EP

Distr.
RESTRICTED

UNEP/WG.118/7
2 May 1985

Original: ENGLISH

United Nations
Environment
Programme

Third Meeting of the Working Group for
Scientific and Technical Co-operation
for MED POL

Athens, 27-31 May 1985

Long-term Programme for Pollution Monitoring and Research
in the Mediterranean Sea (MED POL - PHASE II)

# ASSESSMENT OF THE PRESENT STATE OF POLLUTION OF THE MEDITERRANEAN SEA BY PETROLEUM HYDROCARBONS

(document prepared by the International Oceanographic Commission)

C O N T E N T S

INTRODUCTION

The Mediterranean, an enclosed marginal sea, with a surface area of 2.97 million $km^2$, is surrounded by mountains except on the southeastern desert coast. The coastal plains are small and narrow compared to the general feature along the Atlantic Ocean. Large alluvial plains are situated in the deltas of great rivers such as the Ebro, Rhone and Po. In addition the Nile delta is an essential part of the eastern Mediterranean environment.

The average depth of the Mediterranean is 1500 m with maxima of 5000 m. The sea has a volume of 3.7 million $km^3$ and a renewal period of 80 years for its water. There are three important sills in the Mediterranean: the Straits of Gibraltar (365 m depth), the Sicilian Channel (350 m) and the Dardanelles (100 m). The first one, with a width of 15 km separates the Mediterranean from the Atlantic Ocean and makes it an almost enclosed sea; the second divides it into a western and an eastern basin; the third separates it from the Sea of Marmara and the Black Sea. The average salinity of the Mediterranean is $38^{o}/oo$ against 35 $^{o}/oo$ in the Atlantic Ocean.

The Mediterranean is surrounded by 18 countries, some of which are among the most industrialized countries in the world. Over 250 million people live along its coasts and in areas which contribute to river run-off into this sea.

Oil pollution is not a new phenomenon in the Mediterranean. Natural seeps have existed over geological times, particularly in the northeastern parts. However, the oil pollution of anthropogenic origin is substantial and considerable amounts are frequently observed, mainly as lumps of tar on beaches or off-shore often together with surface film contamination. In fact, the Mediterranean is considered to be relatively more polluted by oil than any other sea for which data are available (NAS, 1975; UNEP, 1980).

The Mediterranean has so far been spared from major oil spills. However, a large number of minor accidental spills occur each year in addition to an even larger number of deliberate spills (Le Lourd, 1977). The most polluted parts of the Mediterranean are along the tanker routes particularly in the eastern parts of the sea (IOC, 1981). However, considerable quantities of oil pollution are also released from coastal industrial complexes (UNEP, 1977). The most heavily industrialized coastline is in the northwest. Figure I shows the main production zones and transport routes for oil in the Mediterranean. The figure also shows the areas where oil discharging is permitted. Figure II shows the oil pollution from land-based sources obtained during the MED POL (X) Project on Pollutants from Land-based Sources in the Mediterranean.

A number of research activities to assess the fate and effects of oil pollution in the region have been carried out from Mediterranean research centers. These studies have mostly been part of the Mediterranean Action Plan. Although there still is a lack of knowledge in a number of fields, parts of the problem have been studied during the last decade, for example the quantitative and qualitative assessment of dissolved/dispersed hydrocarbons in water and of tar on beaches and in surface waters.

DYNAMICAL PROCESSES AFFECTING THE BEHAVIOUR OF OIL POLLUTION

Any input of oil into the marine environment, once introduced to the recipient water body, is subject to a subsequent series of physical processes. Under the influence of these physical-dynamical processes in the sea, oil-derived pollutants are spread, drifted and dispersed around their source. Then, they get mixed with sea-water and thus become available for uptake by marine organisms, while some eventually reach the sediments and settle to the bottom.

Thus physical factors and processes have the most significant initial effect upon oil discharged into the marine environment. Factors like spreading, dispersion, evaporation, dissolution and aerosol formation, emulsification, sorption onto particulate matter and settling of the oil alter the potential impact on the living marine resources. Meanwhile dynamical processes such as current, wave and tidal movements have also a pronounced effect on the marine oil pollution as they, together with the wind, control the advective and dispersive behaviour of oil in the sea. Talbot (1972) and Weidemann and Sendner (1972) among several others investigated the effect of these factors and processes in greater detail. However, some attention is given here to the transport processes of oil pollutants in the Mediterranean, as far as they affect the distribution and fate of oil in the marine environment. Since we are dealing mostly with light polluting substances such as oil slicks and floating tar, we find that the winds and surface currents are the main advective agents affecting these pollutants.

In general, circulation of the Mediterranean is influenced by several factors: the internal density distribution, the surface wind speed, the coriolis force and the topographic features of the sea bottom. The tidal current has a negligible role in the general circulation of the Mediterranean. Except in certain limited areas such as the Gibraltar region, the Strait of Messina, the Gulf of Gabes, the North Adriatic and at Bosporus and Dardanelles, the tidal amplitudes are small by world ocean standards. This, together with the existence of narrow continental shelves, results in very little tidal amplification along the Mediterranean coasts. Thus, as far as the net circulation is concerned, the tidal movements themselves generate very little net motion and are not considered as contributing to the net circulation.

The Mediterranean circulation pattern has some stationary general features, but with noticeable seasonal variabilities. The winter pattern of the circulation has been obtained using geostrophic calculations by Ovchinnikov (1966) and a numerical model by Gerges (1976, 1977). The principal features of the winter circulation as obtained by both authors, as well as by previous investigators based on the distribution of hydrographic properties of the different water masses (e.g. Nielsen, 1912; Lacombe and Tchernia, 1960 and 1972; Wüst, 1961; ..., etc.), indicate the tendency for general eastward flow along the north African coast and following the shore of Asia Minor into the Aegean and back to the Western Mediterranean as a general westward flow.

According to Gerges (1977), the velocities of the surface drift currents are ranging from 15 to 30 cm/sec, having a general cyclonic direction. Due to the narrowness of the Gibraltar Strait, the velocities of the drift currents in this region are weaker (5-10 cm/sec). Greater velocities are noticed in the Ionian Sea, where values exceeding 35 cm/sec are indicated.

In addition the existence of some interbasin scale features has also been confirmed, e.g. the cyclonic features between Cyprus and Crete and between Crete and Cyrenaica. Another cyclonic feature exists in the northern Ionian, while in the south, in the Gulf of Sirte, an anticyclonic feature is indicated which is dynamically reminiscent of the Alboran anticyclone (Hopkins, 1983a). These features of gyratory motions are of particular importance, since in some other ocean areas, such as in the Sargasso Sea, gyres of the surface circulation tend to accumulate floating tar (IOC, 1981). Thus, one might expect that higher concentrations of oil be observed in the areas where gyres are usually dominating features.

This general surface circulation of the Mediterranean has, in fact, much greater detail, particularly in the coastal areas. Moreover, it is also well known that the summer surface flow is more complex owing to more diverse and smaller-scale wind regimes. The increased complexity in summer is often minifested in smaller gyre-like flow cells; for example, the Tyrrhenian may have several cyclonic surface features in contrast to one basin-wide winter cyclone (Hopkins, 1983b). However, the principal features of the Mediterranean surface circulation as described by Ovchinnikov (1966) and Gerges (1976, 1977) are generally persistant.

SOURCES AND INPUT OF PETROLEUM HYDROCARBON POLLUTION IN THE MEDITERRANEAN

Input of petroleum hydrocarbons into the marin environment can range from diffuse chronic inputs (terrestrial runoff and natural seeps) to large point source releases (e.g. tanker spills). Deliberate release of oil into the world oceans from marine operations or land-based activities are relatively more important than accidents involving single massive input of oil (table 1). Although there is an almost total absence of data for the relative importance of the different sources in the Mediterranean, the deliberate chronic oil pollution is considered far more important compared to accidental pollution (Jeffery, 1974; Le Lourd, 1977).

No figures or estimates are available regarding the amounts of petroleum hydrocarbons carried directly through land run-off into the Mediterranean or indirectly via rivers. As the pollution load and pollution pattern vary widely in rivers it seems impossible to transfer the results of detailed analysis from rivers outside the region without substantial amendments. However, as several of the countries surrounding the Mediterranean are among the most industrialized in the world, it seems very likely that considerable amounts of oil are entering the sea through run-offs from land. No studies to attempt to quantify the amount of oil entering the Mediterranean through atmospheric fall-out are available. However, it can be expected that considerable quantities arrive via the atmosphere as many of the Mediterranean countries are heavily industrialized and consequently burn large amounts of oil.

There are more than 60 oil refineries located along the coasts of the Mediterranean. The input of petroleum hydrocarbons from these sources into the Mediterranean has been estimated at 20,000 tonnes per year (Rout, 1975). The main part of this oil comes from the old refineries, which were not designated with water treatment as a priority (table 2). Their water consumption is high and effluent streams are often not segregated. Often the waste water is only subjected to primary treatment. These refineries have a higher waste water flow and much higher pollutant load per tonne of crude processed, compared to the modern refineries. The modern refineries apply either air or recirculating water for cooling purposes which generate minimal quantities of waste water (table 3).

