Effects of Pollutants at the Ecosystem Level
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CASE 7.5

Accidental Oil Spills: Biological and Ecological Consequences of Accidents in French Waters on Commercially Exploitable Living Marine Resources

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7.5.1 INTRODUCTION

Torrey Canyon, The name of the 118 000-tonne Liberian tanker that went aground off Land's End in the United Kingdom on 18 March 1967, still conjures up unpleasant memories. Although far from being the first accident involving an oil tanker, it was the first time that such a large quantity of oil (over 80 000 tonnes) was spilled into the sea and caused so much damage to marine life. Since then more than twenty or so accidents of the same type have occurred all over the world. Some, like the wreck of the *Amoco Cadiz* off Brittany in 1978 or the blowout at the Ixtoc well off Campeche in the Gulf of Mexico, have each involved quantities of oil in excess of 200 000 tonnes.

Why this sudden and disturbing increase? It may be ascribed mainly to:

1. The spectacular expansion in world oil production from 280 million tonnes in 1938 to over 3000 million tonnes in 1980.
2. The increase in tanker size from 10 000 tonnes at the begnning of the century to over 500 000 tonnes now.
3. The increase in the amout of drilling and the number of production wells offshore.

One of the areas most frequently and most seriously affected by such accidents is the south coast of the English Channel, particularly the coast of Brittany, which has suffered five major spills in the last 8 years caused by the *Olympic Bravery* in February 1976, the *Bohlen* in October of the same year, the *Amoco Cadiz* on 16 March 1978, the *Gino* on 28 April 1979 and the *Tanio* on 7 March 1980 (Table 7.5.1). These accidents clearly showed that the extent of damage to marine life does not depend entirely on the amount of oil spilled. There are also several other

Table 7.5.1 Summary of some significant oil spills of the past few years. (Modified from Maurin, 1981. Reproduced by permission of Centre National pour l'Exploitation des Oceans)

Event	Date	Quantity Spilled (t)	Location
Torrey Canyon	1967	117 000	Cornwall
World Glory	1968	45 000	Durban
Ocean Eagle	1968	10 000	Puerto Rico
Arrow	1970	12 000	Canada
Polycommander	1970	13 000	Spain
Oceanic Grandeur	1970	35 000	Straits of Torres
Chryssi	1970	31 000	NE Bermuda
Texaco Oklahoma	1971	30 000	East Coast USA
Ennerdale	1971	42 000	Seychelles Islands
Trader	1972	35 000	Mediterranean Sea
Nelson	1973	20 000	Bermuda
Metula	1974	50 000	Straits of Magellan
Olympic Bravery	1976	1 000	Brittany
Bohlen	1976	10 000	Brittany
Urquiola	1976	107 000	Spain
Ekofisk	1977	20 000	North Sea
Amoco Cadiz	1978	230 000	Brittany
Gino	1979	40 500	Brittany
Ixtoc	1979	500 000	Mexico
Tanio	1980	6 500	Brittany

factors which help to aggravate or—quite the contrary—limit the damage caused by oil products. These are, in particular:

1. The site of the spill.
2. The physical and chemical properties of the oil.
3. The time of year at which the accident occurs.

To this list should also be added the effects of the agents used to treat the oil.

The aim of this case study is to assess the effects on exploitable living marine resources of those accidents which have taken place in French waters. The assessment will be based mainly on data gathered after the *Amoco Cadiz* and *Gino* accidents. These occurred in very different conditions and involved entirely distinct types of oil.

In the case of the *Amoco Cadiz*, the vessel grounded on a reef immediately off a rocky coast; its cargo tanks contained 223 000 tonnes of light crude which was less dense than sea water and not very viscous. The *Gino* on the other hand sank in 130 metres of water following collision with another ship. The bottom on which the wreck settled is made up of coarse shell sand which forms ripples known as 'ridins' by French sailors. The spot is about 24 nautical miles off Ushant and 36 miles from the Brittany coast. The vessel was carrying 40 500 tonnes of carbon black oil, a relatively heavy product slightly denser than water and fairly compact.

To provide a clearer picture of the ecological impact of these accidents we shall deal with the following points in the order given:

1. The population size of those living marine resources of interest to the fishing industry in the areas affected by the accidents, i.e. the Brittany coast around Saint-Brieuc, Paimpol, Morlaix and Brest.
2. The principal factors determining the extent of the ecological consequences of the accident.
3. The immediate effects.
4. The medium- and long-term effects.

7.5.2 MAIN LIVING MARINE RESOURCES OF INTEREST TO THE FISHING INDUSTRY IN NORTH AND NORTHWEST BRITANNY

The geographical area affected by the oil spills which took place in French waters mainly covers the coast and coastal waters between Saint-Brieuc and Brest, a distance of some 350 kilometres. It is an area of small-scale in-shore fishing businesses engaged in gathering algae and fishing for crustaceans and molluscs and one in which fish farming, particularly shellfish breeding, plays a major role. We felt that it would be useful to begin this study by describing the coastal resources affected by the *Amoco Cadiz* spill and, to a lesser extent, the *Tanio* accident, and to add some information on the sea bottom in the area where the *Gino* sank.

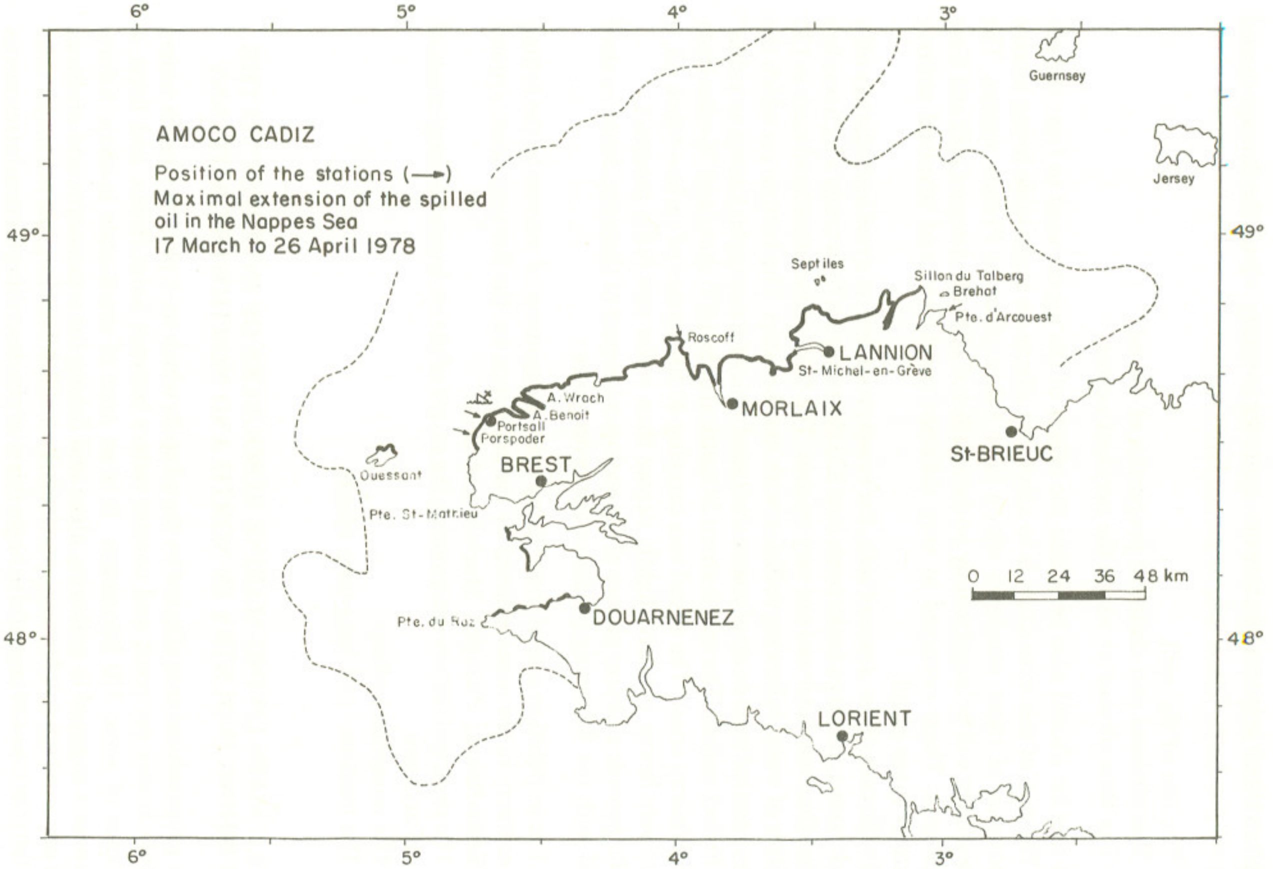

Figure 7.5.1 Map of the Coast of Brittany indicating the extent of pollution from accidental oil spills

7.5.2.1 In-shore Fisheries Resources

Algae

The Breton coast between Sillon de Talbert, which marks the northern limit, and the Saint-Mathieu headland, which marks the entrance to Brest roads, is far and away the most important French seaweed harvesting centre (Figure 7.5.1). When the *Amoco Cadiz* went aground, all coastal waters in the area were being worked. This marine vegetation is still being actively gathered, mainly in the Finistère area between Le Conquet and Goulven Bay, around Roscoff and the island group of Molène and Ushant. There are also large seaweed resources in the Department of the Côtes-du-Nord but here exploitation has only recently begun; the most important centre is between Perros-Guirec and Paimpol.

Several species are used as a basis for manufacturing products particularly sought after by the industry producing sulphated and non-sulphated polysaccharides. The species concerned can be classified in two main groups: brown seaweed and red seaweed.

Brown seaweeds or Phaeophyceae are used for the manufacture of alginic acid. The most plentiful are *Laminaria digitata* followed by *Fucus serratus*. Other brown seaweeds such as *Ascophyllum nodosum* and *Fucus vesiculosus* are also gathered mainly to prepare meal for cattle feed.

Of the red seaweeds or Rhodophyceae, *Chondrus crispus* and *Gigartina stellata* are used in the manufacture of carragheenins. In the area in question most of the algae are gathered between Paimpol and Brest roads, mainly between Portsall and Porspoder, i.e. in the area most affected by the *Amoco Cadiz* spill.

Whereas the exploitation of seaweed in France was for a long time experimental, it has developed a great deal in the last 15 years, mainly because harvesting has been

Table 7.5.2 Exploitable marine resource production (tonnes, wet weight) of maritime areas in North Brittany (from merchant marine statistics) in 1978. M: mussels, O: oysters

	Algae			Molluscs		
Maritime Area	Red	Brown	Crustaceans	Harvesting	Breeding	Fish
Saint Brieuc	–	–	277	5 320	6 400 M	483
Paimpol	625	5 236	958	1 444	259 O 12 M	54
Morlaix	489	6 319	3 380	333	4 613 O	837
Brest	1 198	27 311	2 010	699	1 329 O 438 M	484
Total	2 312	38 866	6 625	7 796	13 051	1 858
Percentage of national production	80.4%	95.4%	23%	21.3%	8.9%	0.6%

mechanized. The building of modern factories has allowed the exploitation of seaweed to expand rapidly into a relatively important regional, national and even international activity.

The official French fishing statistics published by the Merchant Marine indicate that in 1978 total seaweed production for the area between Saint-Brieuc and Brest amounted to just over 44 000 tonnes (wet weight); this represented 95.6 per cent of national production. The total breaks down into some 40 000 tonnes of brown seaweed, i.e. 95.4 per cent of total French production, and about 4000 tonnes of red seaweed, i.e. nearly 80 per cent of all such seaweed gathered in France (Table 7.5.2). The coastal area of Brest alone, which includes Portsall where the *Amoco Cadiz* went aground, provided over 27 000 tonnes of brown seaweed, i.e. 68 per cent of national production, and almost 2000 tonnes of red seaweed or over half the total national harvest of this species.

Crustaceans

The northern and northwestern coasts are rocky and, hence, particularly suit the large crustaceans and attract those fishing for them. On average, the coastal areas of Saint-Brieuc, Paimpol. Morlaix and Brest supply some 23 per cent of all crustaceans harvested in France in a year (7600 tonnes in 1977, 6600 tonnes in 1978, 6000 tonnes in 1979). The most productive areas are the coasts around Brest and especially Morlaix. The catch consists mainly of edible crab (*Cancer pagurus*; about 70 per cent) and spider crab (*Maja squinado*; 27.5 per cent). Lobsters account for a relatively small percentage by weight (1.6 per cent) but as they command a high price they represent 12.5 per cent of the total worth of crustaceans landed in the area.

The most active crustacean fishing ports are Primel, Moguierec and Le Conquet. Most of the year the catches come from the rocky shore areas. Spider crab catches are biggest in spring and summer, as this crustacean remains out at sea in winter.

Molluscs

Mollusc production in the area between Saint-Brieuc and up to and including Brest roads is extensive for both naturally occurring shellfish and cultured molluscs. The main natural species fishes is the scallop which is caught in Saint-Brieuc Bay, in the coastal area of Paimpol and, to a lesser degree, in Morlaix Bay and Brest roads. Stocks of this mollusc were, therefore, relatively unaffected by the oil spills which, with the exception of the *Tanio* spill, hardly touched Saint-Brieuc Bay. But the same cannot be said of other types of natural shellfish such as the variegated scallop and carpet shell and especially of cultured molluscs.

Although most of the mussels in this part of Brittany are based in the coastal area of Saint-Brieuc, oyster breeding was, and in most instances still is, a major activity in the Ria de Morlaix and the Penzé (both estuaries), in the estuaries known as the abers (Aber Benoît and Aber Wrach) and in Brest roads. In spite of the parasite infection which affected the common oyster stock (*Ostrea edulis*) from 1968 onwards, at the time of the *Amoco Cadiz* accident this oyster was still being bred in the abers, the Penzé and Morlaix estuaries, the Paimpol area and in Brest roads. By the beginning of 1978, the Pacific oyster (*Crassostrea gigas*) had been introduced in many breeding centres and was already accounting for most of the production.

Still according to official statistics, the production of uncultured molluscs in the four coastal areas concerned amounted to 7800 tonnes in 1978 (over 6500 tonnes being scallops) and this represents 21.3 per cent of total national production. Where cultured shellfish are concerned, total production for the same year came to almost 7000 tonnes of mussels (mainly in the Saint-Brieuc area) and a little over 6000 tonnes of oysters (mainly in the Morlaix and Brest areas). The figure for mussels was slightly higher than in 1977 as the mussel beds are outside the areas affected by the pollution, whereas the oyster figure was slightly lower. Taken as a whole, the volume of shellfish bred in the area represents some 7 per cent of total national production.

Fish

Apart from a few areas of Morlaix and Lannion and in Saint-Brieuc Bay, the seabed off the north and northwest Brittany coast is rocky and therefore unsuitable for trawling. This explains why few fish are landed along this coast and why, for all practical purposes, only small gill nets, drift nets or lines are used. At about 2200 tonnes in 1977 and 1860 tonnes in 1978, the total fish landed in the coastal areas of Saint-Brieuc, Paimpol, Brest and Morlaix represented only 0.6 per cent of the national catch. The species most frequently caught are either sedentary fish living in rocky areas (e.g. the Labridae, sea eel, ling, catfish and ray), open water coastal species (e.g. grey mullet and sea perch) and migratory species only present in the area at certain seasons (e.g. pollack and mackerel).

