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STATUS OF THE PETROLEUM POLLUTION IN THE WIDER CARIBBEAN SEA

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ABSTRACT

In 1976, the IOC-UNESCO and UNEP convened a meeting in Port of Spain to analyze the marine pollution problems in the Region and noted that petroleum pollution was of region-wide concern and recommended to initiate a research and monitoring program to determine the severity of the problem and monitor its effects.

Actually, the Wider Caribbean is potentially one of the largest oil producing areas in the world. Major production sites include Lousiana and Texas, USA; the Bay of Campeche, Mexico; Lake Maracaibo, Venezuela; and the Gulf of Paria, Trinidad; all which are classified as production accident high-risk zones.
Main sources of petroleum pollution in the Wider Caribbean are: production, exploitation, transportation, urban and municipal discharges, refining and chemical wastes, normal loading operations and accidental spills.
About 5 million of barrels are transported daily in the Caribbean, thus generating an intense tanker traffic. It has been estimated that oil discharges from tank washings within the Wider Caribbean could be as high as 7 millions barrels/year.

The results of the CARIPOL Regional Programme conducted between 1980-1987 pointed out that a significant levels of petroleum pollution exists throughout the Wider Caribbean and include serious tar contamination of windward exposed beaches, high levels of floating tar within the major currents system and very high levels of dissolved/dispersed hydrocarbons in surface waters.

Major effects of this petroleum pollution include: high tar level on many beaches that either prevent recreational use or require very expensive clean-up operations, distress and death to marine life and responses in the enzyme systems of marine organisms that have been correlated with declines in reproductive succces. Finally the presence of polycyclic aromatic hydrocarbons in tissues of important economic species have been reported with its potential carcinogenic effects.

RESUMEN

Desde 1976, la contaminación por petróleo fue reconocida como un problema de importancia regional en el Gran Caribe.

Actualmente, es una de las regiones de mayor producción petrolera en el mundo y los sitios más productivos son las plataformas de Louisiana y Texas en los Estados Unidos de América, la Sonda de Campeche en México, el Lago Maracaibo en Venezuela y el Golfo de Paria en Trinidad; los cuales se consideran como zonas de alto riesgo.

Las principales fuentes de contaminación por petróleo en la región son: la producción, explotación y el transporte, descargas urbanas e industriales, los desechos de refinerías y petroquímicas, operaciones de carga y derrames accidentales; considerándose que se transportan por día más de 5 millones de barriles de petróleo crudo en el Gran Caribe.

Los resultados del Programa Regional Caripol (1980-1987) señalan que niveles significativos de contaminación por petróleo existen en la región y que incluye altas concentraciones de alquitranes en playas, elevados niveles de breas y flotantes y muy altos niveles de hidrocarburos disueltos en aguas superficiales sobre todo en áreas cercanas a sitios de producción.

Los principales efectos negativos de ésta contaminación incluyen elevados costos de limpieza en playas turísticas, pérdida de áreas recreativas y turismo, alteración metabólica y muerte de la vida marina, declinación en el éxito reproductor de algunas especies y efectos carcinogénicos por la presencia de hidrocarburos aromáticos.

INTRODUCTION

In general, the marine pollution by petroleum and its derivatives has aroused great interest in the scientific community, especially after the large oil spills from tankers such as the "Torrey Canyon" in England, the "Tampico Maru" on the coast of Baja California and the "Amoco Cadiz" on the Brittany coast of France, and from the Ixtoc-I oil well in the Gulf of Mexico, where thousands of tons of crude oil were spilled. Recent estimates (National Academy of Sciences, 1975) indicate that a total of 6.2 million tons of crude oil are released into the world's oceans from various sources, 2.2 million tons from the major source, maritime transportation. According to Gundlach (1977), 28 per cent of all petroleum released into the ocean winds up in coastal zones.

The main sources of fossil hydrocarbons in oceans and coastal zones are the following:
a) anthropogenic hydrocarbons produced by various human activities;
b) biogenic hydrocarbons produced naturally by marine organisms;
c) hydrocarbons from natural seeps.

In the open sea, concentrations of hydrocarbons are generally low and their origin is not always easily determined. By contrast, in bays, estuaries and coastal areas, hydrocarbons may be present in high concentrations, as a direct effect of oil pollution resulting from spills, wastes from petrochemical plants and refineries, normal loading operations and tropospheric transport.

The effects that large oil spills and the use of dispersants have on marine biota have been widely documented and published (Blumer et al., 1970; Blumer and Sass, 1972; Sanders et al., 1972; Portman and Connor, 1968; Crapp, 1971). Nevertheless, very little is known about the biological and physiological effects of oil pollution in coastal waters or estuarine systems.

