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for the Control and Reduction of Pollution

IMPACT REFERENCE SYSTEM

Effects of Oil in the Marine Environment:
Impact of Hydrocarbons on Fauna and Flora

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Impact Reference System - Effects of Oil in the Marine Environment: Impact of Hydrocarbons on Fauna and Flora

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INTRODUCTION

Background

Annex II of Decision 86/85/EEC of the Council of the European Union called for the establishment of a compendium bringing together, inter alia, "existing information on the impact of hydrocarbons on marine fauna and flora". This is implemented by the Impact Reference System (I.R.S.) which forms an integral part of the Community Information System (C.I.S.). The I.R.S. presents the information requested by the Council Decision in the form of a set of impact reference cards (fiches). This form of presentation was considered to be more appropriate and useful than a detailed and lengthy compendium which would have duplicated existing published literature.

Purpose

The purpose of the Impact Reference System (I.R.S.) is to enable the responsible authorities to assess quickly and with reasonable accuracy an oil spill event in terms of its actual or potential damage to marine life and biological resources. Better assessment and prediction of oil spill impacts, and of the effects of counter-measures, should help to improve decision-making generally, make more effective use of resources, and achieve clean-up with minimal environmental or ecological damage or disruption.

Scope

The impact reference data assembled and presented in the I.R.S. covers the biological effects of hydrocarbons on marine and estuarine organisms. The information is presented so that it can be used by non-biologists in oil spill emergency situations in order to evaluate spill impacts. The I.R.S. does not provide guidance on counter-measures, nor does it contain information on local oceanography, geography of the area impacted or threatened, nature and composition of the threatened environments, economic value, political or social priorities, effectiveness of the proposed actions and their adverse environmental effects. Such additional information is essential in order to achieve successful and efficient protection of threatened areas, recovery of spilled oil, and clean up of contaminated habitats, and the I.R.S. is therefore intended to be used in conjunction with other sources of information and data.

USING THE IMPACT REFERENCE SYSTEM

The table of contents and index provide an entry to the system. Each of the reference cards (fiches) listed can be used as a source of data and/or information on the impact occurring or expected.

- The first four fiches (**G1 to G4**) deal with **General** issues and provide background information on:
  - types of hydrocarbons and their properties;
  - the mechanisms and pathways by which oil affects marine life;
  - the factors which affect the severity of the impact; and
  - guidelines on the ecological sensitivity of a range of marine and coastal environments.

- The next group of thirteen fiches (**E1 to E13**) provide brief notes on the most frequently encountered **Environments** or ecosystems, their principal characteristics, ecological and/or economic importance, and sensitivity to oil pollution damage.

- The impact of hydrocarbon spills on the exploitation of biological **Resources** is covered by the third group of four fiches (**R1 to R4**). The resources include:
  - wild-stock fisheries;
  - marine and estuarine aquaculture;
  - seaweed harvesting;
  - coastal agriculture.

- The final group – consisting of five fiches (**T1 to T5**) – provides further information on the impact of hydrocarbons on specific **Taxa** or groups of related organisms, with emphasis on species which are mobile and/or of economic or ecological importance.

In a spill emergency, it is recommended that the first four fiches should be consulted in addition to the relevant ecosystems, resources and taxonomic group fiches. These general fiches provide information basic to the understanding of oil spill impacts, and may be used to assist or develop the ability to evaluate changing circumstances arising during the emergency or after it.

For more thorough assessment or prediction of the ecological impacts of oil spillages, the use of both local information and an oil spill model is advisable. The Impact Reference System has therefore been designed to interface with or be used as an input to models of spill behaviour and fate. Systems combining both local information and a spill behaviour model in a single package will provide an opportunity for integrating the three elements.

TYPES OF HYDROCARBONS

Crude oil and refined petroleum products are not specific chemical substances – they are mixtures of hydrocarbons and other compounds with widely differing physical and chemical properties which determine their behaviour and fate when spilled as well as their impact on marine life and biological resources. The classification proposed here is generalised, emphasising those characteristics which have the greatest effect on living organisms. The intention is to bring the multiplicity of oil types into a small number of usable categories; each category includes therefore a range of crude oil and product types.

In referring to impact throughout the remainder of the Impact Reference System, the following categories will be used:

I **Light volatile oils:** mostly light products such as petroleum spirit, gasoline, kerosine or paraffin, automotive diesel.

II **Moderate to heavy oils:** most crudes and intermediate products such as marine diesel, gas oil, light fuel oil, light lubricating oil.

III **Heavy oils:** very waxy crudes, water-in-oil emulsion (chocolate mousse), heavy lubricating oil.

IV **Residual oils:** bunker and heavy fuel oils, weathered crude in the form of tarry lumps, asphalt.

Oil entering the marine environment will not generally remain in the same category throughout the duration of an incident. In changing its state, e.g. by evaporation or weathering, a light crude (type II) will lose its most volatile components and may also form a mousse; and either of these changes will bring it into type III.

TABLE G.1.1. **Classification of oils based on general properties which influence their ecological impact.**

Type of oil	Volatility	Solubility in water	Natural dispersion	Response to dispersants	Stickiness	Biological harmfulness
I Light volatile	High	High	Easily disperses	Responds very well	Not sticky	Highly toxic
II Moderate -heavy	Up to 50% can evaporate	Moderate	Some components disperse	Responds early on	Slightly to moderately sticky	Variable toxicity
III Heavy oils	<20% can evaporate	Low	Little dispersion	With difficulty	Very sticky	Smothering, clogging
IV Residual	Non-Volatile	Very low	No dispersion	Not at all	Very sticky to solid	Smothering, low toxicity

TABLE G.1.2. **PHYSICAL, CHEMICAL AND TOXICOLOGICAL PROPERTIES OF OILS**

I Light volatile oils

Very toxic to biota when fresh, but toxicity will decrease quickly because of evaporation.

Physical/chemical properties:
- Low viscosity, will spread rapidly.
- High rates of evaporation.
- Relatively high solubility in water.
- Will rapidly penetrate most substrates.

Toxicological properties:
- Acute toxicity related to the content and concentration of aromatic fractions (high toxicity correlated with presence of naphthalene and benzene compounds).
- Heavy molecular weight compounds are immediately less toxic, but may be chronically toxic since many of these are either known or potential carcinogens.
- Acute toxicity will vary among species due to differences in the rates of uptake and release of aromatic fractions.
- Penetration and persistence of aromatic compounds in sediments may cause long-term damage to salt marsh plants, mangroves etc.

II Moderate to heavy

Variable toxicity depending on aromatic content.

Physical/chemical properties:
- Low to moderate viscosity.
- Tend to form stable emulsions under high physical energy conditions.
- Will penetrate substrates to a degree determined primarily by substrate grading size.
- Light fractions may contaminate interstitial water.
- Under warm weather conditions or in a tropical climate, rapid evaporation of volatiles and solution of water-soluble fractions will give rise to a less toxic weathered residue.
- Potential for sinking after weathering, particularly in a silt-laden environment.

Toxicological Properties:
- Acute and chronic toxicity to marine organisms likely to result from a mixture of mechanical/physical coverage (smothering), chemical toxicity (exposure to very toxic aromatic fractions), and/or a combination of both these effects.
- Acute toxicity will decrease with time and weathering as the volatile fractions evaporate.

III Heavy

Relatively low toxicity.

Physical/Chemical properties:
- High viscosity, limited spreading.
- When weathered will form tarry lumps at ambient temperatures, but these may soften and flow when exposed to the sun.

Toxicological properties:
- Acute and chronic toxicity occurs more from smothering effects than from chemical toxicity, due to the small proportion of toxic aromatic fractions in heavy oils.
- Marine plants (especially mangroves) and sedentary organisms are more likely to be affected than mobile organisms.
- Damage may also result from thermal stress caused by elevated temperatures in oiled habitats, particularly in warm water areas.

IV Residual

Relatively non-toxic.

Physical/Chemical properties:
- Semi-solid, non-spreading.
- Will form tarry lumps at ambient temperatures, but these may soften and flow when heated.

Toxicological properties:
- Very small amount of toxic aromatic fractions.
- Low toxicity in most environments.
- Toxicity becomes a problem only when the oil is trapped for long periods in sensitive environments such as salt marshes or mangroves.

HOW OIL AFFECTS MARINE

Oil affects living animals and plants both directly and indirectly, as individuals and as members of communities of organisms inhabiting a particular environment and interacting with the environment and with each other. The resulting impacts are complex and variable, and their severity will depend on a variety of factors. These factors are discussed in ***Fiche 3****; here we examine briefly the mechanisms by which hydrocarbons exert their impacts on marine organisms.*

The *direct effects* **of oil on living marine organisms result from:**

1. Lethal toxicity (immediate or delayed).
2. Sublethal effects.
3. Physical interference with locomotion, feeding or other behaviour (clogging).
4. Direct coating or smothering, causing asphyxia or, under certain conditions, heat stress.
5. Tainting or accumulation of hydrocarbons.

Indirect effects **take place through alterations in the function and structure of biological communities. Mechanisms for this include:**

1. *Starvation* of organisms following selective elimination by oil of species or functional groups of organisms which they use as *food*.
2. Unchecked *proliferation* of organisms following selective elimination by oil of species which feed on them (their *predators*).
3. *Disruption of certain species interaction* in the community following elimination or weakening of *key species* which control or dominate these interactions.
4. *Modification of the habitat* following cleanup actions such as substrate alteration or removal.

Although the direct effects of oil vary from species to species within a particular taxonomic group, it is recognized that some groups are more sensitive than others. Also, early stages of development may be affected by processes which leave the adults unharmed. *A quick guide to the sensitivity of taxonomic groups* to the direct action of oil is presented in **Table G2**. See also the discussion of population sensitivity in **Fiche G4**.

DIRECT EFFECTS

Lethal toxicity

Lethal toxicity results in the immediate or delayed death of the organism, and is caused by exposure to or ingestion of toxic components such as soluble aromatic hydrocarbons and some heterocyclic compounds. These are usually volatile and will evaporate readily, causing a reduction in toxicity the longer the oil remains exposed to the atmosphere.

Immediate or acute toxicity is caused by the disruption of the organism's basic functioning, and leads to rapid mortality. *Delayed toxicity* occurs when the organism's ability to survive is diminished, i.e., there is a reduction in the organism's resistence to environmental stresses and/or biological aggression, e.g. disease, parasites, predation. Following an oil or chemical spill, marine organisms may appear to be dying as a result of disease or parasitism, but the underlying cause could be a decrease in their resistance to the pathogen.

Delayed toxicity may also occur through the food chain or web, the organism accumulating a burden of toxic hydrocarbons over a period of time as a result of ingesting contaminated food. If transferred to an uncontaminated environment, the organisms will generally detoxify or excrete the contaminant.

Sublethal effects

Sublethal effects are those which diminish the ability of a population to maintain itself, e.g. because of a reduction in fecundity, disruption of communication between individuals or between the individual and the environment, reduced growth, physiological or behavioural alterations leading to a lowering of resistance to stress at the population level, reduction in ability to find or consume food, delays in egg-laying or hatching, etc.

Physical interference with locomotion, feeding or other behaviour

Dispersed particles of oil in water can result in the clogging of filter- feeding organs, gills, spines, etc. If filter-feeding mechanisms are affected, the animal will be unable to obtain its food and may also ingest enough oil to cause a toxic effect. If gills are affected, the organism will be unable to obtain oxygen, and water-soluble hydrocarbons may enter the blood stream. Generally such conditions arise only when there are heavy concentrations of naturally or chemically dispersed oil in the water.

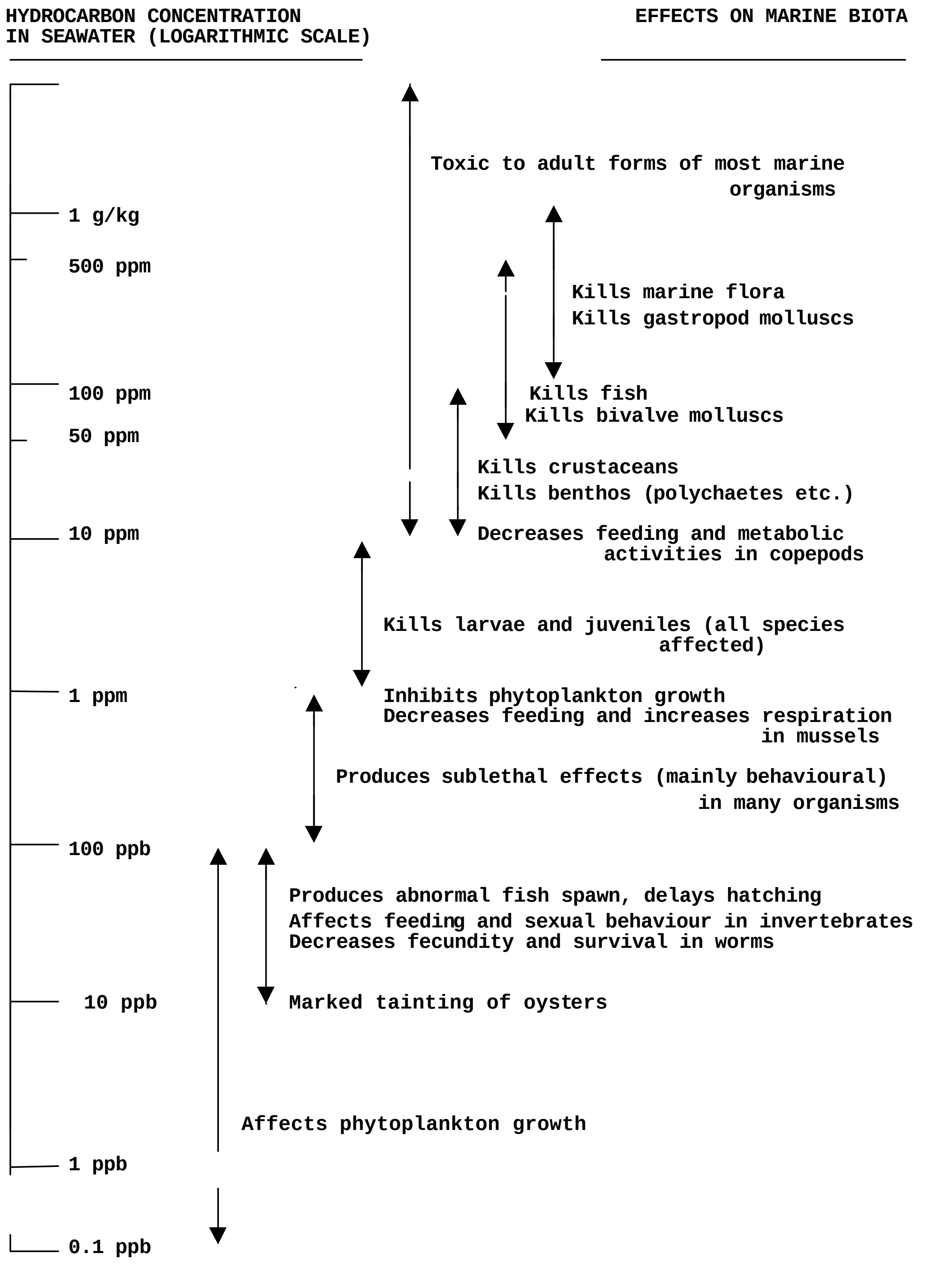
Smothering or direct coating

Birds, salt marsh plants, certain rocky shore biota, and marine mammals can become coated with oil especially following a large spill of heavy oil. Light oils will rarely adhere sufficiently to cause smothering. If the substrate is dry, adhesion is increased. Materials which are naturally oily, such as the feathers of seabirds, will readily attract oil.

Tainting or accumulation of hydrocarbons

The incorporation of minute amounts of hydrocarbons in the tissues of living marine organisms can affect predators which eat the contaminated organisms. The predators may ingest sufficient amounts of oil to cause toxic symptoms or, in the case of man, an unpleasant or unacceptable taste may be perceived in the fish or shellfish being eaten. Such a taste, alien to the normal taste of the food, is referred to as tainting. If present, it may cause economic losses (see **Fiche R2**).