Table 1. Inputs of petroleum hydrocarbons in the marine environment (million metric tonnes per annum). (From IMCO, 1981; and Baker, 1983)

| | Best estimate | | Probable range | |
|---|---|---|---|---|
| Transportation | 1.49 | | 1.00-2.60 | |
| Tanker operation | | 0.71 | | 0.44-1.45 |
| Drydocking | | 0.03 | | 0.02-0.05 |
| Marine terminals | | 0.02 | | 0.01-0.03 |
| Bilge and fuel oil | | 0.32 | | 0.16-0.60 |
| Tanker accidents | | 0.39 | | 0.35-0.43 |
| Non-tanker accidents | | 0.02 | | 0.02-0.04 |
| Production platforms | 0.05 | | 0.04-0.07 | |
| Atmospheric | 0.30 | | 0.05-0.50 | |
| Municipal, industrial wastes, run-off | 1.40 | | 0.70-2.80 | |
| Natural seeps/erosion | | 0.03 | | 0.03-2.60 |
| Total | | 3.6 | | 1.80-8.60 |

Table 2. Weighed average volume of liquid effluent discharged ($m^3$) per tonne of crude oil processed for European refineries (CONCAWE, 1977)

| | Refineries constructed before 1960 | 1960-1969 | since 1969 |
|---|---|---|---|
| 1969 performance | 10.45 | 2.17 | |
| 1974 performance | 6.37 | 0.92 | 0.38 |

Table 3. Weighed average oil content of European refinery effluents expressed as kg oil in effluent per 1000 tonnes or crude oil processed (CONCAWE 1977)

| Refinery location | before 1960 | 1960-1969 | since 1969 |
|---|---|---|---|
| Coastal | 80 | 10.6 | 1.82 |
| Inland | 56 | 4.1 | 0.92 |

Despite the considerable increase in the amount of oil transported over the world's oceans during the last 10-15 years (table 4), there has been a significant reduction of the quantity of oil discharged into the sea during transportation (IMCO, 1981). This has been explained by the entering into force of international agreements on prevention of pollution of the sea, notably the International Convention for the Prevention of Pollution from Ships, 1973, and the related Protocol of 1978 (MARPOL, 73/78). In particular the worldwide implementation of mandatory provision of segregated ballast tanks (SBT), dedicated clean ballast tanks (CBT), and crude oil washing systems (COW) for new and existing oil tankers have significantly brought down the quantities of oil released to the environment.

In 1977 Le Lourd estimated that the total amount of oil released into the Mediterranean was between 0.5 and 1 million tonnes per year, compared with 4 million tonnes on a world wide basis. Based on the most recent available estimates of the total oil movements at sea (table 4), that 350 million tonnes of oil cross the Mediterranean each year (Smith, 1975), and assuming that the input quantities on a worldwide basis (table 1) can be directly related to the amount of oil under transportation, this exercise gives an estimate of around 0.8 million tonnes of oil entering the Mediterranean each year.

Table 4. Quantities of oil movement at sea and the size of the world's merchant and tanker fleets in 1970 and 1980 (from IMCO, 1981)

| | 1970 | 1980 | Ratio 1980/70 |
|---|---|---|---|
| Oil movement at sea (million tonnes) | | | |
| Crude oil | 1,100 | 1,319.3 | 1.20 |
| Product oil | 255 | 268.9 | 1.05 |
| Total | 1,355 | 1,588.2 | 1.17 |
| World's merchant fleet | | | |
| No. of ships | 55,041 | 73,832 | 1.34 |
| Tons gross tonnage | 247,202,634 | 419,910,651 | 1.70 |
| World's tanker fleet | | | |
| No. of ships | 6,292 | 7,112 | 1.13 |
| Total deadweight tonnes | 169,354,743 | 339,801,719 | 2.0 |
| Average deadweight tonnes | 36,900 | 47,800 | 1.78 |

CONCENTRATIONS OF PETROLEUM HYDROCARBONS IN THE MEDITERRANEAN

Even though the number of reported data on hydrocarbon concentrations in water, sediments and on beaches has increased during the last 10 years, there are unfortunately only very few measurements from several areas, particularly from the central and southern parts, available. However, as a part of the MED POL and IOC/WMO (MAPMOPP) projects, a relatively large amount of analysis has been carried out, at least with regard to measurements of water concentrations. In tables 5, 6, 7, 8 and 9 available data from the region are given regarding dissolved/dispersed hydrocarbons in water, petroleum hydrocarbons in sediments, floating tar and tar on beaches.

Analytical Techniques

A description of the recommended techniques for measuring oil pollution in water, sediments and on beaches is given in UNESCO 1982 and UNESCO 1984. When evaluating data on petroleum hydrocarbon concentrations in the Mediterranean it should be noted that there is a lack of uniformity in the analytical techniques applied. Furthermore, if the sampling methods are described, which is rarely the case, there is also a lack of conformity in the procedure for the collection of the sample. Furthermore, results of beach tar studies are expressed sometimes in units of weight/area and sometimes in weight/meter of beach line, in addition to differences in frequency of sampling. It is also clear that the frequency distribution of any data set for any given area will only be revealed with a sufficiently large number of samples thereby allowing an adequate statistical analysis. Hence to enable the assessment of spatial and temporal changes in the concentration of hydrocarbons, similarly large data sets should be available from each point. Extreme care should therefore be taken when interpreting data and drawing conclusions as to the state of pollution.

The UV fluorescence technique has frequently been applied when measuring concentrations in water samples. Often the results are reported in terms of chrysene standard equivalents and include comparison ratios of various crude oils to chrysene. The method is simple and sufficiently sensitive to indicate very low concentrations of aromatic compounds from mineral oil. However, the disadvantage of the method is that it is sensitive to a variety of other compounds as well as the aromatic constituents of petroleum oil.

Techniques using GC and GC-MS, especially with capillary column, single known compounds can be quantified, thus eliminating many of the ambiguities arising from the use of UV fluorescence. In the selected ion monitoring mode, GC-MS sensitivities are comparable with those of UV fluorescence. In contrast to UV-fluorescence both GC and GC-MS are sensitive to all components of petroleum.

Table 5. Dissolved/dispersed petroleum hydrocarbons

| Area | Year | Concentrations | Technique | Reference |
|---|---|---|---|---|
| Western Mediterranean | | | | |
| Northern part, offshore | 1973 | 10-2200 ppb (surface) (av. 448) | Fluorescence | Monaghan *et al.*, 1974 |
| | | 3-37 ppb (10m) (av. 15) | " | " |
| Southern part, offshore | 1973 | 2-17 ppb (surface) (av. 8.5 ppb) 2-7 ppb (10m) (av. 4.3) | " | " |
| Tyrrhenian Sea | 1973 | 8-614 ppb (surface) (av. 180) 3-19 ppb (10m) (av. 7) | " | " |
| French coast Villefranche-sur-Mer | 1969 | 75 ug/l (50m) | GC | Barbier *et al.*, 1973 |
| Alboran Sea | 1975-77 | 4.3-14.6 ppb (surface) (av. 7.9) | Fluorescence | Faraco & Ros, 1978 |
| North part of Western basin | " | 2-6 ppb (surface) (av. 3.3) | " " | " " |
| South part of Western basin | " | 1-123.5 ppb (surface) (av. 17.5) | " | " |
| Tyrrhenian Sea | " | 1.9-20.5 ppb (surface) (av. 7.4) | " | " |

Table 5. Continued

| Area | Year | Concentrations | Technique | Reference |
|---|---|---|---|---|
| Western Mediterranean | | | | |
| French coast, Banyuls-sur-Mer | 1975-78 | 0.05-5.0 mg/l (av. 0.58) | IR | UNEP, 1980 |
| PHYCEMED II cruise, Western Med | 1983 | 0.3-5.0 ug/l | GC, n-alkanes | Sicre *et al.*, 1984 |
| Spanish coast | | | | |
| Castellon | 1983 | 1.36-2.40 ppb[1].(max. 4.7) | | de Leon, 1984 |
| Sagunto | " | 0.06-3.40 ppb[1].(max. 6.5) | | " |
| Valencia | " | 0.63-4.35 ppb[1].(max. 7.6) | | " |
| Spanish coast | | | | |
| Cullera | 1983 | 0.06-3.10 ppb[1]. (max. 4.0) | | de Leon, pers. comm. |
| Benidorm | " | 0.68-1.80 ppb[1]. (max. 2.9) | | " |
| Alicante | " | 0.85-8.26 ppb[1]. (max. 4.0) | | " |
| Guardamar | " | 1.15-3.15 ppb[1]. (max. 5.8) | | " |
| Portman | " | 0.26-6.50 ppb[1]. (max. 2.1) | | " |
| Cartagena | " | 0.26-3.22 ppb[1]. (max. 4.7) | | " |
| Italian coast | | | | |
| Taranto, Mar Piccolo | " | 0.2-11.6 ug/l[2]. (av. 3.26) | GC | Strusi, pers. comm. |
| " | " | 0.5-23.0 ug/l[3]. (av. 7.42) | " | " |
| " | " | 0.1-36.0 ug/l[4]. (av. 7.98) | " | " |

Table 5. Continued

| Area | Year | Concentrations | Technique | Reference |
|---|---|---|---|---|
| Central Mediterranean | | | | |
| South Ionian Sea | 1973 | 3-423 ppb (surface) (av. 58) | Fluorescence | Monaghan *et al.*, 1974 |
| | | 2-120 ppb (10m) (av. 16) | " | " |
| Malta, coastal waters | 1977-78 | 0.02-0.29 ug/l | " | UNEP, 1980 |
| Libyan coast | | | | |
| W Sedra, Tripoli harbour Zawia | 1980 | 20-28 ppb | " | Gerges & Durgham, 1982 |
| Janzur, W&E Brega, Zawia W Khoms | " | 12.5-19 ppb | " | " |
| Zlitan, Zwetina, Benghazi, E Sirte, Tajura | | 4.6-5.3 ppb | " | " |
| Sabratha, Derna, Sidi Blal | | 0.6-2.9 ppb | " | " |
| Libyan coast 5. 171 samples from coastal areas | | 0.0-27.6 ppb (av. 3.6 ppb) | " | MFRC, Tripoli 1981 |
| Adriatic | | | | |
| Yugoslavia, Rijeka Bay | 1976-77 | 1-50 ug/l | " | UNEP, 1980 |
| | | 0.1-1.1 mg/l | IR | |
| " " | | below 0.1 ug/l | GC | Ahel & Picer, 1978 |
| " " | 1976-78 | 1-7 ug/l ("polluted")<br>0.2-0.5 ug/l ("unpolluted") | Fluorescence | Ahel, 1984 |

