey of the 'Santa Barbara' Channel Oil Spill 1969–*

1970, Allan Hancock Foundation, University of Southern California, Ch. 12.
Bugbee, S. L. and Walter, C. M. (1973) The response of macroinvertebrates to gasoline pollution in a mountain stream. In *Proc. of the Joint Conference on Prevention and Control of Oil Spills, Washington DC, 13–15 March 1973*, API/EPA/USCG, pp. 725–731.
Burk, J. C. (1977) A four-year analysis of vegetation following an oil spill in a freshwater marsh, *J. Appl. Ecol., 14*, pp. 515–522.
Cabioch, L., Dauvin, J. C., Mora Bermudez, J. and Rodriguez Babio, C. (1980) Effets de la marée noire de l' 'Amoco Cadiz' sur le benthos du nord de la Bretagne, *Helgoländer Meersunters., 23*, pp. 192–201.
Calpouzos, L. (1966) Action of oil in the control of plant disease, *Ann. Rep. Phytopath., 4*, pp. 369–390.
Chapman, V. J. (ed.) (1977) *Ecosystems of the World. 1. Wet Coastal Ecosystems*, Elsevier, Amsterdam, London, New York, 428 pp.
Clark, R. B. (1979) The health of the Mediterranean, *Marine Pollution Bull., 10*, pp. 277–278.
CONCAWE (1979a) Protection of ground water from oil pollution, *Report 3/79*, CONCAWE, Den Haag, 61 pp.
CONCAWE (1979b) The environmental impact of refinery effluents, *Report 5/79*, CONCAWE, Den Haag, 4 sections, numbered separately.
CONCAWE (1980a) Sludge farming: a technique for the disposal of oily refinery wastes, *Report No. 3/80*, CONCAWE, Den Haag.
CONCAWE (1980b) Disposal techniques for spilt oil, *Report No. 9/80*, CONCAWE, Den Haag, 52 pp.
CONCAWE (1980c) Performance of oil industry cross-country pipelines in Western Europe, *Report No. 10/80*, CONCAWE, Den Haag, 12 pp.
CONCAWE (1981a) Revised inland oil spill clean-up manual, *Report No. 7/81*, CONCAWE, Den Haag, 152 pp.
CONCAWE (1981b) A field guide to coastal oil spill control and clean-up techniques, *Report No. 9/81*, CONCAWE, Den Haag, 112 pp.
Cowell, E. B. (1978) Pollution of coastal zones by hydrocarbons. Oral submission to the European Parliament, 4th July 1978. European Parliamentary Hearings, 4th July 1978, pp. 14–15.
Crapp, G. B. (1971) Zoological studies on shore communities. In E. B. Cowell (ed.) *The Ecological Effects of Oil Pollution on Littoral Communities*, Applied Science Publishers, London, pp. 102–216.
Davis, J. E. (1974) Skomer Island National Nature Reserve Grey Seals (*Halichoerus grypus*). Warden's report on 1974 breeding season with special reference to the effects of oil pollution.
Dicks, B. (1973) Some effects of Kuwait crude oil on the limpet, *Patella vulgata, Environ. Pollut., 5*, pp. 219–229.
Dicks, B. (1976) Offshore biological monitoring. In J. M. Baker (ed.) *Marine Ecology and Oil Pollution*, Applied Science Publishers, Barking, pp. 325–440.
Dicks, B. and Hartley, J. P. (1982) The effects of repeated small oil spillages and chronic discharges, *Phil. Trans. R. Soc. London B, 297*, pp. 285–307.
Drew, E. A., Forster, G. R., Gage, J., Harwood, G., Larkum, A. W. D., Lythgoe, J. N. and Potts, G. W. (1967) 'Torrey Canyon' report, *Rep. Underwat. Ass. 1966–1967*, pp. 53–60.
Ellis, D. V. (1979) Sea otters at risk from oil spills, *Marine Pollution Bull., 10* (3), p. 68.
Engelhardt, F. R. (1981) Oil pollution in polar bears: exposure and clinical effects. In *Proc. of the Fourth Arctic Marine Oilspill Program Technical Seminar, Edmonton, 16–18 June 1981*, pp. 139–179.
Environment Canada (1981a) Preliminary assessment of certain beach clean-up techniques, *Report No. EPS-4-EC-81-1*, Environmental Impact Control Directorate, February 1981, 57 pp.
Environment Canada (1981b) Oil spill barriers and their use, *Report No. EPS-3-EC-81-5*, Environmental Impact Control Directorate, December 1981, 95 pp.
Environment Canada (1982) Canadian inland waters: coastal environments and the clean-up of oil spills, *Report No. EPS-3-EC-82-3*, Environmental Impact Control Directorate, July 1982, 33 pp.
Farrington, J. W. (1978) Unpublished results quoted in *The International Mussel Watch*, National Academy of Sciences, National Research Council, Office of Publications, Washington DC, 1980, pp. 22–23.
Farrington, J. W., Davis, A. C., Frew, N. M. and Rabin, K. (1982) No. 2 fuel oil compounds in *Mytilus edulis*: Retention and release after an oil spill, *Marine Biology, 66*, pp. 15–26.
F.B.A. (1978) Petroleum hydrocarbons in fresh waters: a preliminary desk study and bibliography. *Occasional Publication no. 9*, Freshwater Biological Association (UK), 52 pp.
Geraci, J. R. and Smith, T. G. (1977) Consequences of oil fouling on marine mammals. In D. V. Malins (ed.) *Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms*, Academic Press, New York, San Francisco, London, Vol. I, 321 pp., Vol. II, 500 pp., pp. 399–410.
GESAMP (1977) The Impact of Oil on the Marine Environment. Joint Group of Experts on the Scientific Aspects of Marine Pollution, *Reports and Studies No. 6*, FAO, Rome.
Getter, C. D., Scott, G. I. and Michel, J. (1981) The effects of oil spills on mangrove forests: a comparison of five oil spill sites in the Gulf of Mexico and the Caribbean Sea. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Clean-up), Atlanta, 2–5 March 1981*, API/EPA/USCG, pp. 535–540.
Golob, R. (1980) Statistical analysis of oil pollution in the Kuwait Action Plan Region and the implications of selected oil spills worldwide to the Region. In *Proc. of IMCO/UNEP International Workshop on Combating Marine Pollution from Oil Exploration and Transportation in the Kuwait Action Plan Region, Manama, Bahrain, December 1980*.
Gordon, D. C., Jr. and Prouse, N. J. (1973) The effects of three oils on marine photosynthesis, *Marine Biology, 22*, pp. 329–333.
Grahl-Nielsen, O. (1978) The 'Ekofisk Bravo' blowout: petroleum hydrocarbons in the sea. In *Proc. of the*

Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978, American Institute of Biological Sciences, pp. 476–487.

Grassle, J. F., Elmgren, R. and Grassle, J. P. (1981) Response of benthic communities in MERL experimental ecosystems to low level chronic additions of No. 2 fuel oil, *Marine Environ. Res., 4*, pp. 279–297.

Griffiths, M. (1972) A field and laboratory study of the effects of crude oil on freshwater phytoplankton, M.Sc. thesis, University of Toronto, Ontario.

Gundlach, E. R. and Hayes, M. O. (1978) Vulnerability of coastal environments to oil spill impacts, *Marine Tech. Society Journal, 12*, pp. 18–27.

Gundlach, E. R. and Hayes, M. O. (1982) The oil spill environmental sensitivity index applied to the Alaskan coast. In *Proc. of the Fifth Arctic Oilspill Program Technical Seminar, Edmonton, 16–18 June 1982*, pp. 311–323.

Gunkel, W. and Gassman, G. (1980) Oil, oil dispersants and related substances in the marine environment, *Helgoländer Meersunters., 33*, pp. 164–181.

Guzman, L. and Campodonico, I. (1981) Studies after the Metula oil spill in the Straits of Magellan, Chile. In *Proc. of the PETROMAR 80 Conference on Petroleum and the Marine Environment*, Graham and Trotman, London, pp. 363–376.