TABLE G2. General sensitivity of marine organisms to concentrations of crude-oil hydrocarbons in water. The duration of exposure will determine the extent to which the effects are observed. The soluble aromatic derivative fraction of oils (SAD) being the primary cause of mortality, effects in the ppm range are estimated assuming an oil with a 10% SAD fraction (adapted from Hyland & Schneider, 1976).



Warning: in considering the above table one should be aware that the impact of an oil pollution depends on many more elements than the simple direct effects (modifying factors, environmental vulnerability and community interactions for example). See "Indirect Effects" below, and also **Fiches G3** and **G4**.

INDIRECT EFFECTS

Indirect effects on organisms through the disruption of communities and ecosystems

Marine plants and animals do not live in isolation from each other; they develop enmeshed in a wide variety of biological interactions. These range from predator-prey relationships to situations in which one key organism or group of organisms will provide a habitat or other necessity for the survival of other species in the community.

Initial damage by oil to individual organisms therefore leads in nearly all cases to alterations in biological community structure and functioning. The mechanisms for this have been listed above. These community/ecosystem effects, which are rarely permanent but may take years to disappear, are discussed in **Fiche G4**.

Members of all groups of organisms – algae, microbes, invertebrates, fish, mammals and birds – may be impacted by an oil spill. Molluscs (**Fiche T5**) are especially susceptible to bioaccumulation of hydrocarbons, while some crustaceans (**Fiche T6**) and fish (**Fiche T3**) can metabolise petroleum contaminants.

NOTE: *Natural variability*

The marine environment should not be regarded as a static, immutable system. Great annual variations due to purely natural factors such as climatic/seasonal changes occur in the sea. Some organisms have populations whose numbers fluctuate naturally. The young of many marine species are subject to an enormous natural mortality. In assessing the long-term impact of a man-induced disruption, these basic attributes of nature must be taken into account.

In general the recovery potential of species which are long-lived and slowly maturing (e.g. birds, corals) or have a low reproductive rate (e.g. mammals) will be less than that of species which are short-lived and rapidly maturing (e.g. the plankton) or have a high reproductive rate (e.g. pelagic fish). Direct and indirect pollution effects involving the former category are likely to cause a more lasting impact than those involving the latter.

FACTORS AFFECTING IMPACT

A variety of factors modify the impact of hydrocarbons on marine flora and fauna, and some understanding of these is essential in order to interpret the generalized impact data which is contained in the "E" series of ecosystem impact reference cards. These factors can be considered as variables with defined ranges or with assumed or known probabilities of occurrence, and can be included in a model as an aid to decision-making.

Eighteen factors are discussed briefly in this Fiche. They are divided into three groups:

(1) **Event descriptors – circumstances of the spill** (quantity of oil spilled; type of oil spilled; location of the spill; type of spill event: catastrophic sudden release or slow leak/seepage).

(2) **Factors modifying spill behaviour** (weather conditions at time of spill and afterwards; tides and currents; oceanographic factors; spill response measures).

(3) **Factors directly modifying the impact of the oil on marine organisms** (seasonal factors; duration of exposure; physical form or state of the oil; concentration of hydrocarbons in water and sediments; degree of contamination of organisms and substrate; presence of other pollutants; prior exposure to oil; post spill environmental stresses).

NOTE 1:
Type of coast

The type of coast will have a major influence on the **degree of biological damage** caused by the spill. Coastal types vary in their sensitivity to oil pollution, this being determined by:

* the extent to which the oil can penetrate the substrate or beach/coast material;
* the amount of natural wave energy available to disperse the oil
* the length of time for which the oil will be likely to persist or remain on the shore;
* the difficulty of mounting a clean-up operation and of removing the oil by manual or mechanical means;
* the presence of sensitive populations or communities of plants or sessile animals on the shore or in the immediate sub-littoral.

In **Fiche G4** seven types of coast together with the general environment of estuaries, the offshore sea bed and open coastal waters are ranked according to their sensitivity. Each of these ecosystems is described in **Fiches E1** to **E10**.

NOTE 2:
Beneficial uses

Socio-economic impacts of a spill will be determined to a major extent *bythe variety and intensity of beneficial uses* of the coastline or nearshore water impacted by the oil. Where biological resources are damaged or affected, the impact of the spill will be perceived as particularly serious, especially where the local economy is wholly or partially dependent on their exploitation. Even if the resource itself is not directly affected, its economic value is liable to be impaired and it may not be possible to harvest or exploit it for some time as a consequence of the presence of the oil (see **Fiches R1** to **R4**).

1. EVENT DESCRIPTORS

1.1 Quantity of oil spilled

The quantity of oil spilled will determine to a significant extent, but not entirely, the severity of the impact sustained by the marine environment. Small spills of, e.g. fuel oil in a sensitive or vulnerable location (see **Fiche G4**) have caused more ecological damage than much larger spills of crude oil in the open sea. Even a relatively minor amount of oil leaking into a sensitive environment could cause major damage.

1.2. Type of oil spilled

Fiche G1 provides four categories of oil types in order of decreasing toxicity. Toxicity alone does not however determine the type or severity of biological damage: heavy sticky oils, with comparatively low toxicity, have the potential to cause considerable mortality of seabirds, especially if spilled near seabird colonies in the breeding season or on their feeding grounds. In general, light and medium refined oils are more toxic; while the heavier oils exert their impact through physical effects.

1.3. Type of spill event: catastrophic sudden release or slow leak/ seepage

The sudden catastrophic event is likely to cause mass mortality of marine plants and animals in the short term and in the immediate vicinity, but recovery will generally take place more rapidly than if the oil was seeping, e.g. from a wreck or from deposits in intertidal or subtidal sediments where it had accumulated following a spill. Chronic oil pollution from land-based sources such as industrial or municipal outfalls also leads to long-term damage and slow recovery rates.

1.4. Location of spill

Certain environments and habitats are much more vulnerable than others, as a result of the nature of the environment or because they support populations or communities of organisms which are particularly sensitive to oil (see **Fiche G4**). A spill located near to such a vulnerable area has therefore a greater potential for causing biological damage. If separated by distance from a vulnerable site, the spill will take longer to reach it, and during this time a proportion of the more volatile and toxic components will be lost to the atmosphere and the volume of the oil will be reduced, thus decreasing the severity of the impact. There will also be more time to make response preparations.

2. FACTORS MODIFYING SPILL BEHAVIOUR

2.1. Weather conditions at time of spill and afterwards

Air temperature and solar radiation will affect the viscosity and the spreading rate of the oil. Wind direction and strength will influence the direction and rate of travel of the slick, and will also determine the sea state which will affect the degree to which the oil may become naturally dispersed, fragmented and/or emulsified. In general, the more energy– wind, wave and solar – present, the faster the oil will become dispersed and volatilised.

Storms and onshore high winds will carry oil to higher levels of the shore from which natural processes will remove it only with difficulty and after a long period of time during which sensitive lichens can become damaged or destroyed.

2.2. Tides and currents

Horizontal water movements (residual or tidal currents) will influence the direction and rate of travel of the oil slick, while the vertical range of the tide (spring or neap tide) will expose a greater or lesser amount of the shoreline to the oil. During spring tides, oil may be carried to the upper levels of the shore, to become deposited in areas where it will remain for a long period of time, causing damage to upper shore flora and fauna. Similarly, at low water spring tides the flora and fauna of the lower intertidal zone or sublittoral fringe will be exposed to oil coming ashore at that time. The potential for biological damage is therefore greater during a period of spring tides than during neaps.

2.3. Oceanographic factors

These include wave heights and direction, ocean swell if present, water temperature, salinity and suspended particulate matter. The amount of wave energy available at the time of the spill, i.e. the sea state (see factor 2.1 above), will significantly influence the rate at which the oil becomes fragmented, dispersed and eventually degraded biologically. But water-in-oil emulsions may also form under wave action and retard those dispersion processes. Over a longer time period, the extent to which the shore is exposed to wave action will influence the rate at which the oil becomes effectively removed from the intertidal zone by natural means.

Higher water temperatures will generally speed up the rate of microbial degradation of spilled oil. Under Arctic or very cold conditions the rate reduces to near zero. The salinity of seawater increases its density over that of fresh water, allowing slicks to remain buoyant as their density increases by evaporation of the lighter fractions. In silt-laden water however, as when the quantity of suspended particulates rises during or following a storm, silt particles will adhere to patches of heavy oil (III) or to lumps of residual oil (IV), and will increase the rate at which the oil sinks to the sea bed.

2.4. Spill response measures

Well-chosen or appropriate spill response measures will lessen impact and biological damage, while inappropriate measures will increase the damage caused by a spill. The choice of shoreline protection, oil recovery, dispersion and cleanup methods and procedures is therefore extremely important; whenever possible, methods having the least ecological impact should be selected.

3. FACTORS DIRECTLY MODIFYING ECOLOGICAL IMPACT

3.1. Seasonal factors

The potential of an oil spill to cause biological damage, i.e. its ecological impact, is significantly affected by seasonal factors. Many species of marine organisms are more sensitive to oil pollution during their breeding or spawning periods, and eggs or larvae are generally more sensitive than adults. Seabirds gather in certain locations during the nesting season, and their high concentrations make them especially vulnerable to even a relatively small spillage during that time. Bird migration patterns will also influence the numbers of birds present, especially in salt marshes and on mud flats where migratory species roost and feed. Fish eggs and larvae will also be present on the breeding grounds only during certain relatively short periods.

3.2. Duration of Exposure

At low levels of pollution, when sublethal and cumulative effects become important, the longer organisms or communities are exposed to oil pollution, the greater will be the overall mortality. The continuing presence of oil will also inhibit recolonization by plants or animals from neighbouring shores, and will delay recovery of the impacted ecosystem.

3.3. Physical form or state of the oil

If the oil remains in the form of a slick at sea, its principal impact will be on seabirds and on organisms floating on or just below the sea surface. If the slick encounters a shoreline, its primary impact will be on the intertidal organisms at the level on which it comes ashore. As the oil becomes fragmented and dispersed, the zone of impact will extend into the water column where small droplets are likely to be taken up by filter-feeding organisms.

If a water-in-oil emulsion ("chocolate mousse") is formed the total volume of pollutant may increase by up to four times; it is also more sticky and viscous than the oil from which it was formed, and taking longer to break down it will exert an impact in the marine environment over a longer time period.

In shallow water, some of the oil is more likely to sink because of the presence of particulate matter, and this will have the effect of transferring some of the impact to biological communities on the sea bed. If the oil subsequently becomes incorporated in seabed sediments, its principal impact will be on burrowing organisms.

The water-soluble fraction present in all crude oils and in some refined products is generally toxic, and its impact will be experienced mainly in semi-enclosed or confined areas of the sea where adequate dilution is not available.

3.4. Concentration of hydrocarbons in water and sediment

The actual concentration of hydrocarbons as a dispersion, in the form of droplets, or as a water-soluble fraction in water or sediment will significantly influence the degree of mortality. There is a close relationship between the concentration of hydrocarbons and the survival time of living organisms exposed to such concentrations (see **Table G2**). Extensive concentrations of hydrocarbons in water above 1 ppm are reached in only a minority of spill situations but have occurred in semi-enclosed areas such as bays or tidal inlets. In locations subject to chronic pollution, concentrations of hydrocarbons in sediments can reach values higher than those in Table G2.

3.5. Degree of contamination of organisms and substrate

In addition to the concentration of hydrocarbons in water or sediment, the organisms themselves or the substrate on which they move or feed, e.g. the surfaces of rock, seaweed or sand grains, may become contaminated. The degree of contamination will determine the extent to which the organisms are prevented or inhibited from feeding or moving about, and will influence the extent to which hydrocarbons will be taken up or ingested by the organisms.

3.6. Chemical evolution of the oil

As the oil remains exposed to the natural conditions of the environment, it will undergo weathering (see 2.1 and 2.3 above) and the process of chemical degradation under the control of physical factors (light through photo-oxidation for example) and biological factors (bacteria through biodegradation for example). Degradation commonly produces intermediary and end products that are more toxic than the parent molecule. Some organisms are capable of de-toxifying these products for their on benefit but, while remaining unaffected, they will pass them on in one form or another to the next link in the foodweb. Recent evidence suggests that the UV radiation of sunlight further increases the toxicity of hydrocarbons absorbed by organisms by generating highly reactive free radicals or singlet oxygen.

3.7. Presence of other pollutants

Other pollutants, e.g. industrial waste discharges, will increase the environmental stresses to which all living organisms are naturally exposed. In the presence of such pollutants, certain organisms and biological communities will become more sensitive to the presence of oil, and greater mortality will be caused by a spill.

On the other hand, biological communities adapted to living in an organically polluted environment (such communities usually consist of large numbers of very few species) may experience very little structural change following an oil spill, and the numbers of some organisms may increase.

3.8. Prior exposure to oil

Previous oil spillages in the same general area may have weakened the ability of a biological community to survive, and the impact of a spill or pollution incident may be greater than expected. This has been shown to be the case in salt marshes particularly, where after repeated oilings the vegetation has been severely damaged.

On the other hand, previous oil spillages are likely to have led to an increase in oil-tolerant organisms; these species, together with oil-degrading bacteria, will usually increase in numbers following a relatively minor spill, especially if the oil involved is not in the high toxicity range.

3.9. Post spill environmental stresses

After a spill has occurred, natural environmental factors may either speed up or delay recovery of the impacted ecosystem. For example, unusually hot or cold weather may (especially if it coincides with spring tides) impose additional stresses on intertidal organisms.

A GENERALISED ECOSYSTEM SENSITIVITY RANKING

In this impact reference card we move from considering the impact of oil on individual organisms and communities to providing a framework for the comparison of impacts on whole ecosystems. The concept of a sensitivity index provides a useful ranking device; it is not however meant to supplant pre-existing local sensitivity indices, but may be useful where these indices have not yet been compiled. Habitats or ecosystems should not be considered in isolation; protecting one may have the effect of causing greater impact on another. Biologically sensitive areas should be identified in advance and protected in preference to less sensitive areas.

Before considering the relative sensitivity of different ecosystems, one should be familiar with some basic concepts: look up the definitions on the next page. **The overall sensitivity of an ecosystem to oil pollution is determined by:**

* **the** *vulnerability* **of the habitat or physical environment;**
* **the** *sensitivity* **of the populations or communities of organisms in that environment;**
* **the** *resilience* **of the living community as a whole.**

Combining these ecological characteristics allows us to develop a *general sensitivity ranking for ecosystems*. Many such rankings or indices have been suggested, and the system proposed here has been developed by comparing such rankings with recent data on oil spill effects.

ECOSYSTEM SENSITIVITY RANKING

High	Mangrove forests (**Fiche E11**) Coral reefs (**Fiche E12**) Salt marshes (**Fiche E10**) Sheltered tidal flats (**Fiche E8**) Concentrations of seabirds, mammals or turtles (**Fiches T1**, **T2**)
Medium-high	Sheltered rocky coasts (**Fiche E7**) Sea-grass flats (**Fiche E4**) Estuaries (**Fiche E9**) Arctic/subarctic ice (**Fiche 13**)
Medium	Shingle and gravel beaches (**Fiche E6**) Subtidal seabed on sheltered coasts (**Fiche E5**)
Low-medium	Fine-grained sandy beaches (**Fiche E3**) Tidal sand flats exposed to wave action (**Fiche E4**) Subtidal seabed on exposed coasts (**Fiche E5**)
Low	Rocky and boulder shores exposed to wave action (**Fiche E1**) Open coastal waters (**Fiche E2**)

Warning: Local conditions and the presence of biological resources such as shell-fish beds, mariculture (**Fiche R3**) or productive wild-stock fisheries (**Fiche R1**) must also be taken into account, and will alter the ranking. The economic value and sensi-tivity of such resources, together with other uses of the coast for tourism, recreation and industry, will also influence local priorities for protection and cleanup.