Table 5. Continued

| Area | Year | Concentrations | Technique | Reference |
|---|---|---|---|---|
| Eastern Mediterranean | | | | |
| Greece | | | | |
| Coastal waters | | below 3 ppb | Fluorescence | Mimicos, 1980 |
| Saronikos Gulf | 1980-81 | 1.6-5.6 ug/l | " | Gabrielides *et al.*, 1984 |
| Aegean Sea | " | 2.9-13.7 ug/l | " | " |
| Thessaloniki harbour | 1976-79 | 1.5 mg/l [7] | IR | UNEP, 1980 |
| Cavala harbour | " | 2.6 mg/l [8] | " | " |
| Strymonikos Bay | " | 1.1 mg/l [8] | " | " |
| Patraikos Gulf | 1977-83 | 0.12-28.2 ug/l | Fluorescence | Mimicos *et al.*, 1984 |
| Ackeloos River estuary | " | 1.3-4.5 ug/l | " | " |
| Turkey | | | | |
| Mersin-Akkuyu | 1977-78 | 8.2-39.4 ug/l | " | UNEP, 1980 |
| Southern coast | 1980-82 | 0.5-3.5 ug/l (av. 1.5) | " | Sunay *et al.*, 1982 |
| Offshore between Turkey and Cyprus | " | 2.0-6.0 ug/l | " | " |
| Iskenderun Bay | " | 0.7-7.0 ug/l | " | " |
| Sea of Marmara | 1983 | 0.88 ug/l (max. 8.07) | " | Sakarya *et al.*, 1984 |
| Izmit Bay | " | 0.75-5.0 ug/l | " | " |
| Aegean Sea | " | 0.14-1.39 ug/l | " | " |
| Mediterranean coastal waters | " | 0.02-1.1 ug/l | " | " |
| Iskenderun Bay | " | 0.11-1.0 ug/l | " | " |
| Candarli Bay | 1983-84 | 1.20-80.0 ug/l | " | Topcu & Muezzinoglu, 1984 |
| Aliaga | " | 0.53-7.30 ug/l | " | " |
| Saros Bay | 1983 | 0.77 ug/l | " | " |
| Izmir Bay | " | 9.40 ug/l | " | " |
| Southern Aegean Coast | " | 0.86 ug/l | " | " |

Table 5. Continued

| Area | Year | Concentrations | Technique | Reference |
|---|---|---|---|---|
| Eastern Mediterranean | | | | |
| Offshore South of Cyprus, Southeast of Crete | 1975-76 | 10-40 ug/l | Fluorescence | UNEP, 1980 |
| Israel | | | | |
| Ashkelon | " | 9.4-19.4 ug/l | " | " |
| Haifa Bay | " | 15.0-15.6 ug/l | " | " |
| Plamachin | " | 10.7-12.5 ug/l | " | " |
| Bardawil Lagoon | " | 20.6 ug/l | " | " |
| Tel Shikmona | " | 1.1-45.3 ug/l | " | " |
| Egypt | | | | |
| Alexandria | 1978-79 | 0.7-35.2 ug/l (av. 3.7) | " | Aboul-Dahab & Halim, 1980b |
| Alexandria | 1979-80 | 6.6-41.4 ug/l (nearshore) | " | Wahby & El Deeb, 1980 |
| | | 0.7-3.9 ug/l (offshore) | " | " |
| Mouth of Suez Canal | 1980-81 | 0.5-14 ug/l | " | Samra *et al.*,1982 |
| Cyprus, Limassol Bay | 1983 | 2.6-8.1 ug/l | " | (report to IOC), 1984 |
| Larnaca Bay | " | 4.2-13.6 ug/l | " | " |

Dissolved/Dispersed Petroleum Hydrocarbons

Western Mediterranean

The concentrations of dissolved/dispersed petroleum hydrocarbons in this part of the Mediterranean have been reported by Barbier et al., 1973; Monaghan et al., 1974; UNEP, 1977 and 1980; Faraco & Ros, 1978; Sicre et al., 1984; de Leon, 1984; and Strusi, 1984 (see table 5). Samples collected near-shore frequently show concentrations above 10 ppb, particularly if they were taken close to industrialized areas or river mouths.

From the Spanish coast between Castellon and Cartagena results have been reported from sampling along 9 transects (de Leon, 1984). This study showed concentrations between 0.06 and 8.26 ppb as mean values at each station.

In Mar Piccolo, Taranto, Italy, concentrations ranging from 0.1-36 ug/l have been reported (Strusi, 1984). Mean values are 3.26, 7.42 and 7.98 ug/l from 3 sampling occasions.

Few or no values are available from countries along the North-african coast.

Adriatic

Results of analyses of water samples have been reported by UNEP, 1980; Ahel & Picer, 1978; and Ahel, 1984. However, all these studies have dealt with the Rijeka Bay area. Concentrations from this area range from 0.1 ppb and below in unpolluted to 50 ppb in polluted parts of the bay.

Central Mediterranean

The only concentrations reported from sampling off-shore are those from Monaghan et al., 1974. From near-shore areas (Libyan coast) Gerges & Durgham (1982) report concentrations between 0.6 and 28 ppb. The highest values (10-28 ppb) are reported from areas near main ports and oil terminals while relatively low concentrations (0.6-2.9 ppb) are reported from areas far from major industrial activities. Similar concentrations ranging from 0 (unpolluted) up to 27.6 ppb (polluted) were reported in a study by Marine Fisheries Research Center, Tripoli (MFRC, 1981).

From coastal waters around Malta concentrations between 0.02 and 0.29 ug/l have been reported (UNEP, 1980).

Eastern Mediterranean

The relatively largest number of data are available from this area (UNEP, 1980; Aboul-Dahab & Halim, 1980b; Wahby & El Deeb, 1980; Mimicos, 1980; Samra et al., 1982; Sunay et al., 1982; Sakarya et al., 1984; Gabrielides et al., 1984; and Mimicos et al., 1984).

From Greek coastal waters values ranging from 0.1-2.6 ug/l are reported (Mimicos et al., 1984; Gabrielides et al., 1984; Mimicos, 1980; UNEP, 1980). The highest concentrations (1-2.6 mg/l) are reported from harbour areas and were measured by infrared spectroscopy. However, some studies in areas quite far from major land-based industrial activities such as off-shore in the Aegean Sea show suprisingly high concentrations (over 10 ppb). Sakarya et al., (1984) reported values between 0.14-1.39 ug/l from the Aegean Sea.

From Turkish waters data ranging from 0.02-40 ug/l are reported (Sunay et al., 1982; 1984; Sakarya et al., 1984). Low concentrations (around 1.5 ug/l) are reported from coastal waters southewest of Mersin (Sunay et al., 1982). However, the same authors report concentrations of 2.0-6.0 ug/l from offshore areas between Turkey and Cyprus. The explanation to these relatively high concentrations might be contamination caused by the ship traffic in this area. Concentrations up to 7.0 ug/l were reported from the industrialized Iskenderun Bay (Sunay et al., 1982). Sakarya et al., (1984) reported concentrations ranging between 0.11-1.0 ug/l from the same area. These authors also found up to 5.0 ug/l in Izmit Bay and concentrations ranging from 0.02-1.1 ug/l from the northeastern Mediterranean coast off Turkey.

Relatively high concentrations of oil have been reported from the coastal waters off Israel (UNEP, 1980). Concentrations between 10 and 20 ug/l have been reported from areas close to harbours, oil refineries, river mouths, etc. However, quite high concentrations (2-5 ug/l) were found also in coastal areas more distant to industrialized zones. High concentrations of dissolved hydrocarbons were found south of Cyprus (25-40 ug/l) and southeast of Crete (10 to above 40 ug/l).

Several reports are available on the oil contamination of coastal waters off Egypt (Aboul-Dahab & Halim, 1980b; Wahby & El Deeb, 1980; Samra et al., 1982). Concentrations up to 30-40 ug/l have been reported from areas influenced by various industrial activities (Aboul-Dahab & Halim, 1980b; Wahby & El Deeb, 1980). The same authors report concentrations below 10 ug/l and usually below 5 ug/l in offshore waters. One study of the petroleum hydrocarbon content of the waters reaching the Mediterranean from the Suez Canal has been reported by Samra et al, 1982. This study showed that the water contained 0.5-14 ug/l.

From coastal waters off Cyprus concentrations ranging between 2.6 and 8.1 ug/l are reported from Limassol Bay and levels from 4.2 and 13.6 ug/l from Larnaca Bay (unpublished report to IOC, 1984).

Results of MAPMOPP in the Mediterranean

The results of MAPMOPP have been reported in the "Global Oil Pollution" (IOC, 1981). Generally, the concentrations of dissolved/dispersed petroleum hydrocarbons were less than 5 ug/l in the region. However, heavily contaminated areas were frequently observed outside industrialized zones along the coast. Also, along shipping routes patches of highly oil contaminated water were often encountered. These patches were predominantly in the eastern region, which is one of the regions which have an area where discharges of oil wastes from ships are permitted (figure 1). The concentrations here were up to 50 ug/l or even higher, which would suggest that particulate forms of petroleum residues were present. By comparison, concentrations in the central and western regions were at least an order of magnitude lower. With the entering into force of the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 relating thereto (MARPOL 1973/78) this picture is likely to gradually improve.

The concentrations of dissolved/dispersed petroleum hydrocarbons for various regions of the world ocean, according to the results of MAPMOPP (IOC, 1981) are given in table 6.

