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Information Bulletin

Fate and Effects of Marine Oil Spills

A discussion of the fate of oil spilled at sea and the major impacts it has on marine plants and animals and coastal environments.

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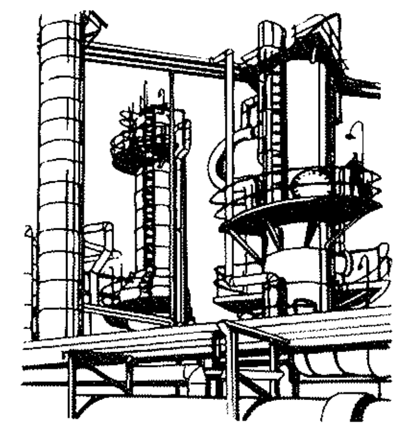
INTRODUCTION



Oil enters the marine environment from a wide range of sources, including discharges from marine vessels, industrial operations and offshore oil and gas activities; urban runoff; tanker accidents; atmospheric fallout, and natural seeps. Despite the many millions of tonnes of oil introduced to the world's oceans over the years, there is fortunately little evidence of build up of oil residues in the sea. This is due to a number of factors, not the least of which is the ability of the marine environment to disperse and assimilate oil.

Oil spilled at sea is subject to many physical, biological and chemical forces and undergoes many changes. The fate of oil spilled at sea and the resulting effects of that oil on the marine environment are largely dependent on the type and characteristics of the oil, the quantity of oil, the prevailing climatic and sea conditions and whether the oil remains at sea or is washed ashore. Spilled oil will ultimately end up on the open water, within the water column, in benthic environments, or on shorelines and will often have markedly different effects on each of those environments.

To more fully understand what happens to spilled oil, one needs first to understand those properties of oil which most significantly affect its fate.

PROPERTIES OF OIL

Type

One of the most important factors to be considered when evaluating the fate of oil spilled at sea is the oil type, whether it is non-persistent (and would therefore tend to disperse quickly) or persistent (and would dissipate much more slowly). Non-persistent oils are products like gasoline, naptha and kerosene, while crude oils are generally regarded as persistent.

Specific Gravity

Specific gravity is the property of an oil which compares its density to that of water. Most oils have a specific gravity less than that of water which is 1.0, meaning they are lighter than water and will float.

Specific gravity is not only indicative of whether a particular oil will float, it also provides a measure of its composition. Oils with a low specific gravity, for example, tend to be rich in volatile components.

Distillation Characteristics

The temperatures at which the various oil components boil determine its distillation characteristics. As the temperature is raised, different components reach their boiling points and are distilled off. The components which boil off early or at lower temperatures are said to be more volatile. Distillation characteristics are usually expressed as the percentages of the parent oil which distill within certain temperature ranges.

Viscosity

Viscosity is a measure of resistance to flow. Therefore, high viscosity oils, like Bunker C flow with difficulty and lower viscosity ones, like gasoline, flow freely.

Pour Point

The pour point is the temperature below which oil will not flow.

FATE OF OIL ON OPEN WATER

Oil releases to the marine environment are dynamic events, and while initially the oil may only affect the water surface, a number of processes may come into play and result in more widespread effects. The physical and chemical changes which oil undergoes in the marine environment, like evaporation, dissolution and emulsification, are collectively known as **"weathering"**.

By its very nature, each oil spill is unique. There are, however, two major types of oil releases that could occur in the marine environment - a continuous discharge of oil from an oil well blowout or a land based source and a batch spill from a tanker accident or an accident on land. While the continuous event results in a comparatively small but steady flow of oil, in a batch event, a large quantity of oil can reach the water in a relatively short period of time.

The fate of oil spilled on open water is determined by the following factors: oil spreading, oil movement and oil persistence. Other processes, which affect the physical and chemical characteristics may also come into play and influence the impact which the spilled oil could have.

Oil Spreading

Surface spreading is a significant feature of any marine oil spill. The main driving force behind the initial spreading of the oil is its weight. The force of gravity acting downwards through the thickness of an oil spill tends to spread it out sideways. As the slick spreads, it forms thick patches which contain approximately 90 percent of the oil in about 10 percent of the visible area of the slick. These thick patches are surrounded in turn by thinner sheens containing only about 10 percent of the volume of oil originally spilled but spread over 90 percent of the area.

Early reports about the spill from the "Torrey Canyon", a tanker which grounded off the southwest coast of England, showed evidence of this spreading phenomenon. In the first days after the spill, aerial observation showed that the oil slick was 40 miles long with an average width of 10 miles. The full area of the slick was probably made up of the "sheens" described above and thicker oil patches separated by the sheens.

During the initial stages of a spill, the oil spreads as a more or less coherent mass, but after a few hours the slick will begin to break up and form narrow bands called "windrows' parallel to the prevailing wind direction.

Oil Movement

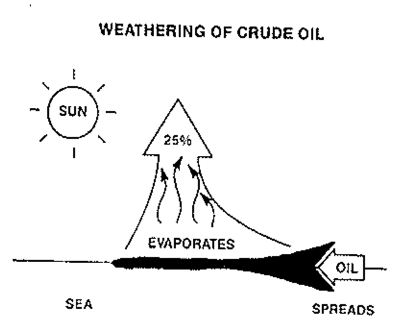
In addition to the natural spreading tendency, oil may be transported away from the site of a spill by water currents, tidal streams and wind-induced surface currents. These processes prevail after the initial few hours

and severely limit the possibility of effective clean up at sea. For example, only 12 hours after a spill, oil can be scattered within an area up to 5 square kilometers.

Oil Persistence

The persistence of oil spilled on the sea surface is determined by three basic processes: evaporation, dispersion and emulsification. Oxidation may also occur, but the influence of this reaction is relatively insignificant.