Heldal, M., Norland, S., Lien, T. and Knutsen, G. (1978) Acute toxicity of several oil dispersants towards the green algae *Chlamydomonas* and *Dunaliella, Chemosphere, 3*, pp. 247–255.

Hellebust, J. A., Hanna, B., Sheath, R. G., Gergis, M. and Hutchinson, T. C. (1975) Experimental crude oil spills on a small subarctic lake in the Mackenzie Valley, N.W.T. Effects on phytoplankton, periphyton and attached aquatic vegetation. In *Proc. of the 1975 Conference on Prevention and Control of Oil Pollution, San Francisco, 25–27 March 1975*, API/EPA/USGC, pp. 509–515.

Hutchinson, T. C. and Hellebust, J. A. (1974) Oil spills and vegetation at Norman Wells. Environmental–Social Committee, Northern Pipelines, Task Force on Northern Oil Development. *Report No. 73-43.* Information Canada Cat. No. R72-10773. QS-1538-000-EE-A1. 129 pp.

I.M.C.O. (1981) Petroleum in the marine environment. Inputs of petroleum hydrocarbon into the ocean due to marine transportation activities. Intergovernmental Maritime Consultative Organisation, November 1981.

Institute of Petroleum (1979) *Code of Practice for the Use of Oil Slick Dispersants*, Heyden & Son on behalf of the Inst. of Pet., London, 34 pp.

IPIECA (1980) *Application and Environmental Effects of Oil Spill Chemicals*, International Petroleum Industry Environmental Conservation Association, June 1980, 19 pp.

IPIECA (1980) *Oil Spill Chemicals: a bibliography on the nature, application, effects and testing of chemicals used against oil spilled in the marine environment*, International Petroleum Industry Environmental Conservation Association, June 1980, 33 pp.

IUCN (1982) Report on the global status of mangrove ecosystems. Commission on Ecology.

Jacobs, R. P. W. M. (1982) Ecological effects of the 'Amoco Cadiz' oil spill on the seagrass system at Roscoff, France. In Component studies in seagrass ecosystems along west European coasts, Doctoral thesis, Nijmegen University, Netherlands, pp. 173–208.

Johannes, R. E., Maragos, J. and Coles, S. L. (1972) Oil damages corals exposed to air, *Marine Pollution Bull., 3* (2), pp. 29–30.

Johnson, J. H., Brooks, P. W., Aldridge, A. K. and Rowland, S. J. (1978) Presence and sources of oil in the sediment and benthic community surrounding the Ekofisk field after the blowout at Bravo. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 488–513.

Kinako, P. D. S. (1981) Short-term effects of oil pollution on species numbers and productivity of a simple terrestrial ecosystem, *Environ. Pollut. (Series A), 26*, pp. 87–91.

King, R. E. (1981) Exploration is moving into deep, hostile waters, *World Oil, 193*, pp. 81–90.

Kinsey, D. W. (1973) Small-scale experiments to determine the effects of crude oil films on gas exchange over the coral back-reef at Heron Island, *Environ. Pollut., 4*, pp. 167–182.

Krebs, C. T. and Tanner, C. E. (1981) Restoration of oiled marshes through sediment stripping and *Spartina* propagation. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), March 2–5 1981, Atlanta*, API/EPA/USCG, pp. 375–385.

Kuhnhold, W. W. (1978) Impact of the 'Argo Merchant' oil spill on macrobenthic and pelagic organisms. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 152–179.

Lachman, W. H. (1944) The use of oil sprays as selective herbicides for carrots and parsnips, *Proc. Amer. Soc. Hort. Sci., 45*, pp. 445–448.

Lasday, A. H., Weiss, H. J. and Ekekwe, E. O. (1981) The Funiwa No. 5 oil well blowout. Manuscript paper presented at the 1981 seminar on the petroleum industry and the Nigerian environment, Warri, Nigeria, November 9–12 1981. Nigerian National Petroleum Corporation, 15 pp.