Table 6. Concentrations of dissolved/dispersed petroleum residues for various regions of the world ocean (n = number of values; c = arithmetic mean, ug/l; s = standard deviation; log c = arithmetic mean of logtransformed data; GM = geometric mean, ug/l), (IOC, 1981)

| Region | Normal Statistics | | | Lognormal Statistics | | | |
|---|---|---|---|---|---|---|---|
| | n | c | s | n | log c | s | GM |
| Baffin Bay | 104 | 0.11 | 0.12 | 93 | -1.05 | 0.37 | 0.09 |
| Indian Ocean | 45 | 60.1 | 92.7 | 36 | 0.95 | 1.29 | 8.9 |
| Japan | 1666 | 0.31 | 1.21 | 1640 | -0.88 | 0.56 | 0.13 |
| Mediterranean Sea | 465 | 2.0 | 5.0 | 462 | -0.48 | 0.94 | 0.33 |
| North American East Coast | 80 | 0.11 | 0.10 | 71 | -1.03 | 0.31 | 0.09 |
| North Sea | 90 | 0.02 | 0.12 | 9 | -0.81 | 0.38 | 0.15 |
| South China Sea | 272 | 0.20 | 0.28 | 256 | -0.98 | 0.57 | 0.10 |
| Strait of Malacca | 14 | 0.11 | 0.12 | 10 | -0.89 | 0.27 | 0.13 |

Table 7. Petroleum hydrocarbons in benthic sediments

| Area | Concentrations | Reference |
|---|---|---|
| French coast (Fos-sur-Mer to Monaco) (1979) | Côte Bleue 13-952 ug/g aliphatics + aromatics<br>Les Embiez 69-93 ug/g, aliph. + aromat.<br>Monaco 51-77 ug/g, aliph. + aromat. | Mille, Chen & Dou, 1982 |
| Spanish coast 1980-82, off Valencia | 0.6-2.3 pp, (D/W) $C_{14}$-$C_{20}$ (GC) 3-10m (0-5cm) | J.A. García-Regueira, J.Rovira J. Sanchez-Pardo, 1983 |
| off Alicante | 0.1-5.8 ppm (D/W) $C_{14}$-$C_{24}$ (GC) | " |
| off Delta del Ebro | 0.3-1.1 ppm (D/W) $C_{15}$-$C_{24}$ (GC) | " |
| vicinity of oil terminals, river mouths and cities between Alicante and Ter river (no dates) | 1-62 ppm aliphatic HC (D/W) (GC, GC-MS)<br>2-66 ppm aromatics H (GC-MS, HPLC) | Albaiges <u>et al.</u>, 1982 |
| Turkey, Iskenderun Bay 1980-82, 10-90m depth | 0.04-0.68 ug/g (PAHs) (GC) (av. 0.24 ug/l) | Sunay <u>et al.</u>, 1982 |
| Cyprus (where?) 90m depth, 1983 | 0.114-0.135 ug/g fluorescence (4 samples) | (Letter IOC) |
| Italy, Taranto, Mar Piccolo, 1983 | 8 stations (1-10m depth)<br>1.3-45 ug/g (D/W) av. 14.73 | (Strusi, pers. communication) |
| Turkey | | |
| Candarli Bay, 1983-84 | 4.3-375 ug/kg (f w), fluorescence | Topcu & Muezzinoglu, 1984 |
| Aliaga, 1983-84 | 17.5-25 ug/kg (f w), " | " |
| Saros Bay, 1983 | 1,000 ug/kg (f w), " | " |
| Izmir Bay, 1983 | 47.7 ug/kg (f w), " | " |
| Southern Aegean Coast, 1983 | 157.5 ug/kg (f w) " | " |

Petroleum Hydrocarbons in Benthic Sediments

Few reports are available on the concentrations of petroleum hydrocarbons in benthic sediments (table 7). From the western Mediterranean, García-Regueiro et al., (1983) report the results from a study off the Spanish coast. The authors found concentrations ranging from 0.1-5.8 ppm ($C_{14}$ - $C_{24}$) using GC. The highest concentrations were found in sediments outside Alicante (5.8 ppm) while outside the Delta del Ebro only 1.1 ppm was found. These concentrations are low compared to those reported by Albaiges et al. (1982) between Alicante and the river Ter. This latter study showed concentrations of 1-62 ppm (aliphatics) and 2-66 ppm (aromatics) in sediments collected outside harbours, oil terminals and river mouths.

Along the French coast between Fos-sur-Mer and Monaco, Mille et al., (1982) reported concentrations of aliphatic and aromatic hydrocarbos ranging between 20 and 950 ppm. The highest concentrations were found outside a refinery.

In Mar Piccolo, Taranto, Italy, average concentrations of 14.7 ppm aliphatic and aromatic hydrocarbons were found at 8 stations at depths from 1 to 10 m depth (Strusi, 1984). The maximum concentrations found in this study was 45 ppm, which seem to be quite high considering the aquaculture of mussels in the bay.

From the eastern Mediterranean results are available from Cyprus and Turkey. From Cyprus concentrations of 0.114 to 0.135 ug/g are reported in sediment samples collected at 90m depth (report IOC, 1984). From Iskenderun Bay, Turkey, average sediment concentrations of 0.24 ug/g were reported by Sunay et al. (1982). The samples were collected at 10 to 90 m depth and the range of concentrations were 0.04-0.68 ug/g.

Oil Slicks, Floating Tar and Tar on Beaches

As a part of the MAPMOPP (IOC/WMO Marine Pollution Monitoring Pilot Project) visual observations of oil slicks were carried out from ships (IOC, 1981). When slicks were observed, position, data, time and slick size were noted. Since it is as important to know which areas are not polluted as it is to know which ones are, a report was made during each 24 hours period even if no pollution was observed. In the Mediteranean, surface slicks were present in more than 10% of the observations almost throught the region (figure 4). These data compared with MAPMOPP results from other regions, provide evidence of a relatively extensive surface pollution in the Mediterranean.

The available reports on floating tar from the Mediterranean are given in table 8. From these data it appears that normal values for offshore areas are up to 5 mg/m$^2$, while in nearshore waters concentrations can be much higher; 10-100 ug/m$^2$. Oren (1970) reported the concentration of tar in the eastern Mediterranean. He found relatively the highest concentrations between Cyprus and the Lebanese coastline. These findings were related to the geostrophic currents which prevail in this area. They form a gyre with calm areas between Cyprus and Lebanon, where the tar is concentrated. During storms, this area feeds the Syrian, Lebanese and northern Israeli coasts with tar.

Table 8. Floating tar

| Area | Concentrations | Reference |
|---|---|---|
| Egypt<br>off Alexandria<br>1978-79 | 0-8.9 $mg/m^2$<br>(av. 2.8 $mg/m^2$ | Aboul-Dahab & Halim, 1980a |
| off Alexandria<br>1977-79 | 0.05-1.33 $mg/m^3$ | Wahby & El Deeb, 1980 |
| off Alexandria | 0.05-1.06 $mg/m^3$ | Wahby, 1978 |
| Western Mediterranean | 0.04 $mg/m^2$-77.7 $mg/m^2$ | Ros & Faraco, 1978 |
| Alboran Sea | 0.6 $mg/m^2$ (av.) | Ros & Faraco, 1978 |
| North part of W Basin | 5.4 $mg/m^2$ (av.) | Ros & Faraco, 1978 |
| South part of W Basin | 3.9 $mg/m^2$ (av.) | Ros & Faraco, 1978 |
| Tyrrhenian Sea<br>1975-77 | 0.9 $mg/m^2$ (av.) | Ros & Faraco, 1978 |
| Alexandria, El-Sallum-<br>Arabs Gulf, 1970-78 | 0-58.3 $mg/m^2$ | El-Hehyawi, 1978 |
| Alboran Sea<br>1981-82 | 0.01-25.6 $mg/m^2$<br>(av. 0.8 $mg/m^2$) | De Armas, 1984 |
| Northeastern Mediterranean<br>1983-84 | 0-33.4 $mg/m^2$ | Saydam <u>et al.</u>, 1984 |

The available data on tar on beaches in the Mediterranean are given in table 9. Unfortunately only some data are given as weight per meter of beach, while in most cases weight per $m^2$ is used. High concentrations of tar are reported from the eastern Mediterranean. Golik, 1982 reports mean concentrations of 884 to 4,388 g/m accumulated on six beaches in Israel during 13 months. Maximum concentrations above 10,000 gram were found on 5 of 6 beaches. The mean amount of tar on the shores of Israel was found to be 3,625 kg/m beach during the MED POL - I project (MED POL, 1977).

Average values around or above 100 gr/$m^2$ during 7 or 15 days have been reported from beaches off Alexandria, Egypt (Aboul-Dahab & Halim, 1980a; Wahby & El Deeb, 1980: Wahby, 1978).

From Cyprus tar concentrations from Lara beach (Paphos) are reported (UNEP, 1980; unpublished report to IOC). Values from the period November 1977 to November 1978 can be compared with values from May to December 1983. There are significantly lower concentrations of tar in 1983 compared to 1977-1978. Mean values per month have dropped from 360.4 g/$m^2$ (range 23.7-967.1) to 90.8% g/$m^2$ (range 17.0-252.0). Unfortunately no other similar comparisons can be made based on the available data.

Petroleum hydrocarbons in organisms

A few studies have been carried out on the uptake of petroleum hydrocarbons in organisms from the Mediterranean. From the Spanish coast analysis of samples of fish and molluscs collected from the mouth of the river Ter and south to Ebro delta, have been reported by Albaiges et al., 1982; Ballester et al., 1982. Albaiges et al., 1984; and Risebrough et al., 1983.

Risebrough et al., 1983 used the technique employed in the Mussel Watch project in a study of petroleum hydrocarbons in molluscs from the Ebro delta. Mussels (Mytilus galloprovincialis), oysters (Ostrea edulis), and clams (Venus gallinae) were selected as the indicator organisms. Levels of petroleum accumulated by mussels were generally high, in the order of 100-800 ug/g. These concentrations were equivalent to those in mussels in the most polluted harbours and bays in California (table 10). The relative distributions of the steranes and pentacyclic triterpanes in the mussels were, however, different from those found in petroleum from a local oil field, indicating that local petroleum was not contributing to the observed contamination.

A study of the petroleum concentrations of tissues of three species of fish (Mullus barbatus, Merluccius merluccius, Trachurus trachurus) have been reported by Albaiges et al., 1984. This study showed that baseline levels in muscle tissues for the area between Barcelona and the French boarder were 5-12 ug/g and 2-7 ug/g (dw) of saturated and aromatic hydrocarbons respectively. Higher concentrations were found in fish off Barcelona and the Ebro river.