7.5.2.2 Fishing Resources in the Area Around the *Gino* Wreck

For a radius of 15 to 20 nautical miles around the Gino wreck, the water is between 100 and 200 metres deep (120 metres at the site of the wreck). The substrate is hard and is made up of coarse sands and mud which contain bryozoa and corals; the bottom is strewn with rocks. It is difficult to use a trawl in this area, which also is relatively poor in expolitable species of fish, so the area is only occasionally visited by fishing vessels—trawlers from Concarneau or Guilvinec, 'caseyeurs' (lobster boats) from Le Conquet and Ile de Sein. Catches are small. This being said, the most representative species are the selachians (catfish, ray), the gades (haddock, blue whiting, pollack, pout, ling, young hake) and gurnards. Mackerel and horse mackerel may be abundant in season. Crustaceans, particularly edible crabs, are present but in relatively small numbers. There are many scallops where there are no rocks but they are too scattered for regular commercial fishing.

7.5.3 MAIN FACTORS DETERMINING THE EFFECTS OF OIL POLLUTION ON RESOURCES

7.5.3.1 The Amount of Oil Spilled

The magnitude of a spill is certainly a major factor but it is far from being the only one which determines the extent of the damage the oil will inflict on exploitable living resources. A few details will illustrate this fact (Table 7.5.1).

In 1967 the *Torrey Canyon* spilled 117 000 tonnes of oil; the oil, a light crude, spread out over a large section of the Eastern Channel and affected both the English and French coasts. The 1000 tonnes of oil spilled by the *Olympic Bravery* in 1976 caused only local pollution. In the same year the *Bohlen*'s 10 000 tonnes did not spread very far either, because the product was highly viscous; nevertheless, the effect on marine resources, particularly the larger crustaceans, was perceptible.

The 20 000 tonnes spilled into the North Sea in 1977 from the Ekofisk field had no major visible consequences because of the existence of converging currents and the distance from the coast. By contrast, the *Amoco Cadiz*'s 230 000 tonnes, a third of which luckily evaporated because the product was light, affected nearly 350 kilometres of coastline. The *Gino*'s 40 000 tonnes of heavy product which settled on the bottom around the wreck and covered an area with a radius of only about four to five sea miles, caused detectable contamination of scallops within a radius of some 20 sea miles.

As for the spill from the Ixtoc well to the North of Campeche on the Yucatan Peninsula of Mexico, the volume of oil spilled from the beginning of June 1979 onwards probably totals some 500 000 tonnes, but this was spread over several months. The pollution, which was carried northwest and then north by various currents, reached the Mexican coast north of Tampico and the south coast of the United States in Texas, the latter being nearly 1000 kilometres from the well.

Finally, in March 1980 there was the *Tanio* accident which occurred 35 nautical miles off Batz Island near Roscoff. As it proved possible to tow the after section of the vessel—containing 10 000 tonnes of No. 2 fuel—to Le Havre, it is estimated that only 6500 tonnes of oil was spilled in the sea while 10 000 tonnes remained in the wreck at a depth of 87 metres. Although the product concerned was relatively viscous, the pollution affected 195 kilometres of the coastline of the Finistère and Côtes-du-Nord Departments, some sections suffering more than others (Berne, 1980).

7.5.3.2 Site of the Accident

The site of an accident plays a major part in determining the amount of damage done to living marine resources. To begin with, it should be pointed out that the productivity of the oceans is not everywhere the same. It is generally accepted that of approximately 100 000 known marine species almost 95 000 live mainly in the coastal areas, on or near the bottom, where the depth is less than 200 metres.

In spite of the very important role of plankton, particularly phytoplankton, in maintaining the biological and physico-chemical balance of the oceans, it may be said that an accident in the open sea has less direct consequences on commercially expolitable resources than one occurring close to the coast. Furthermore, pelagic fish species which are found in the open sea can and do escape from pollution. This was demonstrated when, following the *Amoco Cadiz* accident, open water species such as mackerel and pollack temporarily disappeared from the area.

There are also certain other factors which prove more helpful than not when an accident occurs in the open sea rather than close to land. To begin with, it is easier to lighten and tow a tanker in open sea than in shallow water, particularly if the coastline is dotted with reefs. Compare, for example, what happened to the *Amoco Cadiz*, which grounded on the Portsall rocks, with what happened to the *Tanio*, which was sliced in two at a spot 35 miles from the coast where the water was 87 metres deep. In the first instance towing was impossible, as any ships coming to the rescue of the stricken tanker would in their turn have gone aground; whereas with the *Tanio*, it proved possible to tow the after section of the vessel to Le Havre, thereby preventing 10 000 tonnes of oil from being spilled into the sea.

It should be noted that a wreck still containing oil in its cargo tanks and resting in water sufficiently deep to prevent movement by the swell has every chance of remaining intact, whereas a grounded vessel is quickly broken up by the waves. This fact, too, was illustrated by the *Amoco Cadiz* and the *Tanio*; in the first instance the entire cargo was spilled into the sea, but this was not so in the second.

The greater the depth and volume of water at the site of a wreck, the easier it is for biodegradation to take place. The non-volatile residues have time to oxidize and form tar balls which have little effect on marine life. Also, when the oil slick spreads out far from the coast, as was the case in the Ixtoc and particularly the Ekofisk blowouts, the lighter and more toxic fractions can evaporate completely before the rest is dispersed in the body of water. If a spill occurs in the open sea there is plenty of time for the oil to spread out in a very thin layer which facilitates evaporation and makes treatment with dispersants more effective.

Another helpful factor is the presence of concentric vortex currents which frequently occur in the open sea and whose action prevents pollution reaching the coast. This was the case in the Ekofisk blowout. Dominant currents flowing in a given direction, which frequently occur at some distance from the coast, may also help prevent contamination of the coastal area closest to the site of the accident. As in the Ixtoc case, this does not prevent all coastal pollution, but part of the oil which has been spilled can evaporate and be biodegraded, so becoming less toxic.

Excluding blowouts of oil wells at sea, it may be said that most accidents occur close to the shore mainly because of the presence of reefs and of the heavier traffic. In Europe this is true of the sea around Ushant (at the gateway to the Channel), in Dover Strait and at Cape Finistère.

Quite apart from the absence of the above-mentioned advantages, oil spills close to land cause major damage. As wave action quickly causes the oil and water to mix, the oil may be rapidly emulsified in the water before a proportion of the toxic volatile fractions can evaporate. In the case of the *Amoco Cadiz* this was probably a major factor in the high mortality rate among coastal bottom-living creatures immediately after the accident (Amphipoda, periwinkles, cockles, sea urchins and rock-dwelling fish).

Shoreline species such as seaweed are sedentary or less mobile. They therefore are exposed for the duration of the contamination.

Finally, evaporation of the volatile fraction is followed by the biological or photochemical oxidation of the oil and its adsorption to mineral particles; this causes sedimentation of the oil, particularly in certain sheltered spots along the coastline. Degradation of the product is considerably slowed down by the lack of oxygen so that the toxicity may persist for several years. The aftermath of the *Amoco Cadiz* spill has demonstrated that oil has a maximum toxic effect when it remains trapped in sediment (Gouygou and Michel, 1981a).

The experience has also confirmed earlier observations as to the varying degrees of sensitivity of different types of coast in the sublittoral zone. From this it would seem that a coastline with plenty of wave action is the type which is most quickly decontaminated, as indicated by Owens in 1978. Rocky areas pounded by the sea, followed in decreasing order by firm bottoms covered with pebbles or gravel, and coarse sandy bottoms, are the types of coast which will most quickly and easily return to a state of biological equilibrium because they are more quickly decontaminated. For instance, by November 1978 almost all the oil had disappeared from the subtidal zone of Morlaix Bay and, a year after the catastrophe, there were no longer any traces between Portsall and Batz Island (Beslier *et al.*, 1981).

It is a different matter in sheltered areas in which fine sediments accumulate, for instance in the estuaries of the North Breton coast known as the abers or in marshland. These areas are subject to the most serious and most lasting damage. Some authors expect the pollution to persist there for up to ten years (d'Ozouville *et al.*, 1981).

7.5.3.3 Characteristics of the Oil

The physical and chemical characteristics of the oil are cardinal factors with regard to both the direct consequences of the pollution on the marine resources and the effectiveness of treatment by dispersants.

Volatile fraction

It is thought that oil fractions with a boiling point below 300 °C quickly evaporate from the surface of the water owing to the action of the wind. From a quantitative

Table 7.5.3 Some physiochemical characteristics of oil from accidental spills. (from Maurin, 1981. Reproduced by permission of Centre National Pour l'Exploitation des Océans)

	% Distillation at 210°C	% Saturated HC	% Aromatic HC	Density at 20°C	Flow point
Torrey Canyon	21.3	31.1	33.7	0.866	
Boehlen	0.9	2.5	35.0	1.000	– 12°C
Amoco Cadiz	26.6	31.8	28.0	0.853	
Gino	0	11.5	60.9	1.083	– 30°C
Ekofisk	26.5	42.2	21.7	0.844	
Ixtoc	15.2	35.7	37.6	0.833	

point of view this is important because it helps considerably in the on-site elimination of a pollutant. Column 1 of Table 7.5.3 gives figures for several accidents showing the percentage of hydrocarbons contained in the oil which boil at 210 °C or less. Extrapolating from this, it may be assumed that between 30 and 50 per cent of most light crudes is likely to volatilize rapidly (P. Michel, personal communication). This applies particularly to the benzenes and alkyl benzenes, and has practical consequences, as the light hydrocarbons are the most toxic.

Some crudes, such as the Venezuelan crude carried by the *Bohlen* and *Boscan*, contain no light fraction. This is also true of some residual oils such as those carried by the *Olympic Bravery* (Bunker C) or the *Gino* (carbon black oil). It should also be noted that the evaporation of light fractions is moderated if the oil is emulsified in water and, particularly, if the formation of water-in-oil emulsions is due to water penetrating the oil. This phenomenon is often described as 'chocolate mousse' and is promoted by the presence of impurities such as particles of asphalt. As opposed to a true emulsion which can be biodegraded fairly easily, the mousse is stable and may persist for several months (Nelson-Smith, 1973).

It should be pointed out that while heavy crudes are, generally speaking, less toxic in the short term than light fractions, they may have long-term mutagenic or carcinogenic effects. This is true of polycyclic aromatic hydrocarbons such as benzopyrene or the benzanthracenes. However, as Nelson-Smith (1973) has pointed out, there are many polycyclic aromatics which have no harmful effects; besides, small but significant amounts of benzopyrene occur naturally in the marine environment.

Saturated hydrocarbon content

See Table 7.5.3, column 2.

The presence of saturated hydrocarbons, like that of paraffins, causes no major problems in an oil spill at sea. Only in exceptional cases do paraffins have a toxic effect. Furthermore, their biodegradation is rapid, at least where straight chain compounds are concerned. Oil with a high saturated hydrocarbon content such as that from the Ekofisk field (42.2 per cent) would therefore be less harmful in the short and long terms than oil from the Ixtoc well (35.7 per cent), the *Amoco Cadiz* (31.8 per cent) or, particularly, the products carried by the *Gino* (11.5%).

Aromatic hydrocarbon content

See Table 7.5.3, column 3.
Aromatic hydrocarbons are much more persistent than saturated hydrocarbons. The lightest (the benzenes and alkyl benzenes, the naphthalenes and alkyl naphthalenes) have a high acute toxicity. The heavier ones (aromatics with four or more benzene rings) may have mutagenic or carcinogenic effects. The best known is 3, 4-benzopyrene, for which carcinogenic effects were demonstrated 40 years ago. Fortunately only traces of this compound are present in crude oils.

This is not always true of oil products. For instance, the cargo of the *Gino* contained 60.9 per cent aromatic hydrocarbons (compared with 28 per cent for the *Amoco Cadiz* and 21.7 per cent for Ekofisk oil) and 400 parts per million of benzopyrene.

As we shall see later, in the case of the *Amoco Cadiz*, Gouygou and Michel (1981a) demonstrated that compounds with three and four rings, frequently highly alkylated, are the most persistent. This is true of dibenzothiophene and naphthobenzothiophene which, after a period of 3 years, account for 56.4 and 13.3 per cent, respectively, or a total of almost 70 per cent of the residue.

Specific gravity

See Table 7.5.3, column 4.
Generally, oil is lighter than water and most of it therefore stays on the sea surface. This was the case, for instance, with the oils spilled from the *Torrey Canyon*, the *Amoco Cadiz* and the Ekofisk and Ixtoc wells where the specific gravities at 20 °C were effectively the same: 0.866, 0.853, 0.844 and 0.883, respectively.

Yet, the density of the products carried by the Bohlen (1.0 at 20 °C), which sank in 100 metres of water, was such that some of the oil could float between two masses of water. Some by-products have a density greater than 1. In the case of the *Gino*—whose wreck lies in 120 metres of water—all that has come to the surface is the oil and fuel for the vessel's own use. The *Gino*'s carbon black oil has a density of 1.083 at 20 °C.

Nevertheless, it should be remembered that sooner or later, aging, oxidation and the formation of water-in-oil emulsions make even the lightest oils settle.

Viscosity

The more fluid an oil, the greater its immediate impact on marine resources because it spreads further and mixes more throughly with the water and the sediments, particularly fine sediments.

In the case of some oils or derivatives with a flow-point above 0 °C, this property tends to prevent the oil slick spreading and, therefore, in theory, also tends to limit the size of the contaminated area. This was true of the *Bohlen* and *Olympic Bravery*. As we have seen, although the slick from the *Gino* was limited in extent, there was a certain amount of contamination at quite a distance from the wreck. It should be remembered that the *Amoco Cadiz* oil had a viscosity of some 10 centistokes at a temperature of 20 °C; at the same temperature the equivalent viscosity for the *Bohlen* was 10 000 centistokes while for the *Tanio* it was some 15 000. In connection with the latter, Berne (1980) pointed out that this high viscosity prevented the oil from penetrating massively into the fine sediment, but that it did not prevent infiltration to a depth of 40 centimetres into the coarse granitic sands, a process which was helped along by the higher summer temperature.

Finally, it must be noted that the initial viscosity of the oil increases, partly in proportion to the amount that evaporates and partly in proportion to the formation of water-in-oil emulsions. This is a further factor which suggests that, given comparable quantities, oil spills at sea have less serious consequences than those close to the shore.

7.5.3.4 Time of Year at Which the Accident Occurs

It should be remembered that one factor which affects the consequences of an accidental oil spill on living marine resources is the time of year at which the accident occurs. Its importance lies in the meteorological and physical, chemical and biological aspects.

As far as the meteorological circumstances are concerned, one cannot help noticing that the major accidents involving oil tankers in European waters in the last few years have all happened in March—the *Torrey Canyon* on 18 March 1967, the *Amoco Cadiz* on 16 March 1978 and the *Tanio* on 7 March 1980. This is no coincidence, as this time of the year is a period of particularly violent storms in the Channel and its neighbouring waters.

Apart from the fact that meteorological conditions of this type cause accidents, they also make lightening and towing operations and the treating of oil slicks more difficult and sometimes impossible.

Although the wind helps to spread the oil and encourage evaporation, which is beneficial, it can also lead to rapid mixing of the oil with the water before evaporation can take place; this facilitates the formation of stable water-in-oil emulsions and slows down the process of biodegradation. Unfavourable meteorological conditions of this type also ensure that a bigger geographical area is affected by the pollution. In this connection it has been noted that when there is a high wind the rate of displacement of the slick is higher than its rate of spreading. Its speed of movement is some 2.5–3.5 per cent of the wind speed (Nelson-Smith, 1973).

Where physical and chemical factors are concerned, sunshine and, more generally, heat facilitate evaporation. Similarly, heat helps to lower the density of a product and make it more fluid. We have seen the consequences this had for the oil from the *Tanio*.

