IPIECA REPORT SERIES

VOLUME EIGHT

BIOLOGICAL IMPACTS OF OIL POLLUTION: FISHERIES

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PREFACE

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

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

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

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

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

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

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

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

INTRODUCTION

The fishery resources of coastal habitats have been utilized throughout history, and modern technology has now improved efficiency and extended fisheries to the open ocean and deep waters. Many of the world's important fish stocks are currently harvested at levels believed to be the maximum sustainable without depleting the fishery, and some may already exceed this level. Increasing efforts are being made to farm edible marine species and aquaculture is growing rapidly in many countries.

Fisheries and aquaculture may be affected following oil spills. This report describes the direct effects on the species themselves, and indirect effects through impacts on their habitats. The impact on fishing gear and aquaculture facilities is also considered. Information is included on the basic ecology of the species concerned, and on fishing and aquaculture methods. Response to spills is discussed and reference is made to case history examples.

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ECOLOGY OF FISHERY SPECIES

Biological and ecological groupings

The species covered in this report fall into three main biological groups: fin-fish (fish), crustaceans and molluscs. In some countries other animal groups and seaweeds form important local fisheries.

Fish are further divided into the bony fishes, which comprise the majority of fish species, and a much smaller group, the cartilaginous fishes, which comprise the sharks and rays. There are around 30,000 species of fish but only a very few make up the majority of catches in fisheries around the world.

Crustaceans are animals with a hard but flexible jointed shell or exoskeleton which is periodically shed or moulted to allow the animal to grow. The major commercial crustacean groups are lobsters, crayfish, crabs, prawns and shrimps. Prawn and shrimp fisheries are, by far, the world's largest crustacean fisheries.

Molluscs are commonly referred to as 'shellfish' because the animal lives inside a hard, inflexible shell. The term 'shellfish' is sometimes also applied to crustaceans but its use in this report is confined to molluscs. The majority of commercial shellfish have two hinged shells, e.g. oysters, mussels and clams. The second largest group of shellfish have a single shell which is often coiled; commercial species include periwinkles and whelks. Squid, cuttlefish and octopus are also molluscs but do not have an outer shell. There is a substantial world fishery for squid.

Of relevance in terms of fisheries and potential effects of oil pollution, are various ecological habitat groupings. *Pelagic* fish spend their lives swimming in open water. Most commercial species such as herring, tuna and mackerel, are caught in the upper zone within 200 metres of the surface. Other fish caught in this zone include garfish, dolphinfish, and flying-fish. Squid are one of the few pelagic molluscs. *Benthic* species live and feed on the seabed and include flat-fish, such as plaice, rays, most crustaceans and almost all shellfish. *Demersal* fish live near the seabed, mostly feeding on bottom-living animals. Some, like cod, may also move up into mid-water when feeding. The early life stages of many benthic and demersal species are pelagic.

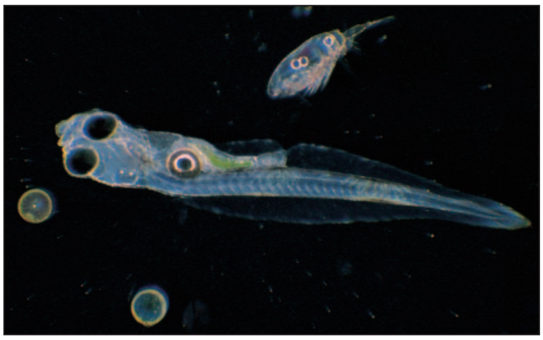
Some fish such as blue-fin tuna undergo long distance migrations from tropical to temperate waters to take advantage of seasonally richer feeding grounds. Others, such as haddock, undertake more local spawning migrations. Fish such as salmon, and sturgeon, undertake spawning migrations from the sea into rivers and estuaries.

Breeding biology

The majority of bony fish produce large numbers of floating eggs. These, and the larvae which hatch from them, drift in the surface currents. Many commercial species spawn at particular times within spawning grounds, from which eggs and larvae drift towards nursery areas, generally inshore. A few commercial species such as herring lay non-buoyant eggs that sink to the seabed and stick to stones, gravel, large algae or seagrasses. Herring eggs may form a dense carpet, often many eggs deep. After hatching, the larvae drift away. Non-buoyant eggs are also laid by many shallow water fish, with the eggs either being scattered over the seabed, or attached to it, where they are guarded by the parents. Sharks and rays lay small numbers of eggs in protective capsules and some give birth to live young.

Most bivalve shellfish, such as oysters, shed their eggs into the water where they develop into floating larvae which drift away. When the larvae are ready to change into adults, they settle onto the seabed wherever the habitat is suitable. In this way, old shellfish beds are maintained and new ones started.

Crustaceans such as shrimps and crabs, carry their eggs around with them attached to modified legs. In this condition they are said to be 'berried'. When the larvae hatch out, they too join the plankton and drift with the water currents.

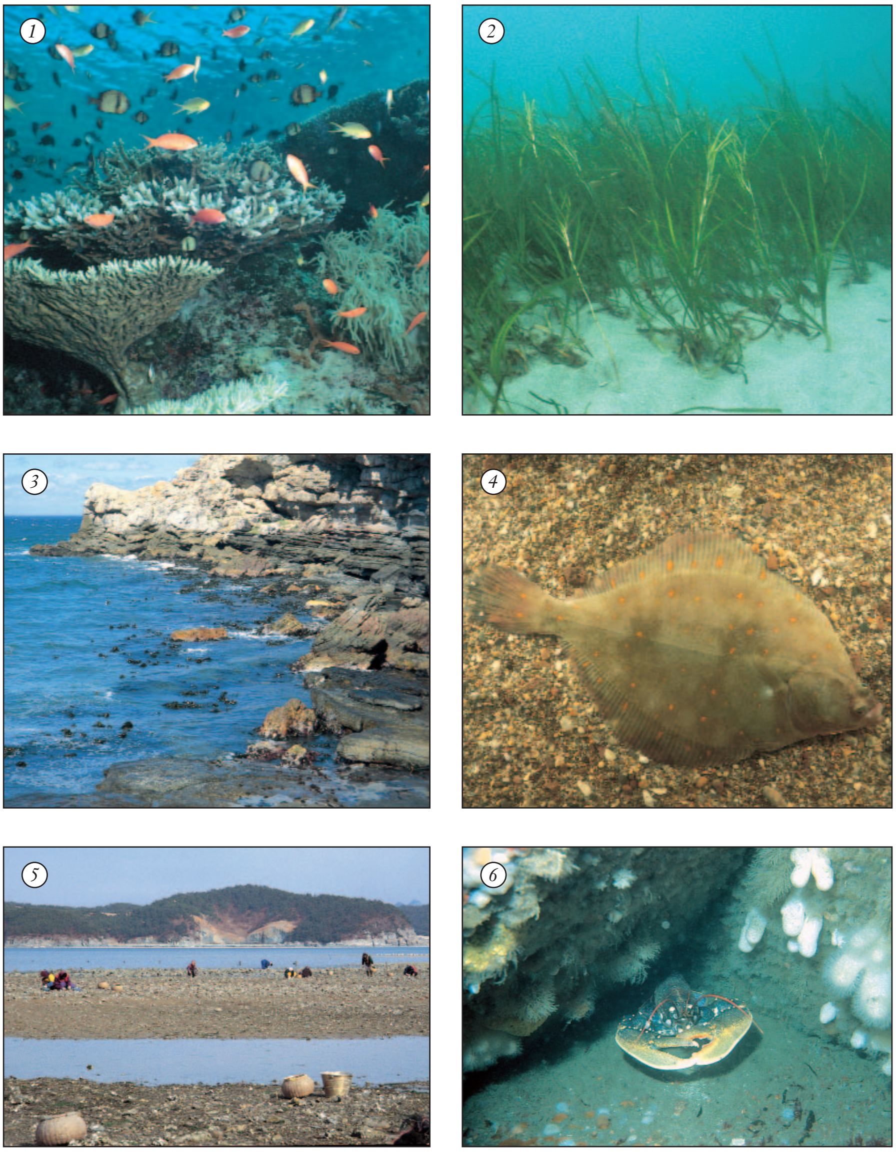


Planktonic fish larva

Supporting ecosystems

Even highly mobile fish may have home territories. They live within complex ecosystems, sometimes moving between systems at different stages of their life cycle. Although not existing in isolation, an ecosystem can be thought of as a self-maintaining, functional unit, comprising the physical and geographical habitat and the animals and plants in it.