In another study by Albaiges et al., 1982, relatively high concentrations of petroleum hydrocarbons were found in bivalves from the same area. In bivalves concentrations of 190-216 ug/g (dw) were found in the vicinity of harbours and river mouths (Ebro river delta). However, pelagic fish showed lower concentrations in tissue samples (less than 10 ug/g). A study by Ballester et al., 1982, of mussels from a drilling platform in the Ebro river delta, showed concentrations up to 20-30 ug/g.

Table 9. Tar on beaches

| Sampling location | Quantities of Tar/ Sampling rate | Reference |
|---|---|---|
| Egypt, Alexandria<br>Sept 1978 - June 1979 | 3-406 g/m/7 days<br>av. 98 g/m/7 days | Aboul-Dahab & Halim 1980a |
| Egypt, Alexandria<br>Apr 1979 - Oct 1979 | 21-347 $g/m^2$/15 days<br>av. 131 $g/m^2$/15 days | Wahby & El Deeb, 1980 |
| Egypt, Alexandria<br>Apr 1977 - Apr 1978 | 3.5-380 $g/m^2$/15 days | Wahby, 1978 |
| Israel (mean of 6 beaches)<br>Apr 1975 - June 1976 | 4.6 $g/m^2$/15 days | Golik, 1982 |
| Malta, Anchor Bay<br>Apr 1977 - Sept 1978 | 62.3 $g/m^2$/15 days | UNEP, 1980 |
| Malta, Marsaxlokk Bay<br>Apr 1977 - Sept 1978 | 6.3 $g/m^2$/15 days | UNEP, 1980 |
| Cyprus, Ladies Mile<br>(Limassol)<br>(Nov 1977 - Nov 1978 | 32.8 $g/m^2$/30 days<br>(range 5.2-102) | UNEP, 1980 |
| Cyprus, Lara (Paphos)<br>Nov 1977 - Nov 1978 | 360.4 $g/m^2$/30 days<br>(range 23.7-967.1) | UNEP, 1980 |
| Lebanon, Ramlet<br>Apr 1977 - June 1978 | 4 $g/m^2$/30 days | UNEP, 1980 |
| Lebanon, Sidar<br>Apr 1977 - June 1978 | 3.4 $g/m^2$/30 days | UNEP, 1980 |
| Turkey, Erdemli<br>1977 - 78 | 24.3 $g/m^2$, 3 samples | UNEP, 1980 |
| Cyprus, Lara (Paphos)<br><br>Makronisos (Ayia Napa)<br><br>Nov - Dec 1983 | 17.0-252.0 $g/m^2$/30 days<br>(av. 90.8)<br>2.5-62.0 $g/m^2$/30 days<br>(av. 17.16) | (Unpublished<br>report to IOC) |
| ISRAEL | | |
| El Arish<br>(13 months, 1975-76) | mean 884 g/m<br>range 30-2,055 | Golik, 1982 |
| Ashgelon<br>(13 months, 1975-76) | mean 3,014 g/m<br>range 391-11,138 | " |

Table 9. Continued

| Sampling location | Quantities of Tar/ Sampling rate | Reference |
|---|---|---|
| Ga'ash (13 months, 1975-76) | mean 4,186 g/m range 254-12,150 | Golik, 1982 |
| Bet Yannay (13 months, 1975-76) | mean 4,114 g/m range 375-14,759 | " |
| Atlit (13 months, 1975-76) | mean 4,388 g/m range 678-13,052 | " |
| Rosh HaNigra (13 months, 1975-76) | mean 3,902 g/m range 4221-13,502 | " |
| SPAIN, 1983 | | |
| Castellon | Aver. 0.10 $mg/m^2$ (max 0.13) | de Leon, 1984 |
| Sagunto | Aver. 7.0 $mg/m^2$ (max 12.0) | " |
| Valencia | Aver. 0.06 $mg/m^2$ (max 2.0) | " |
| Cullera | Aver. 0.06 $mg/m^2$ (max 0.9) | " |
| Benidorm | Aver. 2.0 $mg/m^2$ (max 10.0) | " |
| Alicante | Aver. 0.2 $mg/m^2$ (max 0.4) | " |
| Guardamar | Aver. 0.7 $mg/m^2$ (max 2.0) | " |
| Portman | Aver. 0.1 $mg/m^2$ (max 0.3) | " |
| Cartagena | Aver. 0.7 $mg/m^2$ (max 0.6) | " |
| FRANCE, 1982 | | |
| Valras (Cap d'Adge, May 1) | 19.2 g/m | CNEXO, 1983 |
| Marseille-moutegenet (April 28) | 0.3 g/m | " |
| Antibes (April 27) | 36.4 g/m | " |

Table 10. Distribution of complex hydrocarbon mixtures, principally petroleum, in bivalves from the vicinity of the Ebro delta in 1980, and from the California coast 1978-1979. Concentrations in ug/g dry weight, arithmetic means and standard deviations. Data from Risebrough et al., 1980 and 1983. Species code: 1 = *Mytilus galloprovincialis*, 2 = *Venus gallinae*, 3 = *Ostrea edulis*, 4 = *Mytilus edulis*, and 5 = *Mytilus californianus*

| Area | Species code | No. of samples | Saturate fraction | Aromatic fraction | Total |
|---|---|---|---|---|---|
| Spain | | | | | |
| Vandellos | 1 | 1 | 160 | 7.2 | 170 |
| Ampolla | 1 | 1 | 290 | 10 | 300 |
| Fondeadero del Fangal | 1 | 1 | 18 | 0.4 | 18 |
| | 2 | 1 | 28 | 0.9 | 29 |
| | 3 | 1 | 22 | 0.8 | 23 |
| San Carlos de la Rapita | 1 | 1 | 270 | 22 | 290 |
| Casa de Alcanar | 1 | 1 | 160 | 8.5 | 170 |
| North of Vinaroz | 1 | 1 | 94 | 3.0 | 97 |
| Peniscola | 1 | 1 | 740 | 66 | 810 |
| California | | | | | |
| Bays and Harbours | 4 | 3 | 180±50 | 47±7 | 220±45 |
| Goleta Point, natural seep | 5 | 4 | 115±91 | 290±150 | 410±230 |
| Southern California Islands | 5 | 14 | 10±3 | 3±0.8 | 12±4 |
| Southern California Shore | 5 | 12 | 53±59 | 11±10 | 64±68 |
| Central California Coast | 5 | 16 | 7±3 | 3±1 | 9±4 |
| Northern California Coast | 5 | 16 | 7±3 | 3±2 | 9±4 |

Few studies of the petroleum contamination of organisms from other parts of the Mediterranean are available. From the coast of Turkey notably from Iskenderun Bay, a study of the concentration of PAHs in fish has been carried out (Sunay et al., 1982). This study showed concentrations ranging from 0.04-7.3 ug/g in muscle and liver tissues from five species of fish. The average concentrations in muscles and livers were 0.13 and 0.79 respectively.

From Mar Piccolo, Taranto, Italy, a study has been reported on the levels of petroleum hydrocarbons in mussels (Strusi, 1984). The results, which are given as wet weight concentrations, range from 0.5-10.1 ug/g with an average of 2.7 ug/g. If these concentrations were to be tansformed into dry weight figures they would become roughly ten times higher.

Data on petroleum hydrocarbon pollution have been reported from a large number of areas around the world (see eg. Goldberg et al., 1978; Farrington et al., 1980). Normally elevated concentrations as much as two orders of magnitude above background in remote areas, are found near known sources of inputs of fossil fuel compounds. Background or baseline levels in umpolluted areas are normally below 10 ug/g (dry weight). Hence, the concentrations reported from parts of the Spanish coast (above) clearly indicate a grave pollution situation.

EFFECTS OF PETROLEUM HYDROCARBONS ON THE MEDITERRANEAN ECOSYSTEMS

Oil tainting of seafood products have been reported sporadically from various areas in the Mediterranean Sea. Thus, some reports of oil taste in fish and mussels have been reported from Spain, France, Italy and Yugoslavia (Le Lourd, 1977). Tainting and even deaths of certain marine organisms, especially spiny lobsters, have been reported from Bizerte, Tunisia. Environmental deterioration owing to oil pollution has also been reported in the Marmara Sea and Bay of Izmir in Turkey, as well as the Gulf of Naples and Cagliari, the lagoons of Venice and the Bay of Muggia in Italy (Le Lourd, 1977). In all these cases, the reproduction of fishes and molluscs have been affected and fisheries have suffered. Apart from this, no studies of the effects of oil pollution on the Mediterranean ecosystems are available. However, in other regions some investigations have been carried out which show the full spectrum of effects of oil spills on the various parts of the ecosystems. Such studies are the ones following the accidental discharge from "Torrey Canyon", Cornwall, England, 1967 (Southward & Southward, 1978); "Florida", West Falmouth, Massachusetts, USA, 1969 (Sanders, 1978); the "Arrow", Chedabucto Bay, Nova Scotia, Canada, 1970 (Thomas, 1978); the "Amoco Cadiz", Brittany, Feance, 1978 (Laubier, 1980); the "Argo Merchant", Georges Bank, NW Atlantic Ocean 1976 (Univ. Rhode Island, 1978); and the "Tsesis", Baltic Sea, 1977 (Linden et al., 1979). All these spills have occurred in temperate climatic zones. The higher temperature of the Mediterranean environment may produce a slightly different impact. Thus, the acute effect might be somewhat more pronounced, while in the long-term a recovery may occur more rapidly. However, it appears very likely that the general conclusions that can be drawn from these studies can be applicable also for spills occurring in the Mediterranean. Therefore, a brief summary of the general conclusions from the above mentioned spills will be given below.

The recovery of ecosystems affected by oil pollution varies considerably. In some cases, large spills have caused minor impact, while in other cases only very small quantities have caused severe and indeed long-term effects on large parts of the marine ecosystem. Both abiotic and biotic factors govern the extent of the biological consequences of each oil spill and it is the interaction and relative contribution of each of these factors that are important.

