FISHERIES DEPARTMENT
WESTERN AUSTRALIA

REPORT No. 74

Published by the Director of Fisheries, Perth,
under the authority of the Hon. Minister for Fisheries.

Marine Resources Map of Western Australia

PART 2

The Influence of Oil on Marine Resources and Associated Activities with an emphasis on those found in Western Australia.

BY
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1986

PERTH
WESTERN AUSTRALIA

MARINE RESOURCES MAP OF WESTERN AUSTRALIA

Part 2 THE INFLUENCE OF OIL ON MARINE RESOURCES AND ASSOCIATED ACTIVITIES WITH AN EMPHASIS ON THOSE FOUND IN WESTERN AUSTRALIA.

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INTRODUCTION

Part 1 of the text accompanying the marine resources maps dealt with the resources and the morphological, hydrological and meteorological characteristics of the Western Australian coastal environment. This subsidiary part is concerned with the effects of oil on marine resources and associated commercial and recreational activities.

Accounts of oil on the seas due to natural seepages appeared in Europe in the sixteenth century on the return of Spanish and Portuguese ships from voyages to the Americas. One of the earliest reports of oil pollution from a man-made source was in 1754 when leakages from wooden petroleum barges were prevalent in the Caspian Sea (in Nelson-Smith, 1973). Over a century later, in 1862, pollution from drilling activities occurred after oil from onshore wells in Pennsylvania flowed into Lake Erie (in Nelson-Smith, 1973).

Since then, there have been continual reports of accidental oil pollution from ships and offshore wells which have led to global concern over the impact of oil on aquatic environments.

The advent of large tankers has resulted in several huge spills, the most remembered being the Torrey Canyon accident in 1967, when 117 000 tonnes of oil (about 800 000 barrels) were spilt off the south west coast of England, and the grounding of the Amoco Cadiz in 1978 which released 220 000 tonnes of oil into the sea close to Brittany.

Large spills from offshore wells are less frequent but have been recently highlighted by the estimated 20 000 tonnes flow from the Bravo platform in the Ekofisk field of the North Sea over eight days in 1977 and the blow-out of the Ixtoc No. 1 exploratory well in Campeche Bay, Gulf of Mexico, which released approximately 600 000 tonnes of oil over a period of nine months from June 1979, the largest spill yet encountered.

Although accidents are the most newsworthy oil pollution events, and cause the greatest quantity of oil to escape in a single area over a short time period, it has been estimated that the bulk of the oil entering the oceans results from other sources, including ballast disposal, terminal and bunker operations, coastal refineries, municipal wastes, river runoff and atmospheric fallout. A comparison of estimates from three authorities of the amount and sources of oil entering the oceans annually around 1969 to 1971 has been made by the National Academy of Sciences, USA (1975). Figures varied from 6 million tonnes for the NAS study to 11 million tonnes for the Massachusetts Institute of Technology Study.

POSSIBLE SOURCES OF OIL SPILLS IN WESTERN AUSTRALIA

1. TERMINAL OPERATIONS

Only one refinery exists in W.A., at Kwinana, 20 km south of Fremantle, but tanker loading of crude oil at Barrow Island and Broome and unloading of refined petroleum products at Fremantle, Port Hedland, Port Walcott, Dampier and to a limited extent at other ports occurs, while bunkering activities are considerable at the Port of Fremantle. The proposed Woodside Joint Venture just south of Withnell Bay at the Burrup Peninsula will involve transfer of condensate to tankers.

Oil spillages during these operations would be expected to be quickly curtailed and of a small size.

2. MARINE TRANSPORT

According to the estimate by the National Academy of Sciences, USA (1975), marine transportation, including terminal operations and bunkering, accounted for 35% of the total annual input of petroleum hydrocarbons entering the oceans around 1970. Approximately half of the 35% resulted from deliberate discharge of oily waters while only about a tenth of this figure resulted from tanker accidents.

Figures obtained from oil companies for 1977 showed that approximately 560 000 tonnes (3.9 million barrels) of oil were carried to and from W.A. ports per month in about 20 shiploads. The quantity per ship varied from 3000 to 85 000 tonnes and 80% of the oil was transported to and from the refinery at Kwinana in approximately 14 shiploads per month. The oil varied from crude to refined with densities ranging from 0.66 to 1.03. The highest proportion for a single oil type, 43% or 238 000 tonnes per month, consisted of crude oil, density 0.86, transported from the Middle East to Kwinana. Second to this was 13% or 73 000 tonnes per month of crude oil, density 0.84, carried from Barrow Island to Kwinana.

More recent figures from the Commonwealth Department of Transport (1979) showed that 8.55 million tonnes of oil were handled annually in W.A. ports, of which 64% was at Fremantle (includes Kwinana).

Nearly 80% of the 452 accidental world oil spillage incidents from tankers over 3 000 d.w.t. during 1969-73 occurred within coastal waters (Card et al., 1975) . This fact, and the considerable oil transport to and from Kwinana, suggests that the sea just south of Perth is the most likely area for an oil spillage to occur. The oil would probably have a density of 0.84 or 0.86 and combative measures should be organised to treat such an oil.

3. OIL EXPLORATION AND PRODUCTION

From 1968, when the first W.A. offshore well was drilled, up to the end of 1984, a total of 192 exploratory wells were drilled offshore without oil spill incidents. The rate of offshore drilling has increased in recent years with the importation of several drilling vessels. Encouraging results have been found and drilling activity has included production wells for the Harriet Oilfield, 20 km north east of Barrow Island, which is scheduled to flow in 1986.

In addition to exploration activities, gas and condensate are in production from the Woodside North Rankin field in the North West Shelf. This has involved construction of a 132 km pipeline from the production platform to the Burrup Peninsula and the drilling of several development wells. Further expansion of production involving neighbouring gas fields is envisaged.

LIKELIHOOD OF OIL SPILLS

There have been several approaches for estimating chances of oil spills from various offshore petroleum activities, and they have concentrated on tanker accidents, well blow-outs and pipeline leakages. Figures are usually derived by using data on past spill events, which may be given in several ways, e.g. per number of port calls, per number of wells drilled, per life of tanker, per life of platform, per length of pipeline, per volume of oil handled; and will depend upon the size of spill considered.