An example of an ecosystem in which fish play a major part is the coral reef. For example, more than 2,000 species of fish live on the rich coral reefs of the Indo-West Pacific, which consequently support numerous, diverse, small-scale local fisheries. Other major ecosystems that contribute to fisheries include mangrove forests, seagrass beds and estuaries. Any factor which affects the productivity of a particular ecosystem may also affect its fish populations.



Different ecosystems which support economically important species are shown on the right. These include:
1. coral reefs (Malaysia);
2. seagrass beds (UK);
3. kelp beds (South Africa);
4. seabed sediments (UK);
5. intertidal rocky reefs (Korea); and
6. subtidal rocky reefs (UK).

THE SEA'S HARVEST

Commercial, traditional and recreational fishing

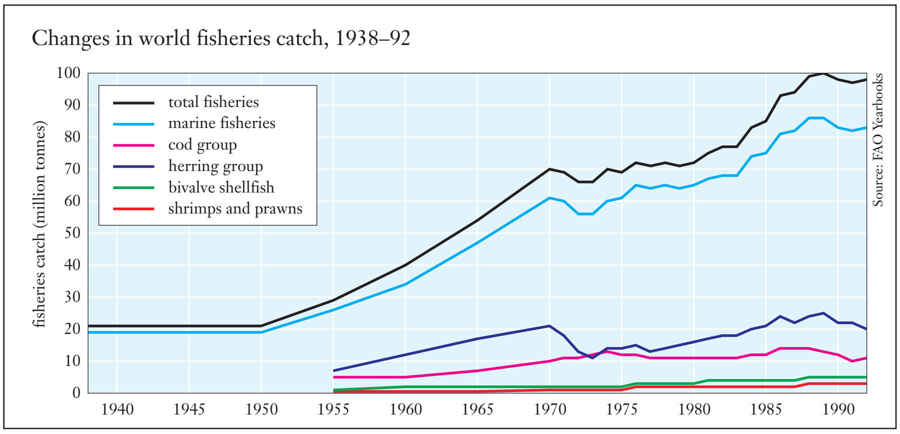
Large-scale fisheries provide most of the world catch which is often widely distributed and exported after freezing, canning, or smoking. About three quarters of this large-scale catch is used as food, whilst the rest is used for the production of oils and fishmeal. Fleets operating far from their home-base often have a 'mother ship' where the fish are immediately processed, whereas coastal fisheries tend to sell their catch fresh through markets near the ports.

Half the world's commercial catch comes from two main groups:

- Pelagic species: herring, sardines and anchovies are the most important fish in this group; squid are the only molluscs included in this category.
- Demersal fish, shrimps and prawns: cod, hake and haddock account for around 10 per cent by weight of total world harvest.

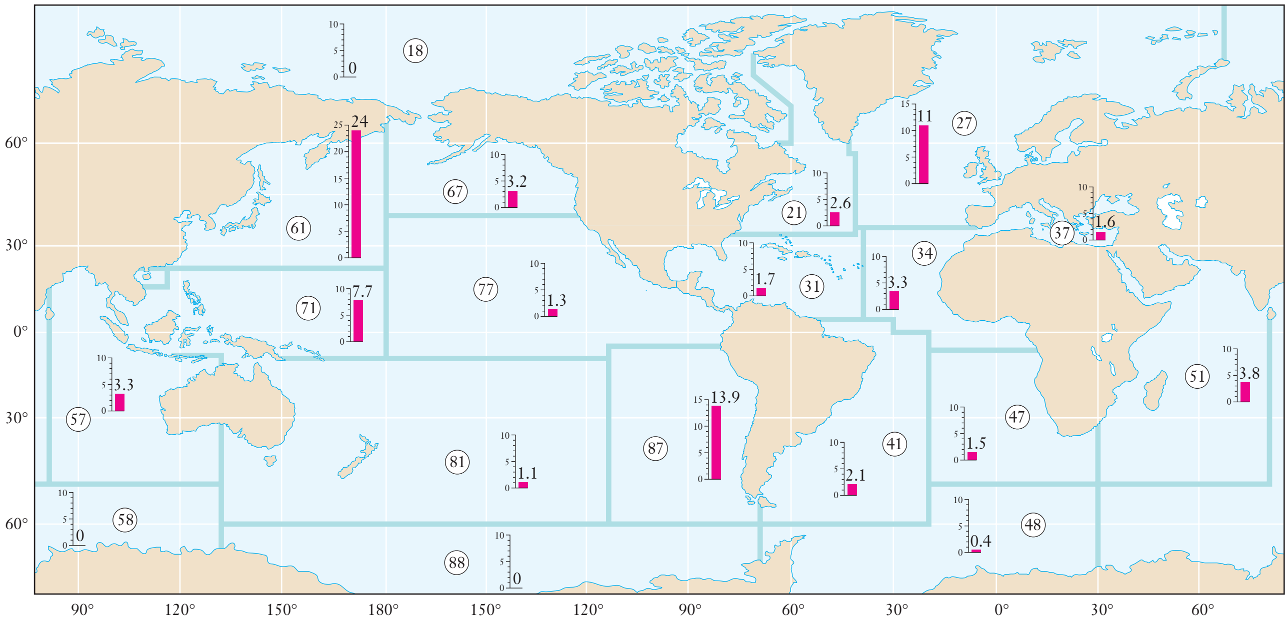
The major mollusc fisheries are for clams, oysters and mussels, with the majority coming from managed natural beds and, in many countries, from extensive aquaculture facilities.

The majority of the world's catch comes from the highly productive waters overlying the continental shelves, relatively close to land. The only major open-ocean fishery is for tuna and related species. The largest catches of fish come from Northwestern Europe shelf areas, Japan, the Bering Sea and the upwelling coastal areas of western South America.



After a 5-fold increase over 40 years, the world catch in marine fishing areas appears to have reached a plateau. Estimates suggest that around 90 per cent of the world's fish stocks are now being exploited at, or in excess of, maximum sustainable levels, indicating the risk of decreases. The accuracy of such estimates is difficult to confirm, but there is no doubt that many fish stocks in all areas of the world have declined in recent years.

Major marine fishing regions of the world
(numbers in circles are FAO divisions of the oceans; histograms show landings for 1992 in millions of tonnes)



Source: FAO Yearbooks

Major marine fishing regions of the world and landings for 1992 in millions of tonnes (Source: FAO yearbooks*)*

The world catch in marine fishing areas went up from about 3 million tonnes in 1900 to 86 million tonnes in 1989. It has now reached a plateau and, according to the latest figures, some stocks appear to be decreasing (see graph on page 7). Estimates suggest that around 90 per cent of the world's available fish stocks are already being exploited at, or in excess of, maximum sustainable levels and are therefore being over-fished. Although the accuracy of such estimates is difficult to confirm, there is no doubt that many fish stocks in all areas of the world have declined in recent years. Declines do not always show up in simple catch statistics but are indicated by a decrease in average size of fish caught and an increase in the effort needed to land the same amount of fish. This is currently the case with stocks such as Atlantic cod. Early examples of the collapse of some of the world's largest fisheries include the Californian sardine in the 1950s, Peruvian anchoveta in 1972 and North Sea herring in the 1970s. None of these fisheries have yet made a full recovery.