Greater biological harm is caused if, for example, the accident occurs in a period of algal bloom (i.e. at the beginning of spring or in autumn), at a time when marine organisms, particularly algae and molluscs, are going through a period of active growth (spring and summer), or during a reproductive period, especially if this period is very short. It would seem that algae are less sensitive to oil spills during their macroscopic phase than during their microscopic one, when the reproductive systems are at their most vulnerable (R. Pérez, personal communication). Observations on biota at the time of the *Amoco Cadiz* accident illustrate these points.

7.5.3.5 Use and Effect of Dispersants

As Pierre Michel pointed out in 1979, if we had methods for the physical recovery of oil spilt in the sea as a result of an accident, the problem of dispersants would never arise. In fact, the mechanical methods tried so far (pumping, collecting in nets, etc.) can rarely be used, due to unsuitable meteorological conditions or because of the nature of the pollution.

On the other hand, although the damage caused by the dispersants in use several years ago was extensive, if difficult to assess, a great deal of progress has been made since then. It may be said that in the last 10 years the toxicity of these products has been reduced by a factor of nearly 1000 (Michel, 1979).

Before summarizing what we know about the advantages and disadvantages of oil dispersants, we should explain what they are. This category of products comprises binders, precipitants and emulsifiers or dispersants. Binders such as rubber crumb are completely innocuous. They can be fairly effective but are difficult to use as they are very light and wind makes it difficult to spread the product. Precipitants such as sawdust and chalk are not toxic either, but are also difficult to use. When not very effective, they cause the salting-out of oil from the water and do not prevent shore-line pollution. When effective, they settle the oil on the bottom and trap it in the fine sediments. At the time of the *Amoco Cadiz* accident, it was thought that precipitants slowed down the biodegradation of the oil. In fact, they were only rarely used and then only to prevent the oil reaching particularly sensitive areas such as Brest roads.

The toxicity of emulsifiers or dispersants varies a great deal with the product. They contain surface-active agents including a lipophilic fraction which fixes the oils and a water-absorbent fraction which fixes the water. Thus, they help break down an oil slick into fine droplets made up of water and oil. In the currently used dispersants these agents are usually mixed with a solvent.

Surface-active agents may be divided into three main categories.

1. Cationic surfactants which, in addition to the lipophilic fatty acids common to

other surfactants, contain a water-absorbent ammonium radical. They are highly toxic, practically nonbiodegradable and are mainly used as bactericides.
2. Anionic surfactants which contain a sulphonic water-absorbent radical. They are very active, not very biodegradable and highly toxic, particularly when mixed with a solvent rich in aromatics. This category includes what we normally call detergents.
3. Nonionic surfactants whose water-absorbent element is a primary alcohol. These agents are more easily biodegradable and their action is less harsh. They are properly known as dispersants.

Generally speaking, the biological effect of surface-active agents is that they make the cell membrane more permeable which increases the penetration of the agent into the cell. When the product contains an anionic surfactant, there occurs a chemical reaction with the proteins of the cell membrane which can cause it to burst. The polycyclic hydrocarbons or light aromatics then penetrate the membrane and concentrate there as shown in Figure 7.5.2 (Nelson-Smith, 1973). On the other hand, if non-ionic surfactants are used there is no chemical reaction with the proteins of the cell membrane so that there is no bursting. But the non-ionic products are still surface-active and as such help the oil penetrate the membrane. This explains why, on the one hand, non-ionic surfactants may be regarded as a thousand times less toxic than their anionic counterparts and why, on the other hand, they can have quite a harmful effect on living organisms.

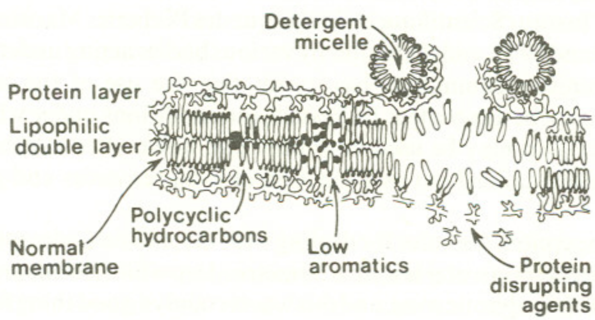

Figure 7.5.2 The effects of various agents on the plasma (cell) membrane. To the left is the normal structure, with a double layer of fatty molecules stabilized on each side by an outer protein layer. The large molecules of polycyclic hydrocarbons penetrate slowly and push the fatty molecules apart, while low-boiling aromatics penetrate rapidly and become solubilized in the fatty membrane, disrupting its spacing. Detergents (surface-active agents) and some other agents not discussed here strip off or break up the protein layer. (Reproduced by permission of Dr A. Nelson-Smith, 1973)

It would seem useful to set out the possible advantages and disadvantages of using dispersants (i.e. non-ionic dispersants).

As far as the advantages are concerned, these products encourage the spreading out of the oil slick and the formation of very fine droplets; they do not apparently prevent the lighter and more toxic fraction from evaporating; they speed up the biodegradation of some oils, can limit damage caused to birds, often prevent deposits forming on solid surfaces and help to slow down the formation of water-in-oil emulsions (Canevari, 1978).

Nevertheless, the disadvantages of using these products justify avoiding their use in coastal areas with a rich population of seaweeds and marine organisms. The products are in fact quite toxic, particularly in their role as surface-active agents. In spite of observations to the contrary made in a laboratory (Canevari, 1978), they do not seem to prevent oils settling on mobile substrates or their penetration of sediments. They do speed up biodegradation in those families of hydrocarbons which are less toxic and degrade easily, e.g. paraffins, but it is far from certain whether they do the same for the aromatics (P. Michel, personal communication). The *Amoco Cadiz* accident showed that water-in-oil emulsions can form almost immediately, before any treatment can be given.

Finally, all treatments are totally ineffective when the oil slicks are thick (*Amoco Cadiz*, Ixtoc) or when the oils have a high viscosity, as was the case with the *Tanio* and the Bohlen.

It should be remembered that after the *Amoco Cadiz* accident, as opposed to the *Torrey Canyon*, only non-ionic surfactants were used at sea. Research carried out in France by l'Institut Scientifique et Technique des Pêcheries Maritimes (ISTPM) between 1970 and 1975, and thereafter by various bodies acting under the auspices of an inter-ministry committee, has meant that the use of the least harmful products can now be advocated. In France, the conditions under which the least harmful dispersants may be used have been laid down after numerous tests on marine organisms carried out as a function of local resources and geographical position.

With one exception, the rules for dealing with the *Amoco Cadiz* spill prohibited the use of dispersants in water less than 50 metres deep which, in this area, is more or less the limit of the euphotic zone, and this was certainly a good thing for the marine resources. The rules did not obstruct the carrying-out of a very effective treatment which helped prevent the pollution from reaching the west coast of the Cotentin, the Channel Islands and the western coasts of Brittany.

7.5.4 SHORT-TERM CONSEQUENCES

This section sets out to deal with the short-term consequences of oil spills in French waters while deliberately limiting the survey to exploitable living resources—algae, crustaceans, molluscs and fish. The problem will be approached from various angles.

1. Direct damage and mortality.
2. The level of contamination.
3. Irregularities in reproduction and growth.

The observations which follow apply mainly to the consequences of the *Amoco Cadiz* accident. However, in an attempt to bring out the differences which can result from differences in the types of oil spilled or the conditions in which an accident of this kind occurs, we shall add some information on the consequences of the wreck of the *Gino*.

7.5.4.1 The *Amoco Cadiz* Accident

Direct damage, mortality

Certain species of algae such as *Fucus vesiculosus* and *Ascophyllum nodosum* live fairly high up in the intertidal zone, just where the oil slicks were at their thickest after the grounding of the *Amoco Cadiz*. Hence, as René Pérez (1978b) commented, these algae were heavily coated with oil. They remained coated with the brown water-in-oil emulsion known as 'chocolate mousse' for several weeks and were only very gradually cleaned by the waves. In September, their surfaces still showed the characteristic sheen which indicates the presence of oil. Nevertheless, observations made on these two species at various sites along the shore provided no evidence of necrosis or abnormal mortality (Pérez, 1978b; Cross *et al.*, 1978).

In order to assess what damage the oil had done to the most widely exploited species, *Laminaria digitata*, Pérez (1978b) established a method for measuring the density and assessing size distribution. To estimate density this author recorded the number of seaweed plants visible to the naked eye in one square metre of shoreline. For size distribution he analysed the structure and population density by using histograms based on the frond length of 250 specimens of *Laminaria*. He repeated these observations every month at seven sites along the coast including the Arcouest headland which had not been polluted and was used as a control. To prevent errors of interpretation, the selected sampling points were in sectors not exploited in 1977. The extent of new mortalities also had to be calculated; to do so the author compared his results with those he had obtained for the same shoreline between 1969 and 1971. From this he calculated that the normal population density of *Laminaria* was 72–95 plants per square metre in February and an average of 65 in March, 47 in April and 43 in May. He attributed this natural mortality mainly to predatory herbivorous organisms, particularly gastropods of the limpet family such as *Helcium pellucidum* (Table 7.5.4).

The author's observations in March, April and May 1978 showed that, in the control area, the figures corresponded closely to these averages. In the more polluted areas the averages were very similar in March and May except in the Portuval area, where the explanation for the slightly lower figures is the extreme exposure of the site to waves. In April the figures were in general above average.

Table 7.5.4 Study of density in algae m^{-2}. Mean values one shown, obtained for *Laminaria digitata* and *Chondrus crispus* at the different sites studied (March to May, 1978). Arcouest is the control station. (From Pêrez, 1978b.)

Location	Number of *Laminaria* m^{-2}			*Chondrus weight*, $g\,m^{-2}$		
	March	April	May	March	April	May
Normal average	65	47	43	4300	5500	3000
Arcouest	63	48	45	4050	4300	4900
Talbert	67	47	42	4100	4600	5000
Perros-Guirec	63	47	43	3900	4400	4800
Pte de Primel	64	48	41	3700	4150	4600
Roscoff	69	51	43	4100	4600	5100
Portuval	60	47	38	3900	4700	5050
Trémazan	67	52	45	4000	4700	5250
Porspoder	65	50	43	3800	4400	4950

Pérez thinks that the explanation lies in the high mortality among predators, as during these months he counted only five *Helcium* per kilogram of algae at Trémazan and three at Roscoff, compared with 18 at the unpolluted control site on the Arcouest headland.

An analysis of the histograms highlights the fact that no necrosis of the thalli was observed. Furthermore, the absence of unusually large quantities of seaweed detritus leads the author to the conclusion that there was no abnormal mortality of *Laminaria* in the polluted area in spite of the high concentration of hydrocarbons.

The red seaweed, *Chondrus crispus*, occupies the lower section of the intertidal zone; therefore, it was highly contaminated by the oil spill. Figures for the North Brittany population of these Rhodophyceae provided by Kopp (1975) indicate that in normal times the *Chondrus* biomass increases rapidly in March and April and the drops in May because the older fronds disappear. Pérez showed that in 1978 the volume of this biomass was considerably below average but that it continued to increase in May. A comparison between the control site and the Trémazan area, which is close to the site of the wreck, indicates that this was mainly a natural phenomenon due to high insulation and lack of nitrogen. The phenomenon was also observed on the French Atlantic coast that year (Figure 7.5.3).

The data provided by the National Association for Marine Algae clearly illustrate the fact that *Laminaria* production in 1978 was good in spite of the net deficit in May, the latter being due to the disturbances caused by the accident. Taken as a whole, production was some 30 per cent up from the 1977 level. By contrast, the red seaweed harvest was very much lower than that for the previous year. It is difficult to be certain about the reason for this drop. We have to distinguish between how much was due to climatic and harvesting conditions and how much can be attributed to the pollution. This is very difficult if not impossible. Nevertheless, the fading and withering of a proportion of the *Chondrus* population

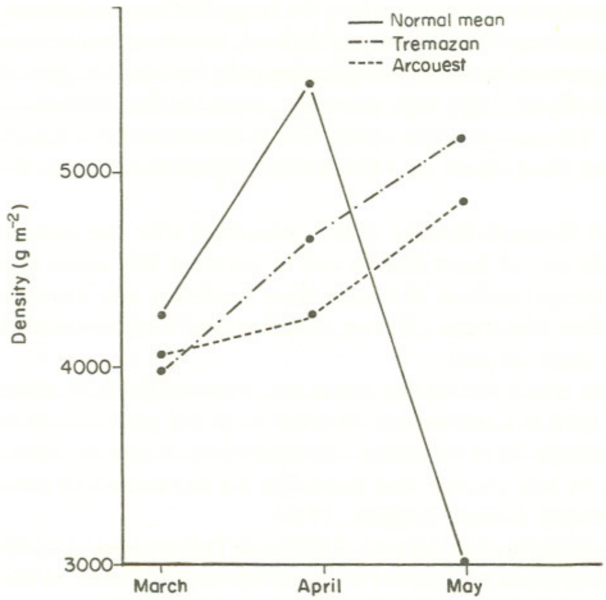

Figure 7.5.3 Variation in biomass of *Chondrus crispus* populations; production was relatively poor in March and April, better in May; the maximum that year coincided with the beginning of harvesting. (From Pérez, 1978b)

during the weeks following the accident may in part be due to the latter. Finally, the *Fucus* and *Ascophyllum* harvests dropped by almost 60 per cent.

No immediate mortality was noted in commercially important crustaceans such as lobster, edible crab (*Cancer pagurus*), spider crab (*Maja squinado*) and crayfish. It is not impossible that crustaceans are among the species which were destroyed at the beginning of the spill when it was not possible to make any observations because the layer of oil was so thick. As we shall see in more detail later, a number of crustaceans caught during fishing experiments in April 1978 between Batz Island and the wreck had a distinctly oily taste.

In May of the same year, tests in the areas around Portsall set aside for crustaceans gave a very good lobster yield. The catches included mature individuals (54.3 per cent of males and 45.7 per cent of females) with an average weight of 1.084 kg (Léglise and Raguenès, 1981).

Elsewhere, Desaunay and his colleagues (1979) pointed out that the common shrimp (*Crangon vulgaris*) disappeared from the coastline and from Morlaix and Lannion bays for several months in 1978. They attribute this either to the mortality which may have affected these crustaceans or to a natural reflex to escape from the pollution.

It should be said that the tanks where the larger live crustaceans are usually kept before being marketed were swamped with oil, which caused enormous damage.

The small species of molluscs living on the rocky bottom along the shore (limpets and winkles) suffered a very high mortality rate in the area between the wreck and Lannion Bay. The same was true of species which burrow down into the sea bottom (cockles, clams, sand clams, etc.) which suffered enormous losses (Cabioch *et al.*, 1978, 1981).

Chassé and Guenole-Bouder (1981) estimated that the destruction among molluscs in the sea off Saint-Efflam and in Lannion Bay alone amounted to 36 million cockles (20 million *Echinocardium cordatum* and 16 million *Cardium edule*), 14 million Mactridae (*Mactra corallina*) and 6 million sand clams (*Pharus legumen* and *Ensis siliqua*).

But scallops, which live further out to sea, were not similarly affected. The first test in April 1978 in Lannion and Morlaix Bays did not indicate any abnormal mortality although there was some contamination. A second series of catches in Lannion Bay in July showed that mortality did not exceed 14 per cent, a figure regarded as nearly normal (Léglise, 1978).

While the mussel beds to the east of Sillon de Talbert were not affected, this did not hold for the oysters bred in the Penzé and Morlaix estuaries, in the abers (Aber Benoît and Aber Wrach), and in the other breeding areas to the west of Sillon de Talbert.