In a report from the Massachusetts Institute of Technology (1974) it was established that the number of tanker spill accidents was proportional to the volume of oil handled and in a subsequent report it was found that such a relationship with oil volume also existed for platforms and pipelines. Accident rates were calculated for two sizes of spills, above and below 1000 barrels (roughly 135 tonnes).

The MIT approach was later used for oil spill risk assessment by the U.K. Department of the Environment (1976) and in 1979 their adaptation was applied to the Australian situation by the Commonwealth Department of Transport.

For tanker spills over 135 tonnes near the Australian coast a figure of 1 spill every 13.5 years was given, while for Western Australia it was estimated that there could be 27 oil spills under 135 tonnes per year, of which 3 could exceed 1 tonne and 1 could exceed 10 tonnes.

For spills greater than 135 tonnes from offshore platforms and undersea pipelines, chances were estimated at 1 every 2.6 years and 1 every 3 years respectively. No spills of this magnitude have yet been experienced in Australia.

For offshore drilling rigs the spill rate (size unspecified) was calculated at 1 for every 455 wells drilled (no distinction was made between exploration and production drilling). No oil spills from drilling rigs have been reported in Australia to date.

In the only operating offshore oil field in Australia, the Bass Strait, the Victorian Mines Department has figures for losses which have been as low as 1 barrel of oil for every 64 million produced.

FATE OF SPILT OIL

The changes undergone by spilt oil will determine its likely effect on marine resources and influence the choice of clean-up approach. They are dependent upon (1) the type of oil (crude or refined, content and composition of aliphatic, alicyclic, aromatic and olefinic compounds, percentage of low boiling point components, specific gravity, viscosity, pour point, sulphur and vanadium contents), (2) weather conditions (wind strength and direction, temperature), (3) sea conditions (surface current strength and direction, waves, tides, water depth, presence of reefs, particulate matter, microbial flora content) and (4) shore conditions (static or dynamic surface, open or enclosed coastline, rocks, pebbles, sand, mud, vegetation).

The physical and chemical transformations which the spill will undergo at sea comprise spreading from the point source, lateral and vertical dispersion, slick movement, solubilization, evaporation, emulsification with water, tar ball formation, photo-oxidation, attachment to particulate material, uptake and metabolism including microbial degradation. These transformations are inter-related and are variable according to space and time. Further information on them, both generally and for specific oils, may be found in many publications e.g. Nelson-Smith (1973), NAS Report (1975), Wardley-Smith (1976), Blaikley (1977), GESAMP (1977), Gerlach (1981), Royal Commission Report (1981), Vandermeulen (1982), Whittle et al. (1982), CONCAWE (1983), Cormack (1983).

Addition of dispersants will modify such tranformations and influence the persistence of the oil at sea, in sediments and on shorelines and its effect upon marine resources.

A comprehensive study of the fate of spilt oil on shorelines was made by Owens and Leslie (1977) and applied to the Canadian coastline. Their study concentrated on the physical littoral processes and geomorphology of the coastline and related this aspect to oil spill clean-up operations. The shoreline residence times of oil from several accidental spills in different parts of the world were also surveyed by Gundlach and Hayes (1978).

These, combined with a limited consideration of biological impacts, formed the basis for their classification of coastal environments by means of an oil spill vulnerability index.

EFFECTS OF SPILT OIL

The factors which control the fate of spilt oil and the physical and chemical transformations which it undergoes, including those resulting from clean-up action, determine its effect on the marine environment.

It would be expected that oil pollution would exert its most severe environmental consequences in shallow, sheltered bodies of water, such as bays and estuaries, where dilution, dispersion and physical removal of oil would be limited. Such areas are usually the most biologically productive. This is emphasized by examples of the observed effects of oil spills of various sizes in different environments. Thus, far greater environmental damage was evident from a small 700 tonnes spill from the oil barge Florida in shallow sheltered Buzzards Bay, Massachusetts (Blumer et al., 1971) and from a 1,500 to 2,000 tonnes spill from the tanker Tsesis in the Stockholm Archipelago (Barnaby, 1977) than from the larger 31 000 and 20 000 tonnes spills from the tanker Argo Merchant and the production platform Bravo 14 in the Atlantic Ocean and the North Sea respectively (Gundlach, 1977; Barnaby, 1977).

A summary of the biological impact of 15 major oil spills between 1957 and 1972 is given in tabular form in the National Academy of Sciences, USA survey on petroleum in the marine environment (1975). First-hand reports of the coastal impact of several spills in the 1970's are included in the review of oil tanker disasters by Gundlach (1977).

The effects of oil may be short term or long term, acute (lethal) or chronic (sub-lethal), direct or indirect and affect organisms, populations, communities, shorelines, recreational activities, scientific research programmes and educational areas and commercial interests such as fisheries, industrial water intakes, port facilities and tourism.

Of the vast numbers of publications on the various effects of oil on the marine environment, the following is a selection of several which are broad in content and which include numerous references to more specialised aspects of the subject: Blumer et al. (1971), Nelson-Smith (1973), Anderson et al. (1974), Evans and Rice (1974), Moore and Dwyer (1974), Royal Commissions Report (1975), NAS Report (1975), Cowell (1976), Hyland and Schneider (1976), Wardley-Smith (1976), GESAMP (1977), McIntyre and Whittle (1977), Wolfe (1977), Gerlach (1981), Royal Commission Report (1981), Clark (1982a), Baker (1983).

A brief survey of some of these effects follows with an emphasis where possible on W.A. resources and activities.

1. SHORELINES

Although considered applicable to the coastline of the U.S.A., the oil spill vulnerability index of Gundlach and Hayes (1978) is not always readily transposable to the Western Australian situation and has been criticised for not taking sufficient account of biological features (Owens and Robilliard), 1981). The scale on their index is from 1 to 10 and emphasises oil residence time. For a scale of similar magnitude to be valid for the Western Australian coast, preparatory field studies of the physical, hydrological and biological characteristics of the representative shorelines would be necessary.