ECOSYSTEM SENSITIVITY RANKING - SOME DEFINITIONS

Environmental vulnerability

The **Vulnerability** of a habitat or environment refers to the ease with which oil can penetrate and persist in the environment, a factor closely related to the difficulty with which oil is removed by natural processes or by cleanup measures. Vulnerable environments are those in which:

* oil will penetrate deeply and/or easily;
* there is little or no natural energy for fragmentation, dispersion or evaporation of the oil;
* oil is likely to persist in the environment or habitat for extended periods of time;
* cleanup by manual or mechanical means is difficult because of access, or nature of the substrate.

Examples of habitats with various levels of vulnerability

Highly vulnerable:	Mangroves, salt marshes.
Medium high vulnerability:	Shingle beaches, sea ice.
Medium vulnerability:	Sandy beaches, coral reefs.
Medium low vulnerability:	Subtidal seabed.
Low vulnerability:	Seawalls, exposed rocky coast, open coastal waters (water column).

Population Sensitivity

The **Sensitivity** of a *population* or *biological community* refers to the ease with which its members can be damaged by oil. Sensitive populations possess some or all of the following characteristics:

* individuals sensitive to toxic petroleum fractions (see Table G2);
* individuals sensitive to smothering or clogging;
* species with a low reproduction rate and/or a small number of offspring, and therefore with a low potential for recovery from mortality caused by the oil spill;
* species with low mobility, and therefore less possibility of losses being replenished by immigration from unaffected areas;
* species with behaviour patterns which increase their degree of contact with the oil;
* species at or near the geographic or climatic limits of their distribution, and which therefore may already be subject to natural stresses which would have the effect of lowering their tolerance to an oil spill.

Examples of populations with various levels of sensitivity

Highly sensitive:	Auks (razorbills, guillemots, puffins) and other diving birds, hard corals.
Medium high sensitivity:	Sea urchins, marine mammals, larvae of many organisms.
Medium sensitivity:	Zooplankton, some bivalve molluscs, some polychaete worms.
Medium low sensitivity:	Phytoplankton.
Low sensitivity:	Adult fish.

Community Resilience

Because of their complexity, which is a function of the network of interactions between species, biological communities take some time to recover after a natural or man-made catastrophe has destroyed many individuals. The power of the community to recover after such an event, and the speed with which it is able to do so, constitute its **Resilience**.

A highly resilient community has a high recovery potential. It will return quickly to equilibrium or to its natural state following the perturbation caused by an oil spill (see box below).

Examples of communities with various levels of resilience

Very low resilience:	Coral reef communities.
Low resilience:	Salt marsh communities.
Medium resilience:	Rocky shore communities.
Moderate resilience:	Sandy beach and sand flat fauna.
Highly resilient:	Plankton.

NOTE: *Natural and oil-related disturbances*

In many ecosystems, especially those from which oil can be quickly removed by natural forces, the effect of a spill is broadly similar to that of a natural disturbance such as a major storm or a very cold winter. Different groups of species are more sensitive in each case, and will be affected to different degrees, but the disturbance is usually localised in time and space, and recolonization will be rapid, initiating the process of recovery along similar time scales. The analogy cannot be drawn too far however, especially on shores which retain oil; in such cases the persistence of the oil will cause a continuous stress which will change and delay the process of recovery.

THE ECOLOGICAL BASIS OF RESILIENCE

Communities which can recover quickly are usually those in an early stage of ecological "succession" and which contain many " opportunistic" species. Ecological succession is the orderly process of community change or evolution, giving rise to a sequence of communities which replace one another in a given area. Early communities are pioneers, later ones are referred to as mature, and the final stage of a fully stabilized community is the climax.

Characteristics of early successional communities and the opportunistic species which they contain are:

- *high reproductive rate;*
- *short life expectancy;*
- *fluctuating population size;*
- *wide physiological tolerance;*
- *broad dispersal ability.*

It is therefore possible to see that these communities will recover more quickly from a spill than those in later stages of the succession.

In environments which are subjected to extreme or large-scale physical changes, the living communities are unable to modify their environment, and succession does not take place. On a sandy or gravel beach for example, the environment is dominated by the strong physical forces of waves and tides, and biological communities remain in an early successional stage with the characteristics noted above.

On sheltered rocky shores and in coral reefs and mangroves, the environment has been modified by living organisms which have evolved a complex web of relationships; such communities are further along the successional path, and are much slower to recover from a major disturbance such as would be caused by an oil spill.

EXPOSED ROCKY AND BOULDER SHORES

Rocky intertidal shores are characterised by solid surfaces colonized by a great variety of marine organisms. Wave action and tidal range determine the position of organisms and communities on the shores, giving rise to zonation in which different groups of organisms occupy different levels from low water spring tides to the splash zone above the highest tidal level. Composition of the biological communities on the shore is influenced primarily by exposure to wave action, but the configuration of the shore may also provide a range of different habitats such as exposed rock faces, crevices, deep or shallow pools, and fissures or protected areas under boulders.

PLANT AND ANIMAL COMMUNITIES

Rocky shores support a rich variety of plants and animals adapted to resisting wave action, to maintaining a strong attachment to the rock surface, and to surviving out of water for lengthy periods. In the various habitats offered by exposed rock faces, boulders and intertidal wave-cut rock platforms, plant and animal communities include:

* *on exposed rocky faces* barnacles, limpets, mussels and seaweeds;
* *in crevices*: small marine snails and a variety of other invertebrates;
* *on the upper shore or splash zone*: slow growing lichens and associated fauna;
* *lower down on the shore*: larger algae, periwinkles and other marine snails, and a wide variety of invertebrates; and
* *in rock pools*: many species unable to tolerate drying or exposure to the atmosphere.

IMPORTANCE

Ecologically important diversity of species; sea angling and shellfish collecting; seaweed harvesting (see **Fiche R3**); visually attractive; seabird breeding sites (high shores); teaching, research and conservation/scientific interest.

IMPACT

I	**Light oils:**	Will be rapidly dispersed with little impact unless confined in significant quantities to a localised area – when major mortality of organisms can be expected.
II	**Moderate-heavy (most crude oils)**	Minor oiling will cause little impact but a major spill will cause mortality of barnacles, limpets, mussels, periwinkles, echinoderms and crustaceans. Seaweeds may be temporarily affected but will rapidly return. Upper shore lichens may be badly affected, and their recovery will be slow.
III	**Heavy oils**	Will cause less mortality initially than moderate-heavy oils, but will have a similar impact in localised areas over a long time scale, especially if the oil is allowed to remain in crevices.
IV	**Residual oils**	Sticky residual oils such as bunker C will eliminate many organisms by smothering. Non-sticky asphaltic oils or tarry lumps will have negligible impact.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Wave action and abrasion against rocks and boulders will lead to rapid fragmentation of any oil coming ashore, resulting in the flushing of the oil from exposed rocky surfaces, and natural dispersion of the oil as droplets. Oil will not generally persist except where:

* wave induced water-in-oil emulsification leads to the formation and trapping of chocolate mousse; and

* adsorption of oil onto particles of silt or sediment, e.g. under storm conditions, can cause sinking of the oil.

If oil becomes stranded high on the shore, e.g. as a result of high tides and onshore winds, it may persist for longer periods, being out of reach of most waves.

Gently sloping rocky shores with extensive crevice networks, or rocky platforms with tide pools are much more vulnerable than steep rock faces or boulders. Tide pools in particular are especially sensitive to damage since they will trap oil and contaminated water. The vulnerability of pools increases further up the shore because of less frequent and less complete flushing by the sea. Shores of large boulders are equivalent in vulnerability to rocks with extensive crevices; oil coming ashore is liable to penetrate deeply and may remain inaccessible.

Sensitivity

Grazing animals such as limpets and periwinkles may be killed by toxic components of the oil, leading to a bloom or exceptional growth of opportunistic green algae. Echinoderms (starfish, sea urchins), detritus-feeding small crustaceans and sessile invertebrates such as high shore barnacles are particularly susceptible to oil damage.

Recovery

Natural recovery rates have ranged from several months to longer than eight years. After severe oil damage return of the complete ecosystem to normal equilibrium may take five to ten years. Much will depend on the frequency of recruitment; most invertebrates have a successful larval settlement every few years, but there may be extended periods when spawning or larval settlement are absent. Natural factors will, therefore, have a marked influence on rates of recovery from pollution.

OPEN COASTAL WATERS - THE WATER COLUMN

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*Broadly defined, open coastal waters are any areas seaward of the low tide level and include large bays and the water overlying the continental shelf. Open waters are not surrounded by land masses, and need to be distinguished from enclosed bays and estuaries (**Fiche E9**).*

PLANT AND ANIMAL COMMUNITIES

The pelagic organisms of open coastal waters include plant and animal plankton, fish eggs and larvae, juvenile and adult fish (**Fiche T3**). They depend on the primary productivity of the plant plankton (phytoplankton) which is determined by factors such as temperature, salinity, light and nutrients. Although upwelling of oceanic waters or the existence of oceanic fronts may produce localised areas of high productivity, there is generally a much lower concentration of plankton and fish further offshore. Of particular interest – where the impact of oil is concerned – is the surface layer of these waters. Rich in planktonic life, and supporting a variety of floating organisms which live at the air/water interface, this is the environment where exposure to the most significant oil concentrations is expected to occur.

IMPORTANCE

The open coastal waters of Europe support extensive and highly productive pelagic fisheries (**Fiche R1**). Commercial fishing and shellfishing; seabird feeding areas; sea angling and other recreation.

IMPACT

I	**Light oils**	Insignificant impact; light oils will be rapidly volatilised and dispersed by natural processes. In shallower areas of the continental shelf the enhancement of natural dispersion by the application of chemical dispersants may cause damage to sea bed organisms (**Fiche E5**).
II	**Moderate heavy (most crude oils)**	Slight impact on organisms close to the surface; no recorded impact on organisms in the water column; significant impact on some species of seabirds (**Fiche T2**).
III	**Heavy oils**	Slight impact on organisms close to the surface; no recorded impact on water-column organisms; severe impact on some species of seabirds depending on season and location (**Fiche T2**).
IV	**Residual oils**	No recorded impact on organisms close to the surface or in the water column; severe impact on some species of seabirds (**Fiche T3**).

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ECOLOGICAL CHARACTERISTICS

Vulnerability

The mobility of oil spills in open coastal waters ensures that the oil does not remain in contact for very long with any particular water mass. In addition the processes of evaporation and dispersion reduce the amount of oil present in surface slicks, but the latter will also have the effect of bringing some of the oil down into the water column. Wave action and turbulence will ensure that the dispersed oil droplets are rapidly spread through the water mass; and the mixing of water masses will generally result in a rapid drop in oil concentration with increasing distance from the slick. These processes ensure that oil concentrations rarely rise to lethal levels, and that only a very small proportion of the total water mass is affected in any way. The water column habitat is therefore of very low vulnerability, but the surface microlayer must be considered more vulnerable.

Sensitivity

Oil spills in open waters do not appear to have as severe an effect on the biota (living organisms) as oil on the shore or in estuaries or enclosed bays. There is no evidence that plankton populations have been significantly altered by oil spills. This may also be due to the mixing action referred to above – the plankton populations are also subjected to some degree of mixing (though not to total homogeneity), and any localized mortality will rapidly become unobservable as a result of replenishment from adjacent populations.

Following the **Tsesis** spill in the Baltic Sea however, there was a decrease in zooplankton and an increase in phytoplankton in the vicinity of the wreck. Long term oiling experiments have confirmed similar effects which can be generally described as a shift from the typical grazing pattern (i.e. zooplankton eating phytoplankton) of coastal waters towards a detritus-based food web.

Fish eggs and larvae are extremely sensitive to very low concentrations of hydrocarbons but are also subjected to many natural hazards. The survival of most fish species depends on the production of enormous numbers of eggs, and any mortality of eggs or larvae observed during an oil spill will not necessarily reduce recruitment to the commercial fish stock (see **Fiches R1** and **T3**).

Certain species of seabirds, as predators of fish in the upper layers of the water column, are particularly sensitive to pollution by floating oil slicks (see **Fiche T2**).

Benthic invertebrates living on the sea-bed in the immediate vicinity of offshore oil storage and production facilities have also been shown to be affected by chronic pollution.

Recovery

Planktonic populations have the ability to recover rapidly from oil pollution. Fish eggs and larvae are also so numerous that fish populations possess extensive powers of recovery. The only open-water organisms which do not possess this power are some species of seabirds whose slow rate of reproduction and sensitivity to pollution lowers their ability to recover from a pollution incident.

SANDY BEACHES

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*Depending on the degree of exposure to wave action, sandy beaches may be distinguished by the size of the sand grains and the slope of the beach. **Exposed** sandy beaches contain well-sorted fine to very coarse sand, in general steeply sloping with intermediate flatter areas. The more **sheltered** beaches are composed of less well sorted fine sand near low water mark with medium or coarse sand further up the beach. They are also more gently sloped except near the higher tidal levels.*

PLANT AND ANIMAL COMMUNITIES

The mobile substratum of sandy beaches generally prevents the development of complex biological communities. Most organisms are burrowing and adapted to life in a mobile material. The macrofauna (larger animals) include burrowing bivalve molluscs (**Fiche T5**) and polychaete worms which are generally confined to more sheltered sites. The meiofauna include a very large number of crustaceans (**Fiche T4**) and nematode worms which are adapted to remaining at the surface of the sand, digging through the sand or moving between the sand grains. On more exposed beaches this fauna may be absent or greatly reduced.

IMPORTANCE

Recreation; access to water; shrimp fishing and stake netting for flat fish in some areas.

IMPACT

I	**Light oils**	Minor impact, but more serious impact likely where adhesion of the oil to sand has increased the exposure of the fauna to toxic fractions.
II	**Moderate-heavy (most crude oils)**	Heavy pollution will eliminate most sand-dwelling fauna; light oiling will have only a minor effect. Any impact will be more heavily experienced around the lower levels of the intertidal zone and in the shallow sub-littoral where oil may have accumulated, or on the splash zone above high water mark after strong onshore winds.
III	**Heavy oils**	Heavy pollution will eliminate most sand-dwelling fauna; light oiling will have only a minor effect. Impacts on the upper or lower levels of the beach will be similar to those in II.
IV	**Residual oils**	Will not penetrate sand, and therefore will not have a serious impact. Greatest impact of sticky residual oils is generally on maritime vegetation above the high water mark on sandy beaches and in the subtidal zone where oil/sand mixtures have accumulated by sinking.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Oil coming ashore can rapidly penetrate sandy beaches, particularly if the oil is mobile and the sand dry. Under conditions of strong wave action and light oiling, any oil on the beach will be dispersed fairly rapidly. Heavier oils coming ashore are liable to form oil-sand-water mixtures which are heavier than water and may persist for long periods of time at or below low water mark.

The upper shores of sandy beaches may also be vulnerable as the oil is more likely to remain in the sand and become buried and re-exposed.

Sensitivity

The sensitivity of the intertidal fauna of sandy beaches is extremely variable, and depends significantly on the degree of oiling and extent to which the oil has become incorporated into the sand. Following most oil pollution incidents, there are no reported effects on sandy beach fauna, but this may be due more to lack of detailed investigations.

After the **Amoco Cadiz** spill most species of clams (Solenidae, Mactridae, Veneridae), the epipsammic crustaceans (Mysidaceae, Crangonidae) and the heart urchin were depleted. Even polychaete worms such as *Nereis diversicolor*, *Arenicola marina* and *Audouinia tentaculata*, which were later found to withstand the oil best, were seriously affected. Other sand dwelling species increased rapidly in numbers however, and these "blooms" are believed to result from increased amounts of algal detritus, organic matter and nutrients derived from the oil spill.

Recovery

Sand dwelling organisms have the ability to recover quickly, except following large-scale and intensive pollution. In such cases the continuing presence of oil trapped in sediments and the difficulty of migration from unpolluted sites will cause recovery to take three to four years. After the **Amoco Cadiz** spill an initial phase of degradation and impoverishment of the fauna lasted two to three years before recovery began.

EXPOSED TIDAL SAND FLATS

Tidal sand flats are extensive low-tide zones, frequently cut by flood-tide, ebb-tide or river channels, and backed by sandy beaches, dunes or salt marshes. Tidal flats also occur as offshore isolated sand banks. The substrate varies widely from compacted fine sand, mixtures of mud and sand, or loose unconsolidated mud or sand. Sea grasses may be present from low water spring tides to mid tide levels.