In order to assess to the amout of damage done, l'Institut des Pêches monitored all oyster breeding areas in northern Brittany and the western Cotentin from March 1978 onwards, paying regular visits at every major tide between March and May. Surveillance continued in the abers (two stations per aber), the Penzé estuary (five stations), and in the Ria de Morlaix (11 stations). The pollution had spared all the centres east of Sillon de Talbert (Figure 7.5.1). To the west of this point, oil was present in the oyster beds in the form of sheen, tar balls or more or less thick puddles. All three forms were present in the abers where the pollution was enormous. Contamination appeared to be less marked in Morlaix Bay and at Penzé but in fact it turned out to be high. Pollution also seriously affected the Saint-Efflam, Trébeurdan and Ile Grande areas around Lannion and, to a lesser degree, the beds in the Ria de Tréguier (Grizel *et al.*, 1978).

Nevertheless, it turned out that mortality was patchy, particularly in the abers. Mainly affected were those oysters covered by a thick layer of oil. It is difficult to put a figure to the mortality rate. For Aber Benoît it has been estimated at 50 per cent of all oysters which had not been transferred and for Aber Wrach at 20 per cent (Maurin, 1978). Elsewhere the mortality rate was low and nearly normal in spite of the fact that large quantities of hydrocarbons were found during analysis (Grizel *et al.*, 1978).

During the days immediately following the grounding, the species of fish living among the rocks immediately around the site of the accident (wrass, ling, sea-eel) suffered high mortality. The same was true of coastal species such as the grey mullet (*Mugil*) and seaperch (*Dicentrarchus labrax*). The populations of trawlable species in Morlaix Bay do not appear to have been affected by the pollution. By contrast, in Lannion Bay the piscine fauna appeared to be depleted in spring 1978 during the acute phase of the pollution. This depletion or disappearance affected mainly catfish, whiting, pout (*Trisopterus luscus*), silver-sides and horse mackerel (*Trachurus*).

Other strictly benthic fish like *Gobius*, gurnard, plaice and dab disappeared in December. This disappearance may be regarded as abnormal and connected with the pollution, either directly or because of the lack of food. Sole and yellow sole (*Buglossidium*) were equally abundant in April and December which would seem to indicate that the pollution had a selective effect, as stated by Desaunay *et al.* (1979). The same authors marked 76 plaice taken from Lannion Bay at the end of April 1978 and released them in Morlaix Bay. They reported that ten were recaptured, seven in the first 3 months. Two were taken close to Roscoff, one in Morlaix Bay, three off Beg and Fry and four in Lannion Bay. According to Desaunay, this shows that the plaice tended to return to shallow coastal waters in spite of their being very polluted.

In summary, it may be said that in the short term, catches of fish decreased immediately after the accident. Throughout the spring and autumn, catches made by professional fishermen were not abundant, the fish being few in number and small in size.

As we shall see in the next section, many observations and analyses by l'Institut des Pêches showed that in April 1978 several types of fish (pollack, gurnard, ray) were contaminated by the oil. Yet the percentage of contaminated fish rarely seems to have exceeded 15 per cent of total catches (Maurin, 1978). From this point of view, the situation seemed to be almost normal in May.

Short-term contamination

With a view to detemining whether the hydrocarbon content of substances extracted from *Laminaria* was too high to permit their use, Pérez (1978b) extracted alginates from samples which were assumed to be polluted. He analysed the alginates and compared them with a control alginate extracted from *Laminaria* collected in December 1977. Gas chromatography analysis provided additional results. To summarize his findings, the author noted that the hydrocarbon content of the alginate extracted from algae collected in April and May on the Primel Headland and at Trémazan, close to the site of the accident, amounted to 60 ppm and was only slightly higher than the level found in the controls (50–55 ppm). Extracts from *Fucus serratus* gathered on the shore at Trémazan contained hardly more hydrocarbons than the controls, and the same was true of samples of carragheenins obtained from *Chondrus crispus* (45–55 ppm).

While these analysis figures show that, after treatment, the hydrocarbon content of the seaweed extract was almost normal, it is nonetheless true that the analyses were not representative of the contamination of the tissue of the seaweed. An analysis of aliphatic hydrocarbons carried out in June and August 1979 at nine sites along the Breton Coast by Topinka and Tucker (1981) demonstrated a high and persistent level of contamination in *Fucus vesiculosus, Fucus serratus, Fucus spiralis* and *Ascophyllum nodosum* along the coast near the site of the wreck and, particularly, in the abers, which suggests that the level of pollution was high at the start.

Anylyses by l'Institut des Pêches carried out in March and April 1978 demonstrated that the flesh of crustaceans (edible crab, spider crab), which smelled slightly of oil, contained only slightly more hydrocarbons than normal (40–67 ppm). By contrast, high levels of hydrocarbons were found in the liver—up to 296 ppm whereas the average is between 100 and 150 ppm. It appears that not more than 5 per cent of the crustaceans caught were contaminated (Maurin, 1978).

The scallops sampled in Morlaix and Lannion Bays had a total hydrocarbon content of between 44 and 76 ppm—three to four times higher than normal (Maurin, 1978).

Although the recorded mortality among oysters was relatively localized and confined to the abers, the level of contamination was fairly high in this area and sufficiently high in the Morlaix and Penzé estuaries to justify destruction of the stock.

In the days immediately following the accident, the total hydrocarbon content of the oysters in the abers was around 300 ppm. Two months after, in mid-May, this level increased to a maximum 444 ppm in samples coming from Aber Benoît and to 643 ppm in those from Aber Wrach, as reported by Grizel *et al.* (1978). In 1981, Laseter and colleagues provided figures that were fairly comparable in view of the much later date at which the samples were taken. The total hydrocarbon content found by these authors in Aber Wrach three months after the accident was 360 ppm ($\pm$170) for the Pacific oyster and 290 ppm ($\pm$35) for the flat or (European) oyster.

Grizel *et al.* consider that the increase they observed could be attributed to the penetration into the abers of treated oil slicks mixed with the mass of water, or to the salting-out of the hydrocarbons trapped in the sediment. Later evidence suggested that this hypothesis was highly probable.

Still according to the same authors, the initial hydrocarbon content was around 220 ppm in the Penzé estuary. Later it tended to decrease by a process which we shall describe when we deal with the medium and long-term effects. The same was true of Morlaix Bay where an analysis of a sample of oysters immediately after the accident yielded a level of 248 ppm.

The first series of analyses on fish was made by the ISTPM on 90 samples taken in April and May 1978 in the polluted area; the analyses were supplemented by organoleptic tests (Michel, 1978) and demonstrated that, generally speaking, the total hydrocarbon content was low, the highest levels being contained in the flesh of rays (up to 85 ppm of total hydrocarbons). The additional organoleptic tests made on this occasion showed that rays, gurnards and pouts tasted strongly of oil. Later more detailed gas chromatography tests using a capillary column were made on 36 further samples of fish from the polluted area. By this method it is possible to distinguish between biogenic hydrocarbons such as squalene and pristane and exogenic hydrocarbons originating in the oil spill. Only two of the 36 samples contained exogenic hydrocarbons, namely heavy alkanes (C_{23} to C_{37}); the first came from a young pollack caught close to Portsall and contained 2.6 μg of alkane per gram of freeze-dried flesh. The flesh of the second, a sole taken in the vicinity of Primel-Trégastel, contained 1.1 μg of alkanes per gram of flesh (ISTPM, 1979).

Short-term disruptions in reproduction and growth

Biological laboratory tests carried out by Steel (1977, 1978) would seem to indicate that the process of fertilization had been upset in the *Fucus* exposed to pollution. Later observation did not confirm these fears. Early on in May, Pérez (1978a) reported:

1. The presence of dark brown spots on the fronds of *Laminaria hyperborea*, which meant that spores were being formed.
2. The fertility of stalks of *Gigartina, Fucus* and *Ascophyllum*.
3. The presence of cystocarps on 35 percent of the stalks of female *Chondrus crispus* plants, which proved that they had been fertilized.

Shortly thereafter, *Laminaria digitata*, in its turn developed spores which the author germinated in the laboratory from June onwards. In the polluted area, 80 per cent of the algae were fertile (Pérez, 1978b).

The appearance of a new generation of plantlets confirmed that reproduction was progressing satisfactorily in this species. At the end of 1978 the new generation accounted for 44 per cent of the *Laminaria digitata* population at Bréhat Island in an unpolluted area, a similar 44 per cent at Roscoff and Porspoder, and 53 per cent at Portsall. An estimate made at the same time of year in 1972 at Porspoder set the figure at 42 per cent (Pérez, 1979).

The same author found that in both the polluted area and the control area there were 31 to 35 per cent of new plants of *Chondrus crispus*. He estimated that in the case of *Fucus* the equivalent figure was 31 per cent.

In order to determine the comparative trends in the growth of *Laminaria digitata* in the polluted area and an uncontaminated one, Pérez (1978a, b) ringed several samples of this species which were about 2 years old. He recorded that there was relatively less growth in April than the average recorded for previous years. Nevertheless, as the difference was about the same for both the control group and the plants in the contaminated area (Trémazan) there is reason to think that this phenomenon was not due to pollution but rather to climatic conditions, which were not very favourable that month.

In any event, in May the metabolism rate increased. Plants grew as much as 31 cm at Trémazan and 32.6 cm in the control area, the usual figures varying between 28 and 34 cm. Thereafter, growth was first normal and then above average. For instance, in October, fronds in the area close to the wreck grew by another 10 cm whereas generally growth during this month is between 4 and 7 cm (Figure 7.5.4).

In the case of *Chondrus crispus* the growth rate turned out to be good. After the harvest, Pérez noted that shoots began to grow from the basal discs. These shoots were more numerous on algae at Portsall and Roscoff than in the control area.

It was not possible to monitor the short-term trends in the reproduction and growth of the large crustaceans. However, Léglise and Raguenès (1981) reported that the percentage of berried female lobsters caught at the end of May 1979 in the Portsall beds was abnormally low for the time of year (25 per cent). Observations made in the Méloines beds near Roscoff prior to the accident showed that the

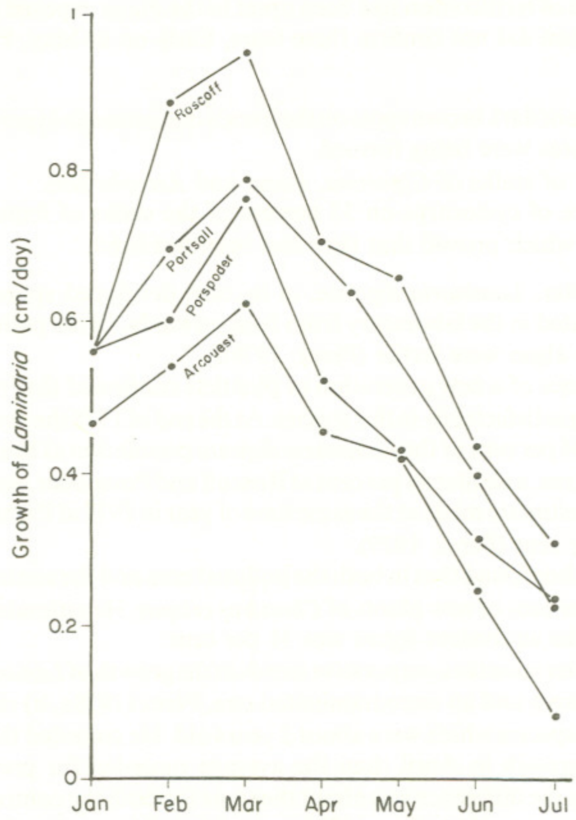

Figure 7.5.4 Growth of *Laminaria digitata* at various stations during the year 1978. Growth was distinctly higher in polluted areas. (From Maurin, 1979; Data collected by R. Pérez)

percentage of females with eggs was 87 per cent in April, 73 per cent in May, 56 per cent in June and 28 per cent in July (Audouin *et al.*, 1971). This led Léglise and Raguenès to the conclusion that some females lost their eggs prematurely or dumped them, a course which they had earlier been observed to take when the eggs were no longer viable.

Balouet and Poder (1981) observed an atrophying of the gonadal cells in oysters from the abers, examined shortly after the 'Black tide'. The figures for the trends in the gonadic indices of the common oyster (*Ostrea edulis*) from Aber Benoît were very much lower for the period May to September 1978 than for the same months in 1977 and were respectively 4.1 to 9.2 and 11.6 to 24.6. The authors did not think there was any reproduction. For the Pacific oyster (*Crassostrea gigas*), the figures seemed to follow a normal trend; in Aber Benoît and at Carantec, still for the period May to September, they were fairly high—11.6 to 31.4 for Aber Benoît and 7.6 to 36.4 for Carantec. Generally this oyster does not reproduce in this region.

The same authors examined the figures indicating the condition of the oysters (dry weight × 100/intervalvular volume) by sampling ten oysters out of each of 142 lots. The results show that in Aber Wrach and Aber Benoît the condition index for 1978 gives an annual curve comparable to that for 1977 for both *Ostrea edulis* and *Crassostrea gigas*. By contrast, in the Morlaix Bay area a certain drop in the condition index was recorded, from the beginning of May, for Pacific

Table 7.5.5 Condition index of oysters after the *Amoco Cadiz* oil spill (from Balouet and Poder, 1981, by permission of Centre National pour l'Exploitation des Oceans)

	Aber Benoît		Aber Wrach		Carante	
	ACP Edulis	ACP Gigas	ACP Edulis	ACP Gigas	ACP Gigas	ACA Gigas
May 1978	102	130	85	161	177	120
June	164	140	160	138	179	76
July	132	223	220	172	130	101
August	151	198	159	165	125	101
September	108	95	118	111	90	110
October	112	154	118	153	99	
November	118	166	244	114	89	82
December				100	66	
January 1979		178	143	160	70	
February	85	150	110	130		62
March	74	134	130			73
April	155	133	176	154		90
May	128	162	176	160	67	71
June	117	187	179	195	75	78
July	166	236	224	160		93
August						
September	128			142		131
October	197			192		120

oysters present in the area at the time the pollution occurred or transferred into this sector immediately thereafter (Table 7.5.5).

Linear growth is considered by Grizel and colleagues (1981) to have been interrupted in 1978 in the abers. They monitored developments in the comparative lengths (in millimetres) of Pacific oysters (*C. gigas*) raised in the Ria d'Auray which is in south Brittany and, therefore, some distance from the affected area, and in the polluted area of the Ria de Morlaix. The results obtained show that growth began late in both the Bay of Morlaix and the Ria d'Auray but that this was made up later. In October, the average length of 100 average sized individuals, which had initially been all the sample size (55 mm), was 83 mm in Morlaix and 88 mm in Auray. Also, 18-month-old oysters weighing 20 to 25 g, which were placed in the beds in Morlaix Bay in February and March 1978, weighted 40 to 60 g in November to December of the same year, so that these results are similar to those obtained for previous years.

While studying the population structure of plaice in Lannion and Morlaix Bays, Desaunay *et al.* (1979), and Desaunay (1981) observed that the structure in April 1978 was similar to that recorded in other Channel areas. In the next few months there were abnormal developments. In particular there were no young at the end of the year, which meant that there had been no reproduction or that the eggs and larvae had been destroyed. In addition, the one-year-olds grew very little (2 cm in eight months) by comparison with the normal rate. In the case of sole, the most obvious factor was the absence of juveniles in 1978. Growth of adults did not appear to have been significantly affected. No recruitment in the dab population was observed.

Miossec (1981a, b) reported irregularities in the reproduction of plaice in the abers in 1978. The gonado-somatic ratio was very low compared with the reference areas. These anomalies were confirmed by a histological study: in the vitellogenesis period the ovocytes were heterogeneous in size, relatively small and widely dispersed in the gonads. The author reported atresia, large numbers of blood vessels and the development of conjunctive fibres. Finally, Miossec reported very little recruitment in the population at the end of the year.