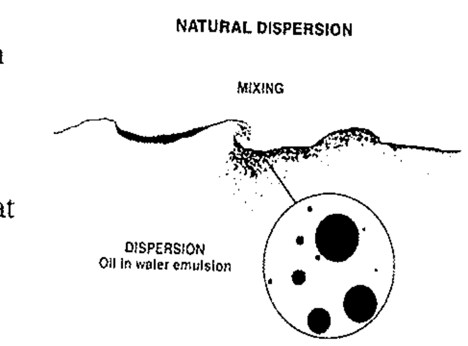
Evaporation - This is one of the most important processes affecting the fate and therefore the effects of spilled oil. The rate of evaporation of an oil slick is controlled by a number of factors including the temperature of the oil and the air; the surface area of the oil in contact with the air (essentially how much the oil has spread); the thickness of the oil, and, most important, the presence and concentrations of volatile components in the oil. The greater the concentration of low boiling point, highly volatile components, the greater the amount of evaporation. Spills of gasoline or kerosene may evaporate completely within a few hours, and even light crude oils can lose up to 40 % during the first day after a spill. Rough seas, high wind speeds and warm temperatures will further enhance the rate of evaporation.



Dispersion - Natural dispersion of marine oil slicks is a poorly understood process, and so cannot be predicted with any degree of accuracy. It is, however, an important factor in controlling the long term fate of oil spilled at sea.

Waves and turbulence at sea attack an oil slick and cause the formation of oil droplets in a range of sizes. Small droplets then become suspended in the water column while larger ones resurface behind the advancing slick, where they may combine with other droplets and form a new slick or spread out in a very thin film.

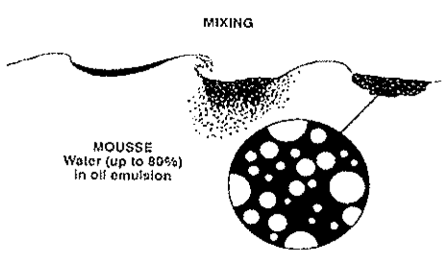
The extent of natural dispersion is largely dependent on the nature of the oil and the sea state at the time of the spill, and is much greater when breaking waves are present.



In a laboratory simulation using 1 part oil in 1000 parts water, 33 % of used motor oil was dispersed within 5 minutes; 13 % of Louisiana Crude was dispersed in the same time period, as was 20 % of Synthetic Crude and 7 % of Hibernia Crude.

Emulsification - This process occurs when oil and water are mixed as a result of wave action, but is potentially much more detrimental than simple dispersion. During emulsification, seawater is actually incorporated into the oil in the form of microscopic droplets, thus increasing the bulk volume of the polluting material by a factor of three to four times. Since these water-in-oil emulsions are extremely viscous, other processes which might help to dissipate the oil, like natural dispersion, are slowed down considerably.

FORMATION OF CHOCOLATE MOUSSE



These emulsions, commonly called "Chocolate Mousse" or simply "Mousse", are also relatively stable and do not easily break down.

Oxidation - Oxidation refers to a chemical reaction involving oxygen. Oil floating on the surface of the sea is subject to attack by oxygen in the atmosphere and to the effect of solar radiation. The hydrocarbon molecules present in oil slicks can react with oxygen and either break down into soluble products or combine to form persistent tars. These oxidation reactions are enhanced by sunlight and, although they can occur as long as the slick is at the surface of the sea, the effect they have on overall dissipation of the slick is minor in relation to the previously described processes affecting the persistence of oil.

ENVIRONMENTAL EFFECTS OF OIL ON OPEN WATER

Oil spills have the potential to affect a number of marine organisms and activities. While the slick is on the surface, many resources are at risk including: marine birds, pinnipeds (seals, sea lions, walruses), cetaceans (whales, dolphins, porpoises) and commercial fishing activities.

Effects on Birds

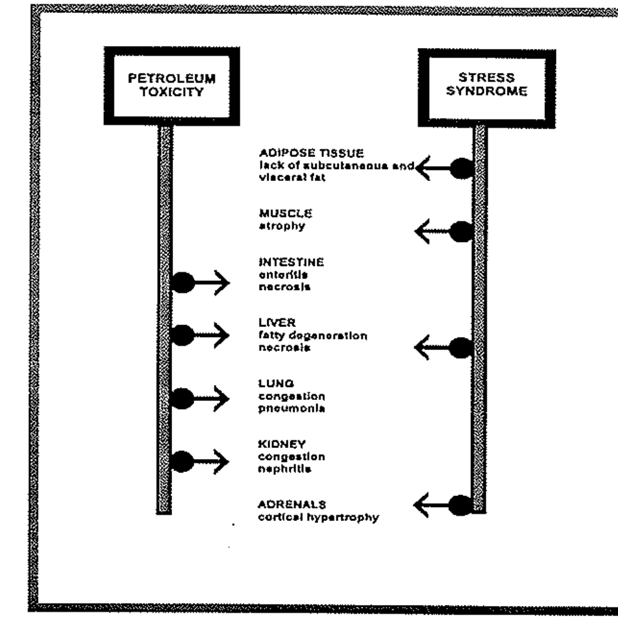
Marine birds are the creatures most vulnerable to the effects of an oil spill, and are also those creatures most visibly affected. Birds become oiled through direct contact with oil slicks in the offshore environment, through direct contact in nearshore waters, or through contact with oil stranded in coastal environments where they nest or feed. The most significant way that oil affects marine birds is through contamination of their feathers. Normally, a bird's outer layer of feathers provides an efficient waterproof barrier covering its skin and the downy, inner layer of feathers which insulate it from the cold. This outer layer of feathers consist of individual strands which overlap each other and are bound tightly together by rows of tiny hooks.