Mackin and Hopkins (1964) have postulated that in certain coastal areas the continental release of oil-derived products has little or no effect upon the populations or productivity of the region. However, other researchers suggest that some important biological processes, such as photosynthesis and respiration, are affected by relatively low concentrations of petroleum (Gilfillan, 1973; Jacobson and Boylan, 1973; La Roche, 1973; Parker and Menzel, 1974; Pulich et al., 1974).

Generally speaking, the biological or biochemical activity of oil components in estuaries and coastal zones is dependent on the following parameters:
a) the levels at which hydrocarbons are bioaccumulated;
b) the amount of time hydrocarbons remain in the water column and, subsequently, in organisms and sediments;
c) the composition of the hydrocarbons mixture in the water and subsequently in organisms.

Furthermore, in marine organisms these parameters are modified by biological factors such as lipid content, efficiency of hydrocarbon consumption and hydrocarbons entry and waste routes.

Actually, there is growing evidence that pollution of coastal waters is accelerating in the Wider Caribbean Region as industrialization and urbanization overtakes the capacity of existing municipal infraestructures. Based on information available on the inputs of contaminants in the coastal waters of the region, the contaminant most likely to give rise to public health and ecological problems is sewage.

However, oil is the most found pollutant in the region, and its impact on coastal ecosystems and reacreational beaches is well documented for both the Gulf of Mexico and the Caribbean Sea areas.