On a more general scale of low to medium to high environmental vulnerability to oil spills the shorelines of Western Australia may be tentatively categorised as follows, using the geomorphological mapping units of Table 1, Part 1.

Low vulnerability - Mapping Units - 6,7,8,9,10,17,18,20.

Medium vulnerability - Mapping Units - 1,2,3,4,5,16

High vulnerability - Mapping Units - 11,12,13,14,15,19.

Shorelines expected to be least vulnerable to an oil spill are exposed rocky headlands and sheer cliffs. These have little or no horizontal areas and are exposed to considerable wave action, so the oil does not settle and is quickly dispersed. Such shorelines are inhospitable to colonisation by plants and animals.

Mangrove areas are considered to be under the greatest threat. They are flat and muddy, the oil clings to the root systems and is difficult to remove, and recovery times are reported to be long. Salt marshes are also productive areas, but compared with mangrove areas they are less common in Western Australia.

Where mangroves and salt marshes occur in a mapping unit it is considered to be of high vulnerability. For example, mapping units 1 and 17 (Part 1) would be raised to high vulnerability status under such circumstances.

The environmental vulnerability of sandy shorelines depends considerably upon the grain size of the sand, strength of wave action and degree of shelter, presence of rocky outcrops and the level of colonisation by biota. Oil penetrates course-grained sand more readily than fine-grained sand from which it can be more easily removed by physical means. Recovery times of the organisms, mainly molluscs, amphipods and worms, may thus be shorter on fine-grained sandy beaches and tidal flats.

In rocky areas with protected beaches, where oil may remain in tidal pools for some time if wave action is slight, and in sheltered estuaries, where the variety and numbers of organisms may be large, there is likely to be considerable destruction of flora and fauna.

The broad categories of vulnerability given above should be treated with caution and are only applicable to shorelines. Reefs, especially of coral, where damage is related to their proximity to the water level, and near shore waters, in which organisms such as seagrasses or schooling salmon may be in danger, are not included.

2. ORGANISMS

As with other pollutants, most measures of the effect of oil upon aquatic organisms employ laboratory tests in which the concentration of oil required to kill 50% of the test population within a specified time, usually 48 or 96 hours, is recorded. However, the toxicity value for a pollutant tested in laboratory conditions may differ in the natural environment where synergistic or antagonistic effects may occur in the presence of other pollutants, or the pollutant may be precipitated, combined with other material or changed into a more or a less harmful form or species. This is especially so with oil where the various transformations at sea, particularly spreading, dispersion, solubilisation and evaporation, are difficult to simulate in the laboratory and, additionally, avoidance reactions of mobile organisms may not be possible in laboratory apparatus.

Besides lethal effects due to contact with a slick or with toxic soluble fractions leading to smothering or poisoning, oil may cause sublethal effects which may be difficult to detect. These may contribute to the death of an organism or a decline in population although such a result would not be evident from laboratory tests. For example, the organism's ability to detect and escape predators or to resist other forms of stress may have been lowered or its reproductive capacity impaired.

Where edible organisms are concerned, oil may cause tainting or an unsightly appearance which renders the organism unsatisfactory to the consumer. Oil accumulated within an organism can be passed on through several links in the food chain and can lead to concentrations harmful to the organism or its consumer which would not be evident in short-term tests.

In addition to direct effects of oil upon an organism there are indirect effects which result from the complexity of ecosystems. These may be injurious, e.g. the destruction of sea grasses used as breeding areas or as habitats for juvenile fish, the loss of an organism in the food chain of a higher species, or they may favour an organism by removing its competitors or predators and so change the balance of an ecosystem. Thus because perturbation to one component of an ecosystem may influence other components it is not always possible to confidently predict the eventual effect of oil pollution upon an organism.

Toxicity testing of oil has been carried out on many species in the world but only on a few in Australia, and up to the end of 1984 no such tests had been done in W.A. For organisms such as sea grasses, macroalgae and mangroves this type of testing is less easily conducted in a quantifiable manner and in the case of birds, where coating is important, information has come from the aftermath of actual oil spills and a knowledge of the habits of particular bird species.

Lethal effects of oil are considered to be mainly due to the soluble aromatic hydrocarbon components (Anderson et al. 1974; Evans and Rice, 1974; Hyland and Schneider, 1976). Thus refined oils, which usually contain a greater concentration of these components, are generally more toxic than crude oils. However, a large proportion of the low molecular weight volatile components of oils, including soluble aromatic hydrocarbons, is lost through evaporation and, depending upon the type of oil and weather conditions, this may account for up to about 25% to 50% of the oil within 8 to 24 hours (Whittle et al., 1982; Cormack, 1983). These results were for sea conditions in Northern Europe; a higher evaporation rate would generally be expected for similar oils in the Indian Ocean.

A survey compiled from literature reviews (Moore, 1973; Moore, Dwyer and Katz, 1973) of the concentrations of various petroleum products which are lethal to different classes of organisms has been summarised in tabular form by Hyland and Schneider (1976). Part of this table (Table 1) is given below. It should be noted that larvae are more sensitive than adults and it is generally considered that the early stages in the life-cycle of a species are the most susceptible to oil. Values estimated for lethal concentrations of soluble aromatic hydrocarbons are as low as 0.1 ppm for larvae and 1 ppm for adult organisms.

These authors have also updated a review by the National Academy of Sciences, U.S.A. (1975) covering a considerable number of sub-lethal effects of petroleum products on marine organisms. For soluble aromatic hydrocarbons Moore and Dwyer (1974) reported that sub-lethal effects may result from persistent concentrations as low as 10 to 100 ppb.

Table 1. Lethal Toxicity of Oil (ppm) to Classes of Organisms[1]

Class of Organisms	Soluble Aromatic Hydrocarbons	No. 2 Fuel Oil	Crude Oil	Kerosene
Flora	10-100	50-500	10^4-10^5	10^2-10^3
Finfish	5- 50	25-250	10^4-10^5	50-500
Larvae (all species)	0.1-1.0	0.5- 5	10^2-10^3	1-10
Pelagic Crustaceans	1- 10	5- 50	10^3-10^4	10-100
Gastropods	10-100	50-500	10^4-10^5	10^2-10^3
Bivalves	5- 50	25-250	10^4-10^5	50-500
Benthic Crustaceans	1- 10	5- 50	10^3-10^4	10-100
Other Benthic Organisms (Polychaetes, etc.)	1- 10	5- 50	10^3-10^4	10-100

(1) Adapted from Hyland & Schneider (1976).