PLANT AND ANIMAL COMMUNITIES

The more exposed sand flats are relatively poor in fauna, and are similar to exposed sandy beaches (**Fiche E3**), while the more sheltered flats (which often occur in estuaries - see **Fiches E8 and E9**) are biologically rich. With the exception of sea grasses in semi-sheltered and sheltered areas, tidal sand flats support no algae or other plants. Most of the invertebrate animals are similar to those on the lower tidal levels of sandy beaches, i.e., burrowing and adapted to life in a mobile material. The macrofauna (larger animals) include burrowing bivalve molluscs and polychaete worms which are confined to more sheltered sites. The meiofauna include a very large number of crustaceans and nematode worms which feed at the surface of the sand, dig through the sand or move between the sand grains. On more exposed sand flats or intertidal offshore sand banks these may be absent or greatly reduced. Sea-grass flats are particularly rich in invertebrate life. Their use by shorebirds and seabirds as feeding areas increases their biological interest and value.

IMPORTANCE

General ecological significance; bird feeding areas; flatfish nursery areas; shrimp feeding grounds; bait digging.

IMPACT

I	**Light oils**	Minor impact except on sea-grass flats.
II	**Moderate heavy (most crude oils)**	Minor impact except in the event of a large spill which could cause mortality of sand-dwelling fauna and destruction of sea-grass beds.
III	**Heavy oils**	Oil stranded at low tide will be likely to cause mortality of fauna and destruction of sea grasses.
IV	**Residual oils**	Sticky residual oils are likely to adsorb on to sand and remain on the sea bed, causing localised mortality. Non-sticky tarry lumps will have negligible effect.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Because of exposure, sediment mobility and location at lower tidal levels, oil is less likely to become incorporated into sand flats. On areas with a high water table oil may not stick to the sediment and it may remain mobile. With decreasing exposure, and especially with the presence of sea grasses, the vulnerability of sand flats increases.

Sensitivity

The sensitivity of intertidal sand flat fauna is similar to that of sandy beach fauna (**Fiche E3**). Intertidal sea-grass communities are very sensitive – both the grasses and the associated fauna are likely to be significantly damaged by an oil slick stranding on the sea-grass beds at low tide.

Recovery

Recovery is likely to be rapid except in semi-sheltered areas or following a major spill. The recovery of sea-grass beds is generally much slower.

SUBTIDAL SEABED OF COASTAL SEAS

The subtidal seabed includes all of the seafloor from below extreme low water spring tides to the edge of the continental shelf, ranging in depth from one to several hundred metres. Depending on geological factors and on the degree of exposure to wave action and currents, the sea bed may be rock, large stones, gravel, shell fragments, sand, silt, clay, mud or a mixture of these materials. Each type of substrate provides a different habitat for communities of benthic organisms

PLANT AND ANIMAL COMMUNITIES

In shallow water, seaweed (macroalgae) dominate rocky or stony substrates while sea grasses (higher plants) occupy large areas of low-energy sand bottoms. The principal macrophytes provide a habitat for a rich variety of mobile and attached fauna including many species of inshore fish. Where the sea-bed is muddy or sandy, the bottom fauna may be dominated by bivalve molluscs, polychaete worms or starfish. In deeper water and on soft substrates generally, burrowing and surface-scavenging invertebrate animals and bottom-living fish are the principal life forms. Plant communities disappear from the sea bed at depths greater than a few meters (in very productive coastal areas) to a few tens of meters, depending on water clarity, because light is absorbed by water and suspended material, and fails to reach the bottom in sufficient amount to sustain plant life.

IMPORTANCE

The sea bed of coastal seas supports the fish and shellfish stocks that are exploited by trawling, dredging, potting etc. (**Fiche R1**); shallow areas support coastal mariculture operations (**Fiche R2**); some pelagic species use the sea bed to spawn (e.g. the attached eggs of herring) and many areas are used as nurseries; the bottom sediments play a role in nutrient cycling which is important for the overlying waters.

IMPACT

I	**Light oils**	Insignificant impact.
II	**Moderate-heavy (most crude oils)**	If it reaches the sea bed by sinking or dispersion, heavy oil pollution will eliminate a proportion of the fauna, decreasing with depth, but increasing with the amount of hydrocarbons which have become incorporated into the sediment.
III	**Heavy oils**	Similar impact to II.
IV	**Residual oils**	Sticky residual oils will have impacts similar to II and III; non-sticky oils and tarry lumps have negligible impact on marine organisms but may remain on the sea bed for long time periods.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Rocky or stony substrata have a low vulnerability, oil usually being swept away by currents or wave action. Oil will not normally reach this habitat except by sinking, or through the build up of high concentrations of dispersed oil droplets in shallow water as a result of wave action or the application of dispersants close to the shore. This is one of the principal reasons why the use of dispersants in relatively shallow water (less than 10 metres) is not normally recommended except in special circumstances.

Sensitivity

Bottom-living or benthic shellfish are sensitive because of their filtering or surface-scavenging methods of feeding. During the first weeks following the **Amoco Cadiz** oil spill, large numbers of subtidal razor clams and heart urchins were killed. Over the following year, benthic amphipod crustaceans disappeared from polluted sediments to a depth of 30 metres.

The impact of oil on submerged sea-grass communities has shown great variation, ranging from very little impact (**Amoco Cadiz** spill) to severe impact with high mortalities (**Zoe Colocotronis** spill).

In deeper offshore waters, the benthic communities are not vulnerable to the occasional spillage, but chronic oil pollution (e.g. from an offshore oil storage facility) may have a localised detrimental effect.

Recovery

The recovery of subtidal sea-bed communities to an equilibrium or 'normal' condition after oil impact has generally been thought to be quite rapid. However, the rate of recovery is significantly affected by the extent to which oil has penetrated and become incorporated into the sediment.

On rocky or stony seafloors, recovery will be rapid unless there has been widespread elimination of fauna and flora by a spill of massive proportions.

Benthic communities affected by oil contamination of the sediment may take several years to recover from a spill because of the continuing exposure of the organisms to hydrocarbons.

Where sea grasses have been damaged or destroyed, other components of the ecosystem have declined or disappeared, detritus production has fallen, erosion of the substrate has increased, and blooms of filamentous blue-green algae have occurred, hindering recovery.

SHINGLE AND GRAVEL BEACHES

Shingle (or cobble) and gravel beaches include a wide variety of stony habitats in which the stones range in size from fine gravel to small boulders. They may be sheltered or exposed; in the former the stones may be relatively immobile in a poorly sorted matrix of mud or fine sand, whereas on exposed beaches the stones are generally very mobile, well-sorted and rounded by abrasion. On exposed beaches the substrate is very unstable, with steep seaward-facing slopes which are altered regularly by wave forces or tidal currents, giving rise to cycles of erosion and deposition.

PLANT AND ANIMAL COMMUNITIES

If the stones are well-sorted and mobile, as for example on exposed shingle or gravel beaches, there is a very sparse fauna composed of only a few species. More sheltered and poorly-sorted beaches, especially those on which the shingle or gravel is mixed with mud or sand, support a richer fauna, feeding mainly on detritus. Fauna may be more diverse in the lower intertidal area, and many shingle beaches also support a varied flora of maritime plants in the splash zone above high water mark.

IMPORTANCE

Shingle and gravel beaches are not normally of ecological importance except in some locations where the upper shore may support an unusual flora of maritime plants or may be used as a nesting site by terns. They constitute important natural sea barriers in some cases, preventing shore erosion.

IMPACT

I	**Light oils**	Negligible impact on wave-exposed beaches; temporary effects on sheltered beaches.
II	**Moderate heavy (most crude oils)**	Principal impact on fauna and flora at highest and lowest levels of sheltered or semi-sheltered beaches; short-term impact on exposed beaches.
III	**Heavy oils**	Oil which has penetrated the beach may persist for years, affecting fauna and maritime flora, particularly at highest and lowest levels.
IV	**Residual oils**	Sticky oils will have an impact similar to type III; non-sticky oils and tarry lumps will have little biological impact.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Shingle and gravel beaches are very vulnerable, especially to low viscosity and/or light oils which will penetrate the substrate rapidly, become buried, and may persist for several years in areas of low or moderate energy. The cycles of erosion and deposition on exposed beaches may also lead to re-emergence of the oil or of contaminated stones after a period of months or years. The vulnerability of more sheltered beaches containing a significant amount of sand or silt is similar to the environments described in **Fiches E3** and **E4**.

Sensitivity

The sparse fauna inhabiting exposed beaches is not generally sensitive to oil pollution, but in more sheltered areas the richer and more diverse communities will be affected around low water mark, and (if the beach is sufficiently stable) the maritime flora and fauna of the splash zone may become damaged. Oil driven onto these upper shore areas by onshore winds and high tides is also likely to remain in place for months or years.

Recovery

Recovery of affected biological communities on any part of a shingle or gravel beach will be slowed by the penetration of oil into the substrate. Thus, organisms may be exposed to low and/or changing levels of hydrocarbons for several years.

SHELTERED ROCKY COASTS

Sheltered rocky coasts are characterised by solid surfaces which, because of the absence of heavy wave action, support a wide variety of marine organisms. They include boulder shores, sheltered intertidal rock platforms which may be cut or dissected by numerous gullies and crevices, deep and shallow rock pools, sheltered overhangs and caves. On many such coasts, soft sediment or sand has accumulated in the bottoms of pools and hollows.

PLANT AND ANIMAL COMMUNITIES

Tidal range is the principal factor determining the position of organisms and communities on sheltered rocky shores, giving rise to a zonation similar to that on exposed rocky shores where wave action plays a greater role (**Fiche E1**). Because of the variety of habitats, plant and animal communities are very varied, but are generally rich in species, with extensive growth of seaweeds. The diversity and complex structure of rocky shore communities provides a degree of ecological stability, but it ensures that any significant disturbance will have a lasting impact on the relative abundance of species present. Natural factors, both seasonal and irregular, can also cause marked changes in the relative abundance of particular species.

IMPORTANCE

Ecologically important diversity of species; sea angling and shellfish collecting; seaweed harvesting (see **Fiche R3**); visually attractive; teaching, research and conservation interest.

IMPACT

I	**Light oils**	Small quantities will cause little impact if rapidly dispersed or volatilised, but larger quantities are liable to cause massive mortality as a result of locally high concentrations of toxic fractions.
II	**Moderate heavy (most crude oils)**	Minor oiling will cause only a moderate impact but a major spill will lead to heavy mortalities of barnacles, limpets, mussels, periwinkles, echinoderms, crustaceans and other organisms. Seaweeds may also disappear but can rapidly return.
III	**Heavy oils**	Will cause less mortality initially than I or II but will remain in the environment over a long time scale, causing localised damage to sensitive species.
IV	**Residual oils**	Sticky residual oils will eliminate many organisms, and recovery of the affected area will be slow. Non sticky asphaltic oils or tarry lumps will have negligible impact.

ECOLOGICAL CHARACTERISTICS

Vulnerability

The low wave energy available in sheltered rocky intertidal areas permits stranded oil to remain on the shore, especially where there is a network of cracks, crevices and pools, or spaces between boulders. The presence of silt will lead to further retention of the oil through adsorption and sinking. Sheltered crevices and rock pools are particularly vulnerable, and macroalgae are also liable to trap oil and to become heavily contaminated, resulting in widespread mortality of the plants.

Moderate wave energy can lead to the deposition of oil on rock surfaces in the upper intertidal zone, and such oil stranded high on the shore will not be removed quickly by natural processes. As in the case of more exposed rocky shores, tidal pools are especially vulnerable since they will act as traps for oil and contaminated water. Flat shorelines with a shallow gradient, eg. rocky platforms, are more vulnerable than steeper shores.

Sensitivity

Certain key groups such as echinoderms, detritus-feeding micro-crustaceans, grazing limpets and high intertidal barnacles are sensitive to oil pollution damage. Limpets and other grazing molluscs, together with predatory snails, are responsible for maintaining the appearance of the shore and for preventing excessive colonization by algae, barnacles and mussels. The sensitivity of grazing animals to oil spill damage has in many cases led to a bloom or exceptional growth of opportunistic green algae.

Recovery

Natural recovery rates have ranged from several months to more than eight years. Return to normal equilibrium following severe oil spill damage may take five to ten years. As in the case of exposed rocky shores, natural factors such as the success or failure of larval settlement or recruitment of mobile stages will have a marked influence on recovery rates.

SHELTERED TIDAL SAND OR MUD FLATS

*Sheltered tidal sand or mud flats occur where coastal circulation patterns favour extensive sediment deposition and where there is adequate shelter from wave energy. They are common on all coasts of Europe, being particularly associated with sheltered bays and estuaries (**Fiche E9**). Such shelter may also be provided by a chain of islands (e.g. in the Wadden sea environments). The sediments are generally poorly-sorted, but may grade from fine sand or mud around low water mark to medium or coarse sand and stones at higher tidal levels. The stability of the sediment may vary from very stable sand/mud mixtures to loose unconsolidated mud and very fine sands which are in a constant cycle of slow deposition and erosion. They are frequently backed by salt marshes or mangrove forests.*

PLANT AND ANIMAL COMMUNITIES

These habitats support a wide variety of burrowing, filter-feeding and detritus-feeding organisms on stable sediments. The more mobile sands and muds support relatively simple communities of organisms. In both cases organic detritus provides the major food source for the invertebrate fauna which in turn provide food for commercially valuable fin-fish such as flounder, sole, mullet and sand eel. Wading birds and diving ducks are also attracted in large numbers by the abundant food supplies. Seals may also be present.

IMPORTANCE

Sheltered tidal sand and mud flats provide a productive habitat for marine life (fish, invertebrates and birds) and valuable nursery grounds for commercial fisheries (**Fiche R1**).

IMPACT

I	**Light oils**	No post-spill data but likely to cause widespread mortality.
II	**Moderate heavy (most crude oils)**	Rapid reduction in numbers and variety of invertebrate fauna; birds and predators will also suffer damage by direct contact and through the food web.
III	**Heavy oils**	Similar to II above.
IV	**Residual oils**	Potential serious long term impact if the oil becomes incorporated into sediment; otherwise moderate impact with reduction of some species of invertebrates.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Owing to the relative shelter and low wave energy, oil is likely to persist for long periods of time in sheltered muddy or sandy intertidal areas. Coastal geomorphology has a major influence, not only on determining the level of wave energy, but also in keeping the oil confined to a particular area and reducing the likelihood of geographical dispersion to other localities. The cycles of erosion and deposition in these environments also affect their vulnerability to stranded oil. In an eroding area, oil is unlikely to accumulate; but in an area where accretion is taking place the oil may become buried under a layer of sediment. Burial of stranded oil will result in longer exposure of burrowing organisms to toxic fractions and will delay degradation by natural processes. The high silt content of the water close to sheltered tidal flats also promotes the sinking of floating slicks.

Sensitivity

Like other near-shore communities which depend on detritus as their principal food source, the potential for oil contamination and bioaccumulation in sand/mud flat communities is high. Most organisms living in these sediments are highly sensitive to toxic components of oil. Polychaete worms and other soft bodied organisms are particularly susceptible to oil contamination, but are more able to resist toxicity than molluscs and crustaceans.

Following the **Amoco Cadiz** spill, some species of lamellibranch molluscs, amphipod crustaceans and echinoderms suffered the heaviest mortalities. Burial of oil in intertidal sediments, whether it occurs naturally or is caused by cleanup operations, may lead to long term decline in the number and variety of species present. Diving birds, especially ducks, and some wading birds are very sensitive to oil spillages (see **Fiche T2**).

Recovery

The fauna of stable sheltered intertidal sand or mud flats generally includes longer-lived species than the less stable sediments of exposed sandy beaches. Opportunistic species are also generally less dominant on sheltered intertidal flats. Recovery periods will be determined to a large extent by the degree of penetration and persistence of the oil in the sediment. Experimental work has indicated two to four years for recovery. Recovery times after oil spills have varied very greatly, but generally tend to confirm the experimental findings.