Fishing harbour at Sile on the Turkish Black Sea coast

Artisanal and small-scale traditional fisheries are widespread among coastal people. Unlike commercial fisheries which concentrate on only a few species, they utilise many different species. The 10 per cent of the world's catch provided by such fisheries may seem insignificant in the global context, but is vitally important to many communities. The catch is usually consumed close to where it is landed, and is often sold in local markets.

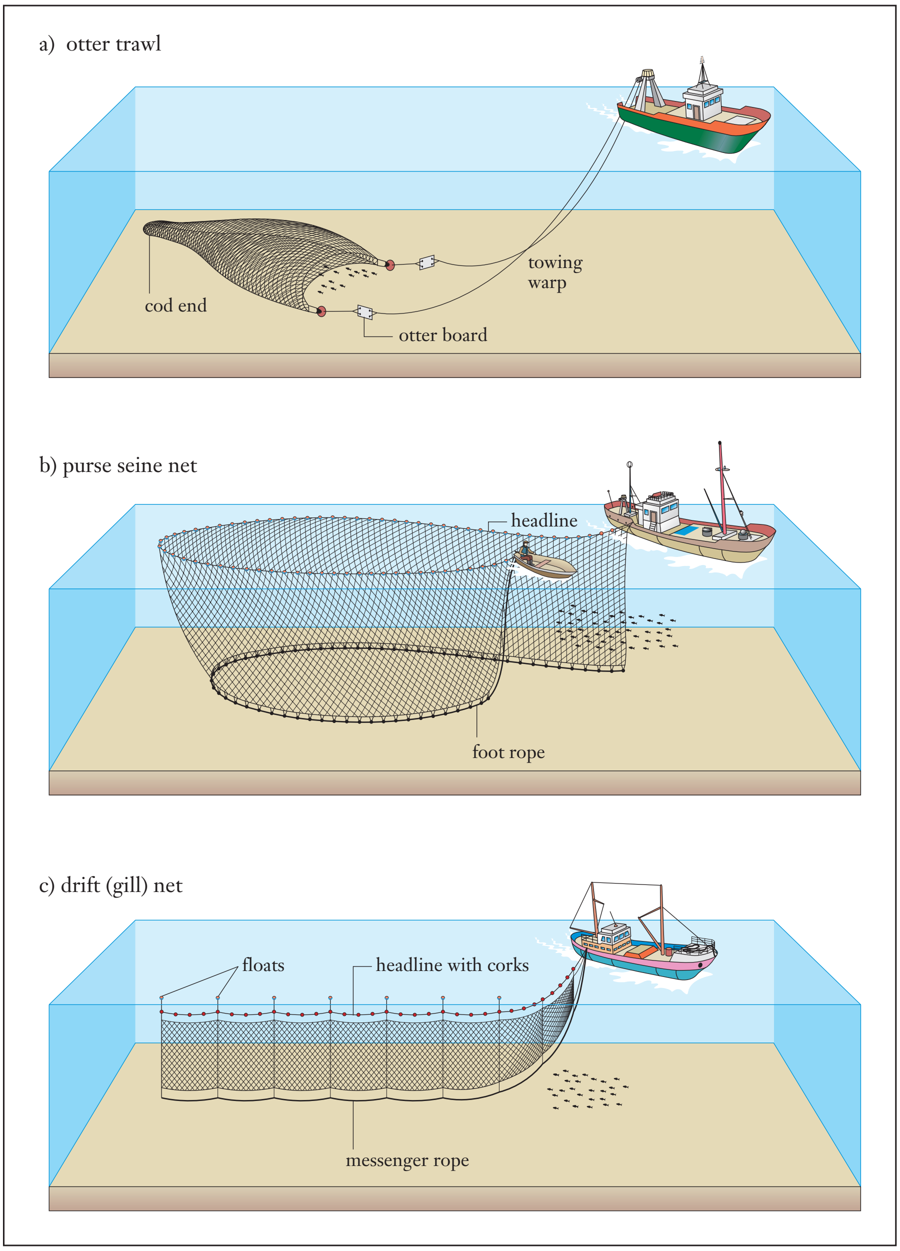
Recreational fishing is big business in many countries—examples include marlin, sailfish and, to a lesser extent, shark fishing in the USA. Provision of such fishing opportunities to tourists may be an important source of income for small communities.

Fishing methods

There are more than a million large-scale fishing vessels and twice as many smaller-scale fishing boats at work on the world's oceans and seas. They use a wide range of nets and other equipment, including trawl, seine and gill nets. Long-line fishing using baited hooks or lures is used to catch fish such as tuna, particularly in Japan and Korea. Modern fleets use sophisticated equipment to detect submerged fish shoals, and helicopters and aircraft to spot surface shoals such as tuna.

Commercial fishing boats hauling in a school of fish

Boats used in traditional fisheries are often small, and some are still unmotorized. Shore-based fisheries are common and whole families are often involved. Knowledge of feeding and spawning grounds, migrations, and behaviour of target



A selection of fishing nets in popular use is shown in the diagram on the left.

a) The otter trawl is used for catching demersal species. A large bag-like net is held open by rigid otterboards and pulled along the seabed. Back on board, the narrow 'cod-end' is undone to release the fish. Modified trawls can be used in mid-water.

b) The purse seine net is used to catch pelagic fish shoals such as sardines and tuna. A curtain of fine mesh is hung vertically in the water, and the shoal encircled. The bottom of the net is then drawn shut before it is hauled in.

c) The drift (gill) net is suspended vertically from the water surface and left to drift with the current. Fish swim into the net and are trapped by their gills.

fish is handed down through the generations. Traditional fishing gear includes a wide and ingenious array of equipment of which the main types are:

- permanent and semi-permanent tidal traps in shallow water; these may be constructed from stone, wood or wire;
- baited crab, lobster and fish traps set and hauled from boats or shore (these are also used on an industrial scale);
- seine and cast nets set from beach or boat as encirclement traps, and nets set across tidal creeks and channels;
- line fishing using a wide range of techniques;
- hand fishing using push nets, spears and bows and arrows; and
- traditional shellfish collection in intertidal areas.

The photographs below show examples of traditional fisheries, including:
1. beach seine (Philippines);
2. clam fishing (NW Spain);
3. fish traps (United Arab Emirates);
4. fish trap (Indonesia);
5. Venezuelan boats selling their catch in Curaçao; and
6. a local fish market in Korea.

Fish farming and other aquaculture practices

A wide variety of marine and freshwater species are cultivated in a worldwide context. The most important groups are fin-fish, prawns and shrimps, other crustaceans, molluscs and seaweeds. The term *aquaculture* includes both fresh and sea water culture, whilst *mariculture* refers exclusively to marine culture. Efforts are mainly concentrated on species that command a premium price in the market (e.g. salmon, prawns) and on those that produce a high yield under intensive culture (e.g. mussels). Species that can tolerate changes in the saltiness of the water, and bottom-living species, are more often cultivated than marine open-water species. Freshwater aquaculture presently contributes a far greater world yield than mariculture. More than 80 per cent of aquaculture production originates from Asia. In Europe and the Americas there has been a dramatic increase in commercial mariculture in the past 10 to 20 years.

Table 1 Some commonly cultivated marine species.