Conan and Friha (1979, 1981) estimated trends in growth for sole and plaice in Aber Benoît. To do so they compared figures for the standard length of the fish, and those for otoliths observed over a period of 4 to 5 years prior to the wrecking of the *Amoco Cadiz*, with the figures for 1978. This showed that there was a clear difference between 1978 and previous years. In 1978, growth was abnormally slow in all age groups. Growth in sole dropped to 25 per cent of normal in young and 88 per cent of normal in adult fish. But the opposite was noted for plaice: growth in young fish was 88 per cent of normal while in adults it was 30 per cent.

7.5.4.2 Other Accidents: The *Gino*

We have fewer biological and ecological records of which fishing resources were affected by other accidents occurring in Brittany waters than we have for the

Amoco Cadiz. There are various reasons for this, particularly for the *Bohlen* and the *Gino*, as these wrecks lie in relatively deep water—around 100 m—and the latter is quite far from the coast. Where the *Tanio* is concerned, her pollution affected almost the same sections of the coast as the *Amoco Cadiz* spill, which made it difficult to identify what damage was done. We will therefore note only a few facts which will permit some comparisons.

Mortality

The *Bohlen*'s cargo was a highly viscous crude which included approximately 60 per cent asphalt, some polymerized products, 35 per cent aromatic hydrocarbons and 2.5 per cent saturated hydrocarbons. Although relatively small, the quantity involved (about 10 000 tonnes) caused significant mortality in various species, particularly edible crab (*Cancer pagurus*). The reason for this mortality may be that, with a density almost equal to that of water, the highly toxic product spread throughout the water column and blocked up the branchiae of the animals.

In the case of the *Gino*, the carbon black oil in its cargo tanks contained 60.9 per cent toxic aromatic hydrocarbons, 11.5 per cent saturated hydrocarbons, 15.8 per cent resins and 11.8 per cent asphaltenes.

The earliest observations made on board the *Roselys* and the *Thalassa* at the beginning of May 1979 showed that in the area around the wreck the scallops were alive, but that some of them were stained with a brown, flaky, viscous material which came from the tanker's cargo. The piscine fauna, comprising mainly gurnard (*Trigla lucerna*), horse mackerel (*Trachurus*), pout and capelin (*Trisopterus luscus* and *minutus*), Blue whiting and catfish (*Scylliorhynus*) appeared to be unaffected by the pollution (ISTPM, 1979, 1980).

A year later, within a radius of some 7 miles of the wreck, Michel observed evidence of recent mortality in scallops, frequent atrophy of the gonads, and absence of reaction in some living individuals.

Contamination

After the *Gino* spill, in the fish analysed, even in the viscera, there were no signs of significant amounts of accumulated hydrocarbons. Traces of low-level contamination were found in crustaceans (*Cancer pagurus*). Microscopic examination of eggs in the females of this species showed no detectable contamination (Michel and Abarnou, 1981).

Scallops, which make excellent indicators of contamination in the open sea because they are active filterers, were highly contaminated (up to 100 ppm of aromatic hydrocarbons in the muscles) within a radius of up to 5 to 10 miles of the wreck, depending on the compass bearing. Up to a distance of 15 miles (and occasionally more than that), the aromatic hydrocarbon content in the muscles was some 20 ppm. At a distance of 15 to 30 miles the content was generally 5 ppm or less.

7.5.5 MEDIUM AND LONG-TERM CONSEQUENCES

The public is most deeply moved by the immediate consequences of an oil spill. But these consequences do not always reflect the actual situation. In fact, in order to have any real idea of the impact on resources, the ecological situation has to be monitored over a period of years. Although the period separating us from the *Amoco Cadiz* accident is too short and that for the *Gino* even shorter, and it is therefore still too early to make any final pronouncements, it has been possible to make some observations. These are interesting enough to merit an attempt to summarize them.

We focused attention on three points which we found important, namely:

1. The spread of the contamination.
2. The ecological, teratological and pathological effects.
3. Developments in stocks.

We will begin by giving examples for the *Amoco Cadiz*. For the *Gino* we shall keep mainly to how contamination progressed, as this is the only factor about which we have any definite knowledge so far.

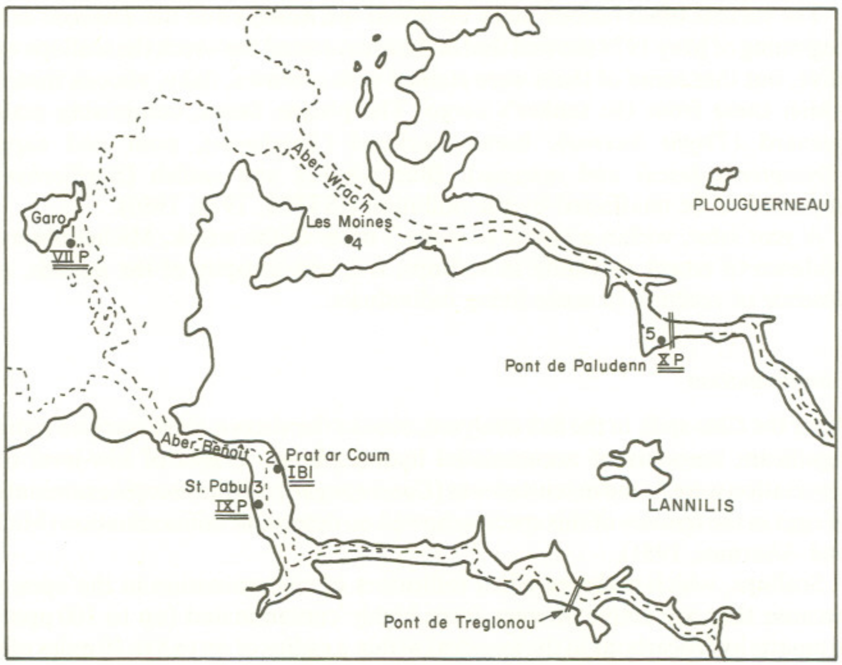

Figure 7.5.5 Map of stations observed in Abers Benoît and Wrach. (Reproduced from Grizel *et al.*, 1981, by permission of Centre National pour l'Exploitation des Oceans)

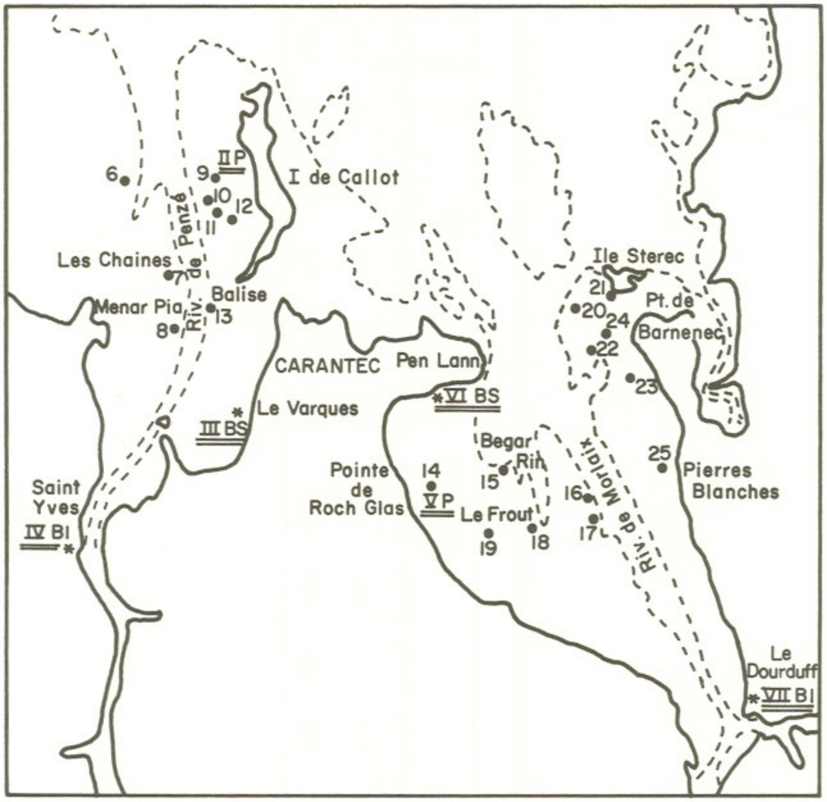

Figure 7.5.6 Map of stations observed in Penzé and in Morlaix Bay. (Reproduced from Grizel *et al.*, 1981, by permission of Centre National pour l'Exploitation des Oceans)

7.5.5.1 The *Amoco Cadiz*

The spread of the contamination

We have taken oysters as an example of how contamination caused by the *Amoco Cadiz* oil spread, since these molluscs, which are easy to sample or transfer, struck us as highly representative.

First Grizel, Michel and Abarnou (1978) and then Grizel *et al.* (1981) monitored this development in respect of oysters from the North Brittany shellfish breeding areas. The authors made observations on 5325 Pacific oysters (*C. gigas*) from 213 lots of 25 individuals each, and on 400 common oysters (*O. edulis*) from 16 lots of 25 each. The samples came from three stations in Aber Benoît, two in Aber Wrach, eight in the Penzé estuary (right and left banks) and 12 in Morlaix Bay (also the right and left banks) (Figures 7.5.5 and 7.5.6).

Table 7.5.6 Level of contamination of abers oysters shown by ppm total petroleum hydrocarbons per kg wet weight. (From Maurin, 1979; compiled from data collected by P. Michel and H. Grizel)

	1978										1979					
Stations	5 Apr	25 Apr	25 May	26 Jun	20 Jul	17 Aug	17 Sep	19 Oct	15 Nov	15 Dec	1Feb	27 Feb	28 Mar	20 Apr	25 May	20 Jun
Aber Wrach	293	131	643		304	208	277		106	140	260	155	188	154	159	150
Aber Benoit	310	298	444	154	155	188	222	193	200	203	247	114	162	167	154	187

The authors state that the average reference value for eight different regions not affected by pollution from the *Amoco Cadiz* was around 60 ppm ($\pm$20) of total hydrocarbons.

The authors' preliminary data are for the kinetics of the *in situ* decontamination of oysters. In Aber Benoît, the highest and lowest averages established per station went from 298–310 ppm in April 1978 to 275–444 ppm in May and 154–188 between June and August. In October to November, when the sediments were again stirred up by the swell, the levels were 193–203 ppm. There was then a slight drop for the period between the end of February and April 1979 (114–167 ppm). In June the level was again some 187 ppm (Table 7.5.6).

In Aber Wrach the average levels for each station went from 142 and 293 ppm, in April, to 131 ppm for the station at the mouth of the aber and 643 ppm for the station upstream, in May. Levels of between 304 and 208 ppm remained unchanged from July to September and then started decreasing, beginning in November, particularly at the entrance to the aber (106 ppm). The contamination level rose again (to 260 ppm, upstream) and then settled at around 160 ppm from April to June.

Thirteen months after the accident, Laseter *et al.* (1981) found 225 $\pm$ 23 ppm of total hydrocarbons (of which 131 $\pm$ 12 ppm were aromatics) in the Pacific oyster and only 59 $\pm$ 9 ppm (of which 30 $\pm$ 6 ppm were aromatics) in the common oyster. This means that decontamination was much less rapid in the Pacific oyster

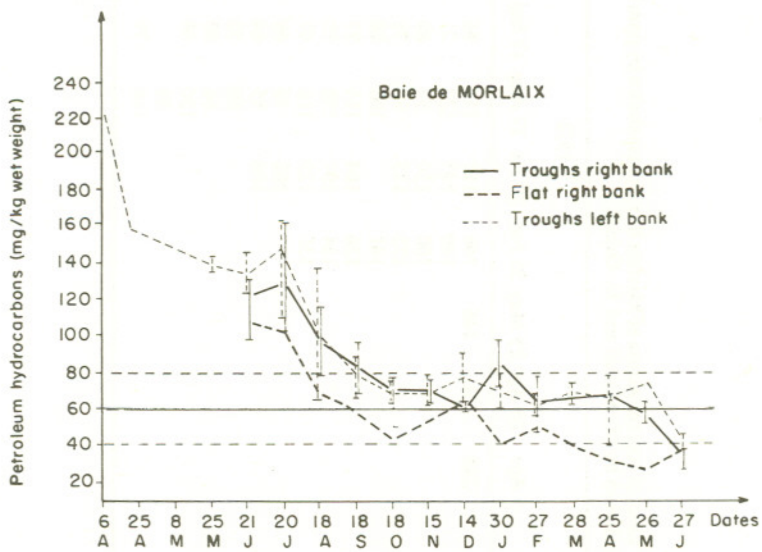

Figure 7.5.7 Purification kinetics of Morlaix Bay oysters. (Reproduced from Grizel *et al.*, 1981, by permission of Centre National pour l'Exploitation des Oceans)

Table 7.5.7 Level of contamination of Morlaix Bay oysters shown by ppm total petroleum hydrocarbons per kg wet weight (From Maurin, 1979; compiled from data collected by M. Michel and H. Grizel)

	1978										1979					
Stations	5 Apr	25 Apr	25 May	26 Jun	20 Jul	17 Aug	17 Sep	18 Oct	15 Nov	14 Dec	1 Feb	27 Feb	30 Mar	20 Apr	25 May	20 Jun
9	248	161	146	146	111	118	86	78		79	28	68	77	79	75	38
2				140	145	120	71	57	45	64	77	62		53		50
5				100	136	99	80	39	50	70		60		45		39
6				175	113	91	71	55	50	65	57	56	57	52	73	42
10				141		105	80	76	75	92	72	69	62	74		
11				126	164	111	87	77	61	83	63	63	77	79		48
12				134	191	138	90	71	80	68	74	71	73	40		45
17				135	129	116	97	74	78	59						
18					102	78	69	76	67							
1					106	95	64	56	56	56	74			54		32
19						69	58	50	62	64	71	48	67	66	53	28
12*						66	88									
13						120	68									
14						88		65								
15						116	79	67								

*(repeat)

(*C. gigas*) than in the common oyster (*O. edulis*), since the values the authors found in May 1978 were some 360 ± 170 ppm of total hydrocarbons (of which 210 ± 100 ppm were aromatics) for the former species and 290 ± 35 ppm (of which 150 ± 12 ppm were aromatics) for the latter.

For Morlaix Bay, as for the Penzé estuary, the only figures available are those provided by Grizel and colleagues (1978, 1981). In Morlaix Bay the Pacific oysters, whose flesh contained between 204 and 220 ppm in April 1978, decontaminated themselves fairly completely between May and October of that year. The hydrocarbon content was 145 ppm on the right bank and 142 ppm on the left bank, in May, and remained stable in June and July (120 to 128 ppm on the right bank and 136 to 151 ppm on the left bank). Contamination levels then dropped again, to 71 ± 12 ppm on the right bank and 72 ± 6 ppm on the left bank. The authors reported a slight increase in December 1978 and January 1979 (62 ± 3 to 80 ± 10 and 85 ± 20 to 73 ± 8 ppm, respectively) followed by a stable period. Average values in May 1979 were between 58 ppm and 75 ppm and then fell in June to 33–44 ppm (Table 7.5.7, Figure 7.5.7).

Grizel *et al.*, reported findings similar to those of Laseter and his colleagues in observing that the figures for the Pacific oyster are always higher than those for the common oyster. In the latter species, average contamination levels decreased from 110 ppm in June 1978 to 30 ppm in May 1979 (right bank).