ESTUARIES

Estuaries are semi-enclosed bodies of coastal water having a free connection with the open sea and in which the seawater is measurably diluted with fresh water derived from a river or land drainage. Brackish water and regular changes in salinity are features of all estuaries, and result from the dynamic interaction between the fresh-water outflow and the rise and fall of the tides. Many estuaries contain extensive sand and mud flats derived from marine and/or river-borne sediments.

PLANT AND ANIMAL COMMUNITIES

The constantly changing environmental conditions in estuaries inhibit ecological succession (see **Fiche G4**) and the development of complex stable biological communities. Estuarine communities are derived from those inhabiting marine and freshwater environments and are restricted primarily to those species which have adapted to changing salinities and high silt levels. Such adaptation imposes stress, the communities are less complex but are extremely productive, sustained by quantities of organic detritus and nutrients derived from land drainage and run-off. They include the invertebrate communities of sand and mud flats, the sessile and grazing animals of rocky and stony shores which feed on algae and detritus, estuarine plankton communities, and the populations of fish which feed in or migrate through estuaries. Salt marshes and brackish wetlands may also be present, and estuaries also support large populations of seabirds feeding on algae, invertebrates (molluscs and crustaceans) and fish.

IMPORTANCE

Estuaries contain a wide variety of habitats and environments described in previous fiches (e.g. sheltered sand or mud flats (**Fiche E8**), sheltered rocky coasts (**E7**), shingle or gravel beaches (**E6**), exposed tidal sand flats (**E4**) and sandy beaches (**E3**)). But they pose special problems for oil spill cleanup and are also significant in terms of their value for fisheries (**R1**), recreation, transport, industry and waste disposal. For these reasons, the impacts of oil in estuaries are summarised in this fiche.

IMPACT

I	**Light oils**	Will generally be dispersed and volatilised with minor impact unless concentrated into a small area when toxic effects may be expected.
II	**Moderate heavy (most crude oils)**	Significant impact on estuarine ecosystems, affecting soft shore animals, birds and salt marshes.
III	**Heavy oils**	Long term adverse impact if allowed to become incorporated into sediments through sinking or stranding on the shoreline. Will seriously affect estuarine birds, upper shore ecosystems, and demersal fish and shellfish.
IV	**Residual oils**	Long term adverse impact if sticky residual oils become incorporated into sediments. Tar balls and heavily weathered oils unlikely to cause significant effects.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Estuaries tend to trap or accumulate materials as a result of the physical processes taking place within them, e.g. silt, dissolved and particulate organic matter, heavy metals, oil and chemicals from effluent discharges, and floating litter. In most estuaries the action of the tides will also distribute within the estuary any floating or particulate pollutant. Oil will behave similarly, and estuaries must be considered highly vulnerable because:

* floating slicks and dispersed oil droplets will tend to remain trapped within the estuary;

* it is very difficult to prevent the stranding of oil slicks on the shore, especially in estuaries with strong tides;

* the actions of tides and wind will distribute oil widely within the estuary;

* high levels of suspended silt in the water will increase the rate at which the oil will sink and become incorporated into sediments;

* many estuarine shores and habitats are specifically vulnerable to oil pollution, e.g. sheltered rocky and muddy shores, salt marshes;

* when oil has penetrated the estuarine environment, natural processes of removal and degradation are slow, and cleanup of polluted shores may be difficult and biologically damaging.

Sensitivity

Many estuarine organisms feed by filtering or scavenging organic detritus, and are sensitive to dispersed oil droplets or to slicks stranded on the shoreline. Salt marsh plants fringing estuaries are also sensitive to repeated oil spillages. Many species of plants and animals survive at the limit of their ecological tolerance in estuaries and are therefore particularly sensitive to additional stress, e.g. that caused by an oil spill.

Recovery

Estuaries impacted by major oil spills have been slow to recover, primarily as a consequence of the oil having become widely dispersed and incorporated into estuarine sediments and fauna. Recovery of estuarine ecosystems would normally require more than a year, with larger spills requiring longer.

SALT MARSHES

Salt marshes are flat muddy intertidal areas colonized by salt-tolerant low vegetation. The vegetated surface is normally just about mean high water level, and is dissected by non-vegetated muddy creeks and channels. The vegetation traps sediment, resulting in continuous build-up of the marsh and its advance into lower intertidal areas. This advance may be halted by erosion, leading to a dynamic balance between vegetation-covered and non-vegetated areas of intertidal sediment.

PLANT AND ANIMAL COMMUNITIES

Salt marshes, like mangroves (see **Fiche E11**), exhibit a zonation in plant communities from the seaward fringe to the highest tidal level. Distinct groups of fauna are associated with each plant zone. The drier upper portion of salt marshes supports purely terrestial vegetation and fauna. Between the tides, the vegetation consists of salt-tolerant plants, the majority of which are perennial and whose presence is vital structurally and functionally for the maintenance of the marsh environment. Algae grow as epiphytes on the stems of these plants, or may be embedded in the mud among them. Other algal species drift freely, and algal mats often constitute a significant proportion of the vegetation. Fauna, feeding either directly on the living plants or on their dead remains, includes crabs, gastropod snails, clams, oligochaete and polychaete worms, and bacteria. Food chains based on detritus are of greater importance and are more complex than direct plant/herbivore/carnivore food chains. Many bird species use salt marshes for feeding and nesting.

IMPORTANCE

Salt marshes exhibit an extremely high biological productivity. They export detritus and nutrients to adjacent coastal waters and serve as nursery areas for commercially important fish species. Industrialization and urbanization have destroyed many marshes, and those remaining are threatened by pollution. Owing to their importance as feeding and roosting areas for shore and seabirds, and the intrinsic value of their plant and animal communities, many salt marshes are protected or classified as areas of scientific interest.

IMPACT

I	**Light oils**	Widespread mortality of flora and fauna.
II	**Moderate-heavy (most crude oils)**	Extensive destruction of the marsh community, all organisms being affected.
III	**Heavy oils**	Similar to II above.
IV	**Residual oils**	Serious long-term impact if oil becomes incorporated in sediments and in the root system.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Salt marshes are extremely vulnerable habitats. Oil spilled in or entering a salt marsh will be partially adsorbed on particulate matter in the water column and on the stems and roots of vegetation and exposed sediments. A high organic content in the marsh sediments will promote te sorption to the oil. The sediments will function as a sink for hydrocarbons, and the absence of wave energy will lead to very slow dispersion or breakdown of the oil.

Sensitivity

Salt marshes are diverse, complex marine habitats, and they are considered very sensitive to oil pollution. Their sensitivity depends on the type and amount of oil spilled, the extent to which the oil has become weathered, the species and ages of the plants, the time of year and the characteristics of the soil/sediment.

Oil entering a salt marsh will adhere firmly to plant surfaces and will not be lifted off by successive tides. Oil may also penetrate the plant tissues, travel within the plants, and disrupt cellular functions. The presence of oil in the sediment will also affect root functions of plants and may damage burrowing animals. Annual plants are likely to be severely reduced in numbers because they are unable to recover by developing new growth, and their seedlings are sensitive to oil. Microalgae are also sensitive, but will recover more quickly.

Birds will suffer from oil presence through contamination of their plumage and by ingestion through preening and feeding. Contamination of detritus may result in transfer of oil throughout the food chain, particularly affecting filter and detritus feeders. Gastropod snails, crabs and fish feeding in tidal channels are also sensitive.

Recovery

Natural recovery processes in a salt marsh depend on regrowth of vegetation, seeding of plants, and recolonization of benthic populations through recruitment of juveniles and immigration of adults. The length of the recovery period depends on the type of oil, extent of oiling, and season of the year.

Light oilings, and pollution by less toxic oils permit quick recovery, occasionally within weeks or months. Heavier oilings require a recovery period of one to two years, while the recovery of a marsh from fuel oil has been reported to take four or more years.

Benthic faunal populations may recover more slowly than the marsh vegetation, especially if there is a continued presence of oil in the sediment. At one heavily oiled site, recovery of the fiddler crab population did not take place until seven years after the spill.

MANGROVE ECOSYSTEMS

Mangrove ecosystems, generally termed mangrove swamps or forests, are confined to tropical and sub-tropical areas. They occur on relatively flat sheltered intertidal areas with soft sediments. They are dominated by distinctive species of salt-tolerant trees which root in the organically rich and anoxic sediment, and rise through shallow water into the air to develop a full canopy. There are many species of mangroves but all exhibit morphological and physiological similarities.

PLANT AND ANIMAL COMMUNITIES

Mangroves, like salt marshes (see **Fiche E10**) exhibit a zonation in plant communities from the seaward fringe to the highest tidal level. Some tree species (e.g. Black Mangrove) have an extensive root system that sprouts upward-growing organs from the sediment into the overlying water or air, and supply oxygen to the roots. Other species (e.g. Red Mangrove) are supported on prop roots descending through the water into the sediment. Distinct groups of fauna are associated with each plant zone and with each type of mangrove community. Food chains based on detritus are of greater importance and are more complex than direct plant/herbivore/carnivore food chains. Mangrove communities are dependent on the existence of the mangrove plants themselves which stabilise the environment and provide habitats for many species. Birds and epiphytic plants occupy the canopy and trunk (supratidal). Other epiphytes, together with algae, sponges, flatworms, hydroids, worms, barnacles, oysters, clams, shrimps, mussels, snails, crabs, sea urchins and other marine organisms inhabit the intertidal prop roots. The muddy substrate between the plants and in channels within the forests supports other plant and animal species, including fish.

IMPORTANCE

Mangrove ecosystems are widely distributed in tropical regions where they replace salt marshes on sheltered coasts and in estuaries. The mangrove forest consolidates the shoreline and offers shelter for many large species of fish, mammals and reptiles. It also provides shelter for the young stages of commercially important fish and crustaceans. Coastal peoples living at subsistance level fish in the creeks and drainage channels and collect mangrove shellfish from among the prop roots. They also use the wood for burning, building and tanning.

IMPACT

I	**Light oils**	Likely to cause widespread mortality of associated fauna and to affect the health and reproductive success of trees.
II	**Moderate heavy (most crude oils)**	May cause death and subsequent decay of mangrove trees with permanent alteration of habitat.
III	**Heavy oils**	Similar to II above.
IV	**Residual oils**	Long-term effect on system stability. Particularly damaging to black mangroves through asphyxiation of the root system.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Mangroves are extremely vulnerable habitats. Oil spilled in or entering a mangrove will be partially adsorbed on particulate matter in the water column and on the stems and roots of vegetation and exposed sediments. The sediments will function as a sink for hydrocarbons, and the absence of wave energy will lead to very slow dispersion and breakdown of the oil.

Sensitivity

Mangrove swamp communities are sensitive to oiling through direct contamination of the mangrove plants' roots and leaves, leading to defoliation, die-back and reduced seed-germination success. Smothering of pneumatophores will cause asphyxiation of the root system and upset the salt-balancing mechanism. The effects of oil contamination on the survival and growth of mangrove trees may vary widely, depending on the prevailing environmental and climatic conditions after exposure to the oil.

Oil penetration of sediments and detritus may lead to severe contamination of the food web and to depletion of food resources for commercially important fish and shrimp species. Filter- feeding organisms (e.g. barnacles, anemones, oysters and sponges) and grazing animals (e.g. limpets and snails) may be affected lethally or sublethally. Fish, sea turtles and birds inhabiting the mangroves are also very sensitive.

Recovery

The recovery rate of mangrove forests depends primarily on the dominant mangrove species involved. Death and subsequent decay of fallen mangrove trees may expose the forest to increased erosion, altering the habitat sufficiently to postpone the recovery indefinitely. Decomposition of dead mangroves may take as long as three years. Evidence exists that oil trapped in muddy habitats after a massive oiling maintains toxic effects for at least 20 years after the spill.

Communities dominated *Rhizophora* species may take eighty years for complete recovery whereas others grow more rapidly. It is generally estimated that twenty-five to forty years may be required for a mangrove community to re-establish itself. Recovery of the associated organisms is highly dependent on recovery of the mangrove plants, and will thus take a similar length of time.

CORAL REEFS

Coral reefs are continuously-growing limestone structures of biological origin which extend from the bottom of tropical seas towards the surface. Fringing reefs grow from the shore and remain connected with it; barrier reefs and atolls rise from deep water and enclose a shallower lagoon; coral knolls and patches form smaller, isolated constructions; coral banks rise from the seafloor without reaching the sea surface. Coral reefs show a well-defined biological and physiographic zonation from the deep fore reef to the shallow lagoon area, going through an outer slope, a reef front, a crest (reef edge, reef flat and rear zone), and a back-reef area

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PLANT AND ANIMAL COMMUNITIES

Coral reefs are the richest and most complex of all marine systems. The organisms responsible for determining the shape of the reef are the hard corals (madrepores and hydrocorals) and the coralline algae. The biological community also includes a large variety of invertebrates (sponges, echinoderms, molluscs, crustaceans etc.) and fish that contribute to the formation and maintenance of the reef. The reef environment also attracts pelagic fish, reptiles, mammals and birds. The primary producers that sustain the entire food chain are microalgae living inside the corals tissues. Other primary producers (fleshy algae, coralline algae, phytoplankton) have a lesser importance in the reef economy.

IMPORTANCE

Coral reefs constitute the major, and sometimes only, source of life and organic production in nutrient-poor, unproductive marine areas. The ability to create their own substrate, intercept marine currents and wave energy, fix light energy, trap and recycle nutrients makes reef systems unique. Reefs offer protection to the shorelines they fringe and to the lagoon/coral-island complex they have produced. They provide habitats for associated communities including fish of the outer reef, lagoon fish, shellfish, sea- grass beds and mangroves. Many of these are exploited by local populations at the artisan level.

IMPACT

I	**Light oils**	Widespread mortality of corals that have been in contact with the oil. Mortality may be delayed.
II	**Moderate-heavy (most crude oils)**	Widespread damage to corals, fish, invertebrates and birds visiting the reef crest. The reef community may degrade and become colonized by algae.
III	**Heavy oils**	Mortality of corals and reef-dwelling organisms. Reef degradation may occur in affected areas.
IV	**Residual oils**	Potential long-term impact locally if the oil becomes incorporated in the sediments.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Reefs are vulnerable only to the extent that the benthic community which composes them is exposed to the oil. Oil settling on the corals themselves or becoming entrapped in the reef crest structure or in the sediments may have a catastrophic effect. Fortunately, many reefs form narrow bands of substrate that remain covered by water most of the time: oil spills may quickly pass over them without affecting them at all. The vulnerability of reefs therefore depends on reef type and structure: submersed reefs surrounded with deep water have a low vulnerability; emergent reefs are highly vulnerable, particularly where the coral cover on emerged areas is dense; fringing reefs are generally more vulnerable than barriers and knolls because oil may become absorbed in their sediments.

Sensitivity

Reef-building corals are extremely sensitive to oil. The growth rates of corals over which oil has floated for a few hours may be reduced for several months after the incident. Direct contact with the oil will generally be fatal to the corals, but death may be delayed several weeks or even months. Short exposure to oil can be survived by certain species. Chronic exposure to oil-contaminated sediments may cause widespread coral injury. When coral colonies have been denuded of their living tissue they may quickly become colonized by filamentous and fleshy algae. The characteristic fauna associated with living corals is then replaced by a very impoverished assemblage of grazers and other opportunistic species.

Recovery

Once reef communities are invaded by algae they may deteriorate completely, particularly in the presence of other stresses such as siltation or nutrient input from land. In some cases, erosion of the reef framework may occur. Recolonization of denuded reefs must happen through either settlement and development of new coral larvae or regeneration of surviving portions of colonies. Both processes are severely hindered by the presence of opportunistic algae. Coral growth is itself very slow, and full recovery in the most favorable conditions will take many years.

ARCTIC AND SUBARCTIC REGIONS

The Arctic region comprises all areas north of the Arctic circle, i.e. the latitude of 66°33'N. It is characterised by low temperature, a long winter period with little or no daylight, permafrost and large areas with pack ice and permanent ice. Many different ecosystems are found in the region, of which ice edges, leads and polynias (areas of open water) and the ice-water interface are the most characteristic. Subarctic regions share many environmental characteristics with the Arctic but enjoy a longer ice-free season and a higher biological diversity.