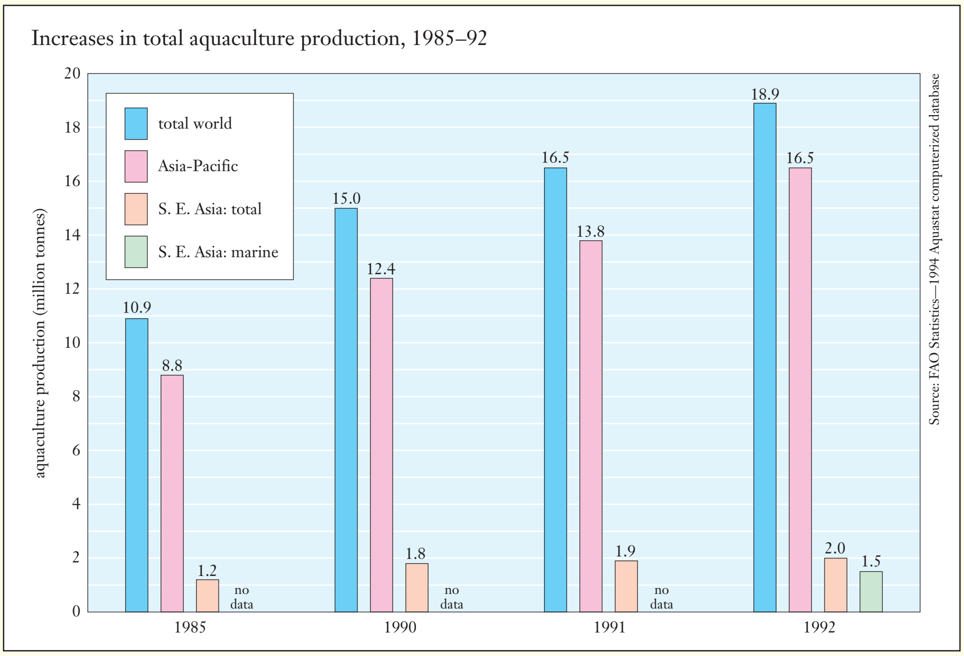
Species	Area	Installation
Atlantic salmon *(Salmo)*	Northern Europe, mainly Norway	Anchored floating cages
Pacific salmon *(Oncorhynchus)*	North America, Japan	Anchored floating cages
Flat-fish (various)	Northern Europe, Korea, Japan	Onshore tanks, cages, semi-open coastal waters
Milkfish *(Chanos)*	S.E. Asia	Brackish ponds
Yellowtail *(Seriola)*	S.E. Asia, Korea, Japan	Floating cages
Seabass, groupers, snappers, bream	Asia-Pacific, Mediterranean	Cages, semi-open coastal waters
Shrimps and prawns *(Penaeus, Metapenaeus)*	Asia-Pacific, S. America	Ponds
Oysters *(Ostrea, Crassostrea)*	Worldwide	Seabed; intertidal and sub-tidal racks; hanging ropes
Mussels *(Mytilus)*	Worldwide	Posts and stakes; seabed; hanging ropes
Clams *(Anadara, Tapes, Mactra, Mercenaria, Meretrix)*; and Abalone *(Haliotis)*	Worldwide	Seabed
Seaweeds	Asia-Pacific	Suspended culture

EXAMPLES OF COASTAL AQUACULTURE IN THE ASIA-PACIFIC REGION

Coastal aquaculture has been practised in Asia for more than 500 years, much of it in the form of small-scale subsistence farming. Many small communities depend on these activities for their livelihood. The last two decades have also seen the development of commercial-scale production in this region, e.g. yellowtail fish farming in Japan and Korea. In 1992, the Asia-Pacific region accounted for 87 per cent of world aquaculture (freshwater and marine) production, amounting to nearly 17 million metric tonnes out of a world total of nearly 19 million metric tonnes (see chart, below). China is by far the largest producer in the region in this respect. Major coastal aquaculture producers (i.e. those producing the largest number of tonnes per kilometre of coastline) are Thailand, Taiwan, China, Korea and Japan.

Brackish water pond culture is an important system, mostly created from fringing mangrove habitats. Species cultured in ponds include milkfish, other fish and shrimp. In many cases, fry are still collected from the wild by fishermen using nets. Marine cage culture was introduced in the Asia-Pacific region in the early 1970s, mainly for the culture of high value species such as groupers, seabasses and snappers. The cages are located close to the seashore in semi-open coastal waters. Large-scale cultivation of shellfish is practised in several countries; examples include the sea-bed culture of cockles, and oyster and mussel culture on fixed stakes or suspended ropes.

Many fish farms are located in areas of heavy domestic and industrial activities and this often leads to conflicts over the use of natural resources. This can only be minimized through appropriate resource allocation and management. Whilst oil and other pollution may adversely affect aquaculture, the aquaculture itself may cause environmental problems such as the loss of habitats for some wild species through conversion of mangroves to fishponds, and excessive organic load on the seabed under fish cages.

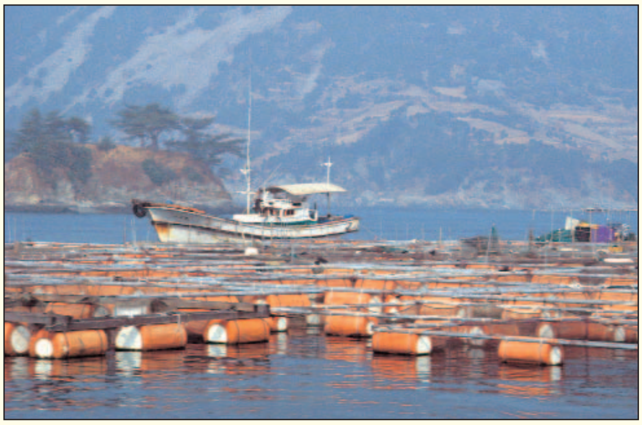


In 1992, the Asia-Pacific region accounted for 87 per cent of world aquaculture (freshwater and marine) production, amounting to nearly 17 million metric tonnes.

(Asia-Pacific includes 27 countries from Iran and Pakistan in the west to Japan and China in the east, plus Australasia. Within the Asia-Pacific region, S.E. Asia includes Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.)

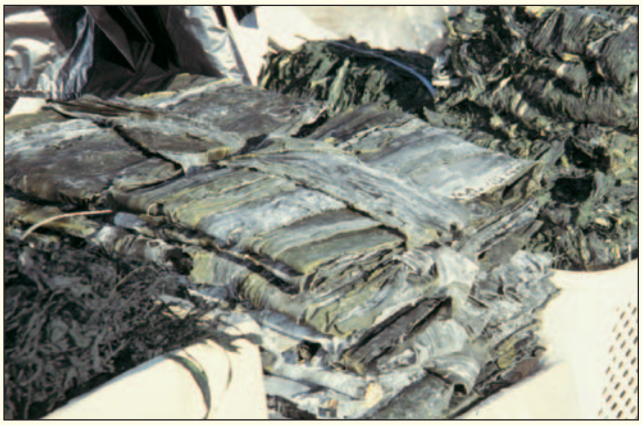
The milkfish (Chanos) *is widely farmed in ponds.*

Extensive oyster farms near Xiamen, China



Floating fish cages in Korea

Typical ponds used to rear fish and crustaceans



Laver seaweed or nori (Porphyra *spp.*) *is cultivated in Japan and Korea.*

Tiger prawn, a valuable species

EFFECTS OF OIL SPILLS

Spills may impact fisheries' resources in the following ways:

- direct effects on the fish themselves (lethal or sublethal);
- direct effects on fisheries (tainting, or interference with fishing activities); and
- indirect effects through ecosystem disturbance (e.g. impacts on food chains).

Direct biological effects on fishery species

Kills

There is no evidence to date that any oil spill has killed sufficient numbers of adult fish or their young stages in the offshore open ocean ecosystem to significantly affect adult populations. For example, no adverse effects on adult fish were reported following the *Ekofisk* blowout and the *Argo Merchant* spill. This is because in most open water spills, the concentration of oil below the slicks is low, ranging from a few parts per million (ppm) to less than 0.1 ppm. The concentration of chemically-dispersed oil also decreases rapidly with time and depth (see the 1993 IPIECA report *Dispersants and their Role in Oil Spill Response*).