Levell, D. (1976) The effect of Kuwait crude oil and the dispersant BP1100X on the lugworm *Arenicola marina L.* In J. M. Baker (ed.) *Marine Ecology and Oil Pollution*, Applied Science Publishers, Barking, pp. 131–188.

Lewis, R. R. (in press) Impact of oil spills on mangrove forests. Proc. program of 2nd Intl. Symp. on Biology and Management of Mangroves and Tropical Shallow Water Communities, Papua, New Guinea.

Little, D., Baker, J. M., Abbiss, T. P., Rowland, S. J. and Tibbetts, P. J. C. (1981) The fate and effects of dispersant-treated compared with untreated crude oil, with particular reference to sheltered intertidal sediments. In *Proc. of the 1981 Oil Spill Conference (Prevention,* *Behaviour, Control, Cleanup), Atlanta, 2–5 March 1981*, API/EPA/USCG, pp. 283–293.

Loya, Y. (1975) Possible effects of water pollution on the community structure of Read Sea corals, *Marine Biology, 29*, pp. 177–185.

Loya, Y. and Rinkevich, B. (1980) Effects of oil pollution on coral reef communities, *Mar. Ecol. Prog. Ser., 3*, pp. 167–180.

Lugo, A. E. and Snedaker, S. C. (1974) The ecology of mangroves, *Annual Review of Ecology and Systematics, 5*, pp. 39–64.

Macleod, W. D., Jr., Thomas, L. C., Uyeda, M. Y. and Jenkins, R. G. (1978) Evidence of 'Argo Merchant' cargo oil in marine biota by glass capillary g.c. analysis. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 137–151.

Macnae, W. (1968) A general account of the fauna and flora of mangrove swamps and forests in the Indo-West Pacific region, *Adv. Marine Biol., 6*, pp. 73–270.

Malins, D. (1981) The chemical and biological degradation of petroleum: a foremost challenge for the analytical chemist. In *Proc. of PETROMAR 80 Conference on Petroleum and the Marine Environment*, Graham and Trotman, London, pp. 319–343.

Malins, D. C. and Hodgins, H. O. (1981) Petroleum and marine fishes: a review of uptake, disposition and effects, *Environ. Sci. Tech., 15* (11), pp. 1272–1280.

Malley, D. G., Ho Sinn Chye and Charles, J. K. (1978) Beaches, rocky shores and coastal swamps. In C. Thai-Eng and J. A. Mathias (eds.) *Coastal Resources of West Sabah: An Investigation into the Impact of Oil Spill*, Penerbit Universiti Sains Malaysia, Pulau Pinang, pp. 152–170.

McCown, B. H. and Deneke, F. J. (1972) Plant germination and seed growth as affected by the presence of crude petroleum. In *Proc. of Symposium on the Impact of Oil Resource Development on Northern Plant Communities. 23rd AAAS Alaska Science Conference at University of Alaska, Fairbanks, 17 August 1972*, pp. 44–51.

McCown, B. H., Deneke, F. J., Rickard, W. and Tieszen, L. L. (1972) The response of Alaska terrestrial plant communities to the presence of petroleum. In *Proc. of Symposium on the Impact of Oil Resource Development on Northern Plant Communities. 23rd AAAS Alaska Science Conference at University of Alaska, Fairbanks, 17 August 1972*, pp. 12–33.

Meikle, K. M. (1981) An oil slick igniter for remote areas. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Atlanta, 2–5 March 1981*, API/EPA/USCG, pp. 617–621.

Minshall, W. H. and Helson, V. A. (1949) The herbicidal action of oils, *Proc. Amer. Soc. Hort. Sci., 53*, pp. 294–298.

Morson, B. J. (1978) The 'Argo Merchant' oil spill: impacts on birds and mammals. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 180–195.

Morson, B. J., Hillman, S. O. and Gosey, W. F. (1982) Alaskan Beaufort Sea oil spill response considerations manual. In *Proc. of the Fifth Arctic Marine Oilspill Program Technical Seminar, Edmonton, 15–17 June 1982*, pp. 297–310.