PLANT AND ANIMAL COMMUNITIES

The marked seasonal changes and the shortened season for plant growth, have brought about species assemblages acclimated not only to low temperature but also to seasonal feeding and energy storage in fats and related substances in the winter period. Large animal populations occupy the ice edges , leads, and polynias. Highly specialised and adapted species of fish (arctic charr, arctic cod), seabirds (over 160 different species, 30 of these breeding in the region), and marine mammals (polar bear, whales, seals) appear in high concentrations. Also typical is the under-ice algae/crustacean community.

IMPORTANCE

The Arctic shelf seas are among the most productive in the world and the subarctic region is known for its valuable fishery grounds. Many higher species are producing their young in the Arctic at the time of the year when marine productivity is greatest. The Arctic is an important feeding ground for whales: Beluga whales are observed from early spring to late autumn. Other toothed whales include narwhal, killer whales, white-beaked dolphins and sperm whales.

IMPACT

I	**Light oils**	These oils will not evaporate as quickly as in temperate environments, causing a greater risk for intoxication since the lighter components are known to be the most toxic. In icy waters, diesel has been found to spread faster than crude oil and to contaminate approximately twice as large an area.
II	**Moderate-heavy (most crude oils)**	Are more likely to adhere to the skin and fur of mammals and to the feathers of birds, leading to a reduction of thermal insulation and of the water repellent quality of feathers.
III	**Heavy oils**	Similar to II above.
IV	**Residual oils**	As the weathering progresses, the density of the spilled products may increase to the point that they sink to the seabed.

ECOLOGICAL CHARACTERISTICS

Vulnerability

Whereas in warm waters the oil spreads to a very thin layer, surface tension spreading in cold water seems to be quite limited and the equilibrium thickness may be several millimetres. Ice will modify the pattern of spreading and disappearance of an oil spill, tending to move or concentrate oil in leads and openings including breathing holes. Evaporation of volatile organic compounds is slower than in warmer areas. Ice-cover duration plays a role in ice exchange an oil removal. Ice leads and polynyas are especially vulnerable to oil contamination. Oil trapped in the ice may drift unaltered on long distances before being released when the ice melts. Fast ice lasting less than 2 months will release its oil easier and closer to the spill area than fast ice lasting over 6 months.

Sensitivity

Ice leads and *polynias* appear essential for the feeding, migration and reproduction of many species. Shallow coastal lagoons are heavily utilised by birds and fish populations at certain times of the year. Functional sterility and genetic defects have been observed in fish (pink salmon, herring) spawning in oiled area. Oiling of birds leads to a reduction of the insulating and water repellent quality of their feathers and may cause mortality (**Fiche T2**). Polar bears are likely to be impacted through oiling of fur, ingestion of oil from grooming , and possibly by feeding on oiled seals or seabirds; skin damage and hair loss have been reported after contact with oil (**Fiche T1**). Birth and postnatal care of the ringed seal occur in subnivean (under snow) birth lairs, with access through the ice surface. Oil that concentrates in these areas may cause coating and inhalation toxicity. The ecological impact of oil in *ice-free beach environments* is likely to be less dramatic as they tend to be biologically impoverished due to the severe weather conditions.

Recovery

There is little doubt that the rate of recovery following a severe oil spill will be much slower in *Arctic areas* than at lower latitudes. Due to the low temperature biodegradation in the Arctic is slow. Biological recovery will also be delayed because of the reduced fecundity, dispersal, and growth rates of many polar species. Arctic ecosystems are usually more simple than other systems, involving a lower diversity of species but comparatively high numbers and biomasses. This means that severe reduction of a population, particularly if it represents an important throphic link, might have serious consequences for the biological community. Many of the animals grow slowly, mature late, breed only once annually and/or or produce relatively few young during each breeding season.

Subarctic spill histories may give an insight on the recovery potential of cold marine systems. Seven years after the '*Exxon Valdez'* spill (60°61'N) the Baltic Eagle population had fully recovered. However, Harbour Seal populations continued to decline at a rate of 6% a year, while the Pigeon Guillemots population declined by 40% in 7 years. Natural changes in food supplies may have played a role here. Killer whales in the spill area produced no young in the two years following the spill.

WILD-STOCK FISHERIES

The coasts and seas around Europe provide a rich and varied selection of fishing grounds which are important economically and socially. The principal catches comprise pelagic (mid-water) and demersal (bottom-feeding) fin-fish and a variety of shellfish. Fishing methods include drift netting, ring netting and purse-seining, bottom and mid-water trawling, and the use of baited long-lines, fish traps, crab and lobster pots, and tangle nets. Shellfish are also dredged or raked from the sea bed, and their commercial productivity may be increased by cultivation methods (see ***Fiche R2***

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HOW CAN OIL POLLUTION AFFECT FISHERIES?

Oil spillages may affect fisheries *directly* and *indirectly* in several ways :

* by causing mortality of adult fish or shellfish;
* by causing mortality of eggs, larval or juvenile stages of commercial fish species;
* by reducing the available food of fish or shellfish;
* by causing tainting of the fish or shellfish;
* by fouling fishing gear and boats;
* by preventing the use of certain fishing grounds;
* by reducing prices and creating difficulties in marketing fish or shellfish.

IMPACT OF OIL POLLUTION

Direct effects on fin-fish

The direct effects of oil on fin-fish are covered in **Fiche T3**. Despite experimental evidence that *eggs and larvae* are very sensitive to small amounts of oil, very few post-spill studies have indicated an impact on fish populations. Mortalities of eggs and larvae would in any event be difficult to detect, since the dead organisms fall out of the water column and decompose within hours, becoming unrecognisable. Some mortalities of *adult fish* have been observed following a number of spills, e.g.***Argo Merchant*** and***Amoco Cadiz***, but in these cases the amounts of oil were very large, and the impact was concentrated in a limited area.

The impact of larval or juvenile fish kills on *fishable stocks* is very difficult to detect – fluctuations in year-class size and in recruitment to the stock, caused by natural factors, are liable to mask any pollution-induced losses. Since a very high proportion of young fish die from natural causes anyway, and the size of the adult population is controlled by other factors having a greater direct impact than larval abundance, it is unlikely that larval mortality caused by oil pollution would significantly reduce commercially available stocks of fin fish in subsequent years.

Direct effects on shellfish

Adult shellfish populations are much more vulnerable to the direct impact of oil, especially intertidal or near subtidal species such as oysters, clams and mussels. Being filter feeders, molluscan shellfish are additionally sensitive to the presence of hydrocarbons in suspended particulate matter, on surface sediments or as dispersed droplets (see **Fiche T5**). Shellfish have the ability to remove the hydrocarbons from their tissues following transfer to an unpolluted area or following removal of the source of contamination, but this is a slow process and in the meantime the shellfish are unmarketable.

Indirect effects through the food chain

There is very little evidence that adult or juvenile fin-fish can be affected by oil via the food chain, and in any event such effects would be extremely difficult to detect. Shellfish, being filter feeders as noted above, have been seriously affected in major incidents, becoming temporarily unmarketable due to tainting.

Tainting

Tainting, or the presence of disagreeable or unpalatable flavours in fin-fish or shellfish, has been attributed to causes other than oil pollution, but is frequently associated with oil spillages or oily-water discharges (although it may have other causes). Lobsters, mussels, oysters and clams have been tainted following oil spillages, making them unmarketable. The threat of possible or suspected tainting has also led to the temporary closure of shellfisheries following major spillages.

Impacts on fishing activities

Even when fish stocks themselves are not directly or indirectly affected, the presence of oil slicks on the sea surface in the vicinity of fishing grounds has led to fouling of fishing gear and catches by oil. In order to avoid this, fishermen have had to abandon temporarily their use of certain fishing grounds, resulting in a loss of income. Shallow- water fisheries, especially those using small-mesh nets, e.g. for shrimp, are particularly vulnerable to small patches or floating globules of oil which can taint a complete catch if hauled in the net.

Impact on sale of fish

Fish or shellfish suspected of having become tainted, or thought to originate from a locality where an oil spill has occurred, may fetch lower prices or may even become impossible to sell. As a consequence, buyers may turn to other sources, leading to long-term losses among the fishing community and to difficulties in restoring the confidence of the market in their catches.

MARINE AQUACULTURE

The culturing of marine organisms for food is an ancient art which has, in this century, been greatly expanded by the development of new techniques, frequently based on an improved knowledge of the life cycle and biological requirements of the cultured fish or shellfish. Mariculture operations are very diverse (see ***Table R2****) and they exist in many places in coastal waters from the northern seas to tropical areas. They include some of the most sensitive systems to oil pollution and should always be clearly identified on sensitivity maps.*

HOW CAN OIL POLLUTION AFFECT MARICULTURE?

Marine and estuarine aquaculture operations are in general more vulnerable to oil pollution than wild-stock fisheries: in the case of aquaculture the fin-fish are held captive and cannot avoid the oil slicks or areas of greatest hydrocarbon concentration, and the sale of farmed seaweed, fish and shellfish is particularly dependent on a high quality, pollution-free image.

Oil spillages may affect marine aquaculture operations in several ways:

* by smothering or contaminating seaweed, culture racks and gear;
* by causing direct mortality of stocks of marketable fish or shellfish;
* by causing stress to the stocks of fish or shellfish;
* by causing tainting;
* by making harvesting difficult or impossible;
* by affecting water supplies or entering ponds through water intakes;
* by reducing prices and creating difficulties in marketing.

IMPACT OF OIL POLLUTION

Direct mortality

Cultured species most likely to be directly affected by contact with oil are those held in cages near the surface or grown on the intertidal part of the shore. Fin-fish held in cages are less vulnerable than shellfish grown on ropes or in cages close to the surface. Filter-feeding shellfish are most vulnerable, especially in water containing quantities of suspended particulate matter onto which dispersed oil has become adsorbed. Only in the most serious cases has mortality occurred; the impact of oil spillages has generally tended to be sublethal and/or to result in tainting (see below).

Stress

Experimental evidence has shown that the presence of hydrocarbons, even at very low levels, has caused stress in marine organisms. The links between pollution and susceptibility to diseases, infections and parasitism have yet to be identified in detail, but there is some evidence that caged fin-fish are more susceptible to oil pollution following a bacterial infection. Equally, it is possible that caged fish would be more susceptible to diseases or parasites following exposure to oil.

Tainting

The presence of disagreeable or unpalatable flavours in fish or shellfish is known as tainting; it has been attributed to natural causes, but is more frequently associated with oil spillages. Lobsters, mussels, oysters, clams, scallops and cultured seaweeds (see **Fiche R3**) are particulary vulnerable. Even a very small quantity of oil will cause serious tainting in shellfish stocks.

Impacts on harvesting

Harvesting of cultivated species may become impossible or difficult due to the presence of surface slicks. In addition, flotation equipment, buoys, nets, rafts, cages and ropes are likely to become contaminated by floating oil. It is extremely difficult to remove oil completely from fishing gear, especially from fine-mesh netting and other synthetic materials, and replacement is often necessary.

Impacts on water supplies

Land-based coastal fish farms require a continuous supply of clean seawater, generally drawn through intakes located below low water mark, and pumped to onshore tanks. Some onshore farms are based on simple ponds connected to the sea by a channel which floods at high water and which may be closed by valves or sluices. In both cases the presence of slicks near the coast or dispersed oil droplets may cause contamination of the pipework, tanks or ponds, loss or tainting of the stock, or shut-down of the water supply, exposing the fish or shellfish to reduced oxygen levels and increased concentrations of toxic waste products.

Recovery

Shellfish transferred to clean water or removed from the source of oil will eventually cleanse themselves; the taint will disappear after several weeks to a couple of months, but the confidence of the market and the ability of growers to sell their products may be lost for a much longer period. Cultivated species of algae are in general fast growing, and recovery is expected to take place rapidly (see also **Fiche R2**).

Impacts on Marketing

The impacts of oil spillages on the marketing of cultivated fish or shellfish are similar to those on the sale of wild-stock fish, but are generally more serious owing to the greater dependence of aquaculture on a pollution-free image. Aquaculture operations are also more heavily concentrated in suitable sites where even a minor spill may cause disproportionate damage, with consequent adverse publicity.

TABLE R2. TYPES AND METHODS OF CULTURE.

Principal species cultured, and the general methods employed, are:

*	*Mussels: extensive culture*	Laid on the sea bed in intertidal or shallow subtidal sheltered waters.
*	*Mussels: suspended culture*	Attached to ropes or frames hung from rafts or horizontal long-lines.
*	*Mussels: bouchot culture*	Grown on wooden posts placed in the intertidal area.
*	*Oysters: bottom culture*	Laid on the sea bed in shallow subtidal sheltered waters, or placed in net mesh bags on trestles at low water mark, or in coastal ponds.
*	*Clams: bottom culture*	Grown on gravel or sand beds in shallow water.
*	*Scallops: bottom culture*	Laid on the sea bed in subtidal areas.
*	*Salmon/trout: cage culture*	Grown in floating cages anchored in sheltered or semi-exposed inlets of the sea.
*	*Salmon/trout: land-based seawater.*	Grown in ponds or tanks adjacent to the coast, and relying on a supply of clean
*	*Shrimp ponds*	Various species raised in artificial ponds having one or more connections with the sea (tropical waters).
*	*Seaweed farms*	Marine algae grown on extensive artificial fixed and floating structures (e.g. racks, poles, ropes) in many shallow areas (tropical waters).

NOTE: Research is being conducted into the culture of other species such as prawns, shrimps, abalone, and marine fin-fish. The results of this research may further expand the range of species cultured, although the methods are likely to fall into one of the above categories.

SEAWEED HARVESTING

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*Seaweeds, referred to as macroalgae to distinguish them from microscopic algae in the plankton, are important components of intertidal ecosystems especially on sheltered rocky shores. Seaweeds are harvested on European coasts (see **Fiche R4**) primarily as a fertiliser and soil conditioner, either by direct application or after drying, fragmentation and mixing with other materials. Worldwide, they are also harvested industrially for the extraction of alginates and pharmaceutical substances and, on a smaller scale, as a food constituent (e.g. dulse or dilisk, carrageen moss, laver). In the far East, notably Japan, China and South Korea, seaweeds are cultivated extensively as seafood (see **Fiche R2***

ECOLOGICAL IMPORTANCE OF SEAWEEDS

The presence of seaweeds provides shelter and a range of specialised habitats for many invertebrates and for other species of algae (epiphytes) which grow on the larger seaweeds. Algal spores provide a food supply for grazing molluscs, while the fragmentation of dead algae washed from their attachments by wave action (especially during storms) contributes to the supply of organic detritus. See also the discussion of rocky shore environments in **Fiches E1** and **E7**.

HOW CAN OIL POLLUTION AFFECT SEAWEED HARVESTING?

Oil spillages may affect seaweed harvesting in several ways:

* by causing direct mortality of the plants;
* by smothering the seaweed, destroying its market value;
* by contaminating or tainting the seaweed;
* by killing reproductive products;
* by favouring the replacement of valuable seaweed by fast-growing algae on the denuded substrate.

EFFECTS OF OIL POLLUTION

Sensitivity of macroalgae to oil

Very small concentration of hydrocarbons in water have been shown experimentally to cause die-back in growing plants. Algal sperm have been shown to be sensitive to concentrations of oil as low as 0.2 microgrammes per litre. Algae growing in the intertidal zone are most vulnerable to oiling, and are liable to be most seriously affected by a spillage. Following the **Amoco Cadiz** and **Arrow** oil spillages, large masses of oil-contaminated algae became detached from their rocky substrate and were washed ashore. Subtidal algae appear to be less sensitive - and beds of kelp (*Laminaria* sp.) did not appear to be affected at the site of the **Amoco Cadiz** oil spillage.