Further information on lethal and sub-lethal effects of oil on aquatic organisms may be found in other recent review-type articles (e.g. Nelson-Smith, 1973; Anderson et al., 1974, Cowell, 1976; GESAMP 1977) which include experimental results and observations after oil spill incidents.

2.1 Fin Fish

Adult fish deaths as a result of contact with oil have been attributed to toxic effects after ingestion and to suffocation caused by clogging of the gills (see for example Nelson-Smith, 1973).

Unless oil penetrates to the sea bed it is unlikely that demersal fish would be directly affected by spilt oil and it is generally agreed that, owing to their mobility, large scale mortality of pelagic fish would not be expected from even a large spill. Nevertheless, substantial fish kills have occasionally been reported after oil spills (Diaz-Piferrer, 1962; Blumer et al., 1971)

It is to be expected that the greatest threat to fish life would be during and just after the spawning phase when the usually more sensitive eggs and larvae may float on the surface. This would be particularly so if the fish congregate in a small area to breed, such as a sheltered embayment or the mouth of an estuary. Concentrations of oil as low as 100 ppb have been shown in the laboratory to reduce hatching and larval survival in the winter flounder (Kuhnhold et al., 1978) and cause abnormalities and necrosis during maturation of eggs in the starry flounder (Whipple et al., 1978). Even lower concentrations, down to 10 ppb, were reported to delay or inhibit development of eggs from Black Sea fish (Mironov, 1972).

Since each of the major ten local species of fin fish caught commercially (see Part 1, list of W.A. Marine Resources, 1. Professional Fishing) occupies and breeds in habitats over a large area it is unlikely that an oil spill would produce more than a limited local effect. This would be greatest in fish nursery grounds where restricted waters occur and in which the food supply of the juveniles may be harmed.

2.2 Crustacea

As indicated in Table 1 both pelagic and benthic crustacea are usually more sensitive to oil than fin fish or molluscs. Those of significant commercial interest in W.A., the western rock lobster, four prawn species, the blue manna crab and the mud crab are benthic in the adult form. Of these, the crab species are the most likely to be affected by oil as they spend all or much of their adult life in near-shore or inter-tidal shallow environments where the oil may reach the sea floor. The eggs and larvae of all the species, however, are pelagic and thus susceptible to an oil slick.

No local information on the effects of oil on these species is available but there are experimental results on lethal and sub-lethal effects, at concentrations as low as 0.24 ppm, on all stages of similar species in other countries, e.g. Atema and Stein (1974), Wells and Sprague (1976), Brodersen et al. (1977), Forns (1977) and Laughlin et al. (1978), and several reports of severe mortalities after oil spill incidents, e.g. lobsters and crabs after the Tampico Maru spill off Baja California, Mexico (North et al., 1964) and after the Florida spill (Blumer et al., 1971).

2.3 Molluscs

Unlike fish, many molluscs (eg. saucer scallops, mussels, giant clams, western rock oysters, pearl oysters and abalone) are very susceptible to oil spills due to their sessile habit. They are frequently in shallow water areas and thus may come into contact with oil driven below the sea surface or left on the shore. Those molluscs which feed by a filtration mechanism, such as saucer scallops, mussels, western rock oysters and pearl oysters, could ingest and concentrate oil particles.

Several physiological and cytochemical changes in bivalve molluscs caused by petroleum hydrocarbons were reviewd by Bayne et al. (1982). These included a variety of responses in the common mussel, Mytilus edulis, after long-term exposure to a sub-lethal concentration of 30 ppb.

Large scale destruction of molluscs has been shown after several oil spill incidents (e.g. Torrey Canyon, Amoco Cadiz, Florida and Tampico Maru) and where their food source has been algae the destruction has been followed by increased algal growth on the mollusc-free rocks.

Other aspects of oil pollution related to commercial fisheries, such as tainting, are considered in a later section.

2.4 Sea-birds

Death of sea birds through contact with oil is considered to result mainly from loss of plumage insulation and subsequent exposure to cold, which is exacerbated by a lack of buoyancy, mobility and ability to obtain food, and also from toxic effects of oil ingested through efforts to remove it by preening (Nelson-Smith 1973; Bourne 1976; Szar 1977). In addition it has been shown that eggs soiled with oil experimentally or from contaminated birds may not hatch (Eastin and Hoffman, 1978; McGill and Richmond, 1979; White et al., 1979). Such contamination might also arise if oiled plants were used for nest materials.

The number of birds found dead after oil spills has sometimes been very large. For example, 10 000 dead oiled birds were recovered after the Torrey Canyon disaster in 1967 (Smith, 1968), while Mead (1977) reported that at least 30 000 birds died as a result of the release of 9 000 tonnes of oil from the tanker Ferd Maersk in 1955 in the mouth of the Elbe off Germany, and Roland et al. (1977) estimated 20 000 to 50 000 water fowl deaths after an 850 tonnes spill in Chesapeake Bay, Virginia in 1976. Croxall (1975) quoted an estimate of 150 000 to 450 000 for the number of birds killed annually by oil in Europe.

Comprehensive reviews of oil pollution and sea-birds have been produced by Bourne (1976), Szaro (1977), Eastin and Hoffman (1978) and Dunnet (1982).

Where populations of bird species are small in number, concentrated, under stress, have a low reproductive rate and few breeding colonies their survival may be threatened by an oil spill. Predictions that oil spills may be the crucial factor that could cause the extinction of the southern race of the Common Guillemot have been made (in Nelson-Smith 1973), while Bourne (1978) suggested that the Amoco Cadiz spill might exterminate the auk populations in France. Two oil spills have been claimed to have separately caused the death of at least 1 to 2% of the population of Jackass Penguins, which is found only in South Africa (in Nelson-Smith 1973). However, it appears that, at least around the British Isles, the numbers of birds killed by oil are relatively small compared with the total expected annual mortality of seabird populations (Dunnet, 1982).