Moss, B. (1980) *Ecology of Fresh Waters*, Blackwell Publications, 332 pp.

Nadeau, R. J. and Bergquist, E. T. (1977) Effects of the 18th March 1973 oil spill near Cabo Rojo, Puerto Rico, on tropical marine communities. In *Proc. of the 1977 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), New Orleans, 8–10 March 1977.* API/EPA/USCG, pp. 535–538.

Nelson-Smith, A. (1968) The effects of oil pollution and emulsifier cleansing on shore life in South-west Britain, *J. Appl. Ecol., 5*, pp. 97–107.

Nelson-Smith, A. (1973) *Oil Pollution and Marine Ecology*, Plenum Press, New York.

Neumann, L. D. (1979) The protection and development of the marine environment and coastal areas of the Kuwait Conference Region. The Programme of the United Nations systems. In *Proc. of the 1976 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Los Angeles, 19–22 March 1979*, pp. 287–291.

N.O.A.A. (1977) The 'Argo Merchant' oil spill: a preliminary scientific report. US Department of Commerce, National Oceanic and Atmospheric Administration, March 1977.

North, W. J., Neushul, M. and Clendenning, K. A. (1965) Successive biological changes observed in a marine cove exposed to a large spillage of mineral oil. In *Symposium sur les Pollutions Marines et les Produits Pétroliers, Monaco, April 1964*, pp. 335–345.

Norton, M. G. and Franklin, F. L. (1980) Research into toxicity evaluation and control criteria of oil dispersants. *Fisheries Research Technical Report No. 57.* Min. of Agriculture, Fisheries and Food, Lowestoft 1980, 20 pp.

O'Brien, P. Y. and Dixon, S. (1976) The effects of oil and oil components on algae, *Br. Phycol. J., 11*, pp. 115–142.

Odu, C. T. I. (1972) Microbiology of soils contaminated with petroleum hydrocarbons. I. Extent of contamination and some soil and microbial properties after contamination, *J. Inst. Pet., 58* (562), pp. 201–208.

Odu, C. T. I. (1977) Microbiology of soils contaminated with petroleum hydrocarbons. II. Natural rehabilitation and reclamation of soils affected, *Institute of Petroleum Technical Paper I.P. 77-002*, 21 pp.

Odu, C. T. I. (1978) The effect of nutrient application and aeration on oil degradation in soil, *Environ. Pollut., 15*, pp. 235–240.

Owens, E. H. and Robilliard, G. A. (1981) Spill impacts and shoreline clean-up operations in Arctic and sub-Arctic Coasts. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Atlanta, 2–5 March 1981*, API/EPA/USCG, pp. 305–309.

Page, D. S., Mayo, D. W., Cooley, J. F., Sorenson, E., Gilfillan, E. S. and Hanson, S. A. (1979) Hydrocarbon distribution and weathering characteristics at a tropical spill site. In *Proc. of the 1979 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Los Ange-*

les, 19–22 March 1979, API/EPA/USCG, pp. 700–712.

Peakall, D. B., Hallet, D. J., Bend, J. R., Foureman, G. L. and Miller, D. S. (1982) Toxicity of Prudhoe Bay crude oil and its aromatic fractions to nesting herring gulls, *Environ. Res., 27*.

Peters, E. C. Meyers, P. A., Yevich, P. P. and Blake, N. J. (1981) Bioaccumulation and histopathological effects of oil on a stony coral, *Marine Pollution Bull., 12* (10), pp. 333–339.

Potts, G., Gage, J. and Forster, G. R. (1967) Diving studies on the 'Torrey Canyon' oil pollution, *J. Devon Trust Nat. Conservation (July suppl.)*, pp. 22–24.

Ranwell, D. S. (1968) Lichen mortality due to 'Torrey Canyon' oil and decontamination measures, *The Lichenologist, 4*, pp. 53–56.

Ray, J. P. (1981) The effects of petroleum hydrocarbons on corals. In *Proc. of PETROMAR 80 Conference on Petroleum and the Marine Environment*, Graham and Trotman, London, pp. 705–726.