Impact of oil on seaweed harvesting

Naturally occurring seaweeds harvested on European coasts include kelp plants (*Laminaria* and *Saccorhiza* species) cast ashore after storms or raked from rocky subtidal areas, and bladder wrack (*Ascophyllum nodosum*) cut from intertidal rocky platforms. The latter is more vulnerable to oil pollution, as it floats near or on the water surface, and would therefore come into direct contact with oil slicks stranding on the shore. While a certain amount of oil may not necessarily damage the fertiliser and soil conditioning values of the seaweed (see **Fiche R4**), it would destroy its value for alginate extraction. Seaweeds such as laver (*Ulva* and *Porphyra* species), carrageen moss (*Chondrus crispus*) and dulse harvested directly for food would become tainted and unsaleable following even a minor amount of oil pollution.

Recovery

Most species of algae will recover quickly after damage by oil pollution, but there is evidence that kelp forests and some slow-growing species such as *Ascophyllum*, if seriously damaged, may recover only very slowly or not at all. In contrast, some species of algae proliferate extensively after their predators have been reduced by the impact of an oil spill. Blooms of opportunistic green algae such as *Enteromorpha* have occurred after oil spills affecting rocky shores; these may be accompanied by settlements of *Ulva lactuca* and followed by settlement and growth of the *Fucus* species destroyed initially by the spill. For one or two years the shore is dominated by the green algae before its original appearance is restored in the third or fourth years following the spillage.

COASTAL AGRICULTURE

The combination of fertile land and an equable climate as a consequence of close proximity to the sea has resulted in many of Europe's coastal areas becoming important for agriculture. Examples include vegetable and flower growing, over-wintering of cattle and sheep grazing. Where these lands are low-lying or close to sea level, the agriculture may be affected by oil following a spillage.

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HOW CAN OIL POLLUTION AFFECT AGRICULTURE?

Agricultural activities on the coast may be affected by:

* oil droplets or aerosol carried inshore by high winds or sea-spray, causing damage to crops;
* unavailability of seaweed as a fertiliser because of oil pollution;
* damage to sheep grazing on intertidal seaweeds.

IMPACT OF OIL POLLUTION

Damage to crops

Where a major incident has led to the stranding of slicks on the shore or has brought large amounts of floating oil close to the coast, high onshore winds are likely to carry oily spray and an aerosol of oil droplets onto crops. As a result, the crops may be defoliated, tainted or damaged in some other way. It is understood that this type of impact occurred in a few places along the coast of Brittany following the **Amoco Cadiz** oil spillage in 1978, but the extent of the damage was probably limited.

Loss of seaweed fertiliser

Seaweed is collected regularly as a fertiliser and land conditioner on western coasts of Europe, particularly in Brittany where it is also used as animal fodder, and in Ireland and Scotland (see **Fiche R3**). The loss of this seaweed following a major oil pollution incident could arise because:

* farmers were unwilling to apply oiled seaweed to their land despite there being no evidence that this would cause long-term damage to crops (oil adhering to seaweed ploughed into land would in most cases be degraded fairly quickly by bacteria present in the soil); or

* die-back of the seaweed resulted in a loss or complete elimination of a harvestable crop until recolonization of the shore by algal spores.

Damage to cattle/sheep

In low-lying areas, grazing land can become oiled on high tides. On the coast of the Shetland and Orkney islands, sheep also graze on intertidal seaweeds, particularly in winter. On several occasions following spillages of oil which impacted the shore, sheep suffered oiling of their fleeces. The market value of the wool was lost and, in a few cases, sheep were killed as a result of eating oil-contaminated seaweed.

MAMMALS

Marine mammals include seals, sea otters, whales, dolphins, porpoises, sea lions, walruses, polar bears and manatees. All of these are top-level or high order predators, except for the manatee which feeds on submerged vegetation. Sea otters are also endangered species, while most sea mammals (especially seals and dolphins) excite positive human emotions and considerable efforts are made to save them from death or injury caused by pollution.

HOW DOES OIL POLLUTION AFFECT MAMMALS?

Oil affects marine mammals mostly through the following mechanisms:

* loss of body heat following oiling of fur;
* skin lesions and eye damage caused by direct contact with the oil;
* pathology of internal organs when oil is ingested (long term exposure).

EFFECTS OF OIL ON MAMMALS

Vulnerability

The necessity to breathe air increases the possibility that marine mammals will make unavoidable contact with spilled oil on the sea surface. In addition, most species haul out on offshore banks, rocks, islands or ice floes to rest; and they also congregate in large numbers for breeding purposes. Observations of seals, sea otters, whales and dolphins have shown that they do not actively avoid oil or oil-covered water. Little is known about the capability or willingness of other species to detect or avoid oil-contaminated water.

Unlike fish, the body surface of mammals is easily fouled by oil, especially if the body is covered by fur or hairs. Sea otters and seals are capable of removing oil by grooming, but this will result in ingestion of some oil and may lead to illness and death.

Effects of direct contact with oil

Fur-insulated marine mammals suffer changes in body temperature and metabolism following contact with oil. Body heat is lost more easily through the oiled fur, and the metabolic rate increases in order to compensate and maintain core temperature. This may lead to stress and, in cold weather, to death by hypothermia or heat loss. Small amounts of crude oil exert a great effect on the thermal conductance of long hair pelts, but comparatively little effect on short hair pelts.

Contact with oil also causes surface lesions in the skin, especially around the eyes which may become damaged. The effect of such damage on the long-term survival of the animal is unknown.

Effects of ingestion

Ingestion of oil by grooming also leads to stress, to contamination of internal tissues by hydrocarbons, followed by eventual excretion of petroleum residues. There is no evidence that short-term exposure to oil has caused internal physiological changes which have been so severe as to cause death. Long-term exposure has caused severe pathological abnormalities, with possible kidney failure as the ultimate cause of death.

Recovery

Unless subjected to very heavy oiling, most individual mammals will recover fairly quickly. Seals probably take the longest time to recover, while cetaceans (whales) suffer only transient effects. Unlike birds, little is known about suitable methods for, or the effectiveness of, rehabilitation or oil removal methods. Capturing marine mammals, and caring for them while cleaning and oil removal are undertaken, is likely to be extremely difficult.

Recovery of marine mammal populations after loss of a significant number of individuals will depend on the species reproductive behaviour and capacity, including the age at which sexual maturity is attained. Species taking longest to recover are those which do not reach sexual maturity for several years, have few offspring each breeding season, and do not breed every year. Such species include sea otters, polar bears, sea lions, fur seals, elephant seals, dolphins and whales.

BIRDS

Birds are generally susceptible to oil pollution, and any mortality of seabirds receives considerable publicity. The death of birds from oiling generates widespread adverse reaction from conservationists and members of the public, probably because of the strong visual impact created by oil-contaminated birds. Excessive mortality of seabirds from oil pollution in the 1960s and 1970s was one of the principal factors which led to more stringent controls on the discharges of oil at sea. Birds at risk include seabirds and other waterfowl species which extend their range to saltwater habitats. They vary greatly in behaviour: some are waders, others divers, some are more mobile than others. Their vulnerability to oil pollution depends largely on their behaviour and habits.

HOW DOES OIL POLLUTION AFFECT BIRDS?

The impact of oil pollution on seabirds should be considered at two different levels:

* at the individual level, birds are affected directly or, less significantly, indirectly by the oil, and they may die or suffer a diminished resistance to disease and other adverse factors (see also box on rehabilitation of oiled birds at the end of this fiche);

* at the population level, large concentrations or breeding colonies of particularly sensitive species may be hit by an oil spill and become endangered locally as a result of massive mortalities; this is the type of impact which causes the greatest concern to environmentalists (see also box on estimation of bird mortalities).

EFFECTS OF OIL ON INDIVIDUAL BIRDS

Direct effects

The direct effects of oil on seabirds may be summarized as:

* clogging the fine structure of the feathers, and leading to a loss of the feathers' insulating and water-repellent qualities;
* loss of buoyancy and body heat by the bird, leading to death by drowning or by hypothermia;
* exhaustion of the fat and muscular energy reserves as a consequence of the need to increase metabolic activity in an attempt to maintain body temperature;
* ingestion of oil as a consequence of preening oiled plumage;
* impact of the ingested hydrocarbons on the bird's internal physiology, including liver and kidney damage, interference with excretion of salt, temporary depression of egg laying, and reduction of the hatching success of those eggs that are laid.

Indirect effects

Individual birds may also be indirectly affected through eating oil-contaminated food organisms, but this is not considered to be a major cause of bird deaths.

EFFECTS OF OIL ON BIRD POPULATIONS

Vulnerability/ Sensitivity

Birds most at risk are those which congregate in large numbers in coastal waters or on intertidal shores to breed, feed, roost or moult. Among these, diving and swimming species are the most vulnerable. More solitary species such as cormorants, gannets and pelicans which dive to feed can also be affected by oil pollution.

The sensitivity of bird populations depends on the above factors but also on the species' reproductive capacity, breeding habits, population size and seasonal exposure to waters liable to become polluted by oil. Oil vulnerability indices have been produced by a number of researchers; these are based on evaluating survival factors and assigning a vulnerability ranking to each species. A simple ranking in two groups is presented below in Table T2 for first guidance.

Seabird mortalities

Estimated mortalities sustained by seabird populations following some major spills on the coast of Europe range from 6,000 (guillemots and razorbills affected by 600 to 700 tonnes of fuel oil from the tanker **Hamilton Trader** in the Irish Sea in 1969) to 275,000 (scoter affected by 8,000 tonnes of crude oil from the **Gerd Maersk** in the Elbe River in 1955). No consistent relationship is found between the volume of oil spilled and bird mortality. Even small amounts of heavy oil, spilled close to seabird colonies during the breeding season, can have an adverse effect out of all proportion to their size.

Recovery

Seabird populations have recovered from major mortalities, but recovery is generally slow. Species which are very sensitive such as auks (puffins, razorbills) and grebes, are long-lived, do not breed until they are three or more years old, may have only a single egg per year, and do not breed every year. These factors make it difficult for such species to restore their numbers quickly following an oil spill.

However, not all mature birds may be breeding, and these non-breeding adults constitute a dispersed reservoir from which birds lost through contact with oil may be replaced. Recovery is most difficult and uncertain in the case of isolated breeding populations where there may be a low probability of replacement from other colonies. Colonies of small populations exposed to other stresses, e.g. through being exposed to other pollutants or being at the limit of their geographical range, may find survival difficult after significant mortality.

ESTIMATION OF SEABIRD MORTALITIES

An accurate estimate of the number of seabird casualties from oil pollution is not possible. The only figures available are those based on counts of oiled birds found on shore surveys, but these figures are subject to limitations imposed by the difficulties of searching and counting on inaccessible shores, by the reporting efficiency of teams engaged in oil spill cleanup, and by the unknown proportion of birds which die at sea. It has been estimated that fewer than 30% of oiled bird corpses drift ashore.

TABLE T2. **Sensitivity of representative bird species to oil pollution.**

Sensitive species		**Less sensitive species**	
Puffin	*Fratercula arctica*	Great northern diver	*Gavia immer*
Auk	*Plautus alle*	Gulls	Family Laridae, *Larus* spp.
Guillemot	*Uria aalge*		
Eiderduck	*Somateria mollisima*	Terns	*Sterna* spp.
Scoter	*Melanitta nigra*	Skuas	*Stercocarius* spp.
Long-tailed duck	*Clangula hyemalis*	Gannet	*Sula bassana*
Razorbill	*Alca torda*	Frigate birds	*Fregata* spp.
Grebe	*Podiceps* spp.	Albatrosses	Family Diomedeidae
Merganser	*Mergus serrator*		
Shearwater	*Puffinus* spp.		
Fulmar	*Fulmarus glacialis*	Shorebirds	
Cormorant	*Phalacrocorax carbo*		
Shag	*P. aristotelis*	Most waders	
Kittiwake	*Rissa tridactyla*		
Swans	*Cygnus* spp.		
Geese	*Anser* spp., *Branta* spp.		
Phalaropes	*Phalaropus* spp.		
Loons	*Gavia* spp.		

CLEANING AND REHABILITATION OF OILED BIRDS

The cleaning of oiled seabirds is a slow process requiring some training and expertise, considerable patience and devotion to the animal's welfare. It cannot be said to contribute significantly to the recovery of the affected bird population, and it is worthwhile primarily for humanitarian reasons. Care should be taken however that unnecessary distress is not caused to the birds by handling and by the necessary long-term captivity.

FISH

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*Fin-fish are very diverse in their ecology, life history, behaviour and vulnerability to oil pollution. Fish include open-water, migratory species as well as coastal, sedentary types. Some feed on plankton, some are predators, others are bottom dwellers feeding on the seabed flora or fauna. Many fish produce planktonic eggs and larvae but some important pelagic species such as herring produce demersal eggs which they attach to the seabed. The impact of oil pollution on fisheries and fishing activities is described in **Fiche R1**. Here we summarise the effects of oil on individual fish and on fish populations.*

HOW DOES OIL POLLUTION AFFECT FISH?

Individual fish can be affected *directly* by oil spills through:

* ingestion of oil droplets or of oil-contaminated prey;
* uptake of dissolved petroleum compounds through the gills or other body surfaces;
* impairment of the viability of fish eggs and of the survival of fish larvae.

In addition, fish may be affected *indirectly* by oil-induced changes in their habitat or in the ecosystem which supports them.

EFFECTS OF OIL ON FISH POPULATIONS

Effects of severe oil spill impact

Fish populations have shown no sign of significant long-term reduction, even following major oil pollution incidents. Even where larval and juvenile mortalities have been serious, the losses caused by pollution have been masked by the enormous number of young produced, only a small percentage of which survive under natural conditions. The impact of oil spills on fish stocks is also discussed in **Fiche R1**.

Effects of oil on fish schools

When exposed to low levels of oil, fish may lose their normal schooling behaviour and become disoriented, possibly because of effects on the olfactory organs or lateral lines of the fish. Adult fish appear to be able to avoid oil-contaminated water, but not enough is known about the avoidance mechanism or behaviour to be able to say whether or not this ability would be used by fish in a particular situation.

Recovery

Pelagic fish populations do probably recover quickly after a spill impact, larval and adult immigrants replacing the losses. Local breeding populations which congregate in spawning and nursery grounds in shallow areas may take longer to recover if such areas have been severely impacted.

EFFECTS OF OIL ON INDIVIDUAL FISH

Vulnerability

Adult fish are affected by oil pollution to a lesser extent than many other marine organisms, perhaps because of their higher mobility which may reduce their exposure to contaminated water masses. In this respect flat fish which stay in close contact with oiled sediments are exposed to greater risk than pelagic species. Fish metabolize polynuclear aromatic hydrocarbons (PAHs) in their liver and excrete the derivatives concentrated in the bile. Fish are most vulnerable in their early stages of development, and eggs and larvae can suffer considerable losses at low oil concentrations.

Mortality of adults

Adult fish are not normally exposed to high levels of hydrocarbons in water except following major spillages close to the shore or in shallow-water environments such as estuaries (**Fiche E9**). Severe mortality of inshore fish species can result from oil spills in these environments. Following the ***Arrow*** and ***Amoco Cadiz*** spills, there was an immediate mortality of shallow-water demersal fish, but the populations recovered quickly.

Sublethal effects

Longer-term sublethal effects noted in experimental and field situations include:

* increased vulnerability to disease;
* reduction in the rate of tissue repair/regeneration;
* decrease in the growth rate.

Effects on reproduction

Hydrocarbon concentrations of less than 1 ppm have been shown to decrease the ability of adult fish to reproduce through damage caused to gonadal tissues.

Effects on development

Laboratory and field studies have shown that a range of developmental processes can be affected by exposure to hydrocarbons. The hatching success of fish eggs exposed to hydrocarbons was found to be markedly reduced, and many of the larvae which eventually hatched were found to be deformed and incapable of swimming.

The most vulnerable stages appear to be during the early development of the embryo and the transition of the fish larva from feeding on the egg yolk to using external sources of food. The responses of fish larvae to petroleum hydrocarbons include a brief increase in activity, followed by reduced activity, sporadic twitching, narcosis, and eventual death.

Chromosome abnormalities have been experimentally demonstrated in fish exposed to very low levels of hydrocarbons in the laboratory (0.1 microgrammes per litre), but there is no evidence of similar genetic damage to natural fish populations affected by oil spillages.