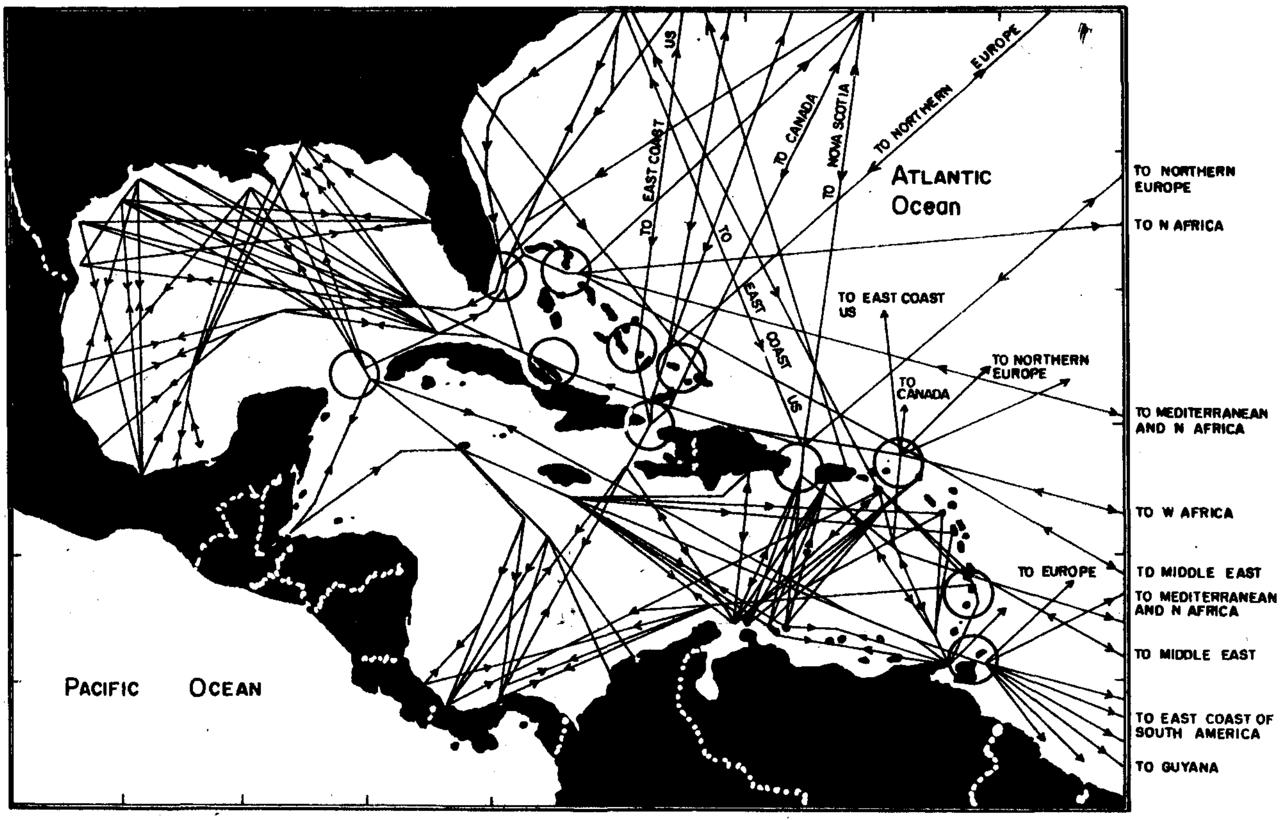
SOURCES

MARINE TRANSPORT

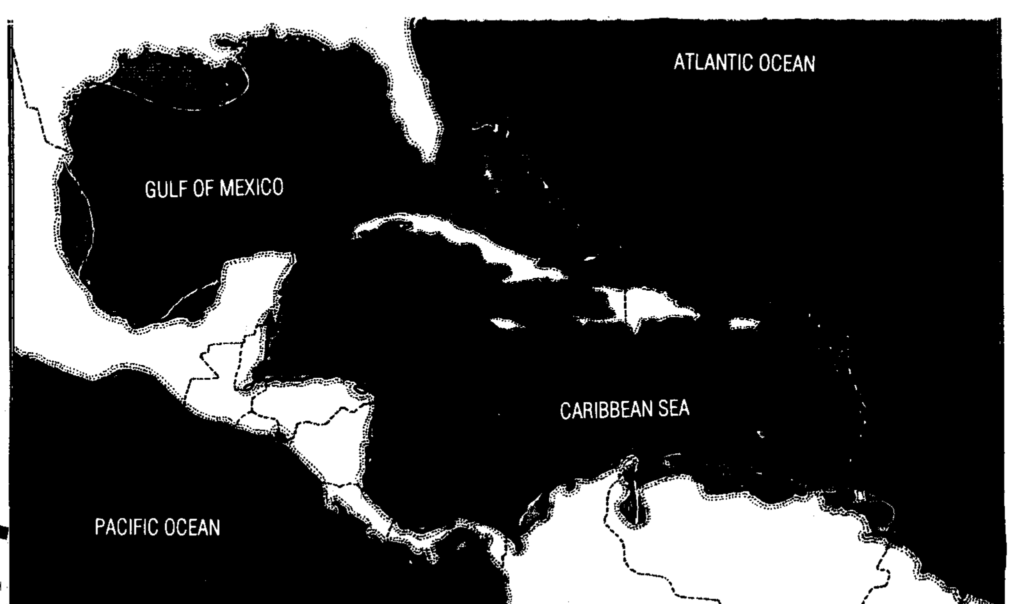
The Wider Caribbean Region is potentially one the largest oil producing areas in the world. About 5 million barrels of oil are transported through the area every day generating relatively intense tanker traffic. Tanker movements through restricted channels and in the vicinity of some ports increase the possibility of shipping accidents. Also, significant discharges of oil into local Caribbean ports occur as a consequence of ballasting, ship cleaning, tank washings and docking and undocking operations.

Tanker traffic through the Caribbean constitutes an intricate network of routes to and from producers, transhipment point, refineries and consumers. The U.S. is the major importer of crude petroleum and petroleum products in the region and "this fact alone establishes most of the vessel routes". In an exercise of risk assessment for the region carried out by the Oil Companies International Marine Forum, it was found that no part of the Caribbean or the Gulf of Mexico could be designated as low risk areas. Of particular concern is the traffic across a number of passages within the region where many traffic lanes converge (Reinburg, 1984).

Table 1 compiled form Reinberg (1984) summarises the straits of least width traversed by most of the tankers, the volumes of oil moved by major exporters and the location of major transhipping facilities. Areas adjacent to, especially those down-wind, of the straights of least width, major shipping ports and transhipping point may be considered as particularly vulnerable to pollution by oil (Figs. 1 and 2).



Sea lanes of the wider caribbean region used in the oil trade.



High risk zones for oil spills in off-shore areas in the Wider Caribbean. Source: IMCO, 1979

SPILLS

Estimates on the annual inputs rates of oil into the marine environment, at a global scale, have been reduced during the last decade from 2.13 x 10^6 tons yr^{-1} (Farrington, 1977) to 1.47 x 10^6 tons yr^{-1} (Farrington, 1985). Nevertheless, both estimates indicate that chronic oil spillage is more substantial than the more noticeable input from tanker accidents.

Accidental or intentional spills of crude or refined petroleum products in the course of tanker operations constitute another significant fraction of the oil reaching the marine environment. Implementation of the "load on top" procedures, whereby dirty ballast waters are cleaned prior to discharge appear to have greatly reduced discharges attributable to routine tanker operations. Despite such precautions tar ball abundance in certain area, has been correlated to frequency of tanker traffic.

Corredor et al. (1985) reported that more than 50% of tar ball occurrence off the southwest coast of Puerto Rico could be statistically tied to the frequency of tanker arrival at a petrochemical complex 15 miles east of the sampling site (Van Vleet and Peuly, 1987). Nevertheless, massive spills are highly visible, receive much publicity and, depending upon the trajectory of the spilled mass, may cause severe ecological damage. In the Great Caribbean Region, the IXTOC-I oil spill off the Mexican coast is, perhaps the best known case (Atwood, 1979), having produced the largest man-made spill prior to the war- related spills in the region of Kuwait in 1991. In the course of the IXTOC-I blowout, approximately 0.5 million tons of light petroleum were release to the marine environment over the course of 9 months before the well was finally capped.