Most shipping incidents occur not in the open ocean but in inshore areas with restricted waters. Here the potential damage to fish is greater, particularly for species with a small stock size, and restricted spawning areas.

The direct effects of oil on inshore shellfish beds, and fish and shellfish in aquaculture units are of particular concern. There is evidence that wild fish are able to detect and avoid oil-contaminated waters, but captive fish and shellfish are unable to swim away into unpolluted areas. There are documented instances of oil spills in which shellfish have been killed in significant numbers (e.g. clams following the *Arrow* and *Amoco Cadiz* spills).

Heavily contaminated sediments are likely to have an adverse effect on local populations of bottom-dwelling species such as flat-fish. Following the massive spill from the *Amoco Cadiz* in 1978, work by French biologists on plaice *(Pleuronectes platessa)* and sole *(Solea vulgaris)* populations indicated the disappearance of the 1978 year class of these two species from some heavily contaminated areas of northern Brittany. This is an extreme case. Subsequent to the spill, the fishery for these two species did not seem to have been affected.

Table 2 A summary of selected published information concerning effects of oil spills on fish stocks. Amounts have been standardized to tonnes using conversion factors in GESAMP 1993. *In all cases, the oil spill area included important fishing grounds.*

Spill (tonnes)	Reported effect	Source
1969: well blowout, Santa Barbara, California; 4,500–10,500 tonnes crude oil	Short-term negative effects on abundance of bonito and jack mackerel. No long-term effects on abundance of any pelagic fish species studied.	Squire (1992)
1976: *Argo Merchant,* Massachusetts, USA; 25,000 tonnes No. 6 fuel oil	Fish eggs moribund; fish larval densities reduced. Fish stocks studied 1975–77 showed no major impacts. Spill did not occur during peak spawning season.	Kühnhold (1978)
1977: *Tsesis*, Baltic, Sweden; 1,000 tonnes medium fuel oil	Herring moved normally through oiled areas during the month after the spill. Contamination not detected in their tissues. Some effects on spawning were recorded the following spring but these may have resulted from causes other than the spill.	Kineman *et al.* (1980), summarized in Linden *et al.* (1979)
1977: *Ekofisk 'Bravo'* blowout, North Sea; 9,000–13,000 tonnes crude oil	Bottom-trawled fish analysed for petroleum hydrocarbons. No evidence that fish had taken up oil during two weeks following the blowout.	Law (1978)
1978: *Amoco Cadiz* N. Brittany, France; 221,000 tonnes light Middle Eastern crude oil	Several tonnes rockfish (e.g. wrasse) and sand eels killed. One-year-old class of plaice and sole disappeared in worst affected areas. Reproduction and growth of bottom-living fish in abers and bays disturbed and histopathological abnormalities still evident in plaice two years later. Little tainting of fin-fish.	CNEXO (1981); Haensley *et al.* (1982)
1979: *Betelgeuse,* Bantry Bay, Ireland; Arabian light crude oil—explosion then leakage for 18 months	Whiting and sprat spawned normally in spring. No serious adverse effects on eggs and larvae of commercial species detected. No apparent reduction in spatfall of scallops in 1979.	Grainger *et al.* (1980), summarized in Myers (undated)
1980: oil spill, Bahrain; estimated 3,300 tonnes arrived at coast	Initially, numbers of dead groupers, jacks, and 'sardines'; no massive mortality.	Linden (1984)
1983: *Castillo de Bellver,* South Africa; 160,000–190,000 tonnes crude oil	Spill remained offshore. Dispersant used on landward edge of spill. Little apparent impact on fishgrounds or stocks. Occurrence and abundance of eggs and larvae normal. Spill occurred prior to main fish spawning season.	Moldan *et al.* (1985)
1989: *Exxon Valdez,* Alaska; 35,360 tonnes oil	See case study on page 24.	Wells *et al.* (1995)
1991: Gulf War oil spill; 800,000–1,000,000 tonnes crude oil	In 1991–92, Saudi Arabian prawn stocks showed a decline in total biomass to 25 per cent of pre-war levels. Exact causes not ascertained.	Price and Robinson (eds.) (1993); Price *et al.* (1994)
1993: *Braer*, Shetland; 84,700 tonnes oil	See case study on page 23.	Ecological Steering Group (1994)

Effects on plankton

Eggs and young stages are more vulnerable to oil pollution than adults. In many fish, mollusc and crustacean species these stages float in the surface waters where contact with spilt oil is more likely. Fortunately, many commercial species (with the notable exception of sharks and rays) spawn over large areas or have several major spawning grounds. Most fish and shellfish species with pelagic young, produce huge numbers of eggs and larvae. A good sized cod, for example, can lay between 3 and 7 million eggs in a season. Of these, only a small proportion will survive to adulthood. The rest are eaten by other animals or die. The number of young that do survive beyond the plankton phase and go on to reach sufficient size to be recruited into the fishable stock varies from year to year. Numerous factors, such as weather and adult reproductive success, affect this recruitment. Any loss due to oil would be less serious in a year of good recruitment.

Following some oil spills (e.g. *Argo Merchant* 1976), direct effects on fish plankton have been recorded, including the deaths of measurable numbers of larvae in the vicinity of the spill. However, because such large numbers of eggs and larvae are produced, and because most species have extensive spawning grounds, no effects on numbers in subsequent adult populations have been found in the few studies that have so far been made. There have been a number of attempts to produce computer models predicting the possible effects of oil spills on fish plankton and the consequent effects on adult populations. However, the results so far have not been entirely consistent.

Stocks could be at risk if the spill:

- was very large; and
- coincided with spawning periods; or
- entered grounds of species whose spawning is restricted to small areas or to physically contained areas (e.g. bays).

An extreme example, in which at least the first two of these criteria were met, concerns the oil spill resulting from the 1991 Gulf war. In 1991–92, Saudi Arabian prawn stocks showed a decline in total biomass to 25 per cent of pre-war levels (see Table 2 on page 15). One of the possible reasons is mortality of eggs and young stages associated with oiling of spawning and nursery grounds in spring 1991 (Mathews *et al.* in Price and Robinson, 1993).

Effects on fish behaviour

In most cases, wild fish will swim away from oil spills and long-term effects on local populations are avoided. There are some cases in which the behaviour of the fish might be altered to the detriment of local fisheries, though actual observations in the field are few and circumstantial:

- Many fish are territorial. Fish moving back into an area following a spill must re-establish territories for feeding and breeding. Thus local fisheries may take some time to recover.
- Fisheries dependent on the seasonal appearance of fish could be disrupted if fish change their migration route as a result of an oil spill.
- Fish such as salmon and sturgeon migrate from the sea into rivers to spawn. Anything that prevents or reduces this spawning migration could affect fisheries in subsequent years, although effects would probably only be localized.

Sublethal effects

Whilst the immediate, lethal effects of oil can generally be measured, sublethal effects are more difficult to quantify. Laboratory experiments have demonstrated effects on reproduction and feeding in fish and shellfish at very low concentrations of oil. Responses include reduced egg hatching, reduced larval survival following exposure of adults during gonad maturation, larval abnormalities and shell closure in shellfish (see references in GESAMP 1993). In lobsters and crabs many activities are guided by their highly-developed sense of smell. Exposure to oil and oil products disrupts these senses and has been shown to affect searching, feeding, and grooming behaviour in lobsters, and mating behaviour in crabs. It is difficult to mimic complex field conditions in the laboratory and some short-term exposure studies have been unrealistic in terms of the actual conditions to which fish are likely to be exposed during an oil spill. Many of the observed laboratory effects do occur at hydrocarbon concentrations similar to those found under field spill conditions. Unfortunately, such studies do not or cannot take full account of aspects such as continuous dilution with time, animal predation and human predation (fisheries), which may in nature completely hide the studied effects. Using laboratory studies on effects of oil to predict impacts in the field remains a difficult problem.