In the Ria de Renzé the kinetics of decontamination were similar to those to Morlaix Bay, for both the right and left banks. The average contamination level of 200 ppm in April 1978 dropped to about 40 ppm in June 1979 (Figure 7.5.8).

These authors also reported on the operations to transfer oysters from contaminated to clean areas (south Brittany) and from clean to contaminated areas. In the first instance, the transfer took place 20 days after the grounding. In the case of oysters from Aber Benoît whose initial hydrocarbon content was 320 ppm, the level dropped to 66 ppm in 18 days. One month later other oysters from Morlaix Bay, which originally contained 248 ppm, contained no more than 54 ppm of total hydrocarbons. In the second instance, oysters from the Auray estuary in South Brittany, with an initial hydrocarbon content of some 47 ppm, had levels of 89 ppm 2 months later. Finally, samples from South Brittany initially containing 27 ppm and transferred to Aber Wrach in January 1979, contained 120 ppm by June that year.

Similar experiments in the abers have been published by Friocourt *et al.* (1981). Here the oysters kept in a polluted area had partially decontaminated themselves after 16 months. Residual contamination levels were still high, particularly as regards aromatic hydrocarbons (32 ± 14 to 66 ± 13 ppm total hydrocarbons, 8.8 ppm aliphatics, 24 ± 13 ppm aromatics). In the polluted oysters transferred to uncontaminated sites, the level of total hydrocarbons decreased rapidly, falling to 16 ± 4 ppm in 6 months, but the aromatic compounds persisted.

Healthy oysters were placed in polluted parts of the abers in May 1978 and again the rapidity with which hydrocarbons accumulate was demonstrated. The

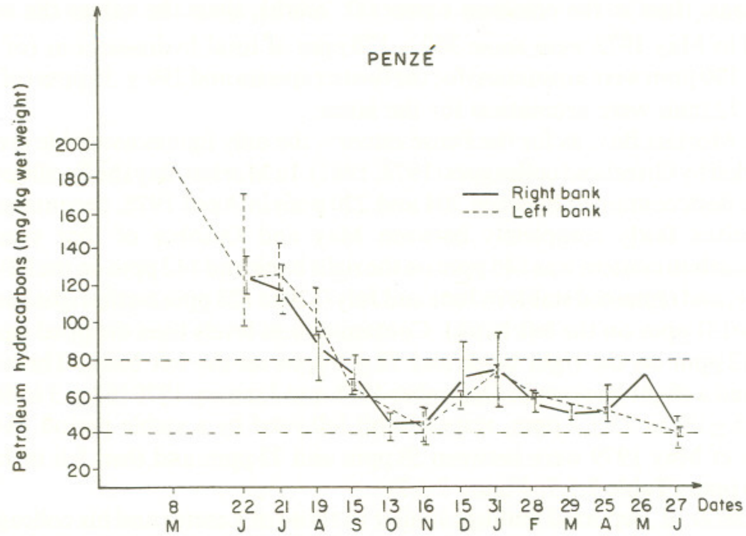

Figure 7.5.8 Purification kinetics of Penzé oysters. (Reproduced from Grizel *et al.*, 1981 by permission of Centre National pour l' Exploitation des Oceans)

aliphatic and aromatic content increased from 4 to 53 ppm in 15 days and then steadily but slowly declined during the following 16 months, as the level of pollution in the environment decreased.

Three years after the pollution occurred, Gouygou and Michel (1981a, b) took up the matter again by studying a batch of health Pacific oysters from Quiberon Bay which were placed in an oyster bed at Saint-Pabu in Aber Benoît in March 1979. The site selected has a mud and sand bottom contaminated by hydrocarbons. The batch of oysters remained in this contaminated area for almost two years.

In February 1981, the total aromatic hydrocarbon content of the oysters was some 49.5 mg kg^{-1} of dry flesh. Analysis showed that the hydrocarbons consisted of nearly 70 per cent persistent thiophene compounds (54.4 per cent alkyl dibensothiophene or DBT and 13.3 per cent naphthobenzothiophene or NBT), about 21 per cent phenanthrene and 4.9 per cent fluoranthenes, pyrenes and their alkylated derivatives. An examination of the results showed that the saturated hydrocarbons initially present in the oil were absent and that the aromatic hydrocarbons such as alkyl benzene and alkyl naphthalene had disappeared. The absence of both clearly demonstrated that no significant chronic or incidental pollution was present to interact with the oil spilled by the *Amoco Cadiz*.

Having clarified this point, it was important for the authors to ascertain the kinetics involved in the process of eliminating the hydrocarbons. Therefore, in

February 1981 they undertook a decontamination experiment in an unpolluted area. The figures they obtained were:

48 mg kg^{-1} after 4 days
41.2 mg kg^{-1} after 18 days
24.4 mg kg^{-1} after 32 days
17.7 mg kg^{-1} after 53 days
14.2 mg kg^{-1} after 69 days.

The composition of the hydrocarbons did not vary significantly from what it had been at the outset.

The authors believe that the compounds they found are present in the oil initially, but in relatively small amounts, and that these may be masked during analysis. This therefore points to the need for both general and specific measurement of aromatics as part of the process of monitoring contamination (Michel, 1981a, b). The experiment also showed that healthy oysters transferred into a contaminated area one year after the accident may, two years later, be flushed of the persistent hydrocarbons they then contained by reintroducing them into an uncontaminated area. The authors consider that decontamination in this case takes longer than after contamination by fresh oil but that, in the case in point, the oysters can again achieve a satisfactory quality after a prolonged stay in clean water.

However that may be, the observations of both Gouygou and Michel, and the other authors referred to here, call for comment on our part. If there were any need for justification, the presence and persistence of thiophenic hydrocarbons in the oysters in the abers, three years after the accident, fully justifies the decision taken shortly after the grounding of the vessel to destroy the remaining stocks in the area. Although, as yet, there is very little data available on the toxicology of these derivatives, we would like to remind readers that Hermann and his collaborators (1979) found a correlation between mutagenesis and the polynucleated aromatic hydrocarbons.

Ecological, teratological and pathological effects

Continuing where Pérez had left off, Kaas (1980, 1981) studied the development between January 1979 and May 1980 of the algal fields on the Brittany Coast between Porspoder and the Arcouest headland south of Bréhat Island. He selected four sites at which he monitored growth. From west to east these were:

1. The St. Laurent Peninsula at Porspoder.
2. The shingle between Trémazan and Portsall.
3. La Rochezu at Roscoff.
4. The unpolluted Arcouest headland, which was used as a control.

During the 16-month period beginning 10 months after the spill occurred, Kaas monitored the apparent average growth of the fronds of *Laminaria digitata*, i.e. actual new growth minus that eroded by wave action. He noted that, on the whole, apparent growth was greater among the algae in the polluted areas than those in the control zone. The difference was particularly marked at the Trémazan site which is closest to the wreck. In the algae at this site, average monthly growth of the fronds achieved a maximum of 210 cm in April 1979, while at Arcouest the highest average (registered in June) was some 50 cm.

For actual growth, calculated by means of the progress of a reference marker, the differences were even greater. For instance, average daily rates of growth at Roscoff reached a maximum of nearly 1 cm (per day) in April 1979 and a minimum of around 0.30 cm in July to August. At Portsall and Porspoder the respective averages were 0.75 cm and 0.25 cm for the same months, whilst at Arcouest growth hardly exceeded 0.60 cm in April and dropped to 0.08 cm in July to August. It should be stated that these figures are borne out by those given by various authors, particularly Pérez (1968), prior to the accident, at least for the summer months in Normandy (Figure 7.5.9).

For the stipe of the seaweed the results are similar. Although figures vary significantly for the various contaminated sites, it may be said that the stipes of

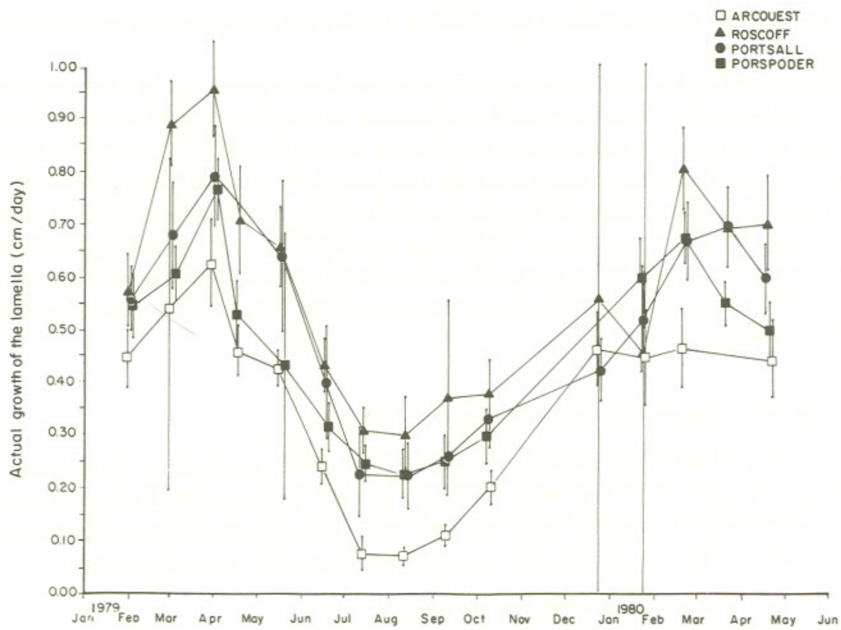

Figure 7.5.9 Actual growth of the lamina of *Laminaria*, from January 1978 to June 1980, at various sites in the contaminated zone and at the control station. (From Kaas, 1980. Reproduced by permission of ISTPM, B.P. 1049, 44037, Nantes Cédex)

seaweed polluted by hydrocarbons grew faster during the period in question than those of seaweed in the control zone.

In all, and in spite of local differences which may be ascribed to the hydrodynamic conditions, it may be said that the seaweed in the polluted areas grew much faster than the *Laminaria* in the control zone. The explanation for this apparently favourable phenomenon lies in the eutrophication caused by an enrichment of the environment by organic matter. We must say 'apparently', as Kaas states that the metabolic activity of *Laminaria* was promoted only up to a certain point. Once this point was reached, physiological deterioration followed, taking the form of increased fragility in the plants. The author stresses the fact that the phenomenon occurred one year after the accident and that two years after the accident the *Laminaria* population of the polluted area was more heterogeneous than that of the control area.

With respect to reproduction, Kaas confirmed the preliminary observations of Pérez reported in Section 7.5.4, that young plants appeared even in the most contaminated areas, and the presence of these young individuals in the algal fields in 1979 is a clear sign that reproduction in 1978 was successful. On some sites young plantlets account for more than 50 per cent of the total population.

This reproductive success was confirmed by further experiments to get the spores of polluted *Laminaria* to germinate in the laboratory, in 1979. The experiments showed that the reproductive potential of the algae did not appear to be significantly impaired.

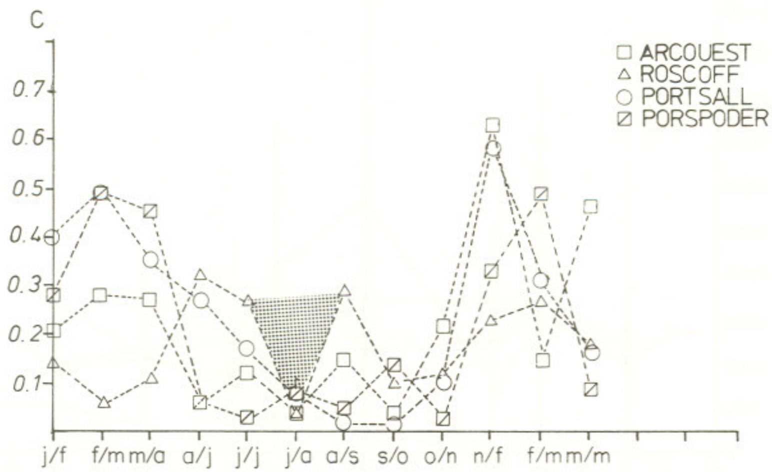

Figure 7.5.10 Variation of the coefficient of contingency for *Laminaria* at three contaminated sites and at the control station (Arcouest). The diagram shows the period of limited fertility (shaded area) of algae at the Portsall site as compared to that at the other stations. (From Kaas, 1980. Reproduced by permission of ISTPM, B.P. 1049, 44037, Nantes Cédex)

However, the author indicated that the number of plantlets was lower at polluted sites than at others. He also noted that the period of fertility was shorter at Roscoff than in other sectors (Figure 7.5.10).

Where the seaweed *Chondrus crispus* is concerned, Kaas noted a net drop in biomass as compared with the years preceding the accident, but he does not attribute this to the pollution or, at least, not entirely. A similar decrease was reported in other geographical areas, particularly Normandy. In conclusion, Kaas considers that, although the oil spilled by the *Amoco Cadiz* may have had a harmful effect on the population of *Chondrus*, this merely accelerated the process of deterioration (Figure 7.5.11).

Where crustaceans are concerned, it is worth drawing attention to one fact reported by Ramirez-Pérez *et al.* (1980). In the course of their study on the pathology of marine crustaceans of the Atlantic coast of Europe, the authors noted a pathological symptom, never before recorded, which manifested itself mainly in skin ulcers in the populations of *Carcinus maenas*, common shore crab, of the Roscoff area. The skin ulcers were frequently associated with internal lesions which caused generalized fatal syndromes. These complications were of two types: septicaemia or penetration of the visceral cavity by the dense substance covering

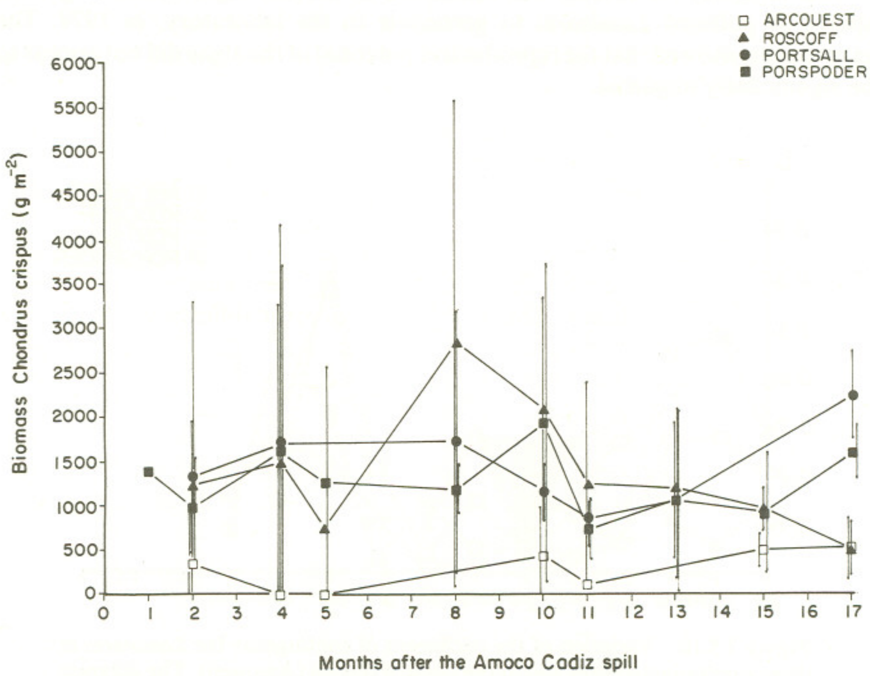

Figure 7.5.11 Development of biomass of red alga *Chondrus crispus* in the contaminated zone and at the control station (Arcouest). (From Kaas, 1980. Reproduced by permission of ISTPM, B.P. 1049, 44037 Nantes Cédex)

the ulcerated area. In the latter instance, irregularly shaped particles of this substance are surrounded by lesions and multicellular haemocyte reactions. The authors noted that, without exception, all the affected crustaceans were from a sector throughly contaminated by the *Amoco Cadiz* spill and that the syndrome had not been noted prior to this accident. They consider that the syndrome is significant as an indicator of pollution and that it could be taken as a demonstration of the delayed pathological effect of such pollution.