When the bird's feathers are oiled, they become matted and lose their waterproofing properties as these interconnecting strands and hooks are clogged. The bird therefore becomes less buoyant and, at the same time, the feathers lose some of their insulating properties. Although oil contamination may be so severe that the oiled bird simply sinks and drowns, the loss of insulation is a more common cause of death, especially in colder climates. Birds maintain a constant body temperature which is well above the ambient temperature of the sea where they spend a large portion of their time. Because of the efficient waterproofing and insulating characteristics of their feathers, this is not usually a problem. After oiling, however, cold seawater penetrates this protective layer and the loss of insulation leads to rapid heat loss. When the bird's body temperature drops below 21-23^0 C, then it normally dies from hypothermia.

Lightly oiled birds can initially compensate for the increased heat loss by increasing their rate of metabolic heat production, but they have to increase their feeding rates to do so. Because of the extra weight imposed by oiled and wet feathers, it is unlikely that a significant number of birds will be able to save themselves in this manner. Unless the insulating properties of the feathers are restored by removing the oil, even lightly oiled birds will die from a combination of exhaustion, starvation and hypothermia.

The birds mainly at risk are those that spend a lot of time actually resting on the water surface and periodically diving for food. These include ducks, loons and grebes. In some instances, they are even attracted to oil slicks because in the area of the slick, the sea surface is calm and may appear to be a potentially good feeding area.

Marine birds are also at risk after an oil spill because they can ingest oil, either by preening (cleaning) their contaminated plumage or by eating oil-contaminated food. Ingested oil can have toxic effects and may lead to physiological damage (damage to the biological functions), histopathological damage (damage to the body tissues), reproductive impairment and death. The following table lists the potential biological effects of oil on marine birds. Some of these effects are caused by the actual toxicity of the oil itself and some are caused by the stress associated with being oiled.

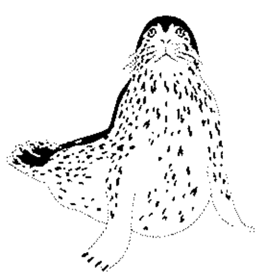


When an oil spill occurs, generally less than 5% of contaminated birds can be captured and only about 50% of those can be saved through cleaning. Cleaning is a tricky operation and could cost up to $30,000 per bird. Cleaning techniques require significant skills and the trauma of being handled heightens the oiled birds' already high degree of stress. Research is currently being conducted into the development of bird scarers to keep seabirds away from oil slicks. These devices, which can be thrown from a helicopter into a slick, emit a series of sudden, sharp sounds to continuously deter seabirds within an 800 meter radius of the scarer. It is equipped with a radio signal beacon for immediate location and pick up.

Effects on Eggs

Scientists observing oiled gulls in the wild noted that adults were able to clean themselves by preening their feathers but that the eggs they were incubating failed to hatch. This indicates that eggs are extremely sensitive to small amounts of oil and oiling at levels too low to cause mortality in adults may be sufficient to cause mortality in the embryos. Oil blocks the pores in the egg shell through which respiration takes place and the embryo is asphyxiated. Reproductive failure could therefore be very high if adult marine birds are oiled during the breeding season.

Effects on Pinnipeds



Pinnipeds are marine mammals which spend a great deal of time in the water and therefore could be exposed to oil in the course of swimming and foraging for food. Three families of Pinnipeds are common in Canadian waters, the Phocidae (earless or hairless seals), the Otaridae (sea lions and fur seals), and Odobidae (walruses).

Although dead Pinnipeds have occasionally been observed after marine oil spills, it has not yet been proven that the oil actually killed the animals. In laboratory studies, seals exposed to a 1 centimeter thick layer of crude oil in a holding pen died within 71 minutes. However, the test animals exhibited considerable stress associated with being held in captivity, and this may have intensified the effects of exposure to the oil. Seals may die then, if they contact oil during naturally stressful circumstances like poor feeding conditions, heavy ice, or moulting.

Marine oil spills could also affect the ability of female pinnipeds to recognize their pups. The young would then be abandoned and face ultimate starvation. Oil affects seals in other ways as well. Eye and nostril irritations have been observed and, if the oil spilled is viscous, the hide may be coated, and both locomotion and breathing will be adversely affected.

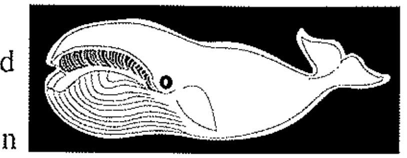
About 24 harp seals are known to have died of suffocation when nose and mouth openings were plugged with Bunker C oil after the "Arrow" oil spill in Chedabucto Bay, Nova Scotia.

Death does not usually result from such exposures and oil is gradually lost from the hide and body openings when the seals relocate to uncontaminated areas.

Oil covering the hide can also adversely affect the thermo-regulatory controls of exposed pinnipeds, particularly those that rely primarily on their fur for insulation. Fur seals have a waterproof fur coat that holds a layer of air against their skin for insulation. Oil contamination can result in matting and clumping of the fur, and a loss of waterproofing and buoyancy. The results could be chilling, hypothermia, exhaustion and death. On the other hand, walruses and earless seals rely on blubber for insulation and the contribution that the hide makes in keeping the animals warm is relatively small. They are therefore probably the least susceptible to this type of thermo-regulatory stress.

Oil spills can indirectly affect pinnipeds by displacing them from their habitats; by making them more susceptible to their predators; by reducing their food supply, and by disturbing their normal living habits.

Effects on Cetaceans



Cetaceans (whales, dolphins and porpoises) come to the surface for relatively limited periods of time to breathe and, in some cases, to feed. During these brief periods, however, they may be subject to some potentially damaging effects from exposure to oil on the water surface. Death of cetaceans has not been documented as a result of oil spills but whales trapped in oil-contaminated areas like enclosed bays may be killed and animals already stressed by disease or other health problems are more likely to be adversely affected.

Studies on gray whales have shown that they respond to surface oil slicks in several ways. They spend less time at the surface, blow less frequently and have faster blow rates. They exhibit altered swimming speeds in oiled areas, and occasionally will make radical changes in the direction of movement.