Direct effects on fisheries

Tainting

Fin-fish and shellfish exposed to crude oil or its products may become tainted and unfit for sale by acquiring oil-derived substances in the tissues which impart unpleasant odours and flavours. Tainting is of particular concern in cultivated species and can result from very low concentrations of oil since caged fish and immobile shellfish cannot swim away.

Fish can become tainted from the water or sediment in which they live via absorption through the gills and skin, or through eating contaminated prey species. Commercial catches may also become externally contaminated from contact with oil-fouled fishing gear. If oil reaches the sea floor, then species living in fine muddy sediments, such as the Norway lobster *(Nephrops norvegicus)* will be at particular risk of tainting because fine sediments can absorb and retain greater quantities of oil than coarse sediments.

So far there is little consensus about which components of oil are responsible for its tainting effect but light to middle boiling range oils are the most potent source. The concentration of oil that may cause tainting varies widely with the oil and the fish concerned (Baker *et al.*, 1990; GESAMP, 1993). Species with a high body-fat content, such as salmon and herring, are more easily tainted and retain the taint for longer periods than lean-muscle species. The time taken to attain a detectable taint varies from only a few hours to days.

Taint is usually lost through the normal processes of metabolism (known as 'depuration') once the oil source has gone, but chemical analyses and sensory testing are required before it can be determined whether fish are fit to eat. In some cases, oil-derived compounds may be present at well above background levels, even though no taint can be detected. Conversely, fish can still be tainted where chemical analysis indicates that contamination is only at background levels. There are no accepted standards for permissible concentrations of hydrocarbons in foodstuffs. Therefore, following an oil spill, criteria to determine acceptable levels should involve a return to levels of hydrocarbons found in stocks of the same species elsewhere that are accepted as marketable. In most cases, chemical tests are, or should be, combined with sensory testing. This is carried out by trained sensory analysts or panellists (who, increasingly, are advised to rely on odour rather than taste), using 'blind' tests where they do not know which are the tests and which the controls. If there is clear evidence of taint, most authorities are likely to consider it a sensible precaution to prevent the sale of such products until regular chemical and sensory testing declares them free of contamination and therefore fit for sale.

The time-scale for loss of taint (once the source has been removed) ranges from days to months depending on the exposure, species, temperature, feeding patterns and other factors. Shellfish that cannot swim away from oiled sediments will remain tainted, but where it is possible to move them to clean water, they can start the process of lowering their hydrocarbon levels sooner. Sometimes severely tainted shellfish or caged fish may have to be destroyed because they cannot be sold.

One of the main concerns over tainting is the possible human health hazard of eating seafoods contaminated by oil-derived compounds. Such compounds may include low concentrations of carcinogens, although these are not necessarily the compounds causing the taint. So far, epidemiological studies have not demonstrated any increased risk of cancer or other diseases in humans through eating seafood from areas where oil spills have occurred (GESAMP, 1993; NRC, 1985).

Fishing activities

Major oil spills may result in loss of fishing opportunities with boats unable or unwilling to fish due to the risk of fouling of boats and fishing gear (see Table 3). Exclusion zones, where fishermen are banned from fishing for particular species, may be imposed until the target species has been declared taint-free. In these circumstances, there will be temporary financial loss to fishermen. Artisanal fishermen, especially in developing countries, may also suffer temporary food shortage.

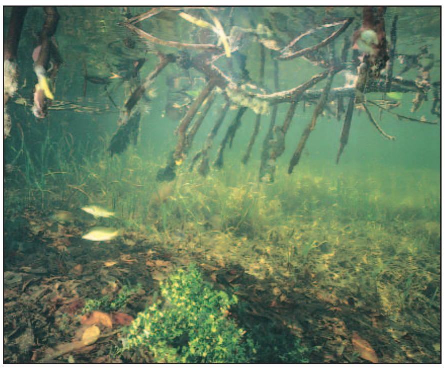
Aquaculture and shellfish

As the number and variety of aquaculture installations increases worldwide, so too does the potential for oil spill impacts (see Table 3). The Asia-Pacific region (see pages 12–13), where coastal aquaculture is widespread and maritime traffic is heavy, is a particularly high risk area. Oil may contaminate fixed aquaculture equipment (such as ropes and cages) and intertidal shellfish, and will damage stock in tanks or ponds if there is an intake of contaminated sea water. Even small spills (e.g. 50 tonnes) can cause serious damage locally, since many facilities are often

Table 3 Sensitivity of fishing gear and aquaculture equipment to damage by stranded or drifting oil (modified from GESAMP, 1993)

Type of fishing gear		Sensitivity
brush traps, staked traps, baskets, fences		high
lift nets, cast nets		moderate
gill, drift, tangle, trammel and push nets		moderate
purse seines, ring nets, beach seines		moderate/low
handlines, longlines, drift lines		low
trawl, dredges, sweep nets		low
Aquaculture method	**Species**	**Sensitivity**
intertidal zone (seabed, fixed posts etc.)	molluscs (shellfish)	high
onshore tanks	fish, crustacea, molluscs	moderate
sea impoundments and ponds	fish, prawns	moderate to low
cages and ropes suspended vertically from surface by floats	salmonids, bass, sea bream, yellowtail, mussel, oyster	moderate to low
seabed (subtidal)	abalone, arkshell	low
seabed enclosures	crab, lobster	low

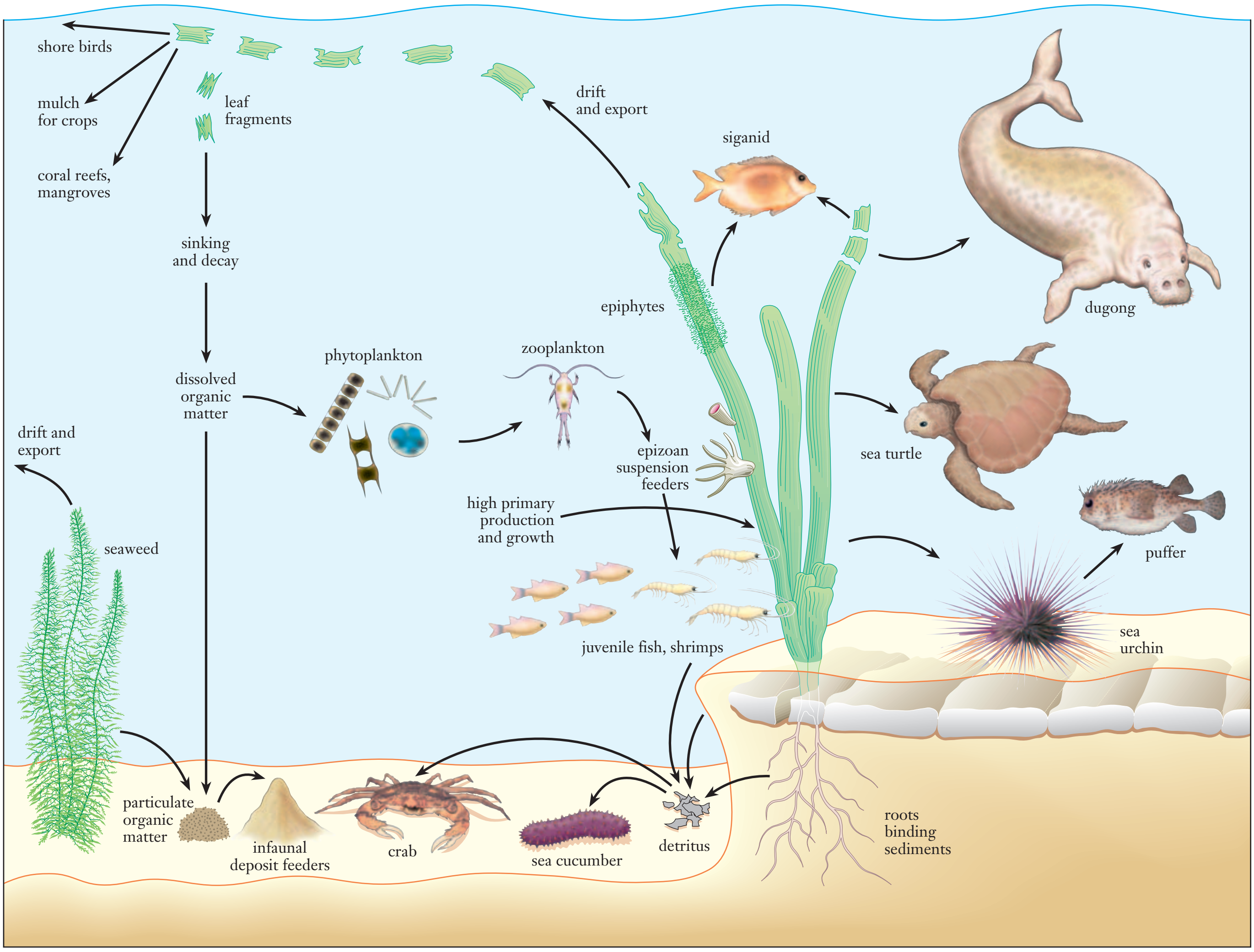
concentrated in small areas. In some cases, effects on shellfish beds may be long-term because of retention of oil in sediments (e.g. sublethal effects on clams *(Mya)* were still apparent six years after the 1970 *Arrow* spill).