An abiotic parameter of importance for the extent of biological damage and the time required for complete recovery is the capacity for the polluted area of water to be diluted to concentrations too low to cause any lethal or important sublethal effects. It is clear that the quantity of oil and the morphology and hydrography of the affected area are important here. Therefore it seems quite obvious that single oil spills in off-shore areas with considerable water depth cause less biological damage than oil spilled close to the coast or in shallow and confined water bodies. The impact on sea bird populations may, however, be serious in any of these cases. The impact of the "Argo Merchant" accident (1976) seems to be an example of a spill which caused comparatively little damage to the ecosystems in the area while the "Florida" spill in West Falmouth, Massachusetts, is an example of a spill close to the shore where the oil concentrations in the confined water body rapidly reached toxic concentrations. However, the type of oil involved is also important in these two cases (see below).

In addition, the spills close to open coasts in areas with large tidal water amplitudes and good water exchange appear to cause considerably less damage than spills in atidal bays and archipelagos where winds and currents cannot dilute the oil. Although locally extensive, the damage caused by the large quantities of oil from the "Torrey Canyon" did not seem to cause very long-term damage. This however, does not, apply to the areas where dispersants were used extensively in the clean-up of the oil. Considering the large amount of spilled oil, the limited results obtained so far from the "Amoco Cadiz" may also indicate a fairly rapid recovery, at least in exposed locations. The "Tsesis" oil spill on the contrary, although only involving a very small quantity of oil, caused comparatively long-lasting damage in the enclosed low-turbulent archipelago.

Most of the spill studies that have shown particularly long-term damage to the marine communities have been spills in which the oil is accumulated in fine-particle sediments in the inter-tidal or sub-tidal region, where the degradation and evaporation of the oil is slow or almost non-existent. The long-term action of the higher molecular weight aromatic hydrocarbons on living organisms will become important under such circumstances. Examples of spills where the oil has been accumulated in sediments, thus prolonging the impact, are the "Florida" (West Falmouth), the "Arrow" and the "Tsesis" oil spills.

Another abiotic factor of high significance for the extent of the damage is the composition of the spilled oil. The light refined products such as No. 2 fuel oil or similar oils containing high proportions of light, readily soluble, aromatic hydrocarbons are considerably more toxic than normal crude oils or heavy refined oils. Furthermore, the light refined oils are usually more easily emulsified into the water body by wave action. The "Florida" (West Falmouth) oil spill involved such a light diesel oil with considerable long-term effects on the near-shore communities. The "Tsesis" oil spill, also occurring close to the coast and involving approximately the same quantity of heavy distillate (No. 5 fuel oil) caused less impact on the coastal ecosystem.

The Extent of Damage in Different Communities

Few studies exist on the effects of single oil spills on planktonic communities. Some effects were observed on phytoplankton following the "Torrey Canyon", Santa Barbara (Straughan, 1971) and "Tsesis" oil spills. These effects were, however, minor. Some impact on zooplankton was observed after the "Torrey Canyon" spill, although the effect was probably related to the toxicity of dispersants rather than oil. The "Amoco Cadiz" oil spill apparently resulted in effects on zooplankton up to a few months after the spill in off-shore areas. Following the "Argo Merchant" spill some effects were observed on zooplankton in the oil contaminated area. These effects did not, however, appear to be very drastic. After the "Tsesis" oil spill zooplankton were severely affected only immediately after the spill and in the close vicinity of the wreck.

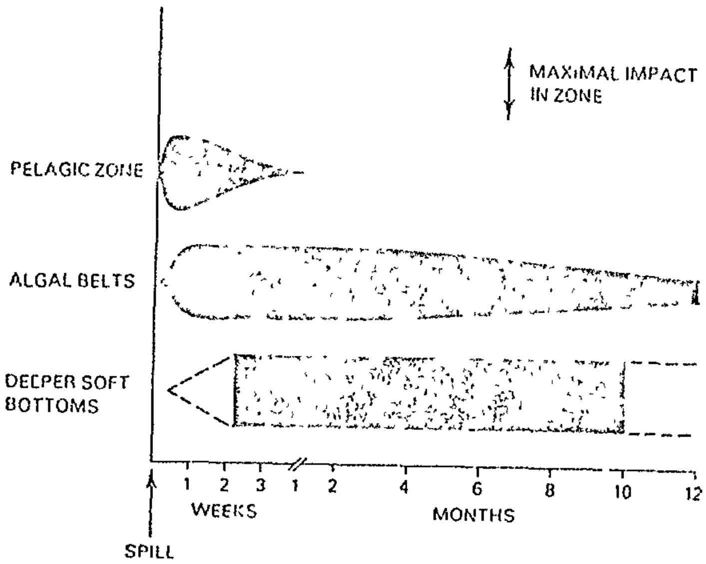
Based on these observations it would appear that the impact of the oil spills on the planktonic community is not of a long-term nature. The water exchange and turbulence in off-shore areas rapidly dilute the oil and replace the affected communities. It seems likely that the period necessary for recovery of the plankton community from single spills, is usually a question of weeks rather than months.

Studies in the littoral zone are more frequent. Extensive and lasting damage was caused to the littoral communities after the "Tampico Maru", "Florida", "Arrow" and "Tsesis" oil spills. These accidents occurred in bays and estuaries where the spilled oil was not diluted sufficiently. In several cases the oil was also accumulated and retained in sediments. The spills from "Tampico Maru" and "Florida" also involved highly toxic products. The spill from "Amoco Cadiz" caused severe acute effects along the coast of Brittany. Except in the estuaries, however, the spill does not appear to have caused very long-term impact in the littoral zone. The oil from the "Torrey Canyon" did not in itself cause drastic long-term effects in the littoral zone. The lasting effects were caused by dispersants.

It appears from these studies that the impact on littoral communities may be drastic and lasting depending on a number of factors. The recovery of affected littoral communities is usually a question of several years. In the worst cases the time necessary for a complete recovery of the ecosystem may take one or more decades.

Only few studies are available on the impact of acute oil spills in benthic sub-tidal and sub-littoral communities. The studies following the "Florida" and "Tsesis" oil spills indicate, however, that the impact in this zone may be severe, and may perhaps last longer than in any other part of the ecosystem. The Tsesis oil spill caused effects in soft bottom sub-littoral communities that lasted longer than those in the littoral zone. The oil was incorporated into sediments and organisms and as the water exchange was limited and the temperature and oxygen content were low, the oil was preserved for a longer period than in the littoral zone.

The figure below shows schematically the impact of the Tsesis oil spill on various parts of the ecosystem.




Duration and intensity of ecological disturbance following the *Tsesis* oil spill in the three major biotopes studied. Intensity is given as a subjective estimate relative to maximum recorded impact in each biotope, since comparisons between biotopes are of questionable validity

(from Linden et al., 1979)

It is not known if this picture also shows the general recovery process which follows all spills in which the oil affects both pelagic, littoral and sub-littoral zones or if it reflects a unique situation. The reason that this is not known is mainly because in very few cases investigations have been carried out simultaneously in all of these three habitats. General knowledge of the stress tolerance of littoral and tidal organisms compared with that of deeper living organisms and of the rate of water exchange and consequently dilution capacity in surface near-shore areas contra bottom areas does, however, indicate that the figure may show a general recovery process applicable to other oil spill cases. In addition, the conditions for oil degradation with regard to temperature and oxygen support the generalizations about the extent of the damage and the recovery pattern observed in the three major marine habitats after the "Tsesis" oil spill.

RECOMMENDED RESEARCH

A review of the current data on the petroleum pollution of the Mediterranean Sea shows obvious gaps in certain areas:

- The extent of petroleum hydrocarbon contamination in several areas is poorly known. Thus, from the southern coastal region, except for Libya and Egypt, there is a complete lack of data on petroleum levels in water, sediments and organisms. However, also from other areas in the north and east, more information is needed on petroleum hydrocarbon concentrations.

- Attempts should be made to monitor the total input of oil in different regions of the Mediterranean Sea. This would mean measurement of petroleum hydrocarbon concentrations in rivers and in effluents from cities and industrial areas in particular. Attempts should also be made to monitor the atmospheric fallout and the input via natural seeps.

- Very little information is available on the effects of petroleum contamination on the Mediterranean ecosystems. Studies should be carried out both in chronically polluted areas as well as in areas exposed to acute spills. Studies should primarily aim at benthic is littoral ecosystems. However, also the impact on bird populations and fisheries are important.

- Regional investigations should be carried out to describe and map coastal ecosystems focussing on oil sensitive shorelines and wildlife, and to determine their relative vulnerability to spilled oil. This information should provide a basis for oil spill response priorities and to aid in the selection of protection and clean-up methods for oil sensitive areas.

CONCLUSIONS

The Mediterranean Sea is one of the most oil polluted areas in the world. Total quantities entering the Mediterranean are estimated to around 0.8 million tonnes per annum. Concentrations of dissolved/dispersed petroleum residues in the water are generally less than 5 ug/l in "unpolluted" offshore areas, while concentrations around 10 ug/l and higher have been observed in coastal areas. Highest concentrations were observed in the eastern Mediterranean. Offshore south of Cyprus, southeast of Crete up to 40 ug/l were recorded, while in coastal areas of Israel and Egypt up to 35 ug/l were found. Relatively high concentrations (10-50 ug/l) have been found close to industrialized areas in most parts of the Mediterranean. Concentrations of petroleum hydrocarbons in benthic sediments are normally much below 1 ppm in unpolluted areas, while close to harbours, oil terminals and river mouths concentrations up to 100 ppm and above have been measured. The concentrations of floating tar are often a few $mg/m^2$, while much higher figures have been observed occassionally (30-80 $mg/m^2$). The degree of tar contamination has been recorded and areas which appear to be particularly exposed to this type of pollution are parts of Cyprus, Israel and Egypt. The concentrations of petroleum hydrocarbons in organisms, particularly in fish and bivalves, have been reported from some areas. Concentrations in fish are normally below 10 ug/g dry weight while much higher concentrations have been reported in bivalves. Thus, in mussels and oysters concentrations in the order of 100-800 ug/g (dw) have been reported from parts of the Spanish coast.