Oil may foul the baleen (the elastic, horny material forming the fringed plates that hang from the upper jaw of baleen whales and strain plankton from the water) and impair feeding, probably by causing structural changes to the baleen fibers. Oil exposure may also cause eye irritation, and respiratory stress could result from exposure to petroleum vapours if surface oil is contacted during the breathing cycle.

Effects on Commercial Fishing Activities

Oil slicks on the surface of the water are most problematic to boats and gear used to catch and/or cultivate marine species. Any floating equipment and fixed traps which extend above the sea surface are likely to be contaminated by a floating oil slick. If the equipment is used in the cultivation of marine species like mussels, then unless it is effectively cleaned, the equipment itself becomes a long term source of hydrocarbon contamination.

A very important indirect effect also arises as a result of the reluctance of some consumers to purchase seafood products harvested in an area of an oil spill. These economic consequences may be significant and long term.

Summary

- The most significant way that oil affects marine birds is through contamination of their feathers.
- Eggs of marine birds are adversely affected by oil. Oil blocks the pores in the egg shell through which respiration takes place, and the embryo is asphyxiated.
- Marine oil spills can affect the ability of female pinnipeds to recognize their young resulting in abandonment and starvation of the pups. Oil affects seals in other ways as well. These include coating of the hide and subsequent impairment of mobility.
- Oil may foul the baleen of whales and impair feeding. Oil exposure may also cause eye irritation and respiratory stress resulting from exposure

to petroleum vapours.

- Floating commercial fishing equipment and fixed traps extending above the sea surface are likely to become contaminated by a floating oil slick.

FATE OF OIL WITHIN THE WATER COLUMN

A large number of processes affect the fate of oil within the water column, the most significant being dissolution, chemical and biological conversion and sedimentation.

Dissolution

A floating oil slick can lose components through the formation of a dispersion of oil droplets and by actually dissolving in the water column. The rate at which oil dissolves in seawater is dependent on a number of factors including the composition of the oil, the extent of spreading, the water temperature, turbulence and the quantity of the surface oil that has physically dispersed into the water column. Since the hydrocarbons present in refined and crude oils are only slightly soluble in seawater, dissolution is not significant in terms of the mass of oil which can dissolve. The process is, however, exceedingly important from a biological perspective since it is the dissolved hydrocarbons that are the most acutely toxic to marine organisms.

Dissolution of hydrocarbons occurs from both the under surface of an oil slick and from oil which has been physically dispersed in the water column. The overall concentration of hydrocarbons in the water column is determined by the amount of soluble hydrocarbons in the spilled oil, the lighter hydrocarbons being the only ones with any appreciable solubility. The lighter hydrocarbons also evaporate more quickly, however, and since components are lost 10 to 1000 times faster by evaporation than by dissolution, the concentrations of dissolved hydrocarbons in the water column after an oil spill are relatively low.

After the spill of bunker oil (a heavy residual oil with few remaining light fractions) from the "Arrow", hydrocarbon concentrations in the water column ranged from 2 to 131 parts per billion. When crude oil (which contains a higher percentage of lighter fractions) was spilled from the "Amoco Cadiz" off the coast France, hydrocarbon concentrations in the water ranged from 26 to 330 parts per billion, and after the "Kurdistan" bunker oil spill off Nova Scotia, they ranged from 0.5 to 5 parts per billion.

Chemical and Biological Conversion

Chemical conversion of oil usually takes place at the air-sea interface through the oxidation reactions previously described in **Fate of Oil on Open Water** on page four. This process also has important implications relating to the fate of oil in the water column, since the products of these oxidation reactions are usually more water soluble than the parent oil, dissolving more readily into the water column where they are toxic to many pelagic (ocean dwelling) flora and fauna.

The biological conversion of oil by marine microorganisms such as bacteria, molds and yeasts is an important factor contributing to the disappearance of oil from the sea. Oil degradation by these microorganisms occurs within the water column, in sediments and on

the surface of particles.

Because a number of diverse factors affect the rate of biodegradation, it is difficult to predict either the quantity of oil that can be removed from the water column via this process, or the rate at which it can be removed.