RCEP (1981) Oil pollution of the sea. *Eighth Report of the Royal Commission on Environmental Pollution, October 1981* (Chairman Sir Hans Kornberg), H.M.S.O., London.

Reed, M. (1981) An oil spill-fisheries impact model, *Spill Technology Newsletter, 6* (5), pp. 200–207.

Reish, D. J. (1971) Effect of pollution in Los Angeles harbours, *Marine Pollution Bull., 2*, pp. 71–74.

Richardson, M. G. (1979) 'Esso Bernicia' incident, Shetland, *Marine Pollution Bull., 10* (4), p. 97.

Riedhart, J. M. (1961) Influence of petroleum oil on photosynthesis of banana leaves, *Trop. Agr. (London), 38*, pp. 23–27.

Rinkevich, B. and Loya, Y. (1979) Laboratory experiments on the effects of crude oil on the Red Sea coral *Stylophora pistillata, Marine Pollution Bull., 10*, pp. 328–330.

Risebrough, R. W., De Lappe, B. W., Walker, H. W., Springer, A. M., Firestone-Gillis, M., Lane, J., Sistek, W., Letterman, E. F., Shropshire, J. C., Wick, R. and Newton, A. S. (1980) Pattern of hydrocarbon contamination in Californian coastal waters. In J. Albaiges (ed.) *Analytical Techniques in Environmental Chemistry*, Pergamon Press, Oxford, pp. 34–40.

Rowland, S. J. and Volkman, J. K. (1982) Biogenic pollutant aliphatic hydrocarbons in *Mytilus edulis* from the North Sea. *Marine Environ. Res., 7*, pp. 117–130.

Sanders, H. L., Grassle, G. R., Morse, L. S., Garner-Price, S. and Jones, C. C. (1980) Anatomy of an oil spill: long term effects from the grounding of the barge 'Florida' off West Falmouth, Massachusetts. *J. Marine Res., 38*, pp. 265–380.

Scholander, P. F. (1968) How mangroves desalinate seawater, *Physiologia Plantarum, 21*, pp. 251–261.

Schultz, D. and Tebo, L. B. (1975) Boone Creek oil spill. In *Proc. of the 1975 Oil Spill Conference on Prevention and Control of Oil Pollution, San Francisco, 25–27 March 1975*, API/EPA/USCG, pp. 583–588.

Schwendinger, R. B. (1968) Reclamation of soil contaminated with oil, *Journal of the Institute of Petroleum, 54*, pp. 182–197.

Scott, B. F., Nagy, E., Sherry, J. P., Dutka, B. J., Glooschenko, V., Snow, N. B. and Wade, P. J. (1979) Ecological effects of oil dispersant mixtures in fresh water. In *Proc. of the 1979 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Los Angeles, 19–22 March 1979*, API/EPA/USCG, pp. 565–571.

Sen-Gupta, R. and Kureisky, T. W. (1981) Present state of oil pollution in the Northern Indian Ocean, *Marine Pollution Bull., 12*, pp. 295–301.

Smith, J. E. (Ed.) (1968) *'Torrey Canyon' Pollution and Marine Life*, Cambridge University Press, 196 pp.

Smith, J. L. and Burns, K. (1978) Hydrocarbons in Westernport Bay mussels. Final Report, Hydrocarbons in Victorian ecosystems, *Task T01-702*. Westernport Regional and Marine Chemistry Unit, Ministry for Conservation, Australia.

Southward, A. J. and Southward, E. C. (1978) Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the 'Torrey Canyon' spill. *J. Fish Res. Board, Canada, 35*, pp. 682–706.

Stephenson, T. A. and Stephenson, A. (1972) *Life Between Tidemarks on Rocky Shores*, W. J. Freeman, San Francisco, 425 pp.

Straughan, D. (compiler) (1971) *Biological and Oceanographic Survey of the Santa Barbara Channel Oil Spill, 1969–70. Vol. 1. Biology and Bacteriology*, Allan Hancock Foundation, University of Southern California, Los Angeles.