Table 1. Estimated annual frequency of transit of straits of least width by cargo laden tankers in the Wider Caribbean Region (1)

Location	Number of tankers 100,000 and over DWT	99,999-10,000 DWT	Under 10,000 DWT
Florida Straits	117	219	65
Yucatan Channel	65	1048	208
Northeast Providence Channel (Bahamas)	52	65	13
Crooked Island Passage (Bahamas)	--	267	--
Old Bahamas Channel (Bahamas/Cuba)	--	312	39
Caicos Passage (Turks and Caicos Island)	--	273	26
Windward Passage (Cuba/Haiti)	--	546	52
Mona Passage (Dominican Rep/Puerto Rico	25	431	13
Anegada Passage (UK Virgin Islands/Puerto Rico	30	350	13
St Vincent Passage (Martinique/St. Lucia)	--	--	13
Galleon's Passage (Trinidad & Tobago)	--	52	--

(1) Compiled from Reinberg (1984)

THE IXTOC-I OIL SPILL

In December 1978, Mexican Oil Company (PEMEX) started to drill the IXTOC-I oil well at the Bay of Campeche about 80 km northwest of Ciudad del Carmen, 92° 13' W and 19°24' N. However, on june 3, the well blew out and caught fire. The explosion and fire destroyed the plataform, which sank and damaged the stack and well casing.

The spill continued up to March 23, 1989 (290 days after the blow out) and a total of 3.2 x 10^6 barrels, approximately 475,000 metric tons, of crude oil had been lost according to PEMEX estimates. Thus, the oil lost polluted a considerable part of the offshore region in the Gulf of Mexico as well as much of the coastal zone, which consists primarily of sandy beaches and barrier islands often enclosing extensive highly productive coastal lagoons (Jernelov and Linden, 1981; Botello and Macko, 1982).

The oil was of a light type containing a high proportion of straigh-chain and cyclic hydrocarbons with less than sixteen carbons atoms and aromatic hydrocarbons with a high percentage of benzene and naphthalene and its methyl derivatives (Botello and Castro, 1980). Considering its chemical composition, a large of the IXTOC-I oil was dissolved in the water and a smaller part evaporated to the atmosphere when compared to other spills. After exposure to chemical and physical parameters the oil increased in density and sank. Another portion reached the beach either deposited there or made to sink in the shallow water.

Since the begining of the blow out, a large scale dispersant spraying commenced using specialised aircraft. However, the total amount of dispersant used for cleanup is still not know. According to information from PEMEX at leat 9000 metric tons were used and of this, at least 6750 metric tons were Corexit products, meaning that the use of dispersant during the IXTOC-1 blowout can be considered as one of the largest in history. The reports and studies done during the blow out speculate that the oil from the IXTOC-1 acutely affected the species and ecosystems in the Campeche Bay area through its chemical toxicity.

Jernelov and Linden (1981), based on data from the IXTOC-1 case analogies with other spills, made an estimation of the fate of the crude oil from IXTOC-1 as follows:

	Percent	Metric tons
1. Burned at well site	1	5,000
2. Mechanically removed at well site	5	23,000
3. Evaporated to the atmosphere	50	238,000
4. Degraded biologically and chemically	12	58,000
5. Landed on Mexican beaches	6	29,000
6. Landed on texas beaches	1	4,000
7. Sank to the bottom	25	120,000

Jernelov and Linden (1981) pointed out that the commercially important species and ecosystems affected by the chemical toxicity of oil were mainly the offshore shrimp and fish populations.

OTHER SPILLS

A summary of data on oil spills and accidents has been recorded in Tables 2 and 3, based on information compiled by Corredor (1991).

Table 2. Major oil spills (more than 2000 m^3) in the Wider Caribbean Region (1962-1991).

Vessel	Year	Affected Areas	Amount (m^3)
Argea Prima	1962	Guanica, Puerto Rico	11,000
Witwater	1968	Galeta Island, Panama	3,000
Santa Augusta	1971	Off St. Croix, USVI	13,000
Colocotronis	1973	Cabo Rojo, Puerto Rico	5,000
Atlantic Empress	1978	Off Tobago	158,000
Aluenus	1984	Off Louisina coast	25,000
Vista Bella	1991	Off St. Kitts-Nevis	2,000

In addition to the spills caused by tanker traffic, the following table summarises oil spills caused by accidents, such as oil leakages, well blowout and refinery operations.

Table 3. Other major oil spill accidents in the Wider Caribbean Region.

Cause	Location	Year	Amount (m^{-3})
Pipeline offshore leak off	Lousiana coast	1967	25,000
Offshore plataform well blowout	Gulf of Mexico	1970	10,000
IXTOC-I well blowout	Campeche, Mexico	1979-80	475,000
RANGER Plataform well blowout	Texas, USA	1985	24,000-52,000
Oil Refinery Las Minas	Panama	1986	8,000

No information was found on any accident involving transport of hazardous substances other than oil by sea, although a large variety of chemical compounds are transported to and from the ports of the region.