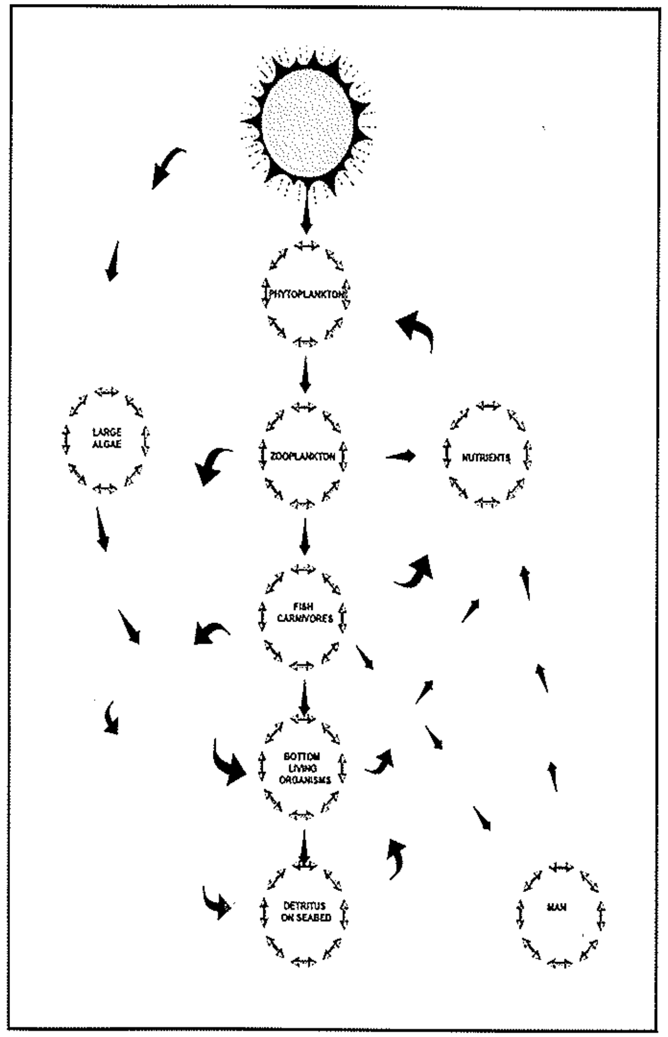
Sedimentation

The process of sedimentation can significantly affect the fate of oil in the water column, especially when there are sediments suspended in the water column. Dissolved hydrocarbons can be adsorbed onto the surface of suspended sediments and sink to the seafloor. Clays and other inorganic materials suspended in the water column have some adsorptive capacity but sediments with a high organic carbon content adsorb much more oil and contribute more significantly to the removal of oil via sedimentation.

Zooplankton (minute aquatic animals) may also assume a major role in the sedimentation of particulate oil in the water column, since they may take in oil during feeding. The oil then becomes incorporated into fecal pellets which fall to the seafloor.

ENVIRONMENTAL EFFECTS OF OIL IN THE WATER COLUMN

Oil in the water column can adversely affect phytoplankton (minute, free-floating aquatic plants), zooplankton and fish. As with all life, life in the sea depends upon sunlight for its source of energy. Through photosynthesis, marine plants, of which by far the most important are the phytoplankton, store this energy in a form which other animals like zooplankton and fish which prey upon them can use. In the sea, there is a very complex food web, simplified in the diagram following.



Effects on Phytoplankton

Phytoplankton are of tremendous importance because they are the organisms which initially fix the sun's energy and produce the biological matter on which all the other marine organisms ultimately depend. They are therefore key to the continued existence of the animals in the marine environment. When an oil spill at sea occurs, phytoplankton are the first organisms to ingest the oil. Because other marine organisms consume large quantities of phytoplankton in their diet, the potential for bioaccumulation of oil is great.

It has been speculated that oil spills could adversely affect phytoplankton in one of three ways:

1. they can block sunlight and cause a decrease in photosynthesis;

2. they can interfere with gaseous exchange at the sea surface and dissolved oxygen levels in the water column will decrease, and

3. they can exert toxic effects.

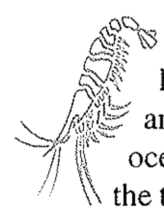
Experience gained from observations after actual oil spill events and laboratory simulations of such events shows, however, that none of these potential impacts is significant in the long term.

For example, experiments have shown that it would require a continuous 2,000 square mile slick of black oil to reduce photosynthesis in the North Sea by only about 1 per cent.

With respect to dissolved oxygen, measurements taken beneath heavy oil slicks show the oxygen saturation to be 98.5 per cent of that in waters outside the slick area. This would have a negligible effect on phytoplankton.

It is true that some components of spilled oils, mainly the low boiling point, water soluble components, are acutely toxic to phytoplankton. However, in considering the potential effects of marine oil spills on phytoplankton, it must be noted that the annual world phytoplankton production is about 150,000 million tons. By contrast, the annual losses of petroleum products to the marine environment vary from 2.5 million tons to a high of 10 million tons, and only a fraction of this petroleum is toxic to the phytoplankton. In offshore areas, the effects of marine oil spills will be local and transitory.

Effects on Zooplankton



Zooplankton represent the next higher level in the food chain. They are the major primary consumers in the ocean food web and could play a role in the transfer of hydrocarbon contamination to higher organisms like fish and mammals.

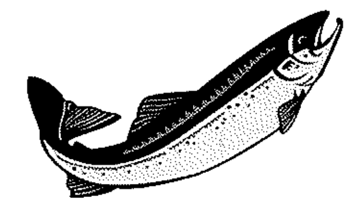
The zooplankton community is a highly diverse one and is made up of many different types of animals from unicellular protozoans to complex polychaetes (worms), molluscs and crustaceans. Fish eggs and larvae are also members of the zooplankton community.

As with the phytoplankton, hydrocarbons, especially low boiling point, water soluble ones, are acutely toxic to zooplankton. Numerous sub-lethal responses to oil have also been observed in zooplankton, ranging from reversible changes in some behaviours to depressed growth and reduced reproductive rates.

It is, however, highly unlikely that significant damage to zooplankton populations would result from marine oil spills. Any possible

adverse impacts would be short-term and would occur in localized areas. Affected populations would be expected to recover rapidly through immigration of new individuals from adjacent, unaffected areas.

Effects on Fish



Any adverse effects of marine oil spills on fish may be of ecological and economic concern. Fish are important predators and prey in the marine ecosystem and commercial fishing activities are a mainstay of many coastal communities. Man has already exerted a direct and measurable adverse influence on fish stocks and added stresses from oil pollution could be significant.

Spilled oil can exert toxic effects on fish and fish kills have been observed after major incidents, particularly when oil is spilled in bays or estuaries where the adult fish cannot avoid the oil.

Various sub-lethal effects have also been observed, some of which are minor, short-term and completely reversible, like increased respiration. Some are more long term and potentially dangerous, such as disruption of growth. Individual fish exposed to petroleum hydrocarbons have suffered liver, gill and renal damage, and muscle degeneration.

As previously noted, marine oil spills can produce harmful concentrations of hydrocarbons in a relatively small impact zone. Elevated concentrations of hydrocarbons can occur within the water column after a marine oil spill, but these tend to be very short-lived and the highest concentrations of hydrocarbons will be found near the surface and at the bottom. In these areas, juvenile fish and eggs can be adversely affected. Therefore, the eggs and larvae of fish like the Atlantic cod which are present at or near the sea surface for several weeks, and the groundfish species that feed at the bottom and rest near the seafloor, would be particularly vulnerable to marine oil spills.