Although all birds should be protected as far as possible from contact with oil, special consideration should be given to those where survival of entire populations may be at risk. Of the sea-birds breeding in W.A. two, the Lesser Noddy and the Red-tailed Tropicbird, are regarded as endangered species. Apart from the Seychelles, where the eggs may be eaten by the locals, the Lesser Noddy breeds only on Pelsart, Morley and Wooded islands in the Abrolhos, while the principal breeding site in W.A. of the Red-tailed Tropicbird is at Sugarloaf Rock near Cape Naturaliste (Fuller and Burbidge, 1981).

Particular habits of sea, shore and wading birds which could cause them to be affected by oil are listed below:

(i) Diving feeders

Australasian Gannet
Masked Booby
Brown Booby
Red-tailed Tropicbird
Osprey
Caspian Tern
Roseate Tern
Little Tern
Fairy Tern
Crested Tern
Lesser Crested Tern

(ii) <u>Feeders which may be submerged and may stay in water for long intervals</u>

Rockhopper Penguin	Pied Cormorant
Little Penguin	Little Black Cormorant
Black-faced shag	Little Pied Cormorant
Great Cormorant	

The Little Penguin is particularly susceptible to inshore oil contact since it cannot fly and usually walks ashore every night.

iii) <u>Sedentary or fluttering feeders which fully submerge for short periods</u>

Azure Kingfisher
Sacred Kingfisher
Collared Kingfisher

(iv) <u>Sedentary or fluttering feeders which only partially submerge</u>

Wandering Albatross	Wilson's Storm Petrel
Royal Albatross (rare)	White-faced Storm Petrel
Black-browed Albatross	Australian Pelican
Grey-headed Albatross	Great Frigatebird
Yellow-nosed Albatross	Least Frigatebird
Shy Albatross	Black Swan
Sooty Albatross	Australian Shelduck
Southern Giant-Petrel	Radjah Shelduck
Southern Fulmar (rare)	White-bellied Sea-Eagle
Cape Petrel	Great Skua
Great-winged Petrel	Artic Jaeger
White-headed Petrel	Pomarine Jaeger
Kerguelen Petrel (rare)	Silver Gull
Soft-plumaged Petrel	Pacific Gull
Blue Petrel	Kelp Gull
Broad-billed Prion (rare)	Whiskered Tern
Lesser Broad-billed Prion	White-winged Tern (rare)
Antarctic Prion	Gull-billed Tern (mainly inland)
Slender-billed Prion	Common Tern (rare)
Grey Petrel (rare)	Arctic Tern (rare)
White-chinned Petrel	Sooty Tern
Flesh-footed Shearwater	Bridled Tern
Wedge-tailed Shearwater	Common Noddy
Short-tailed Shearwater	Lesser Noddy
Hutton's Shearwater	

The young of both the Wedge-tailed Shearwater and the Little Shearwater could be vulnerable to inshore and onshore oil pollution since they first enter the sea by walking through beaches and shallow water and then paddle to deeper waters.

The silver, pacific and kelp gulls are also carrion eaters and could come into contact with oil through eating dead oiled animals.

The White-bellied Sea-Eagle catches its prey in its feet and would thus be in less danger from spilt oil.

(v) Use beach and tidal margins where oil may be deposited

Eastern Reef Egret
Buff-banded Rail
Chestnut Rail
Spotless Crake
Bush Thick-knee
Beach Thick-knee
Pied Oystercatcher
Sooty Oystercatcher
Grey Plover
Lesser Golden Plover
Hooded Plover
Mongolian Plover
Double-banded Plover
Large Sand Plover
Oriental Plover
Red-capped Plover
Black-winged Stilt
Red-necked Avocet
Ruddy Turnstone
Eastern Curlew
Whimbrel
Little Curlew
Wood Sandpiper (very rare)
Grey-tailed Tattler
Common Sandpiper
Terek Sandpiper
Black-tailed Godwit
Bar-tailed Godwit
Red Knot
Great Knot
Sharp-tailed Sandpiper
Pectoral Sandpiper (rare)
Red-necked Stint
Long-toed Stint (rare-coastal)
Curlew Sandpiper
Sanderling
Broad-billed Sandpiper
Ruff (inland)
Red-necked Phalarope

(vi) May breed on beach or shingle areas near high watermark

White-faced Storm-Petrel
Pied Oystercatcher
Sooty Oystercatcher
Hooded Plover
Red-capped Plover

The young of the White-faced Storm-Petrel enter the sea like the young of the Wedge-tailed and Little Shearwaters (iv) and may thus be vulnerable to coastal oil spills.

(vii) Use marine plants for nesting materials which may be oiled

Pied Cormorant (may use weed)
Pacific Gull (may use weed)
Common Noddy
Lesser Noddy

(viii) Breed in or use mangroves which may be destroyed by oil

Pied Cormorant (sometimes)
Great-billed Heron
Striated Heron
Osprey
Brahminy Kite
White-bellied Sea-Eagle (occasionally)
Chestnut Rail
Spotless Crake
Lesser Noddy
Torresian Imperial Pigeon
Azure Kingfisher
Sacred Kingfisher
Collared Kingfisher
Green-backed Gerygone
Large-billed Gerygone
Dusky Gerygone
Mangrove Gerygone
Mangrove Robin
Lemon-bellied Flycatcher
Mangrove Golden Whistler
White-breasted Whistler
Broad-billed Flycatcher
Leaden Flycatcher
Shining Flycatcher
Rufous Fantail
Northern Fantail
White-gaped Honeyeater
Yellow White-eye
Yellow Oriole
Spangled Drongo
White-breasted Woodswallow

Birds which have few breeding areas in Western Australia, and whose populations would therefore be susceptable to diminution by localised oil spills in breeding areas, are the Black-faced Shag, Cape Barren Goose, Common Noddy, Lesser Noddy, Lesser Crested Tern, Least Frigatebird, Masked Booby, Red-tailed Tropicbird, Short-tailed Shearwater and Sooty Tern.