EXPLOITATION AND EXPLORATION

The main non-living resouces which are exploited in the Wider Caribbean region are oil and gas. The petroleum industry along generates 70% of Venezuela's national income, and it is critical to the economies of Trinidad, Tobago, Mexico, and the United States Gulf coast. In terms of oil resources, the Wider Caribbean has over 5% of the world's resources (UN/DIESA, 1979). Offshore oil exploitation is particularly important in the Gulf of Mexico continental shelf where more than 1000 plataform are operating, both in the United States and the Mexico Gulf coast. Oil exploitation in Lake Maracaibo, Venezuela is also important in this respect.

The International Maritime Organization (IMO) estimated that 6.7% of the total offshore oil production, at a global level, is lost through spills into the marine environment as a consequence of pipeline accidents, well blowouts, plataform fires, overflows, and malfunctions.

In addition to the above-mentioned potential accidents, offshore oil exploration has other impacts on the adjacent coastal region. The presence of rigs and pipelines creates exclusion zones for fishing vessels and shipping. Moreover, the elimination and disposal of oil plataform that have reached the end of their usefulness, need to also be considered (GESAMP, 1990).

ACCIDENTS

With regard to pollution caused by accidents, the most important pollutant resulting from shipping operations is oil. The results of a study by the US National Academy of Science published in 1983 indicated that, of the 3 million tons of oil entering the sea from all sources, approximately 1.5 million tons is caused by maritime transportation. Of this 400,000 tons year is the results of maritime accidents. In the Wider Caribbean Region about 5 million barrels of oil are transported throughout the region every day, which generates an intensive tanker traffic. Moreover, the exploitation of oil within the continental shelf of the Gulf of Mexico from more than 1000 oil plataform provide an additional sources of possible accidents.

SEEPS

Literature reviews provide evidence that naturally occurring oil and gas seeps existed in the Gulf of Mexico and the Caribbean Sea for thousands of years. There are also many references in the historical literature of the 16th and 17th century spanish explorers caulking their ships with tar found on the baches off south Texas and Lousiana.

Hydrocarbons have been reported by navigators and explorers at different times, places and forms in the Gulf of Mexico. However, before 1900, floating oil was only casually noticed and reports ever caught the attention of news media. In later years records were kept more carefully. It was, therefore, possible to locate the origin of the oil field and to determine its extent. In the early 1900's the Hydrocarbons Office in New Orleans supplied all ships crossing the Gulf of Mexico with oceanographic reporting forms. Many of the ships reported huge patches of oil, some more than 160 kms long and several kilometers wide, and others were oval-shaped and more than 40 km wide.

In 1933, Price reported a seep on the north end of St. Joseph's Island off the Texas coast. Levorsen (1954) listed natural offshore seeps in the Gulf of Mexico off Yucatan, and in the Caribbean in Vonsetes Bay, Barbados.

Many seeps occur in northern Mexico oil fields in the so-called Golden Lane trend south of Tampico. De Golyer (1932) stated that over 6000 seeps were found in Cerro Azul 400 km south of Brownsville, Texas. In connection with a study of natural seepages in the Gulf of Paria (Venezuela) Ying (1971) noted that for an area which is so prolific in natural oil sepps and as enclosed as the Gulf, there is remarkable absence of obvious oil on the surface waters. This could be the result of the large suspended sediment load in this water which may be sinking down to the bottom with any surface oil, and which would also eventually cover fissures.

Gas seepages are of relatively common occurrence in the northwest Gulf of Mexico. Watkins and Worzel (1978) reported that over 19000 seeps probably exist in a small area about 6000 km^2 on the south Texas shelf.

LEVELS

Most of the information on oil pollution in the Wider Caribbean Region stems from regional studies, particularly the IOC-IOCARIBE/UNEP CARIPOL Project established in 1979. The monitoring of pollution by petroleum hydrocarbons in the Gulf of Mexico and the Caribbean Sea was identified as having the highest priority in a meeting of regional experts convened by IOC, UNEP, AND FAO (IOC Workshop N° 11, 1976). Prior to the establishment of the CARIPOL Project published field data was very sparse (National Academy of Science, 1975). More recently and, as a precursor of CARIPOL. The IOC/WHO MAPMOPP study provided some limited information on the levels and distribution of petroleum hydrocarbons in surface waters of the Gulf of Mexico (Levy et al., 1981).

DISSOLVED/DISPERSED HYDROCARBONS (DDPH'S)

The results of the CARIPOL Project indicate that the distribution of dissolved/dispersed petroleum hydrocarbons (DDPH), are generally low in offshore waters of the region, typical values being below 10 $\mu g\ l^{-1}$ (Corredor, 1989). The highest levels of DDPH were reported for enclosed coastal waters, such as

Cartagena Bay (Garay, 1986), Habana Bay (Cuba, 1984) and Kingston Harbour (Wade et al., 1987), among others.