CRUSTACEANS

Crustaceans, the group to which crabs, lobsters, shrimps and prawns belong, are distinguished by a hard outer shell, composed of movable plates, constituting an exoskeleton which must be shed or moulted periodically to allow growth to take place. The exoskeleton protects the soft interior parts, and in many species is raised into spines which serve as additional protection from predators. Crustaceans form the bulk of the animal plankton (zooplankton) and constitute therefore the major source of food for marine fish. Certain species of Antarctic shrimp are so numerous that they are believed to outnumber any other living animals, with the exception of micro-organisms.

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HOW DOES OIL POLLUTION AFFECT CRUSTACEANS?

Oil contamination may affect crustaceans by:

* clogging gills or feeding mechanisms;
* adhering to body surfaces;
* ingestion of oil droplets or of oil-contaminated sediments, particulate matter or prey;
* uptake of dissolved petroleum compounds through the gills or other body surfaces.
* disturbing behaviour, even at low ambient concentrations.

EFFECTS OF OIL ON CRUSTACEANS

Vulnerability

The most vulnerable crustaceans are those living in the intertidal zone in sheltered environments, particularly those species feeding on detritus or on suspended particulates. These include amphipods, copepods, and some decapod crustaceans (e.g. crabs). Mortalities are common in heavily oiled areas. Species such as barnacles which have the ability to close their shells when uncovered by the tide are less vulnerable.

Effects on behaviour

Crustaceans have been shown to respond to low concentrations of oil in seawater with changes in behaviour. Feeding may become inhibited by the presence of hydrocarbons. Communication systems based on the production of pheromones (hormone-like substances released in the environment by these organisms) may be disturbed, leading to a decrease in the encounter rate of individuals or disruption of their mating behaviour.

Effects on development	The eggs and larvae of crustaceans are generally sensitive to hydrocarbons, and low levels of petroleum will reduce hatching success and will alter or delay the development of the larva. Reduced juvenile settlement, problems with recruitment, and a reduction in the population density appear to be directly related to oil concentration, especially in soft sediment.
Indirect effects	Amphipods, isopods and adult shore crabs were killed in large numbers near the site of the **Amoco Cadiz** oil spill but shrimp populations grew significantly, perhaps because of a decrease in pressure from predators or competitors, and copepod populations living among the macroalgae increased in number by a factor of 20.
Recovery	Some species of crustaceans, notably decapods (crabs, lobsters and shrimp-like crustaceans), have sustained marked and long-term reproductive damage at oiled sites. Most species of smaller crustaceans which reproduce at frequent intervals will recover quickly, or may even increase their populations very rapidly in the short term.

MOLLUSCS

Molluscs include many species of commercially important shellfish (oysters, mussels, scallops, clams, abalone, and periwinkles), distinguished by having a hard outer shell to which additional calcareous material is added as the animal grows. The shell provides protection for the soft-bodied organism within, and two principal forms are common in the marine environment: bivalves (two similar shells hinged together along one edge) and gastropods (a single shell, usually either conical or wound in the form of a spiral, snail-like).

HOW DOES OIL POLLUTION AFFECT MOLLUSCS?

Bivalves feed generally either by filtering plankton and other small organic particles from the water or by sifting mobile layers of sediment on the sea bed. Gastropod snails feed generally by grazing microscopic algae from hard surfaces or by sweeping up detritus; some species are predatory on other marine animals. Because of these modes of feeding (filtering deposit-feeding and grazing), molluscs are generally very sensitive to:

* dispersed droplets of oil in water,
* oil on superficial sediments, and
* presence of oil on the surfaces of rocks and other grazing areas.

EFFECTS OF OIL ON MOLLUSCS

Vulnerability

Species most at risk are the **intertidal species** which may be affected directly by oil. Bivalves are protected to some extent by their normal reaction of closing their shells and lowering their metabolism when uncovered by water. Gastropods such as limpets may easily be covered or smothered by heavy oil, and they become exposed to dissolved hydrocarbons. Molluscs living in intertidal and subtidal **sediments** are susceptible to the sinking or deposition of oil-contaminated particulate matter. Bivalves bioaccumulate oil compounds, particularly the polynuclear aromatic hydrocarbons (PAHs) and lipophilic derivatives, and their ability to metabolize these compounds is limited.

Sensitivity

Some bivalves have been found to survive in sediments containing very high levels of petroleum hydrocarbons. Clams, however, have exhibited altered metabolic and feeding rates, reduced filtration, restriction in growth, and alteration in their shell formation following exposure to oil. Oysters are highly susceptible to tainting, and oil is known to cause inhibition of gonad development in mussels. Oil also disturbs the chemotactic perception of food in snails. Mobile species such as littorinid snails (periwinkles) are susceptible to becoming narcotised by lighter and more toxic petroleum fractions. As a result, they may be loosened from their attachment to the rocky or algal substrate, and be washed into deeper water or become easy prey to their predators.

Recovery

Bivalves affected by oil pollution at the sublethal level will depurate rather quickly once conditions have returned to normal, but populations that have been decimated by an oil spill will require new larval settlement and several years of growth to recover. Gastropods being mobile will repopulate affected areas more readily, but lasting ecological changes in the habitat are likely to inhibit or delay population recovery (see e.g. **Fiches E1** and **E7**).

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GLOSSARY OF TECHNICAL TERMS

Aerosol. Suspension of liquid droplets in air.

Aquaculture. The growing or farming of aquatic organisms such as fish, shellfish or seaweed, in fresh or salt water, for food or other purposes.

Algae. Class of simple non-flowering plants to which marine seaweeds belong. Microscopic algae are important members of the plankton (q.v.).

Amphipods. Group of small crustaceans (q.v.) feeding mainly on detritus and inhabiting intertidal areas.

Benthic. Refers to the bed of the sea; benthic organisms are those which live on the sea bed.

Biota. A general term for all living organisms, plants and animals.

Bio-accumulation. Accumulation of metals, hydrocarbons or other substances by living organisms in their tissues.

Bivalves. Shellfish with two plates or valves; examples include mussels, oysters, clams, cockles.

Blooms. Growth or outbursts of phytoplankton (q.v.) triggered by nutrients from natural sources or discharges. Unusual, excessive blooms are known as red tides.

Bouchot culture. Farming of shellfish, particularly mussels, on vertical posts in intertidal sand/mud flats.

Calcareous. Rich in calcium or lime.

Carcinogen. Cancer-causing agent.

Chemotactic. The reaction or behaviour of a living organism to chemical stimuli.

Chronic. Long-term and debilitating; e.g. chronic pollution is caused by continuous or repeated spillages.

Chocolate mousse. A bulky and viscous emulsion of water in oil also called inverse emulsion.

Communities. Used to describe groups of living species occupying the same habitat (q.v.) and interacting with each other; they are held together as units by the interdependence of their members.

Copepods. Group of generally microscopic crustaceans (q.v.), some species of which occur in enormous shoals and are important as food for fish and whales.

Crustaceans. A class of animals distinguished by a hard outer shell, composed of movable plates, constituting an exoskeleton (q.v.) which must be shed periodically to permit growth. They are mostly aquatic and include both free-swimming and attached animals. Examples : crabs, lobsters, shrimps, barnacles.

Decapods. Group of crustaceans (q.v.) in which the largest five pairs of limbs are adapted for locomotion by walking or swimming; the first of these pairs is usually equipped with claws. Examples include crayfish, crabs, lobsters, prawns and shrimps.

Demersal. Living on or near the bottom of the sea – a term generally applied to bottom-feeding fish such as cod, whiting, haddock, plaice, sole.

Depurate. Remove impurities – a term generally used for the removal of pathogenic (q.v.) bacteria from shellfish.

Detritus. Biological debris : fragments of dead organisms.

Echinoderms. Phylum or distinctive group of marine animals, radially symmetrical, and star-shaped or globular; includes starfish, brittle stars, sea urchins, sea cucumbers and sea lilies.

Ecosystem. Ecological system composed of interacting organisms and their environment; an area or subdivision of the natural environment that includes living organisms and non-living substances interacting with each other so that materials and/or energy are exchanged between the living and non-living parts.

Embryo. An organism at an early stage of development before birth or hatching.

Enteromopha. A type of green alga or seaweed common in brackish areas.

Epiphytic. Living on, or attached to, the surface of a plant.

Epipsammic. Living at the water-sand interface.

Estuary. A river mouth where tidal action brings about a mixing of salt and fresh water – for a more detailed definition see Fiche E9.

Exoskeleton. External skeleton of hard plates, protecting the inner soft parts of crustaceans (q.v.).

Fecundity. Power of a species to multiply rapidly; capacity to reproduce.

Filter-feeding. Method of feeding by which small particles are removed from the water; common among shellfish.

Flatworms. Primitive and simple worm-like animals, both free-living and parasitic, flattened or ribbon-like in appearance.

Food web. The transfer of food energy from its source in plants through a series of organisms with repeated eating and being eaten is referred to as a food chain. Food chains are not isolated sequences but are interconnected in a pattern referred to as a food web.

Gastropods. Snail-like molluscs (q.v.) with a muscular foot adapted for locomotion; many marine species live by grazing microalgae from rock surfaces.

Gonadal. Referring to the gonads or reproductive parts of the organism.

Habitat. The locality or external environment in which a plant or animal lives.

Heterocyclic. Hydrocarbons containing elements other than carbon in their ring structures, e.g. sulphur or nitrogen.

Hydroids. Small colonial organisms attached to rocks or seaweeds, with a free-swimming phase called a medusa (like a small jellyfish) whose eggs develop into a new generation of sessile or attached organisms.

Hypothermia. Drop in body temperature, leading frequently to death by heat loss.

Ichthyoplankton. Small fish and fish larvae (q.v.) which form part of the plankton (q.v.) community.

Interstitial. Referring to the microscopic flora and fauna living in the spaces between sand grains or mud particles, and to water occurring in the same spaces.

Intertidal. Between high-water mark and low-water mark.

Invertebrates. Animals without spinal columns or backbones.

Isopods. Group of crustaceans (q.v.), some of which are parasitic, and others include the common wood louse and the sea slater (*Ligia* sp.).

Kelp. Generic name for large seaweeds growing at or below low water mark, generally *Laminaria* or *Saccorhiza* species.

Lamellibranchs. Molluscan shellfish with plate-like gills enclosed in a shell that develops as two similar valves (see bivalves).

Larvae. Very young animals beyond the embryo (q.v.) stage which become self-sustaining and independent before assuming the characteristic adult features of the organism.

Laternal Line. Longitudinal line at each side of the body of a fish, marking the position of sensory cells.

Lesions. Damage or injury to an organ; in the case of skin damage generally accompanied by a break in the skin.

Lichen. Primitive plant consisting of a symbiotic association of a fungus with an alga; common on rocks above high-water mark.

Littorinid. A type of gastropod (q.v.) or marine snail common in and above the intertidal zone; some species spend more time exposed to air than sumerged in water.

Macroalgae. Large seaweeds or algae (q.v.).

Macrofauna. Larger animals, visible to the naked eye, in contrast to microfauna.

Macrophytes. Larger plants of any type, including macroalgae (q.v.) and sea grass.

Manatee. Large aquatic herbivorous mammal; sea cow.

Mariculture. Culture or farming of fish, shellfish or seaweed in the marine environment (a specific type of aquaculture – q.v.).

Maritime flora. Plants, especially flowering plants, found living near the sea, generally on cliffs or on the shore above high-water mark.

Meiofauna. Animals larger than microscopic, yet barely visible to the naked eye.

Microbes. Micro-organisms, primarily bacteria.

Molluscs. Phylum of soft-bodied animals with a calcareous shell which is usually external but may be concealed; types of molluscs common in the marine environment include bivalves (q.v.), gastropods (q.v.), and cephalopods (the squids and octopuses). See also Fiche T5.

Narcosis. State of unconsciousness or stupor produced by a drug or by a chemical pollutant which affects the nervous system.

Nematodes. Group of small unsegmented worms; may be free-living or parasitic.

Nutrients. Soluble substances essential to life; primarily salts of nitrogen and phosphorus, but also including potassium, calcium, sulphur, magnesium, iron and silicon (referred to as micronutrients).

Oligochaetes. Class of segmented worms with a fairly smooth surface; includes earthworms and a number of aquatic species; contrast polychaetes (q.v.).

Pathogen. Micro-organism which causes disease.

Pathology. Science dealing with disease and with breakdown of the structures or functions of living organisms.

Pelagic. Living or feeding in the water column between the bottom and surface of the sea, generally applied to schooling fish such as mackerel, herring and sprat.

Pergolaria. Vertical open-mesh tubes of netting, used in mariculture for growing mussels.

Pheromones. Hormone-like substance released by a living organism into the water in order to convey information to other individuals of the same species.

Phytoplanton. The microscopic algae floating in the plankton (q.v.) community.

Pioneers. Species which are the first to recolonise an area or surface which has been denuded of living organisms.

Plankton. The floating organisms whose movements are more or less dependent on currents. See also phytoplankton and zooplankton.

Pneumatophores. Air-breathing roots of mangrove plants (see Fiche E11).

Polychaetes. Class of segmented marine worms with numerous chaetae or bristles arising from a series of protrusions along each side of the body; generally burrowing but some may be free-swimming or parasitic.

Productivity. The basic or primary productivity of an ecosytem is the rate at which energy is stored by producer organisms (chiefly green plants) in the form of organic substances which can be used as food by other organisms; generally measured as grams or organic matter accumulated per square metre per day.

Recruitment. Term used to describe addition to the adult stock of young fish as they become large enough to be fished commercially. See Fiche R1.

Resilience. The ability of a biological community to recover or to return to its natural state following a perturbation or disturbance caused by a natural or man-made event. See Fiche G4.

Resistance. The ability to withstand stress without change.

Rhizophora. Species of mangrove plant (see Fiche E11).

Sensitivity. The sensitivity of a population expresses the ease with which its members may be damaged or harmed by disturbance or pollution, e.g. by oil. The sensitivity of an ecosystem depends on more than the simple sensitivity of its biological components. For a fuller explanation see Fiche G4.

Scoter. A type of sea duck.

Sessile. Attached or stationary, fixed to the substrate (q.v.), as opposed to mobile.

Slick. Visible layer of oil on the surface of the sea, generally smoother than the surrounding unpolluted sea surface.

Soluble aromatic derivatives. Water-soluble substances, generally toxic, derived from the partial breakdown of aromatic hydrocarbons.

Splash zone. Part of the shore above high-water mark and exposed to wetting by splash or spray. Contains maritime plants and marine organisms adapted to exposure to air. See also supra-littoral.

Sublittoral. The deeper part of the littoral or shore zone; its upper boundary is uncovered only during spring tides, and most of the sublittoral is never exposed to the air.

Substrate. Surface to which a sessile or sedentary marine organism attaches itself or into which it burrows; generally rock or mud.

Succession. Ecological succession is the orderly process of community (q.v.) change, that is the sequence of communities which naturally replace one another in a given area. See Fiche G4.

Supratidal. Above high-water mark of the highest spring tides. See also splash zone.

Surface microlayer. The aquatic side of the interface between the water surface and the air; inhabited by organisms swimming or resting on the surface, and sensitive to pollution by floating debris or slicks (q.v.).

Suspended culture. Farming of mussels or other shellfish on ropes or nets hung from floating buoys or rafts.

Tainting. Incorporation of enough oil components in the tissues of fish and shellfish to give these products an unpleasant hydrocarbon taste when eaten by men.

Tidal range. Vertical distance between high water and low water; it is greatest at spring tides and least at neap tides.

Volatilised. Said of the volatile fractions lost by evaporation.

Vulnerability. The vulnerability of a habitat or an environment is the ease with which oil can penetrate and persist in the environment. For a detailed explanation see Fiche G4.

Wild-stock. Free-swimming populations of commercial fish species, in contrast to farmed or cultivated fish.

Zonation. Refers to the way in which communities of sessile or relatively inactive animals and plants are ditributed vertically on the shore or away from the shore as a result of climatic conditions or exposure to wave action, forming broad and clearly visible horizontal bands.

Zooplankton. The microscopic animal members of the plankton (q.v.) community.

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