Straughan, D. and Abbot, B. C. (1971) The Santa Barbara oil spill: ecological changes and natural oil leaks. In P. Hepple (ed.) *Water Pollution by Oil*, Institute of Petroleum, London, pp. 257–262.

Swennen, C. and Spaans, A. L. (1970) De sterfte van zeevogels door olie in Februari 1969 in het Waddengebied, *Het Vogeljaar, 18*, pp. 233–245.

Tanos, A. E. (1981) Meredosia Oil Terminal—the Illinois River floods a tank farm. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Atlanta, 2–5 March 1981*, pp. 243–247.

Tuck, L. M. (1961) *The Murres*. Canadian Wildlife Series 1, Department of Northern Affairs and National Resources, Canadian Wildlife Service, Ottawa.

UNEP (1982) Petroleum transportation and the environment, *Industry and Environment, 5* (3), pp. 1–35.

Van Blaricom, G. R. and Jameson, R. J. (1982) Lumber spill in Central Californian waters. Implication for oil spills and sea otters, *Science, 215*, pp. 1503–1505.

Vandermeulen, J. H. and Ross, C. W. (1977) Assessment of the cleanup tests of an oiled saltmarsh—the Golden Robin spill in Miguasha, Quebec. Part 1. Residual Bunker C hydrocarbon concentrations and compositions. Canada Environmental Protection Service, *Environmental Impact and Assessment Report EPS-8-EC-77-1*, 31 pp.

Vandermeulen, J. H., Long, B. F. M. and D'Ozouville, L. (1981) Geomorphological alteration of a heavily oiled saltmarsh (Ile Grande, France) as a result of massive clean-up. In *Proc. of the 1981 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), Atlanta, 2–5 March 1981*, API/EPA/USCG, pp. 347–351.

Vargo, G. A., Hutchins, M. and Almquist, G. (1982) The effect of low, chronic levels of No. 2 fuel oil on natural phytoplankton assemblages in microcosms: 1. Species composition and seasonal succession, *Marine Environ. Res.*, *6*, pp. 245–264.

Wardley-Smith, J. (ed.) (1979) *The Prevention of Pollution*, Graham and Trotman, London, 309 pp.

Wardley-Smith, J. (ed.) (1983) *The Control of Oil Pollution*, Graham and Trotman, London, 2nd edn., 272 pp.

Whittle, K. J., Hardy, R. and McIntyre, A. D. (1978) Scientific studies at future oil spill incidents in the light of past experience. *C.M.–I.C.E.S. E38.*

Whittle, K. J., Mackie, P. R., Farmer, J. and Hardy, P. (1978) The effects of the Ekofisk blowout on hydrocarbon residues in fish and shellfish. In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 540–559.

Wise, S. A., Chester, S. N., Hertz, H. S., May, W. E., Guenther, F. R. and Hilport, L. R. (1980) Determination of trace level hydrocarbons in marine biota. In J. Albaiges (ed.) *Analytical Techniques in Environmental Chemistry*, Pergamon Press, Oxford.

Witham, R. (1978) Does a problem exist relative to small sea turtles and oil spills? In *Proc. of the Conference on Assessment of Ecological Impacts of Oil Spills, Keystone, Colorado, 14–17 June 1978*, American Institute of Biological Sciences, pp. 630–631.

Witherby and Co. (publishers) (1981) Action against oil pollution: a guide to the main intergovernmental and industry organisations concerned with oil pollution in the marine environment. Sponsored by International Tanker Owners Pollution Federation, Oil Companies Institute for Marine Pollution Compensation, Oil Companies International Marine Forum. 20 pp. Obtainable from Witherby and Co., 32–36 Aylesbury St., London EC1R 0ET.

Young, P. A. (1935) Oil mass theory of petroleum oil penetration into protoplasm, *Amer. J. Bot.*, *22*, pp. 1–8.

Youngblood, W. W. and Blumer, M. (1973) Alkanes and alkenes in marine benthic algae, *Marine Biology, 21*, pp. 163–173.

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