A summary of the data on dissolved/dispersed petroleum hydrocarbons for sub-regional areas within the Wider Caribbean Region collected by the CARIPOL Project is presented in Table 4, Figure 3.

Based on the DDPH data gathered by the CARIPOL Project including the experience in the Bay of Campeche during the 1979 IXTOC-I oil well blowout (Atwood and Ferguson, 1982), the background levels for DDPH in the Gulf of Mexico seem to range from 1 to 10 μg l^{-1} with many values >10 μg l^{-1} in the northwestern Caribbean sub- region; as well as the Campeche Sound.

Table 4. Dissolved and dispersed petroleum hydrocarbons levels in water samples of the Gulf of Mexico and the Caribbean Sea (Atwood et al. 1987; Corredor, 1988)

Sub-region	DDPH mg $^{-1}$	S.D.	N° of observations
Western Gulf of Mexico	4.77	5.1	52
Eastern Gulf of Mexico	5.10	8.8	283
Campeche Sound	8.83	10.5	281
Florida Straits	3.10	4.3	119
Northwestern Caribbean	12.58	23.3	239
Southern Caribbean	1.34	3.5	273
Eastern Caribbean	1.26	0.99	181

FLOATING TARS

The information gathered through CARIPOL on floating tars are represented in Table 5, Figure 4. Most of the sub-region sampled are dominated by observations of floating tars in the range of 0.1 to 3.5 mg m^{-2} of sea surface. However, in certain areas such as the Florida Straits values in the range of 1 to 10 mg m^{-2} were determined.

Table 5. Floating tar distribution in the waters of the Gulf of Mexico and the Caribbean Sea. (Atwood et al., 1987; Corredor, 1988)

Sub-region	mg m^{-2}	S.D.	N° of observations
Western Gulf of Mexico	1.32	5.77	36
Eastern Gulf of Mexico	1.58	6.06	328
Campeche Sound	1.31	7.76	39
Florida Straits	1.90	4.74	42
Northwestern Caribbean	1.34	6.61	95
Southwestern Caribbean	0.73	0.63	3
Eastern Caribbean	3.09	2.92	138

The Caripol floating tar data on open waters of the region are comparable ta data gathered in early studies conducted by Jeffrey et al. (1973), Sherman et al. (1973) and the recent MAPMOPP Study (Levy et al. 1981). The above studies reported floating tar values of less than 1 mg m-2. There was also a strong correlations between observations of high levels of pelagic tar and know tanker routes of high traffic within the region.

FIG. 3. DISSOLVED/DISPERSED HYDROCARBONS IN WATER SAMPLES OF THE GULF OF MEXICO AND CARIBBEAN SEA

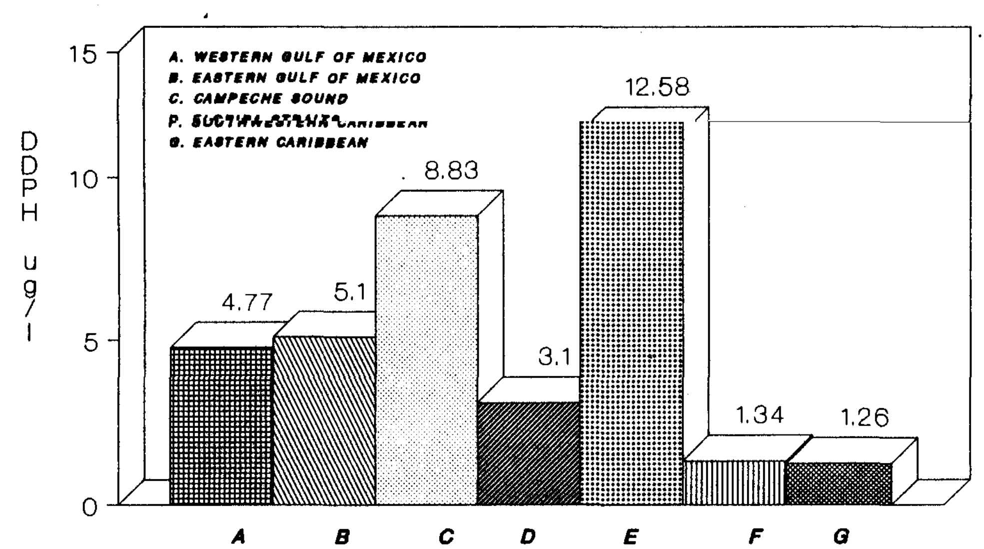
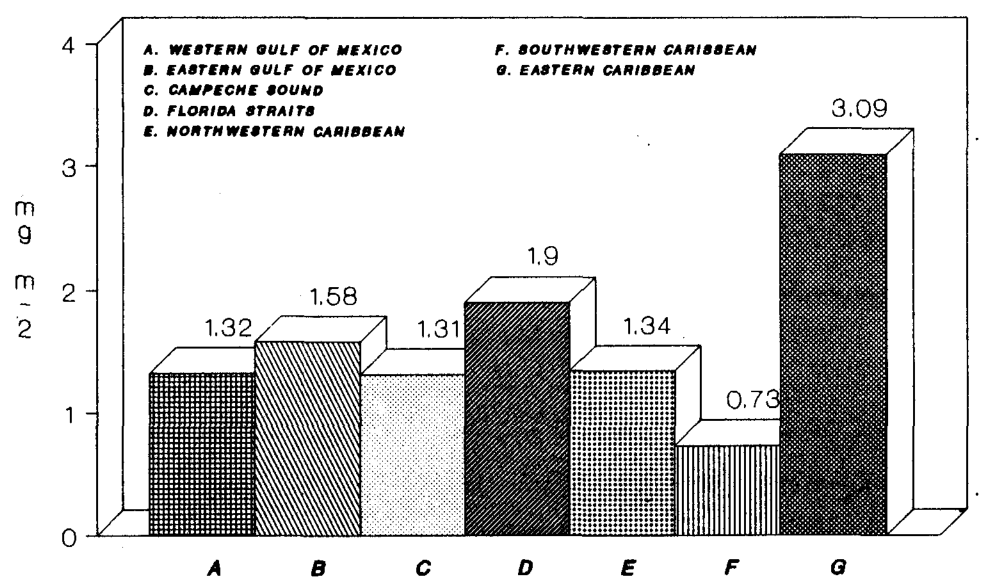