In the course of their study on the biological effect of the pollution caused by the *Amoco Cadiz* oil on shellfish breeding in North Brittany, Balouet and Poder (1981), working on oysters from the abers, noted a degenerative cellular impairment which was particularly marked in the epithelial cells and the digestive diverticulum. They also noted the frequency of inflammation, indicated by the presence of macrophagic cells, and found many large pigmented cells in oysters observed 6 months after the black tide. These authors clearly state that the lesions are not very specific but that they are interesting because of their spread, their frequency and their development. It should be added that, even outside the polluted areas, this type of lesion is not rare in oysters which have suffered stress due to major fluctuations in temperature or salinity or due to having been left out of water for too long, etc.

Balouet and Poder therefore tried to quantify their observations. To do so they used a necrosis index for each type of tissue (branchiae, interstitial tissue, gonads, alimentary tract) and another index for the total incidence of lesions. A score reflecting the seriousness of the lesion was given to each tissue when it was examined under the microscope. In the case of oysters, the total index obtained in this way was 18.8 for batches taken directly from polluted areas, 27.9 for batches transferred to other areas (the high figure could be explained by the phenomenon of extra stress) and 23.1 for healthy oysters bedded in a polluted area. Samples examined in 1977, before the oil spill, were used as controls. Their necrosis index, at 5.3, was very much lower. There was no significant difference between the common oyster and the Pacific oyster.

When changes over a period of time were considered, the most typical fluctuations in the necrosis index were obtained for *Ostrea edulis* in Aber Benoît. There was a considerable increase between May and August 1978, a decrease in October–November of the same year, and a certain degree of stabilization between February and July 1979, although the figures were always higher than those for the control batches. Nevertheless, Balouet and Poder consider that the level of damage in the oysters was not as high as had initially been feared.

Frequent anomalies in fish taken from areas polluted by the *Amoco Cadiz* oil have been reported by several authors. These are not specific either, as similar anomalies have been observed in other regions. Nevertheless, the large numbers of anomalies and their frequency would seem to indicate that in this instance they could have some connection with the pollution.

During the sampling carried out after the *Amoco Cadiz* was wrecked, Desaunay

(1981) noted that in Lannion and Morlaix bays anomalies were observed in several species of fish, from the end of summer 1978 onwards, i.e. some 6 months after the acute phase of pollution. Most of the anomalies were found in flatfish such as brill (*Scophthalmus rhombus*), turbot (*S. maximus*). flounder (*Platichthys flesus*), Dover sole (*Solea vulgaris*), and particularly plaice (*Pleuronectes platessa*). Anomalies also occurred in black sea-bream (*Spondyliosoma centharus*), pollack (*Pollachius pollachius*) and cod (*Gadus morhua*).

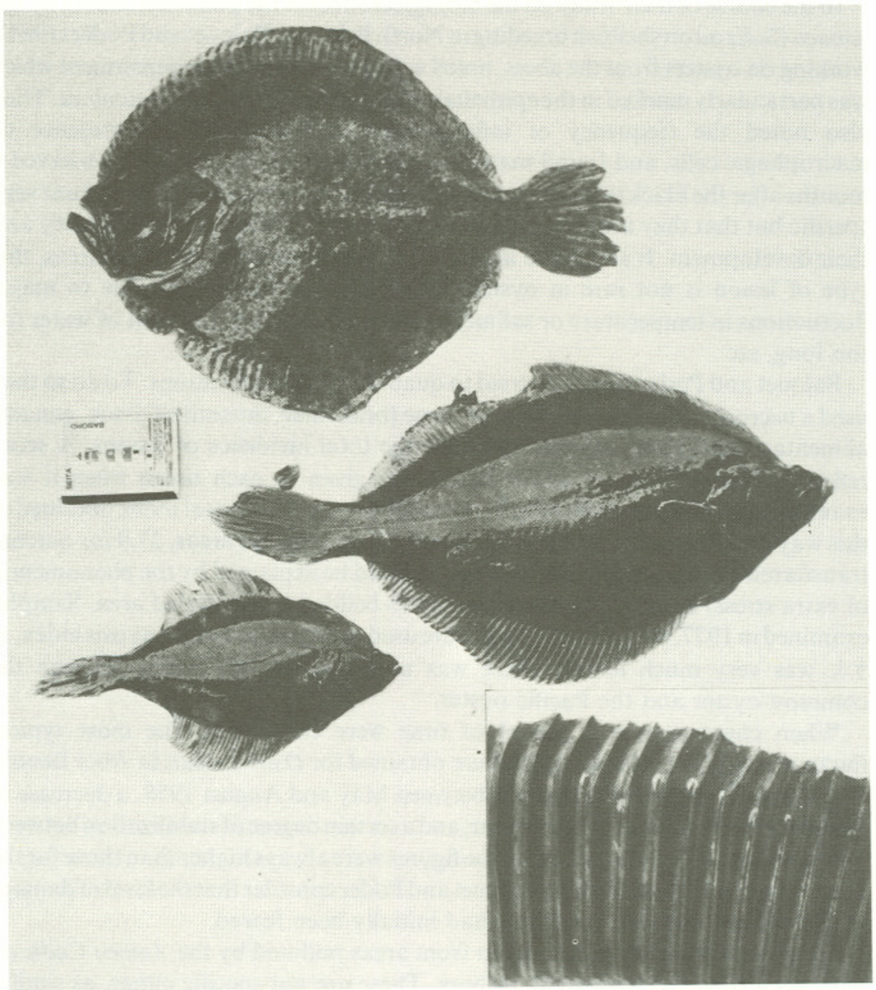

Figure 7.5.12 A young turbot (*Scophthalmus maximus*) and two plaice (*Pleuronectes platessa*) caught in Lannion Bay at the end of 1978, showing 'fin rot'. Insert: 'bent fin ray' phenomenon in a plaice caught in Lannion Bay in May 1979. (From Desaunay, 1981. Reproduced by permission of Centre National pour l'Exploitation des Océans)

The symptoms were excessive blood flow to the fins which congested with blood (frequently noted in sole), total or partial fin erosion or fin rot mainly affecting the caudal fin in Gadidae or the posterior part of the fish, and the caudal fin in plaice, or else bent fin rays. In the latter case the fin looked as if it was broken (Figure 7.5.12). For plaice, the fish in which he observed these deformations most frequently, Desaunay calculated the percentage of individuals affected in the coastal area in which the trials were being carried out. This was 0 per cent in April 1978, 9 per cent in December of the same year, 73 per cent in May 1979, and 2.5 per cent in October 1979.

Conan and Friha (1979, 1981) reported frequent occurrences of the phenomenon of fin and tail rot in plaice and sole from Aber Benoît.

Starting in November 1978, Miossec (1981a, b) made a detailed study of this fin necrosis on a population of plaice in Aber Wrach and Aber Benoît. The study highlighted the fact that there were big fluctuations over a period of time and between different places.

In Aber Benoît, the percentage of fish affected increased from 43.6 per cent in December 1978 to 81 per cent in February 1979, fell to around 63 per cent in April–May of the same year, rose to 86.4 per cent in July, decreased again to 63 per cent in August, increased slightly in September and fell to 15.3 per cent in November 1979. Thereafter there were further fluctuations as follows:

53.8% in December 1979
28% in January 1980
37.5% in March 1980
47.6% in April 1980

Out of a total of 891 plaice captured from Aber Benoît between December 1978 and April 1980, 533 (59.8 per cent) had damaged fins. However, signs of scar formation appeared beginning in September 1979 in 33.3 per cent of the fish observed. Scars were present in 77.3 per cent of fish in February 1980 and in 42 per cent of fish in April of the same year.

In Aber Wrach, the development of fin damage was fairly similar. Starting at 38.7 per cent in November 1978, the figures reached their first peak in January and February 1979 (93.3 and 95.5 per cent) and thereafter a second peak in March 1980 (84.2 per cent). In April 1980 some 57.1 per cent of the fish were still affected. Of a total of 694 plaice fished out of this aber, 369 (53.2 per cent) exhibited anomalies. In this area, the author also observed evidence of scarring from September 1979. Here maximum scar formation occurred in January 1980 (88.9 per cent).

Miossec noted that in both areas, the dorsal, caudal and anal fins were more frequently damaged than the pelvic and pectoral fins.

The author also pointed out the considerable differences in the geographical spread of this necrosis. In a preliminary balance sheet drawn up in October 1979 she noted that, in the case of Aber Wrach, the percentages obtained for all fish observed at this period were 56.3 per cent at the mouth, 63.3 per cent in the middle

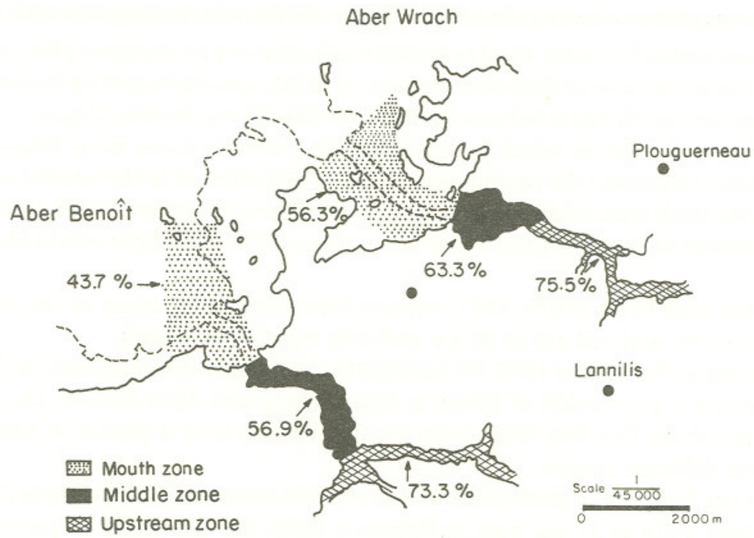

Figure 7.5.13 Percentage of fish (*P. platessa*) affected by fin deterioration in Aber Benoît (left) and in the Aber Wrach (right). (From Miossec, 1981. Reproduced by permission of Centre National pour l'Exploitation des Océans)

of the aber and 75.5 per cent upstream. For Aber Benoît (Figure 7.5.13) the respective figures were 43.7 per cent, 56.9 per cent and 73.3 per cent.

At the end of the study in April 1980 the overall percentages covering 18 months of observations were lower but showed a similar distribution. The highest figure (66.9 per cent) was recorded in the upstream section of Aber Benoît.

It is not impossible that the fluctuations during the period covered by the author reflected the level of agitation in the environment and the availability of food. Where spatial variations are concerned, the explanation could be the nature of the substrate, the finest substrates being the better absorbers of oil.

Finally, Miossec also noted damage to fins in flounders (25 per cent in Aber Wrach and 6.7 per cent in Aber Benoît) as well as in sole (37.2 per cent in the first aber and 41.2 per cent in the second). No anomalies were noted in the fins of dab.

Following a slightly different line, but one which is also connected with the teratological and pathological effects of pollution, Haensly *et al.* (1979) studied the long-term effects of the *Amoco Cadiz* oil spill on plaice taken in Aber Benoît. The conclusion of this major study is that plaice gathered in this estuary had a large number of histopathological anomalies. A comparison with fish of the same species taken in Douarnenez, which was hardly affected by the accident, allowed the authors to establish a relationship between these phenomena and the pollution, at least for a large proportion of the anomalies.

In particular, they consider that hyperplasia and hypertrophy of the lamellar epithelium of the mucous cells of the branchiae are the result of the reaction of tissue to the irritant effects of the oil and an attempt by the animal to avoid absorbing the toxic substances. This reaction had a deleterious effect on respiration, and the dilation of the capillary lamellae was an attempt to balance this effect.

Also according to these authors, the oil constituents caused degeneration of the gastric glands and the pancreas. Lesions occurring in these organs enable the toxic substances to penetrate into the portal system and possibly into the liver.

The oil also affects the skin causing significant hyperplasia and hypertrophy of the mucous cells of the epidermis.

Haensly and colleagues (1979) consider it as a proven fact that the liver of these fish metabolizes the toxic substances. The process requires so much energy that the cellular or hypodermal lipid reserves are used up and the subjects lose weight. The authors consider that the absence of lesions in the kidneys seems to prove that the detoxification process is effective.

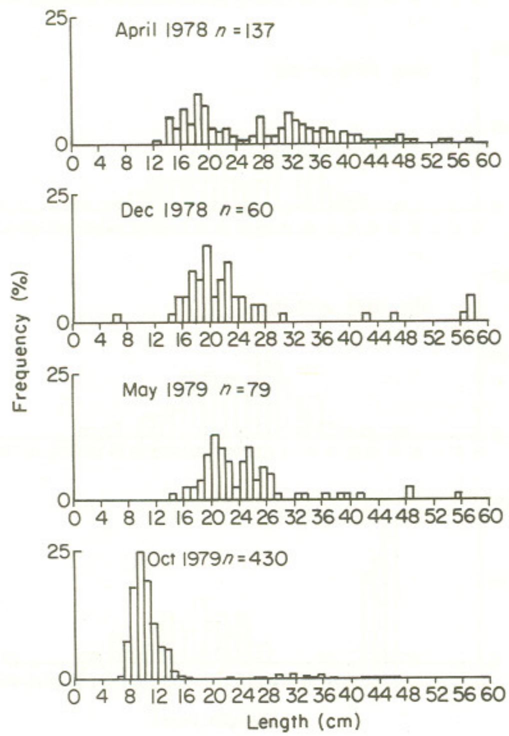

Figure 7.5.14 Demographic structure of plaice populations in Lannion and Morlaix bays. (From Desaunay, 1981. Reproduced by permission of Centre National pour l'Exploitation des Océans)

Developments in the level of stocks

As of mid-1982, the most specific and significant data available on developments in the level of stocks of interest to the fishing industry are on flatfish. Because of the difficulties inherent in conducting a study of this type in the open sea the data are also limited spatially and temporally.

In 1978 and 1979 Desaunay and colleagues (1979) and Desaunay (1981) monitored the composition of the stocks of this type of fish in a coastal area in

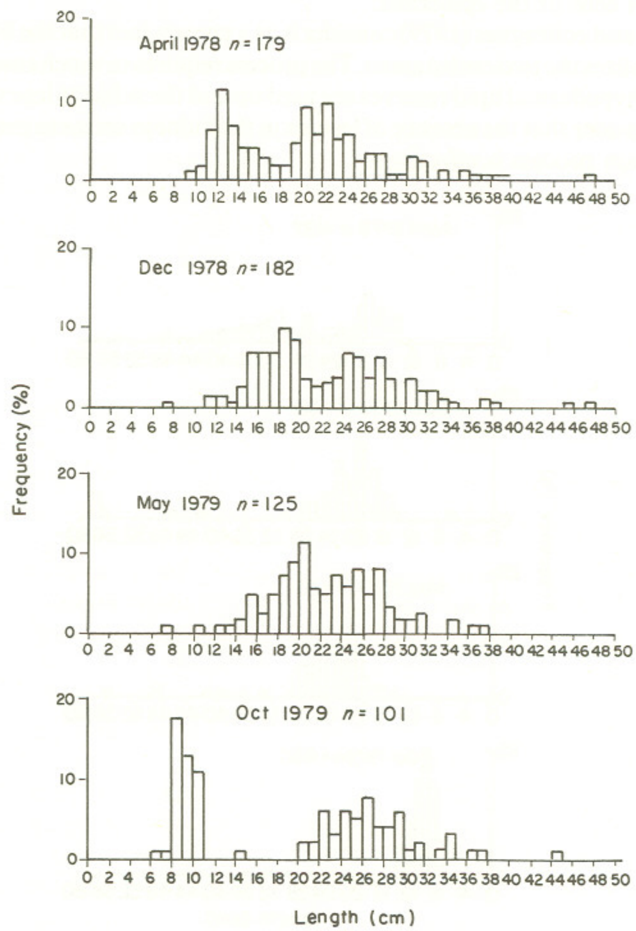

Figure 7.5.15 Demographic structure of sole populations in Lannion and Morlaix bays. (From Desaunay, 1981. Reproduced by permission of Centre National pour l'Exploitation des Océans)

Lannion and Morlaix Bays. Their observations were limited to the southeastern section of Lannion Bay, from the coast to a depth of approximately 20 metres, and to two areas in Morlaix Bay with approximate depths of 10 to 20 metres. This limitation is due to the fact that the bottoms are strewn with rocks and therefore frequently cannot be trawled. The study covered plaice (*Pleuronectes platessa*), Dover sole (*Solea vulgaris*) and dab (*Limanda*).