Mangrove roots provide shelter for young fish and shrimp (Belize).

Indirect effects: ecosystem disturbance

A variety of ecosystems are important both as nursery areas (see Table 4), and for providing habitat and food for older fish. For example, mangrove forests and seagrass beds, in addition to their function as nursery areas, also provide food chain support (e.g. nutrient input from dead leaves) for nearshore fisheries. The vulnerability of mangrove areas to oil pollution has been well documented (see the 1993 IPIECA report *Biological Impacts of Oil Pollution: Mangroves*) and low-energy ecosystems in particular can be damaged by oil over varying periods of time. Natural dispersion and dilution of oil is relatively restricted in semi-enclosed, estuarine and shallow nearshore areas, so there is the possibility of effects on plant and animal species which are used for shelter and food by the fish and shellfish.



Philippine seagrass ecosystem showing food chains and interrelationships with fisheries. (Modified from Fortes, 1990.)

Table 4 Important nursery habitats

Ecosystem	Area	Example
Mangrove forests	Tropical and subtropical sheltered shores	Prawns; many brackish water fish species
Seagrass beds	Worldwide but especially tropical	Prawns and pearl oysters
Coral reefs	Tropical	Many coastal marine fish
River deltas	Worldwide	Many brackish water fish species; mullets.
Estuaries; saltmarshes	Worldwide	Flat-fish; mullets; prawns.
Freshwater marginal vegetation	Worldwide	Many freshwater fish species

OIL SPILL RESPONSE

Prior knowledge of ecosystems and species in vulnerable areas, and their relative sensitivities to oil pollution is essential for contingency planning (see the 1996 IMO/IPIECA report on *Sensitivity Mapping for Oil Spill Response*). Government agencies charged with the management of fisheries or environmental resources, are likely to have information on local fisheries. However, local people can also provide considerable input and, in the case of some traditional fisheries, they may be the only source of information. Relevant planning information includes the location of spawning and nursery areas, fixed equipment and fish farms, fleets and fishing areas and the seasons in which they operate.

Response considerations

Of specific relevance to fisheries is the early notification of oil spills to fish farmers and fishermen, giving them as much opportunity as possible to protect shellfish beds, water intakes, fish cages and other facilities, normally using booms. Consideration may also be given to harvesting the resource before impact, and to transferring the resource to refuge areas. The latter approach is not common because it requires a high degree of pre-planning and advance warning, and is not possible with some facilities.

It is generally prudent that fishing should be suspended in an oil spill area if there is a significant risk of fishing gear or catches becoming contaminated. It is important that such restrictions are lifted once it is established that the problem has been removed and stocks are acceptable in the light of chemical and sensory testing. A cautious approach is often adopted in such situations, recognizing that marketing of contaminated products could lead to severe financial repercussions on a fishery. However, over-caution also can result in severe financial loss.

Fisheries form part of a wide variety of ecosystems and reference should be made to other publications in this series for protection and clean-up options on coral reefs, in mangroves and saltmarshes, and on shorelines. Methods commonly employed to protect fishery interests include:

- deflective booming to move oil away from sensitive areas such as estuaries and onto 'sacrificial' beaches; and
- priority clean-up of:
  - beaches liable to leach oil into nearshore fishery areas; and
  - salmon stream entrances.

The use of dispersants on slicks that are approaching sensitive areas has particular implications where fisheries are involved. The decision on whether to use dispersants should be based on an informed evaluation of the merits of each situation as described in the 1993 IPIECA guide *Dispersants and their Role in Oil Spill Response*.

Aspects relevant to fisheries include the following:

- If the oil is dispersed, eggs and larvae within the upper few metres of the water column may be exposed to elevated concentrations of hydrocarbons. This will be particularly relevant in sheltered, shallow nursery areas and in the vicinity of spawning grounds.
- Chemically-dispersed oil no longer floats and in relatively shallow water, could reach the bottom where it might affect bottom sediments and fauna.
- Contamination of fixed fishing gear and fish farming equipment may be avoided by the use of dispersants.
- The use of dispersants in aquaculture areas increases the risk of tainting of cultivated stocks by dispersed oil droplets.

Case study: fisheries' response to the *Braer* oil spill

The well-documented *Braer* spill of Norwegian Gullfaks crude oil in Shetland, January 1993, was unusual in that severe weather caused the spilt oil to be mixed quickly into the water column and moved over considerable distances. This resulted in contamination of both wild fisheries and farmed salmon. Limited aerial

Salmon farm cages in Shetland

spraying was carried out using a total of 120 tonnes of dispersant. The spill did not result in major mortality of commercial fishery species, nor were significant changes recorded in the abundance or distribution of these species or other important food chain species (e.g. sand eels). However, fisheries were directly affected through contamination of equipment and tainting of fish. Elevated mortalities at some fish farms were accepted as oil-related.

In wild fish the contamination was only light, and fairly low numbers of tainted individuals were found. In farmed salmon, contamination was quite high initially but depurated exponentially to background levels after about 5–6 months. In molluscs, hydrocarbons and taint depurated rapidly to start with but scallops and mussels retained elevated hydrocarbon levels for more than a year. Crustaceans were clear by 7 months with the exception of *Nephrops* (scampi) which was probably being re-contaminated from oil trapped in muddy seabed sediments.

To protect the health of the public and the reputation of the fisheries in unaffected areas, a *Fisheries Exclusion Zone* was set up in which fishing and the sale of farmed salmon were banned until tests on commercial species showed negligible contamination. The order was lifted for wild fish after 4 and a half months, for most crustaceans after 1 year and 10 months and for scallops after 2 years and 1 month. The order remained in force after 2 years and 10 months for *Nephrops* and mussels. Farmed salmon due to be harvested in spring (2–5 months after the spill) were still contaminated and were destroyed. Towards the end of 1993, samples of younger fish due to be harvested showed insignificant contamination, though individual fish retained some taint. The order was not lifted because of concerns about the possible long-term adverse impact on the reputation of the fishery through marketing fish which were known to have once been contaminated, albeit at a low level.