2.5 Reptiles

No information could be found on the effects of oil on crocodiles and very little on the effects on turtles apart from reports by Rutzler and Sterrer (1970) on the death of young sea turtles (Carretta sp.) on oil-contaminated mangrove beaches and by Witham (1978) on the death of two young green turtles attributed to eating tar balls or being covered with oil. A likely means of contamination of turtles would be by beached oil which could be met by adults or juveniles in the vicinity of nesting sites.

2.6 Mammals

Dugongs are classified as rare and endangered creatures because of their increasing scarceness, defencelessness and apparent slow rate of breeding. No information on their reaction to oil is available but, as with seals, eye irritation may occur and an indirect effect via destruction of their food source, sea grass, is conceivable. Due to a combination of sea temperature and availability of sea grass, during the winter dugongs may concentrate in particular areas (Prince, pers. comm.). Oil pollution in such areas (e.g. Shark Bay) may thereby exert a large-scale influence on the dugong population.

The effects of oil on other marine mammals have been recently reviewed by Geraci and St Aubin (1980). A lethal effect on seals has not been established but there have been several reports of eye irritation, and Kooyman et al. (1977) showed that thermal conductance of fur seal pelts increased after oiling. It has also not been established whether seals avoid oil, but they could come into contact with it around foreshores during the breeding season (Part 1).

2.7 Mangroves

There have been several reports of oil damage to mangroves (usually Avicennia and Rhizophora), including leaf loss and death of seedlings, produced accidentally or experimentally (e.g. Rutzler and Sterrer, 1970; Nadeau and Bergquist, 1977, Chan, 1977). Most of the earlier references have been briefly reviewed by Nelson-Smith (1973) and Odum and Johannes (1975). It appears that the major cause of the damage is smothering of lenticels and air holes of prop roots and pneumatophores, but oil spray blown onto the leaves has also been cited.

As the mangrove fauna are essential for turnover of sediment and nutrient flow around mangroves, their destruction by oil may result in adverse effects upon the mangroves (Semeniuk, pers. comm.).

2.8 Seagrasses

There is little information on the effect of oil on sea grasses, but mortality of Thalassia and Phyllospadix species has been reported after oil spills (Diaz-Piferrer, 1962; Foster et al., 1971; Nadeau and Bergquist, 1977). Presumably, genera in W.A. marine waters would show similar susceptibility. Plants exposed by low tide would probably be most affected as the oil could settle on the leaves or become entrapped in the sea floor around the stems.

2.9 Seaweeds

As with seagrasses, those seaweeds exposed at low tide would be most affected by oil but, since many of them have a motile reproductive stage, recolonisation would be expected.

Some reported effects of crude oil or petroleum products on seaweeds in experimental situations are inhibition of photosynthesis in the kelp genera Macrocystis, Laminaria and Phyllophora (Clendenning and North, 1960; North et al., 1964; Wilber, 1969; Percy, 1977), death of sporelings of Polysiphonia and Dilophus spp. (in GESAMP, 1977) and death of zygotes and sperm of Fucus spp. (Steele 1977).

In accidental oil spill situations, mortality of Fucus spp. after the Arrow spill in Nova Scotia was reported by Thomas (1973), while red algae appeared to suffer most after the Santa Barbara, Torrey Canyon and Tampico Maru spills (Nelson-Smith, 1973). Although Macrocystis was considerably affected immediately after the Tampico Maru spill, it quickly recovered and underwent a population explosion which was attributed to the absence of herbivores as a result of the spill (North et al., 1964). However, immediately after the Santa Barbara spill Macrocystis was reported to be unharmed and the green algae Enteromopha intestinalis, Chaetomorpha aerea and Ulva angusta were only slightly damaged (Foster et al., 1971).

With certain species, perhaps due to their outer mucilage content, oil may cling for a long time and has caused overweighted plants to break off after wave action, (Spooner, 1971).

2.10 Algal Mats and Stromatolites

The main organisms in algal mats and in living or dead stromatolite structures are the blue-green algae; now considered as bacteria (Stanier et al., 1971). Because of the relative paucity of stromatolites there have been no references to their susceptibility to oil, but there are a few reports that blue-green algae, such as Oscillatoria, are resistent to oil and may even thrive in polluted areas (Crosby et al., 1954; Spooner, 1970; Baker, 1971).

2.11 Coral Reefs

The question of whether exploratory drilling for oil should be permitted in the Great Barrier Reef area has emphasised the need for understanding the effects of oil on corals. A review by Johannes (1975) showed that there was no clear evidence from experiments or oil spill incidents that corals were directly harmed in the field by oil floating above them (Grant, 1970; Rutzler and Sterrer, 1970; Spooner, 1970; Shinn, 1972), although with four coral species in experiments in enclosed vessels, tissue damage did occur at oil concentrations of 100 to 500 ppm (Lewis, 1971).

Chan (1977) also reported that no effect could be detected upon submerged corals up to six months after an oil spill in Florida Keys, and Bak & Elgershuizen (1976) showed that sediment particles contaminated with oil were rejected in the normal manner by nineteen species of hermatypic corals. However, some experimental studies have recorded harmful effects of floating oil (Mariscal & Lenkoff, 1968; Reimer, 1975), and it has been suggested (Loya & Rinkevich, 1979) that abortion effects in corals induced by oil pollution might be responsible for the absence of recolonisation by corals in the Gulf of Eilat, Red Sea after destruction due to a low tide (Loya, 1975; 1976). Indirect effects on coral growth as a result of interference with their food supply has also been suggested to result from oil pollution (Fishelson, 1973).

When corals have been experimentally coated with oil, tissue destruction, decreased growth rate and death have been reported (Johannes et al., 1972; Birkeland et al., 1973) and these results suggest that oil spills in regions where corals are exposed to the air may cause considerable destruction.

Because of the complexity of coral reef systems it is hard to predict the long term effects of oil pollution. For example, changes leading to increased algal cover could prevent further coral growth by removing areas for settlement and development of additional coral colonies (Fishelson, 1973). Similar inter-relationships will occur in other reef systems which do not contain corals.

A recent comprehensive review by Ray (1981) concluded that oil pollution has not yet been a major threat to coral reefs, but emphasised that the paucity of experimental studies does not allow a thorough assessment of potential damage.