Little information is available on the effects of petroleum contamination on the ecosystems at the Mediterranean Sea. However, the extent of damage to the marine ecosystem and the time required for recolonization and recovery of affected ecosystems, is the result of the interaction and relative contribution of a number of factors:

- The dilution capacity of the polluted water which depends on turbulence, currents, winds and water exchange, closeness to the shore, depth, and quantity of oil.

- The presence of low-energy environments such as muddy estuaries and bays, soft-bottom sediments in sub-littoral and sub-tidal areas.

- The type of oil is important both with regard to the quantity of toxic compounds in the oil and the tendency to form emulsions.

- The meteorological conditions such as winds and wave action, and temperature.

- The geographical distances within the area affected by the spill.

- The season of the year when the spill occurs.

The on-scene spill studies carried out so far indicate that:

- The effects in the pelagic communities are rarely very drastic and the recovery period is usually a question of weeks or one or two months.

- The effects in the littoral and tidal communities can be extremely drastic, and recovery may take years or decades.

- The effects in sub-littoral and sub-tidal communities may also be extremely drastic, and the effects may be present even longer than in the shoreline communities.

- The effects on bird populations are often severe and some species are threatenend by extinction.

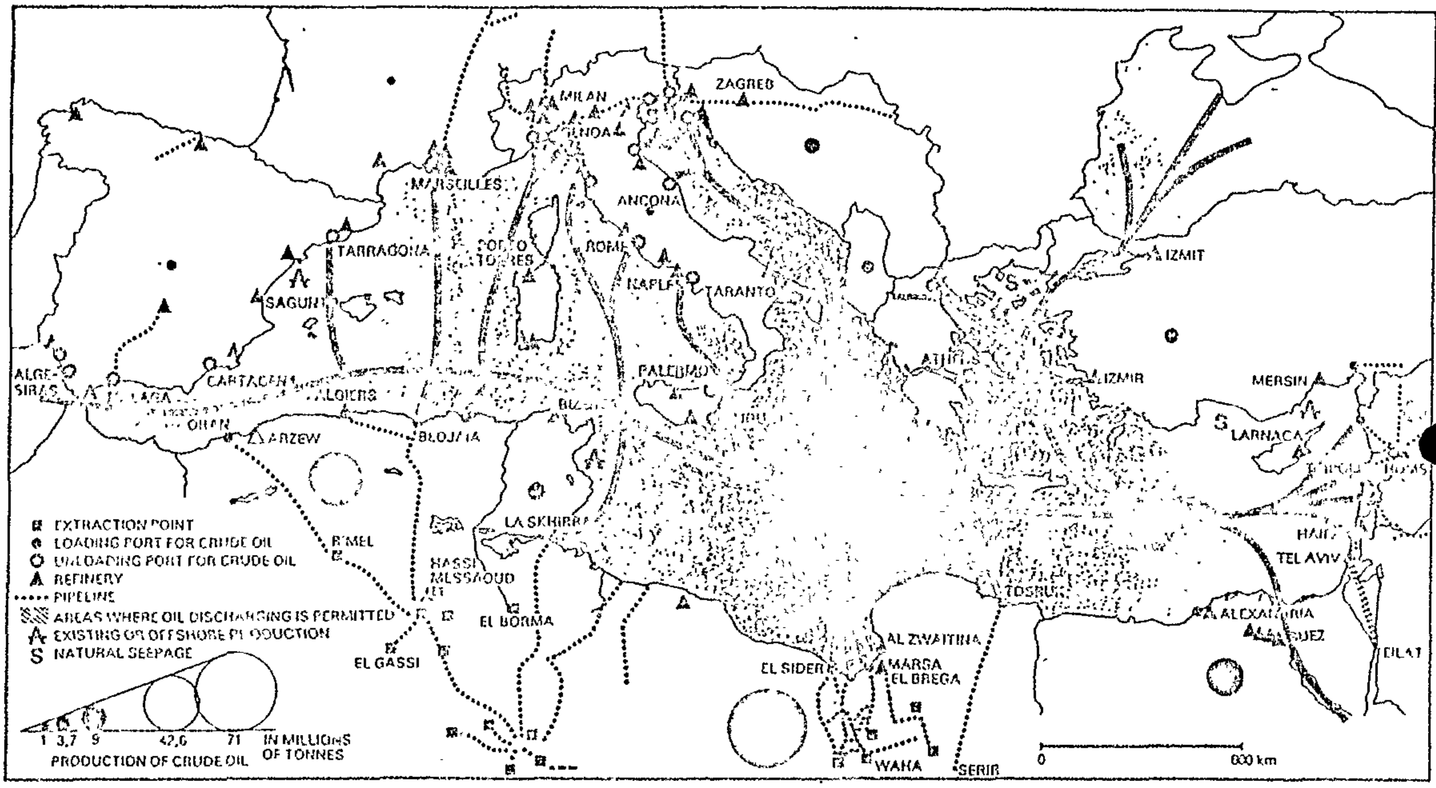
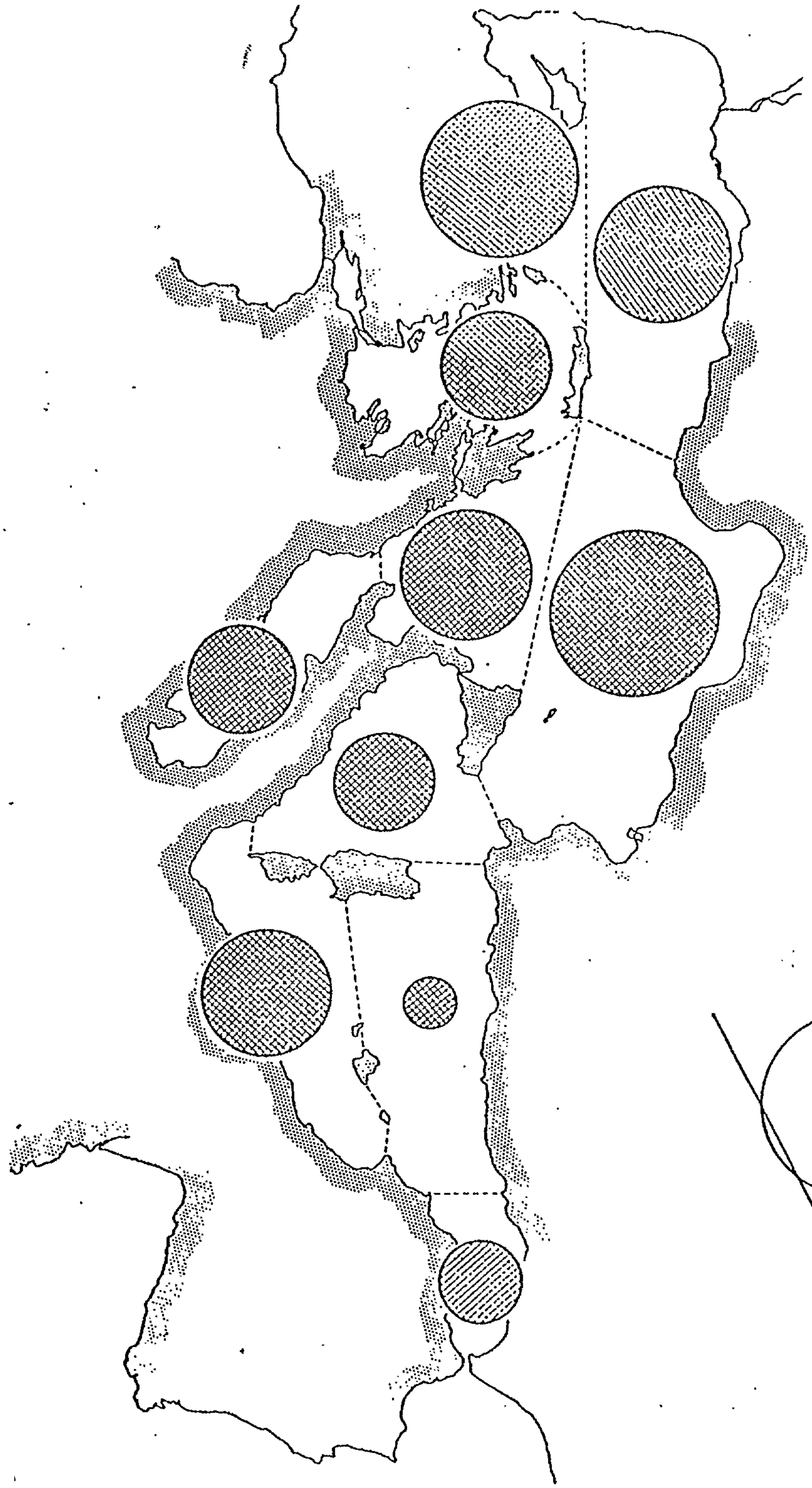



Figure I. Production and transport of oil in the Mediterranean (Le Lourd, 1977)



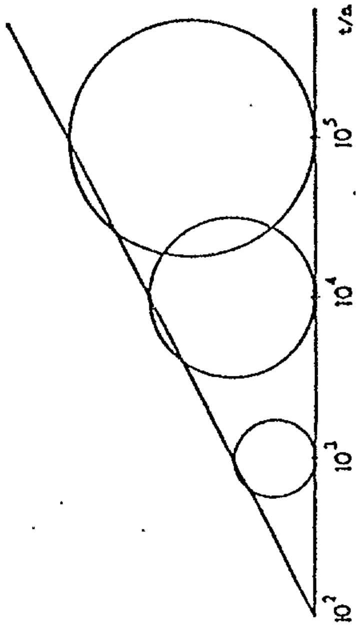



Figure II. Oil pollution from land-based sources
(from MED X project report).