Experience after major oil spills worldwide, however, suggests that these adverse effects are compensated for by recruitment from unaffected areas of the ocean.

One of the more significant adverse impacts of marine oil spills on fish relates to the fact that fish can ingest petroleum hydrocarbons from water, sediments and their food. These hydrocarbons accumulate in the tissue and may never reach levels that are any real danger to the fish, but may be high enough to affect organisms higher up the food chain which prey on the contaminated fish. Also, these hydrocarbons in the fish tissue can cause "tainting" (the presence of "kerosene like" or oily flavour) of the flesh, which would make the contaminated fish unsuitable for consumer marketing.

Summary

- Blockage of sunlight by spilled oil has no real ecological significance for phytoplankton in the open sea.
- In offshore areas, the effects of marine oil spills on phytoplankton will be local and transitory.
- It is highly unlikely that significant damage to zooplankton populations would result from marine oil

spills. Any possible adverse impacts would be short-term and would occur in localized areas.

- Spilled oil can exert toxic effects on fish, and fish kills have been observed after major incidents, particularly when oil is spilled in bays or estuaries where the adult fish cannot avoid the oil.
- Hydrocarbons in the fish tissue can cause "tainting" of the flesh, rendering the contaminated fish unsuitable for consumer marketing.
- Many of the adverse effects of oil spills on fish are compensated for by recruitment of fish from unaffected areas of the ocean.

FATE OF OIL IN BENTHIC ENVIRONMENTS

Oil may reach the seafloor in a number of different ways. Some oils are dense enough to sink immediately after being spilled and reach the bottom in a relatively fresh state. However, there are few oils with a specific gravity high enough to cause them to behave in this way, and the ones that do have very high molecular weights. They are also very resistant to the natural processes of dissolution and degradation and so, when they sink, they remain essentially unchanged on the seafloor. Their major impact is a result of physically smothering marine animals, plants and habitats.

Other spilled oils, some bunkers and crudes for example, will initially float and then, as the lighter components evaporate and dissolve, will get heavier and more viscous, and may sink.

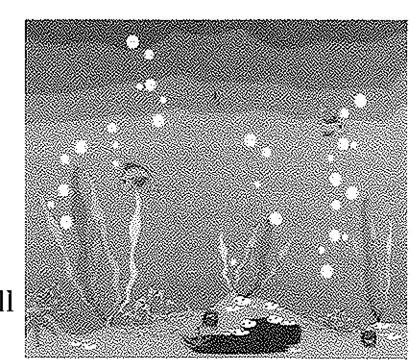
Some oil will be adsorbed onto particulates suspended in the water column and eventually sink, and oil dispersed in the water column which is ingested by zooplankton will also reach the sea bottom in these animals' feces.

The breakdown of oil which reaches the seafloor continues to occur mainly through the processes of dissolution of the water-soluble components, and microbial degradation, both aerobic (in the upper sediment layers) and anaerobic (in deeper layers where there is a lack of oxygen).

EFFECTS OF OIL IN BENTHIC ENVIRONMENTS

Oil which reaches the seafloor can have adverse impacts on a number of marine plants and animals, notably benthic algae, invertebrates, crustaceans (crabs, shrimp, lobsters) and echinoderms (sea cucumbers, sea urchins, star fish), microorganisms, demersal (bottom dwelling) fish and some marine mammals like the bearded seal which forage extensively on the bottom of the ocean.

Effects on Benthic Macro-Algae



In extreme cases, benthic macro-algae can be killed by marine oil spills. Laboratory studies have confirmed that high concentrations of hydrocarbons are toxic to some algae but in real spill situations, the death of

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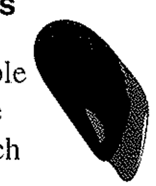
algae is more likely due to physical damage.

After a bunker fuel spill off Cape Flattery, Washington, observers reported that encrusting of oil on kelp fronds caused the death of the affected plants.

Even if kelp is not killed after coating by spilled oil, damage to the fronds can occur and the plant itself may be dislodged by the added weight of oil adhering to the fronds.

Photosynthesis in macro-algae is reduced when the plants are exposed to oil, and in intertidal areas, tumor-like growths, premature fruiting and impeded development of reproductive products have been observed.

Effect on Benthic Invertebrates



Benthic invertebrates most vulnerable to oil which reaches the seafloor are those relatively immobile ones which live in the sediments, mainly the bivalve molluscs and polychaetes (marine worms).

Since these organisms are essentially immobile, they are most susceptible to effects of oil in bottom sediments and can be killed when high concentrations of oil accumulate. The filter feeders, like some molluscs, are less susceptible to oil in the sediments but are much more vulnerable to oil in the water column.

Reduced growth rates have been observed on juvenile polychaetes and clams growing in oil contaminated sediments. In the long term, if oil exposure continues, bivalve molluscs exhibit reductions in shell growth, tissue weight, nutrient storage and gonad development.

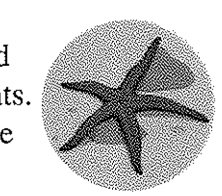
Oil in bottom sediments also causes benthic invertebrates to leave their burrows and respond more slowly than normal to physical stimuli making them more susceptible to predation.

Effects on Crustaceans and Echinoderms

Death of benthic crustaceans like crabs, shrimp and lobsters and benthic echinoderms like sea urchins and starfish has been observed after major oil spills like the Amoco Cadiz. The mortality is dependent upon the quantity of oil reaching the bottom, the dissolution of the hydrocarbons from the contaminated sediments, and the presence of high hydrocarbon concentrations in the near bottom waters.

Sub-lethal effects including premature release of eggs, reduced mating and reduced brood size have also been observed in laboratory studies on crustaceans exposed to oil. The success and timing of moulting in crustaceans has also been adversely affected by oil exposure.

In oil contaminated water, benthic echinoderms have been observed to retract their tube feet, which can result in loss of adherence to the substrate.