Off W.A. the major coral reef areas are north of Carnarvon, e.g. Ningaloo, Dampier Archipelago, Rowley Shoals, Adele Island, Scott Reef and Seringapatam Reef, or at the Abrolhos Islands. Most work has centred on the latter area which is in a zone of biogeographic overlap and contains corals typical of tropical and temperate regions (Wilson & Marsh, 1979).

Annual mass spawning of corals over a period of a few nights has been observed at Dampier (Environmental Protection Authority Report, 1985). Were an oil spill to occur there at the spawning period the total annual reproductive effort could be at risk.

2.12 Non-commercial Invertebrate Fauna

As mentioned in the section in Part 1 headed The Resources, non-commercial invertebrates were not included in the list of marine resources and associated activities. Although not of direct commercial importance, many invertebrates form part of food chains leading to species which are fished commercially, particularly benthic species.

There are numerous studies of the effects of oil spills on invertebrates, both experimental and after shipping accidents. Long-term damage has been reported to result from oil spills in shallow coastal areas, which has led to marked changes in the benthic community structure.

Considerable information on benthic invertebrates is given in Nelson-Smith (1973) and GESAMP (1977). Two more recent reviews which emphasise the effects of oil on benthic ecosystems are Lewis (1982) and Southward (1982).

2.13 Plankton

Phytoplankton and zooplankton were also not included in the resources list. Because of the considerable temporal and spatial variations shown by plankton populations, long-term studies of the effects of accidental oil pollution are difficult to evaluate. However, it is generally agreed that such effects are of slight duration in the open sea, and there are few instances where they have been considered of lasting importance in more enclosed bodies of water.

Most experimental results have dwelt on the toxic effects of oil, but at some concentrations it may stimulate growth of certain planktonic species. As with invertebrate fauna, Nelson-Smith (1973) and GESAMP (1977) have given details on the influence of oil on planktonic organisms. The recent review on oil and planktonic ecosystems by Davenport (1982) is comprehensive and deals with laboratory experiments, artificially enclosed ecosystems, and field observations from chronically polluted areas or from the aftermath of oil spills.

3. MARINE POPULATIONS AND COMMUNITIES

Apart from fears of the long-term effects of repeated oil pollution on certain sea bird species (see previously) there are few indications that oil spills could irrevocably destroy whole populations of a single species, even in a localised region, but there is ample evidence that population numbers, community structure and species diversity may remain altered for considerable periods. In comparison with the number of oil spills, however, there have been few studies which have continued for several years after the spill, and even less which could employ quantitative data on the biological community of the particular environment before the spill occurred or on other stresses which may have existed. Difficulties in the detection and evaluation of long-term effects of oil pollution on marine populations, communities and ecosystems have been discussed by Clark (1982b) and Southward (1982).

In its tabulated summary of the biological impact of several major oil spills, some of the studies quoted by the National Academy of Sciences, USA (1975) were of sufficient duration to yield information on subsequent levels of recovery of various populations. The long-term biological effects of some major oil spills were reviewed by Vandermeulen (1982) and those of the largest tanker spill yet, the Amoco Cadiz, by Conan (1982). In addition, condensed accounts of the long term effects on various biological communities of several oil spills in the 1970's may be found in the 1975 (Chan; Clark *et al*.; McAuliffe *et al*.; Michael *et al*.) and 1977 (Hershner & Moore: Nadeau & Bergquist; Chan; Chan.) Oil spill Conference

Proceedings published by the American Petroleum Institute, while the American Institute of Biological Science published the proceedings of a 1978 conference on assessment of ecological impacts of oil spills which occurred in the same period.

These accounts illustrate that the extent of reported damage is determined not only by the size of the spill and the type of oil but also by the nature of the receiving community, the residence time of the oil, the clean-up method applied and the thoroughness of the study.

An example of different recovery times from oil spills is given by a comparison of the effects of the Chesapeake Bay, Virginia No. 6 fuel oil spill from the barge STC-101 in 1976 (Hershner & Moore, 1977) and the West Falmouth, Massachusetts No. 2 fuel oil spill from the barge Florida in 1969 (Blumer et al., 1971) which were both of a similar size, 650-850 tonnes. At Chesapeake Bay, where mechanical removal of oil on foreshores was attempted, apart from considerable waterfowl deaths little damage to mussels, oysters, snails or marsh grass was evident up to eight months after the spill. This was attributed to relative non-toxicity of the oil, impact at a time of year when most of the biota were relatively inactive and a high energy environment which reduced the residence time of the oil in the marsh. On the other hand, at West Falmouth, which was extensively studied due to its proximity to the Woods Hole Oceanographic Institution, considerable damage was recorded. Over 95% of benthic animals in the substantially affected areas and the most heavily polluted tidal marshes were immediately killed, and sixteen months after the spill only pollution-resistant organisms were re-established in the worst-hit areas. The original animal populations were still absent and oil persisted in the sediments.

There are several instances where major shifts in ecological dominance in communities have been reported after oil spills. A frequent result is extensive occupation of the sediments in the area by oil-resistant polychaetes, particularly Capitella capitata (Reish, 1965; Sanders et al., 1972; Jacobs, 1979).

As previously mentioned the recovery of growth in the kelp Macrocystis pyrifera, leading to massive colonisation of the affected area, which occurred after the Tampico Maru oil spill off Baja California, Mexico was attributed to death of the grazing fauna (North et al., 1964). Similarly, increased rock cover by the macroalga Fucus vesiculosus after a refinery overflow in Milford Haven was considered to result from a decline in the grazing limpet population (Crapp, 1971). After the Torrey Canyon spill such an effect was enhanced by the use of a dispersant toxic to limpets (Nelson-Smith, 1973). Because of subsequent lack of settling areas due to the algal cover the limpets were slow in returning.

Considerable information on the effects of oil on a variety of marine populations, communities and ecosystems may be found in reviews by Nelson-Smith (1973), Hyland & Schneider (1976), GESAMP (1977), Michael (1977) and Clark (1982a).

4. COMMERCIAL INTERESTS

Commercial interests most likely to be harmed by oil pollution are those concerned with beach activities and tourism, fisheries, power stations and industrial plants with cooling water intakes, other industries where sea water use forms part of the production processes, and port facilities.