FIG. 4. FLOATING TAR DISTRIBUTION IN WATER OF THE GULF OF MEXICO AND THE CARIBBEAN SEA (mg m-2)



TAR ON BEACHES

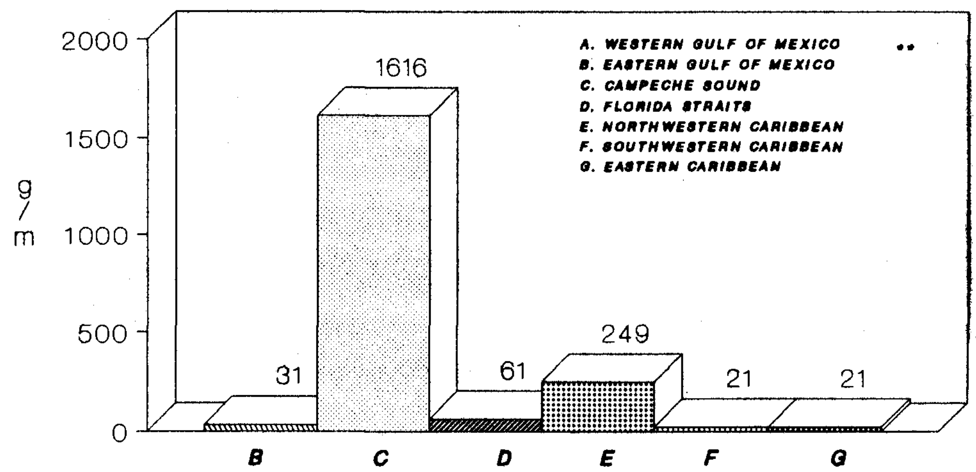
The CARIPOL Project also provided valuable information on the deposition of tar on the beaches of the region, with numerous locations having tar accumulation approaching 100 g m^{-1} (Atwood et al., 1987).

A recurring observation regarding the accumulation of tar on the beaches was that of its prevalence on exposed windward beaches and its relative absence on protected leeward beaches throughout the region. Of special concern are the results gathered on tar accumulation on beaches of the southern Florida coast, the Cayman Islands, Curacao and the windward beaches of Barbados, Grenada, Trinidad and Tobago, among others. Van Vleet et al. (1983 a, b, 1984) demonstrated that pelagic tar levels in the eastern Gulf of Mexico and the Florida Straits were substantially higher compared to other regions of the world, and that as much as 50% of this tar entered through the Yucatan Strait. In this regard, it is important to point out that the results of Romero et al. (1981) on the accumulation of tar on southeast Florida beaches are very similar to those reported by Denis (1959). In table 6, figure 5, the data on accumulation of tar on Wider Caribbean beaches compiled by the CARIPOL Project has been summarised.

Table 6. Tar accumulation on beaches of the Gulf of Mexico and the Caribbean Sea (Atwood et al., 1987; Corredor, 1988).