Most crustaceans and echinoderms are mobile and may be able to emigrate from oil contaminated areas to uncontaminated habitats. The long term impact of marine oil spills on these animals is therefore expected to be low.

Effects on Microorganisms

Marine microorganisms, mainly bacteria and fungi, are affected by and also can have a significant effect on oil in benthic sediments and in the water near the bottom. Some oil-degrading bacteria are found in all marine environments, with larger populations documented near natural oil seepages in the seafloor and near areas of chronic oil discharges from land based industries. Some marine fungi have also been shown to degrade oil.

Obviously, exposure to oil will stimulate the growth of oil degrading microorganisms since this is a major food source for them. The slow but ongoing degradation of oil by these organisms is one reason why levels of petroleum hydrocarbons don't increase in ocean sediments, despite continuing inputs.

Summary

- In extreme cases, benthic macro-algae can be killed by marine oil spills.
- Oil in bottom sediments causes benthic invertebrates to leave their burrows and respond more slowly than normal to physical stimuli, making them more susceptible to predation.
- The long term impact of marine oil spills on most crustaceans and echinoderms is expected to be low since they are mobile and may be able to emigrate from oil contaminated areas to uncontaminated habitats.
- Exposure to oil will stimulate the growth of oil-degrading microorganisms.

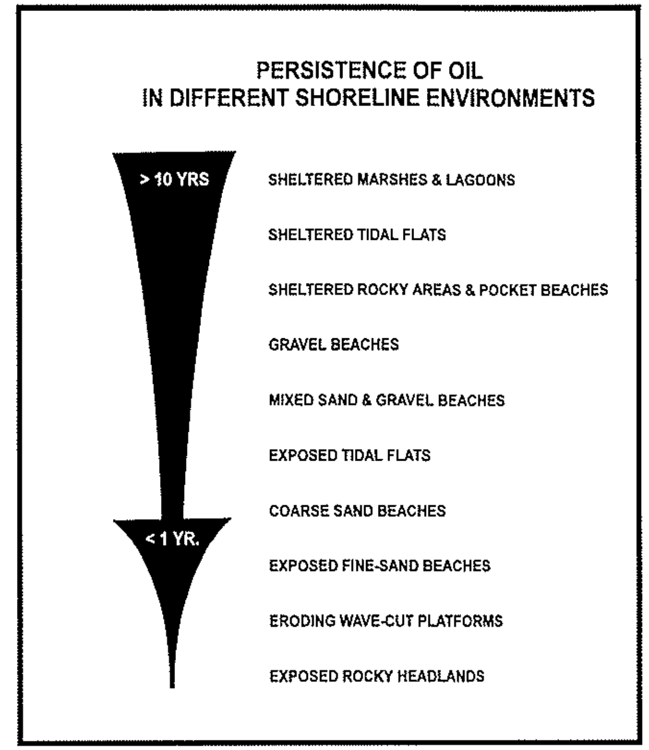
FATE OF OIL ON SHORELINES

The amount of oil spilled at sea which reaches shorelines is affected by the season of the year when the spill occurs; the type and volume of oil spilled; the degree of weathering; the nature of the shoreline; the weather, and the oil recovery methods used in the marine environment.

Fresh oil which is deposited on shorelines weathers rapidly, mainly through evaporation and dissolution, and up to 40 percent of the oil mass may disappear within the first few days after a spill. The remaining, viscous oil resists further weathering.

Movement of beach sediments by wave action and ice movement can bury stranded oil or even transport the oil up the beach into the upper intertidal zone. Oil buried in intertidal sediments resists further weathering and oil stranded in the upper intertidal zone may harden and form an asphalt-like mass that persists for a very long time.

Oil that comes to shore on exposed, high-energy shorelines (those where there is significant wave action) is rapidly removed, often within a single season. Oil persists longest in salt marshes and sheltered intertidal areas with sandy substrates and for the shortest times in rocky habitats, as is shown in the following table.



EFFECTS OF OIL ON SHORELINES

Depending on the type of shoreline, the effects of oil can range from devastating to insignificant, in both ecological and economic terms. The arrival of oil in inshore waters and on beaches can have obvious detrimental effects on recreation, sports and other amenities, with resulting adverse economic impacts on tourism.

Industrial facilities can also be negatively affected, especially those which depend on the intake of clean seawater.

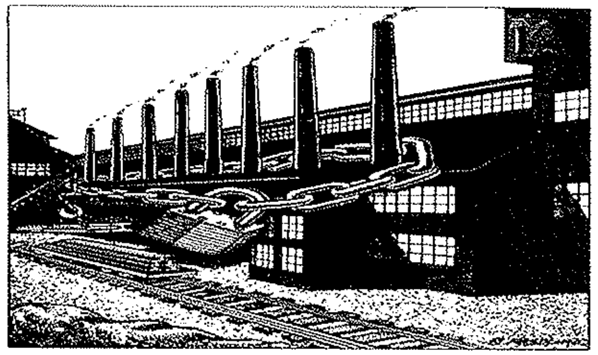
The biological effects on shorelines are also of grave concern, especially in sensitive areas like salt marshes, which are highly productive areas and serve as the breeding ground for many marine species. Intertidal marsh grasses and algae can be damaged and intertidal invertebrates may be exposed to oil contamination. Marine mammals which are normally associated with the shoreline but which spend a lot of time in estuarine waters like sea otters, river otters and lemmings, can also be adversely affected by oil which reaches the shoreline, as can shorebirds and wading birds.

Effects on Coastal Amenities

Contaminated shorelines are one of the most visible and arguably one of the worst consequences of marine oil spills. Spilled oil which comes ashore covers rocks, sand, plants and animals. Weathered lumps of tar can also be stranded on beaches, adding to the overall contamination and the obvious negative impacts on sport and recreation. The impacts are usually not long term, and are of most concern in areas of high tourist trade, during the tourist season.