For plaice, the histograms show that in April 1978, the population of the study area was composed of young fish measuring 12 to 22 cm and of individuals 2 to 3 years of age and over, measuring 28 to 56 cm (Figure 7.5.14).

No young appeared in December 1978, which is abnormal for this time of year. Most of the adults left the study area. We have already seen in the previous section that there was little growth in one-year-old individuals; they grew only 2 cm in 8 months.

One year after the black tide, its effects were confirmed: there were no fish representing the 1978 reproductive season and there had been practically no growth in fish born in 1977. In October 1979 the situation was beginning to return to normal as there was good recruitment of juveniles of 6 to 16 cm and the two-year-olds were growing well. However, there are still very few of the latter.

The absence of juveniles was also noted for sole at the end of 1978 and the beginning of 1979. This could be due either to lack of reproduction or to the destruction of larvae. Growth in adults, on the other hand, appeared to be normal (Figure 7.5.15). There was recruitment of young in October 1979 but it appeared to be less abundant than for plaice. The stock of adults was relatively abundant.

In April 1978 the only representatives of dab in this area were young individuals of 9 to 15 cm. They then practically disappeared from the study area for several months. Only two individuals of the species were caught in December 1978 (Figure 7.5.16). In May 1979 the population, which was larger than in April 1978, was made up of two size groups: 7 to 13 cm and 17 to 22 cm. In October, population growth was good but there were few adults present.

In short, Desaunay therefore considers that the unfavourable consequences of the pollution for these three species is very clearly demonstrated. In his opinion stocks will probably not be back in balance before the end of 1981.

Miossec (1981a, b) provided detailed data on the composition of the stock of plaice in the abers.

A frequency analysis of the size of fish of this species, taken in Aber Benoît, demonstrated the absence during the winter 1978–1979 of the juveniles which should have been spawned in 1978.

Only a few young of this age group appeared in spring 1979. According to the author this absence of young was probably due to the destruction in 1978 of most of the larvae, as spawning had taken place before the black tide. In 1979, two-year-old plaice were well represented but in 1980 a drop in the number of plaice of reproductive age was noted.

Observations for Aber Wrach are similar, but here there were fewer fish born in

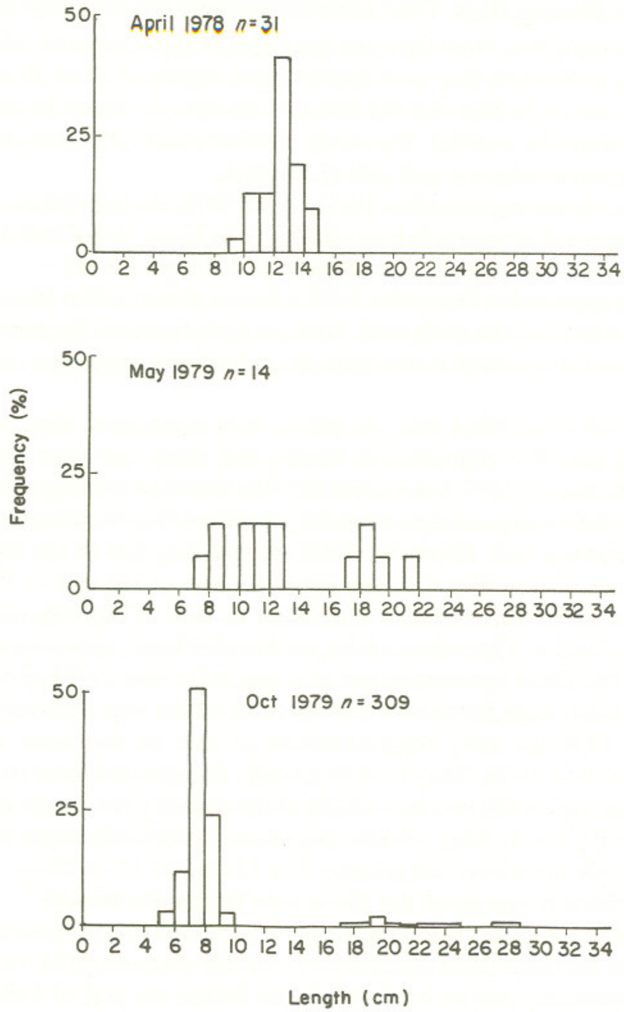

Figure 7.5.16 Demographic structure of flatfish populations in Lannion and Morlaix bays. (From Desaunay, 1981. Reproduced by permission of Centre National pour l'Exploitation des Océans)

1977 than in Aber Benoît. This age group seems to have suffered damage comparable to that which affected Plaice born in 1978.

As other species of flatfish are usually absent from the abers for part of the year, no specific conclusions could be drawn as to the level of their stocks.

7.5.5.2 The *Gino* Accident

Using the oceanographic vessel *Pélagia*, l'Institut des Pêches Maritimes made a third series of observations in April 1981 (Michel and Abarnou, 1981). This research project and the laboratory analysis provided backup for some of the observations made in March 1980, during the previous project.

First of all, contamination of the sediments was low everywhere but clearly present within a radius of 5 nautical miles around the wreck. Slight traces of pollution were still present up to about 8 miles. In the area under examination it was noted that, apart from the actual slick itself, there were well-oxygenated biogenic sediments. This led the authors to the conclusion that biodegradation was progressing actively and was affecting all the hydrocarbons including the aromatics.

An analysis was made of the liver—the organ most likely to accumulate hydrocarbons—of 45 fish taken at a distance of less than 20 miles from the wreck. In spite of this proximity, the average figures obtained were some 2.17 mg kg^{-1} of dry weight with a standard deviation of about 1.3 mg kg^{-1}. These figures may be regarded as indicating an absence of contamination as the liver contains natural compounds which cause interference during analysis.

The first explanation given by Michel and Abarnou (1981) for the fact that the piscine fauna had not suffered the consequences of the pollution is that in this open sea area the fauna comprised adult individuals capable of covering large distances. This would not have been the case if the accident had happened close to the shore where the young are concentrated. The authors think that it may also be due to the fact that, unlike molluscs, fish have a detoxification mechanism (see above, Haensly *et al.*, 1979). They also note that no fish caught in the study area showed anomalies comparable to those described in connection with the *Amoco Cadiz* accident, i.e. skin necrosis, fin erosion, etc.

The results of an analysis of five edible crabs (*Cancer pagurus*) showed that the eggs of these crabs did not contain any significant quantities of aromatic hydrocarbons. Examination under the microscope confirmed that they showed no anomalies and appeared to be viable. The muscle tissues were no longer contaminated. The hepatopancreas of the females contained very small quantities of hydrocarbons (0.9 to 2.9 mg kg^{-1}) while that of the males contained larger quantities (5.6 and 21.3 mg kg^{-1} in one individual).

Where scallops are concerned, 76 stations up to some 25 nautical miles from the wreck were examined in 1981. It proved possible to catch this type of mollusc at 50 of the stations. It was noted first of all, that hydrocarbon levels in the muscles were much lower than in the previous year. The content was low between 8 to 10 and 12 miles from the wreck (13.7 to 3.40 mg kg^{-1}), while beyond that distance the content was normal. This demonstrates that the contaminated area is definitely shrinking.

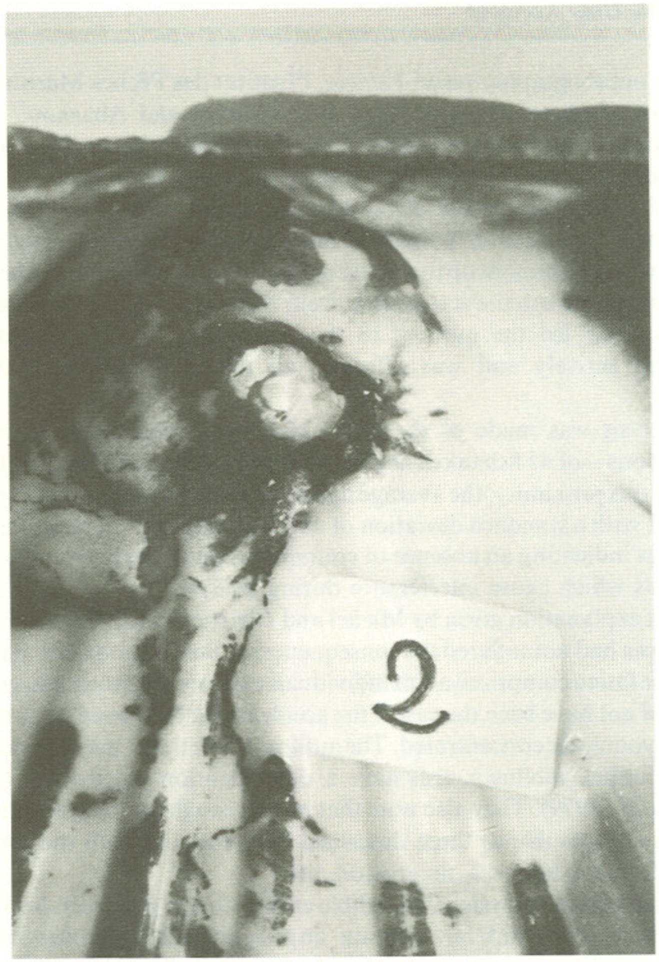

Figure 7.5.17 Detail of a scallop shell collected in the vicinity of the wreckage of the *Gino* in April 1981. Note the presence of oil residues under the mother-of-pearl

The total absence of living scallops close to the *Gino* indicates that mortality was general. It was in this area, within a radius of some 5 miles, that individuals in a poor physiological state had been observed the previous year (Figure 7.5.17).

In addition, the use of mass spectrometers to identify the hydrocarbons enabled Michel and Abarnou (1981) to establish a comparison between the hydrocarbons of the *Gino* and those of the *Amoco Cadiz*. The authors reported two findings:

1. A lower proportion of dibenzothiophene and its alkylated derivates.

2. A higher proportion of aromatic compounds with 4 and 5 rings, as well as their corresponding alkylated derivates.

Compounds with 5 rings were present only in samples taken at a distance of less than 8 miles from the wreck.

To summarize, whereas the pollution caused by the *Gino* seems to have had no harmful consequences for fish, and its impact on crustaceans was small, this cannot be said for scallops which, it should be remembered, are fortunately too scarce in the region affected by the oil spill to be exploited. Nevertheless, their progress should continue to be monitored.

7.5.6 CONCLUSIONS

This study (which was voluntarily limited to exploitable living resources) does not pretend to be an exhaustive analysis of the consequences, for those resources, of oil spills occurring along the coast of Brittany during the last few years or even of the consequences of the *Amoco Cadiz* spill. The study is an attempt to bring together some of the observations made by different kinds of specialists or bodies, particularly l'Institut Scientifique et Technique des Pêches Maritimes. It also aims to point out certain lessons that may be learned from these accidents which were among the biggest to have occurred anywhere in the world.

The first point to be noted is that the pollution caused by the two accidents chiefly investigated did not have an equal effect on all the organisms involved. The physical disturbance to the algae was not as far reaching as might have been feared after the grounding of the *Amoco Cadiz*, even though they were throughly doused in oil. Reproduction was almost normal. Growth and sometimes even population density increased up to a certain level of contamination. Beyond that threshold, certain irregularities in growth and population homogeneity were observed.

It is more difficult to measure the effect on the big crustaceans. Following the *Amoco Cadiz* accident, eggs and larvae appeared to have suffered more than adults. After the *Bohlen* incident, an appreciable mortality rate was noted, mainly caused by the density and viscosity of the oil.

In the event of pollution, fish react either by fleeing if they are not trapped in their habitat or by making use of their mechanisms for eliminating toxic matter. Here too the question of a threshold plays a part. Beyond a certain level the pollution causes mortality, as was seen after the *Amoco Cadiz* accident in the case of species living very close to the shore. Whatever the circumstances, the young, the eggs and the larvae are more sensitive than the adults.

Without question it was the molluscs, particularly the filtering molluscs, which were most seriously affected, due to the accumulation of toxic substances and their persistence. Among the economically valuable species, striking examples of this were provided by oysters after the *Amoco Cadiz* and scallops after the *Gino* spills.

The second important point concerns medium- and long-term damage. This has turned out to be more serious than the immediate effects. Examples are the absence of young in the case of flatfish in the abers and in Lannion and Morlaix bays and the medium-term interruption of reproduction and growth in plaice. Neither should we forget the appearance of frequent anomalies of the skin, the fins and the branchiae, several months after the *Amoco Cadiz* spill.

The same applies to the disturbing persistence of aromatic hydrocarbons in oysters and scallops, and the skin blemishes noted in *Carcinus maenas* at Roscoff along with the later complication of lethal bacterial septicaemia which accompanied these blemishes.

The site of the accident may be a determining factor, as shown by a comparison between the apparently limited effects of the Ixtoc well blowout and the damage caused by the *Amoco Cadiz* spill. Similarly, it may be said that the consequences of the wreck of the *Gino* would certainly have been more serious if it had happened near the coast.

The great importance of the type of oil involved should also be re-emphasized. In the case of the *Amoco Cadiz*, the evaporation of the most volatile fraction definitely helped to limit the damage, at least in the short term. But in the *Gino* accident the stability of the product and its high aromatics content were the cause of the heavy contamination of scallops in an area considerably bigger than that covered by the slick itself, although the *Gino* spilled six times less oil than the *Amoco Cadiz*.

The use of anti-oil agents was a significant factor in limiting the pollution caused by the latter vessel. For instance, it helped avoid contamination of the shores of the Cotentin, the Channel Islands, the Brest roads and the major part of the southwest coast of Brittany. Nevertheless, the ban on the use of the anionic and the more toxic non-ionic surfactants, and the limitation of their use to areas sufficiently far off the coast, also helped restrict the consequences of the surface-active effects on living resources.

Certain accidents which occurred in Brittany have confirmed that dispersants are totally ineffective against heavy hydrocarbons and residual oils.

All these observations taken as a whole mean that we are in a position to advocate certain measures, in particular those outlined below.

1. For each of the areas most likely to be affected by an accident, determination of which species and areas are biologically most sensitive and development of ways and means of ensuring maximum protection for them.
2. The monitoring of the persistence of aromatic hydrocarbons with the help of specific methods of analysis and by paying special attention to the filtering molluscs.
3. Research into and perfection of mechanical methods for removing oil without the use of chemicals.

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