Of these, interference with tourist and leisure activities, such as swimming, surfing and fishing, is probably of the widest economic importance because of the many local ventures which are dependent on, or supported by, the proximity of a good amenity beach.

Oil may affect fisheries in at least three ways - by causing fish mortality, by making the fish unacceptable to the consumer and by contaminating fishing gear and interfering with normal fishing activity.

Lower catches could result from death of any of the stages in the life cycle through contact with an oil slick or toxic soluble fractions of the oil, through impairment of functions such as feeding behaviour, predator avoidance, pheromone detection and breeding activity, through physical changes of habitat, through loss of food supplies and through additional stress leading to increased susceptibility to injurious environmental conditions or pathogenic organisms. All these effects have been demonstrated, either experimentally or after accidental oil spills.

However, there have been no reports of economically important mortalities of fin fish following oil spills and it appears to be generally agreed that oil on the open seas is unlikely to pose a threat to offshore fisheries (Johnston, 1977, GESAMP report, 1977). Furthermore, McIntyre (1982) concluded that no long-term adverse effects on fish stocks can be attributed to oil but that local impacts can be extremely damaging in the short term. Thus oil spills have caused significant destruction of local shellfish fisheries, e.g. Florida spill (Blumer et al., 1971) and Amoco Cadiz spill (Russell, 1979), and could be envisaged as a threat to seasonal fin fish recruitment if they were to occur in an area where eggs or larvae are concentrated.

Studies made on fisheries in regions where chronic oil pollution is rife, e.g. Lake Maracaibo, Venezuela (Battelle publications, 1974) and the Gulf of Mexico (Gusey & Maturgo, 1971) did not indicate any marked decline in fin fish stocks, but changes in species composition were demonstrated.

Fish may be unacceptable to the consumer through tainting, appearance or because they are known to have been caught in a location where oil pollution has recently occurred.

Very small concentrations of oil will cause tainting, and levels in sea water as low as 0.01 ppm have imparted odours to fish (Nitta, 1972). Tainting in sea mullet at Brisbane, Australia (Grant, 1969; Sidhu et al., 1972, Connell, 1974) and in several fish species at Yokkaichi Harbour, Japan (Nitta, 1972) was attributed to chronic oil pollution and there have been several instances of tainting in shellfish fisheries due to oil spills or the dispersants used in clean-up operations, the most recent being contamination of oysters in Brittany after the Amoco Cadiz spill (Russell, 1979). Such incidents have led to closure of fisheries for periods of up to 4 years (GESAMP report, 1977) and to continued marketing problems with catches from the contaminated region, even when contamination is no longer evident (Shelton, 1971; McIntyre, 1982).

Blumer et al., (1971) reported that fuel oil from the Florida spill remained in oysters for at least 6 months during depuration in clean running sea water. However, Neff et al., (1976) showed that fuel oil - contaminated oysters, clams, shrimps and fish lost their hydrocarbon content within 2 to 60 days, the high molecular weight aromatic compounds being released more slowly than the low molecular weight compounds or alkanes.

Contamination of fish traps after an oil spill in Tarut Bay, Saudi Arabia was reported by Spooner (1970), and Shelton (1977) has discussed a similar effect on nets caused by sunken oil.

In W.A. marine waters the fisheries most susceptible to an oil spill would be the prawn and crab fisheries (see Section 2.2). The prawn fishery mainly occurs in Shark Bay and Exmouth Gulf and is thus not widespread, unlike for example the western rock lobster fishery. It is dependent on annual recruitment and would be severely affected were oil to reach the shallow areas where the juveniles are concentrated.

Localised short-term damage from a coastal spill, which would not be catastrophic for the whole fishery, could be expected with Roe's abalone, which are near the surface, with western rock lobsters, especially in important areas of recruitment such as Seven Mile Beach and the Abrolhos Islands or with the more northerly settlements which are in very shallow waters, and perhaps with Australian salmon, pilchard and Australian herring schools if they made no attempt to avoid the oil.

Further information on oil spills and commercial fisheries may be found in reviews by Shelton (1975), Johnston (1976) and McIntyre (1982).

Three power stations in W.A. (South Fremantle, Kwinana and Bunbury) employ offshore cooling water intakes. These intakes are about 3 to 5 m below the sea surface and could be affected if the oil were vertically mixed in high enough concentrations. Industries for which unpolluted sea water is essential are the salt producers at Port Hedland, Dampier and Shark Bay, and the exporters of live western rock lobsters who keep them in flowing sea water in holding tanks prior to export. Those currently existing are at Jurien Bay, Fremantle Fishing Boat Harbour and Coogee and they are active between November and August each year.

DEALING WITH MARINE OIL SPILLS IN WESTERN AUSTRALIA

The organisation directly responsible for dealing with oil spills in W.A. is the State Committee for Combatting Marine Oil Pollution. Under the authority of this committee a State counter-disaster plan has been prepared to deal with pollution of the sea and inland waters in W.A., especially oil pollution.

Two other plans may come into action in the event of an oil spill, the National Oil Spill Plan, which was established to cover oil pollution of the sea by ships, and the Marine Oil Spills Action Plan (MOSAP) of the Petroleum Institute Environment Conservation Executive (PIECE), which covers spills resulting from Oil Industry activities and thus includes those from refineries and offshore oil exploration and production.

Information from the marine resources maps contained at the W.A. Fisheries Department (See Part 1) has been used to delineate areas considered environmentally sensitive to pollution, particularly from oil spills emanating from offshore exploration and production activities. A publication giving details of these areas and procedures for their protection during oil exploration has recently been produced (Jones et al., 1984). Since there is contention on the environmentally harmful effects of dispersant use in the treatment of oil spills (McCarthy, 1977; Royal Commission Report, 1981; Cormack, 1983) the procedures include recommendations on dispersant application.

The information on the sensitive areas and the procedures for their protection from oil spills is taken into consideration in the State Combat Committee Plan and, in addition to environmental advice from Government Departments, will be similarly used in the implementation of any oil spill contingency plan in W.A.

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