Effects on Coastal Industries

Power stations, oil refineries, pulp and paper mills and other industries use large amounts of clean water for cooling purposes. In coastal areas, these industries normally use seawater for cooling purposes making them particularly vulnerable to spilled oil in the vicinity of their water intakes. When oil is drawn into industrial cooling water systems, contamination of the pipes, pumps and other infrastructure can be very damaging. In severe cases, the industry has to shut down while the cooling water system is cleaned. The shut down of a power plant could have serious implications for a coastal community.



Other coastal industries such as ship repair facilities, marine transport and ferry companies, desalination plants (which produce fresh drinking water from seawater) all can have their operations interrupted by marine oil spills which reach the shore.

Of major concern, however, is the effect of oil spills on commercial aquaculture operations, especially since the practice of holding fish in subsurface cages and other enclosures for extended time periods prior to marketing is gaining popularity. Also, the cultivation of seaweed, fish, crustaceans and molluscs frequently involves the use of onshore tanks to rear the young to marketable size, or to a size and age suitable for transfer to the sea. Such facilities are usually supplied with clean seawater drawn from the nearshore zone and could be adversely affected by an oil spill approaching the shoreline. The young stages of these marine plants and animals are usually more susceptible to oil pollution damage.

Effects on Algae and Marsh Grasses

Oil kills intertidal algae and marsh grasses in a number of different ways, including coating and suffocation of plants, direct poisoning, and dislodging of plants due to the added weight of stranded oil. After oil spills have been stranded in intertidal communities, reduced growth and reproduction of marsh grasses has been observed. The magnitude of these effects and the recovery rate of the plant communities is influenced by the season, the extent and duration of the oil exposure, and the sensitivity of the various species to the particular hydrocarbons. The plants are also adversely affected by the loss of that part of their habitat which is oil covered. In most cases, the degree and duration of the loss of intertidal habitat is a function of the persistence of the oil and the weathering processes. In general, plants in low wave energy environments in the upper intertidal zone will be more affected than those in high energy areas where the oil may be more rapidly removed. In addition, oil remaining in marshy sediments will impede new growth.

Effects on Intertidal Invertebrates

The intertidal zone teems with animal life, both relatively immobile types like barnacles, mussels, and periwinkles, and more mobile species like snails, limpets and tube worms. Following an oil spill, the most common cause of death among most of these intertidal animals is smothering by layers of stranded oil, which interferes with feeding, respiration and attachment to the substrate.

Sub-lethal effects of oil exposure on these types of animals have also been observed and range from lower body weight to reduced reproductive ability.

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In general, intertidal habitats are exceedingly vulnerable to oil exposure and their recovery potential is heavily influenced by the persistence of the oil. In exposed, rocky habitats where oil is rapidly dispersed, the invertebrate communities recover very quickly. In low energy areas where oil persists, recovery is much slower.

Effects on Marine Mammals

Some marine mammals are particularly vulnerable to oil spills which impinge on the shore. These are animals which spend a great deal of time on the shorelines and in nearshore waters, such as otters, lemmings, and, in the north, polar bears.

Fortunately, death of these animals due to oil pollution is relatively rare, but a range of adverse effects mainly associated with ingestion of oil during grooming of contaminated fur has been documented. These effects include neurological disorders, anemia, induction of tumorous growths, and increased frequency of disease and parasites. All these animals are mobile species and can, and do, avoid contaminated areas. The long term impacts of oil spills on these animal populations is therefore relatively low, although exposed individuals may be threatened.

Effects on Shorebirds and Wading Birds

Shorebirds (plovers, sandpipers) and wading birds (herons, bitterns) may be adversely affected by oil contamination of shorelines. The birds themselves could be oiled, and oil may then be ingested during preening. Oil can be transferred to eggs during nesting, and oiled birds are generally incapable of long flights. Adverse impacts on shorebirds and wading birds could result if an oil spill occured when large numbers of the birds are migrating through an area like the mud flats at the head of the Bay of Fundy, for example.

Summary

- The deposition of oil on beaches can have significant adverse effects on recreation, sports and other amenities, with resulting adverse economic impacts on tourism.
- Power stations, oil refineries, pulp and paper mills and other industries which use seawater for cooling purposes are particularly vulnerable to oil contamination of the pipes, pumps and other process infrastructure.
- The adverse effects of oil spills on commercial aquaculture operations include fouling of gear, tainting of seafood and the death of some fish and/or shellfish.
- Intertidal algae and marsh grasses are subject to a range of negative impacts: coating and suffocation of plants; direct toxic effects; dislodging of plants, and damage or removal during shoreline clean-up activities.
- Oil on shorelines smothers intertidal animals and thus

interfering with their feeding, respiration and attachment to the substrate.

- The long term impacts of oil spills on otter and lemming populations is relatively low, although individuals exposed may be threatened.
- Populations of shorebirds and wading birds have not been shown to suffer long term damage as a result of oil spills.

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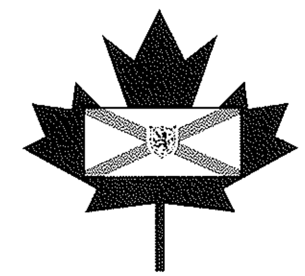

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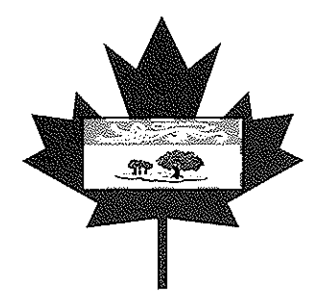

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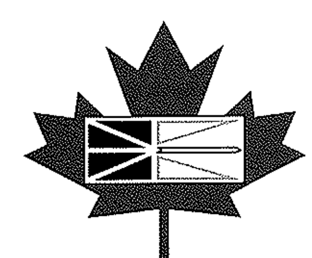

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