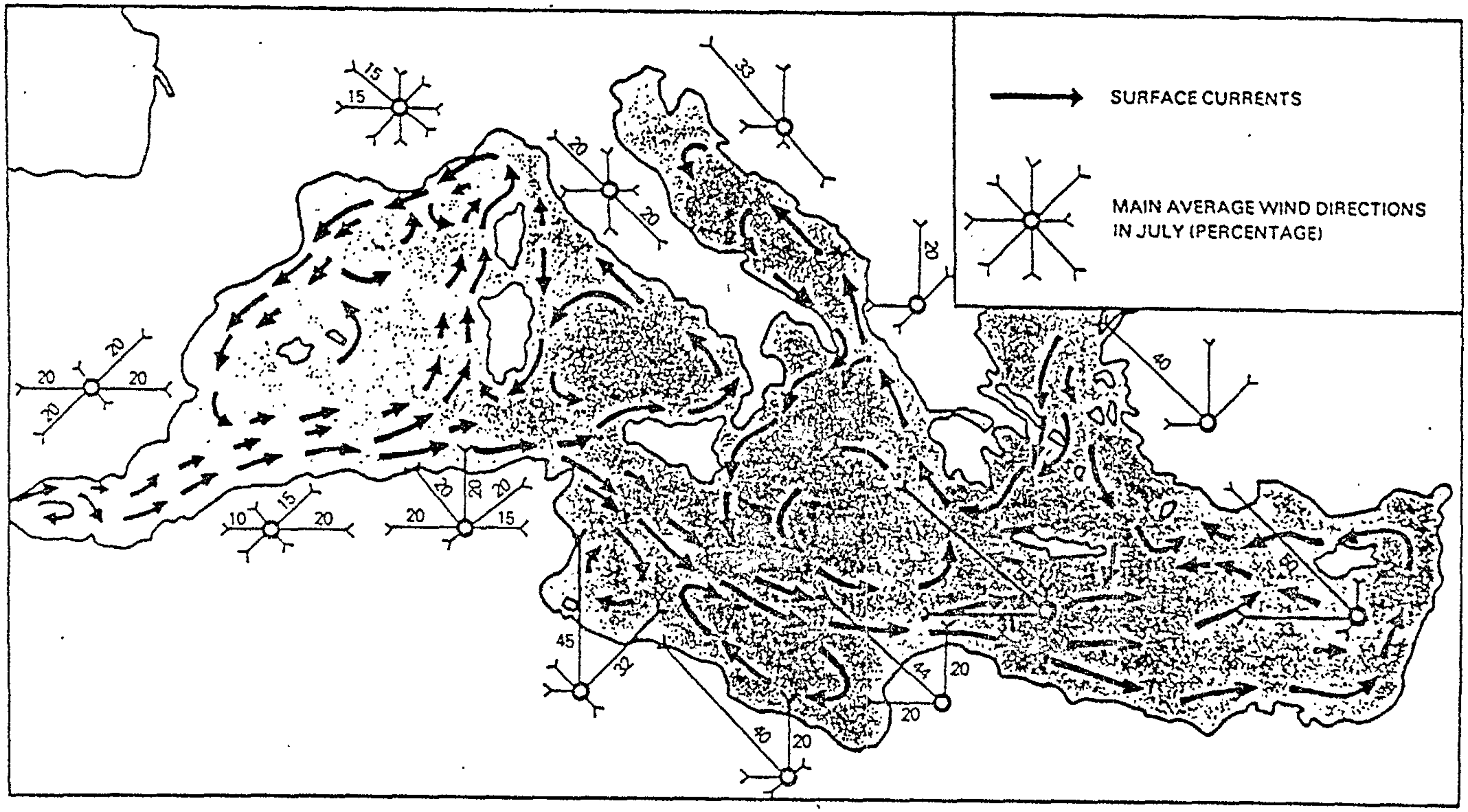
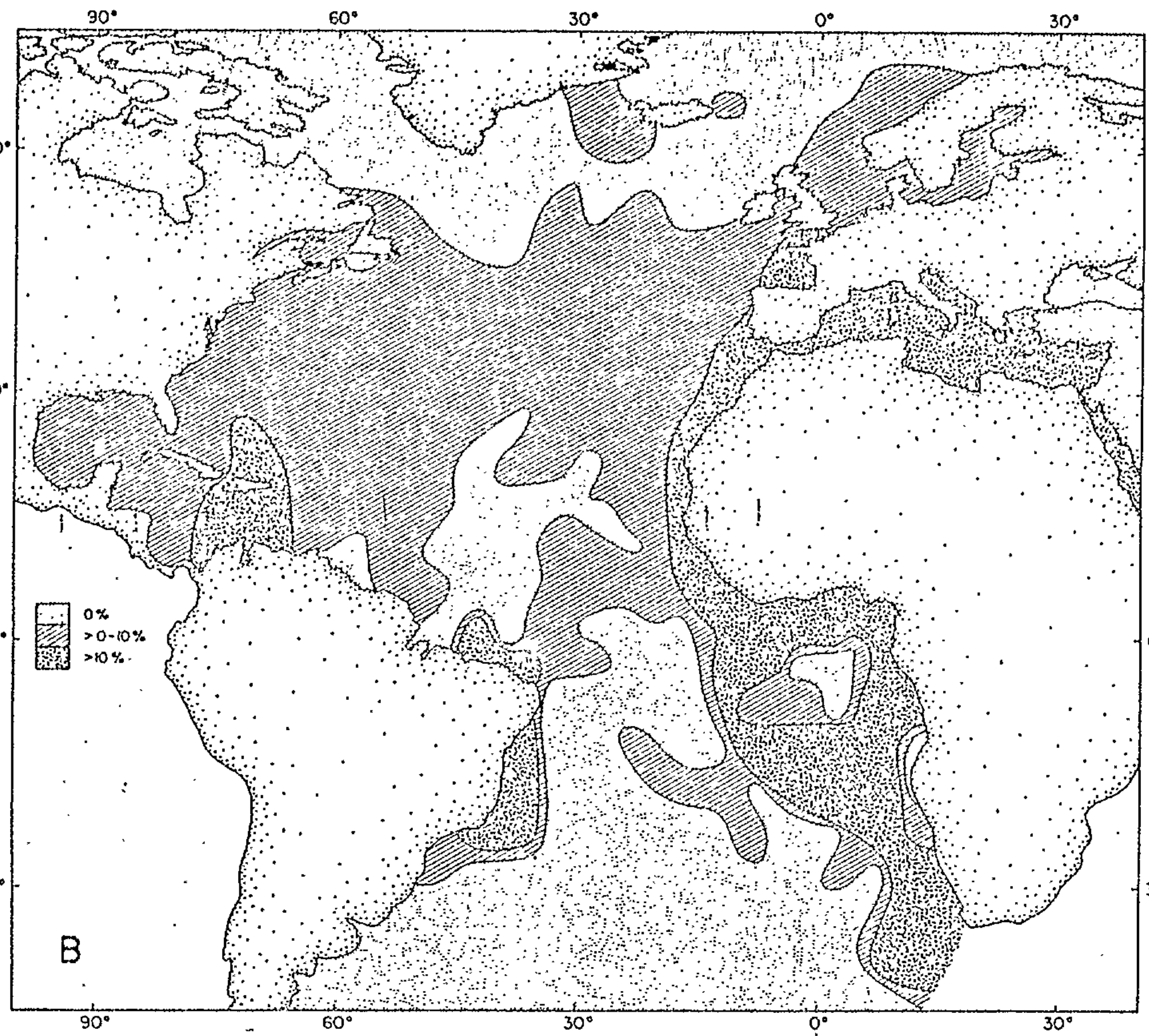



Figure III. Surface currents and main winds in the Mediterranean in summer. From UNEP (1978) and Le Lourd (1977).



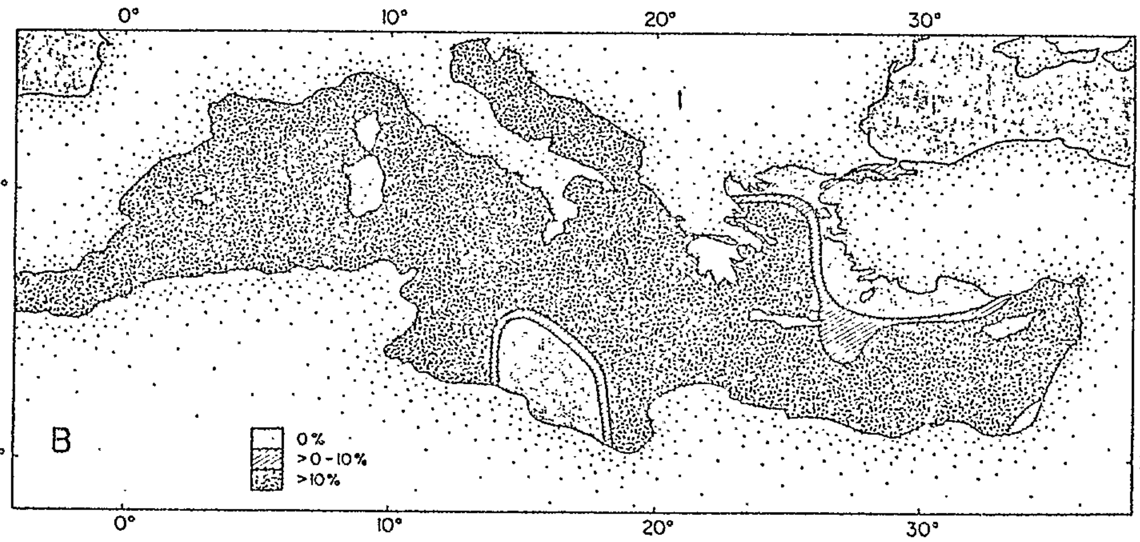




Figure IV. The geographical distribution of oil slicks in the Atlantic Ocean (above) and the Mediterranean as indicated by the percentage of positive reports per 5° x 5° (Atlantic Ocean) or 2° x 2° (Mediterranean) squares of latitude and longitude (IOC, 1981).

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