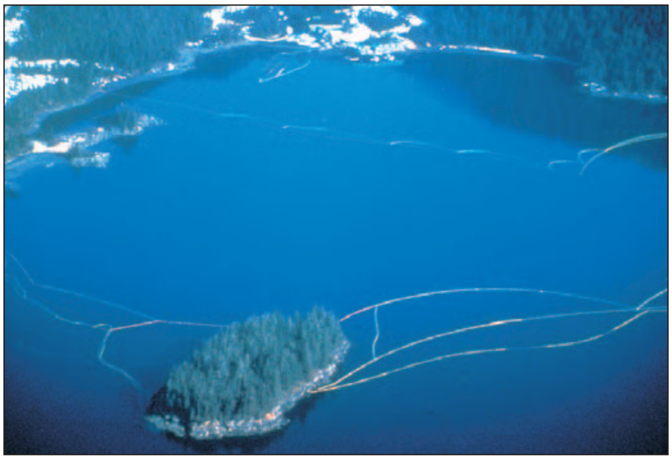
Salmon spawning stream, Alaska.

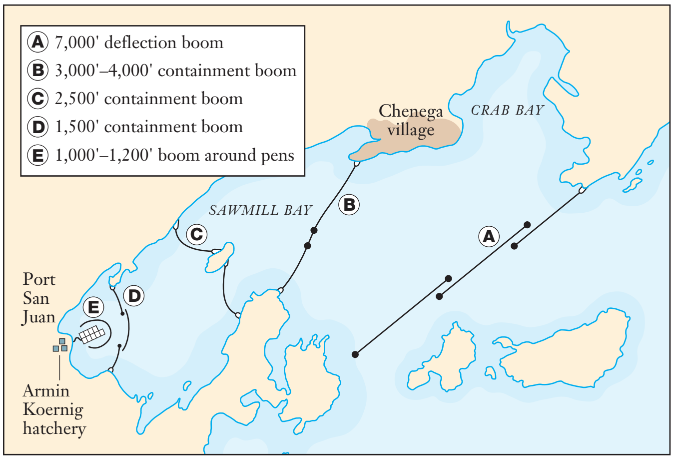
Case study: fisheries' response to the *Exxon Valdez* oil spill

The *Exxon Valdez* spill of North Slope crude oil in Alaska, March 1989, affected a wide range of species and ecosystems. There was concern about possible effects on the extensive fisheries in the area. The most important commercial fisheries are for salmon and herring. Demersal fisheries include Pacific cod, lingcod, halibut, sablefish and rockfish.

Oil spill response actions taken to protect the fisheries included the following:

- Fish hatcheries (salmon) were protected by deployment of booms.
- Salmon spawning streams were identified and care was taken to ensure beach clean-up operations did not adversely affect them.
- The herring fishery in the Sound was closed in April 1989 as a stock preservation measure and as a precaution against oiling of fish and fishing gear.





Booms deployed to protect fish hatcheries and rivers following the Exxon Valdez *oil spill (Exxon 1990).*

Compilation of fishery statistics and other research demonstrated the following:

- No adult herring mortalities were observed at the time of the spill. The herring spawned shortly after the spill, thus exposing the most vulnerable life stages to the oil. Fortunately much of the heaviest spawning was in areas unaffected by the oil. The herring harvest in 1990 was very good. The herring fishing ban in 1989 may have compensated for losses due to the oil spill. However, herring returns for 1993–95 have been poor, resulting in a ban on seine fishing. Such reduced returns are more likely to be the result of long-term cyclical trends than delayed effects of the oil spill.
- No reduction in commercial harvests of pink salmon was observed in 1990–91. The August 1990 catch came from fry hatched just before or during the spill since this species spends only 15 or 16 months in the sea before returning to spawn. This salmon species is unusual because the adults often spawn in estuaries or in intertidal gravels at the mouths of small freshwater streams. The fry feed in shallow nearshore areas during their first summer and would have been in close proximity to heavily oiled areas. Millions of hatchery-reared fry were also released in the Sound in April–June 1989.

It remains unclear whether the oil killed significant numbers of newly-hatched young in intertidal spawning areas or fry in shallow water. If it did, then other factors must have allowed greater than normal numbers of the remaining fry to survive. Sunny weather sustained an extensive plankton bloom immediately after the spill. This would have provided abundant food for emerging fry. Predation of fry may have been reduced by the high death toll of diving birds which normally feed on them. Pink salmon returns in 1992–93 were lower than forecast whilst 1994 gave the third highest yield ever.

These examples highlight the complex influences of various natural and human factors on fish stocks and the difficulties associated with determining the effects attributable to oil spills.

CONCLUSIONS

Fisheries and aquaculture may be affected by oil spills either directly, or indirectly through impacts on their supporting ecosystems (e.g. mangroves, seagrass beds, and areas used for wild-fry collection). Fisheries may also be affected through damage and fouling of boats and fishing gear, with the most vulnerable types of equipment being intertidal fish traps and aquaculture facilities.

There are great difficulties associated with separating out natural and oil-induced population fluctuations. Present sampling methods are not refined enough to allow a categorical no-impact judgement. However, there is no evidence so far that any oil spill has killed sufficient numbers of fish in open ocean situations to significantly affect adult populations. Potential damage is greater in inshore shallow water areas, particularly for species with restricted spawning grounds. At greatest risk of direct effects (death or tainting) are inshore shellfish beds, and fish and shellfish in aquaculture units where there is a greater potential for direct contamination by oil.

Sensitivity mapping for oil spill contingency planning should include the locations of spawning, nursery and fishing areas, aquaculture facilities, and information on seasonal variations. Response options include protection of aquaculture facilities and areas such as spawning grounds, and of supporting ecosystems such as mangroves. The two main approaches to protection (which may be used concurrently) are inshore booming, and tackling slicks before they reach sensitive areas using containment/recovery or dispersants. In some situations a short-term suspension of fishing or harvesting activities may be appropriate.

ACKNOWLEDGEMENTS AND FURTHER READING

Acknowledgements

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We are grateful to the International Tanker Owners Pollution Federation (ITOPF) and Cambridge University for use of their extensive library facilities, and to Dr K. J. Whittle for information on tainting.

Further reading

Baker, J. M., Clark, R. B., Kingston, P. F. and Jenkins, R. H. (1990). *Natural Recovery of Cold Water Marine Environments after an Oil Spill.* 13th AMOP Seminar, June 1990.

Barnabé, G. (ed.) (1990). *Aquaculture*, Volumes 1 and 2. Ellis Horwood Publishers.

Brandt, A. von (1972). *Fish Catching Methods of the World.* Fishing News (Books) Ltd.

Davis, W. P., Hoss, D. E., Scott, G. I. and Sheridan, P.F. (1984). Fisheries resource impacts from spills of oil or hazardous substances. In: Cairns, J. and Buikema, A. L. (eds.) *Restoration of Habitats Impacted by Oil Spills*.

Ecological Steering Group on the Oil Spill in Shetland (1994). *The Environmental Impact of the Wreck of the Braer*. The Scottish Office, Edinburgh.

GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution) (1993). *Impact of Oil and Related Chemicals and Wastes on the Marine Environment*. UNEP.

IUCN (1993). *Oil and Gas Exploration and Production in Mangrove Areas.*
IUCN Gland, Switzerland and Cambridge, UK, with E&P Forum, London, UK.

Moller, T. H., Dicks, B. and Goodman, C. N. (1989). Fisheries and mariculture affected by oil spills. *Proceedings of the 1989 International Oil Spill Conference*, 389–394. American Petroleum Institute, Washington DC.

National Research Council (NRC) (1985). *Oil in the Sea. Inputs, Fates and Effects.* National Academy Press, Washington, DC.

Price, A. R. G. and Robinson, J. H. (eds.) (1993). The 1991 Gulf war: coastal and marine environmental consequences. *Marine Pollution Bulletin,* Special Issue Volume 27, 1993, Pergamon Press.

Full references for Table 2 and the figures on pages 21 and 25 may be obtained from IPIECA.

Other reports in the IPIECA series
Volume 1: *Guidelines on Biological Impacts of Oil Pollution* (1991).
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