Sub-region	g m^{-1}	S.D.	N° of observations
Western Gulf of Mexico	--	--	0
Eastern Gulf of Mexico	31	48	69
Campeche Sound	1616	3070	230
Florida Straits	61	71	157
Northwestern Caribbean	249	855	339
Southwestern Caribbean	21	75	321
Eastern Caribbean	21	18	5885

FIG. 5. TAR ACCUMULATION ON BEACHES OF THE GULF OF MEXICO AND THE CARIBBEAN (g m-1)



SEDIMENTS

With regard to the presence and distribution of total hydrocarbons (including biogenic compounds) in sediment samples of the Gulf of Mexico and the Caribbean Sea, considerable amounts of information have been compiled, particularly from sediments from the Gulf of Mexico. Relevant information has been published by Meinschein (1969) for sediments of the Gulf of Mexico with total hydrocarbons values ranging from 15 to 85 $\mu g\ g^{-1}$ (DW) and more recently by Gearing et al. (1976), Lytle and Lytle (1977) for sediments of the northern Gulf of Mexico and in coastal waters of the US Gulf coast through the Mussel Watch Programme (Farrington et al., 1980, 1982, 1983).

Recent surveys on the presence of petroleum hydrocarbons in sediments from the US Gulf coast are being carried out by the US National Oceanic and Atmospheric Administration (NOAA) Status and Trends Programme. This programme was established to determine how the coastal environment responds to increased or decreased contaminant input, particularly trace organic compounds. For that purpose, 51 sites, away from know point-sources of contamination, were selected for yearly surveys to be conducted.

With reference to the presence of hydrocarbons in sediments and organisms, the above-mentioned programme has placed emphasis in the determination of polynuclear aromatic hidrocarbons (PAH). The published results corresponding to the first year of the programme (Wade et al., 1988) has provided updated information on the concentration of PAH in sediments of the studied area ranging from 5 to 36700 ng g^{-1} (DW) with a mean value of 507 ng g^{-1} (DW).

Additional reports with reference to the occurrence of total hydrocarbons in coastal and offshore sediments from the southern Gulf of Mexico are also available. Botello and Macko (1982) reported concentrations on total hydrocarbons in sediments of nine coastal lagoons and two riverine systems along the Mexican Gulf coast. Sediments from coastal lagoons exhibited total hydrocarbon levels ranging from 12 to 88 $\mu g\ g^{-1}$ (DW), well within the range expected for coastal ecosystems. These authors also reported on high levels of petroleum hydrocarbons in sediment samples collected at the entrance of some of the studied lagoons, attributing the presence of those hydrocarbons to the IXTOC-I blowout and subsequent oil spill.

The highest levels of petroleum hydrocarbons were reported by the above-mentioned authors for sediment samples of the Coatzacoalcos and Tonala river estuaries; total hydrocarbons values ranged from 179 to 2623 $\mu g\ g^{-1}$ (DW) and from 17 to 1829 $\mu g\ g^{-1}$ (DW), respectively.

Polynuclear aromatic hydrocarbons (PAH) were also determined in the sediments of the two rivers with values ranging from 56 to 1025 $\mu g\ g^{-1}$ (DW) for the Coatzacoalcos river and from 17 to 1466 $\mu g\ g^{-1}$ (DW) for the Tonala river. It is important to point out that along the margins of the Coatzacoalcos and Tonala rivers are locate some of the largest petrochemical complexes outside of the US Gulf coast. In a very recent study, Botello et al. (1991) reported the presence of PAH's in coastal sediments from the continental shelf of Tabasco State, southern of Campeche Sound. The results of these study point out that the most conspicuous PAH are those containing 3 to 4 benzene rings as the anthracene, fluoranthene, pyrene, benzo(a)anthracene and chrysene in a range of 34 to 1269 ng g^{-1} (DW). Also, the authors indicated that the origin of these PAH is through pyrolisis or the incomplete combustion of fossil fuels (Table 7, Figure 6).

Also, the concentrations of PAH in this study are in the same range as those publised by Wade et al. (1988) for sediments from the Gulf of Mexico specially the coast of Texas, Louisiana and Florida; which are under the pressure of intensive oil tanker traffic showing high levels of petroleum pollution (Atwood et al., 1987). Corredor (1988) pointed out the persistence of petroleum hydrocarbons once they have reached the sediments at sites exposed to oil spills or tanker and refinery operations along the coast of Puerto Rico.

In a recent study conducted by Gold (1994) reported the presence of PAH's in the continental shelf of Campeche; in a range of 0.006 ± 0.021 $\mu g\ g^{-1}$ being the 2,3,6 trymethylnaphtalene, 2-methylnaphtalene, pyrene and chrysene the most conspicuos compounds.

Ponce-Velez (1995) determined the presence of PAH's in sediments of the continental shelf of Veracruz and Tamaulipas in higher concentrations (2.41 $\mu g\ g^{-1}$) than those previously reported by Wade (1988), Botello (1991) and Gold (1994). The increase in concentrations of PAH's would be attributed to oil activities carried out in the zone since 1950, as well as the presence of natural seeps in the continental shelf of Tamaulipas.

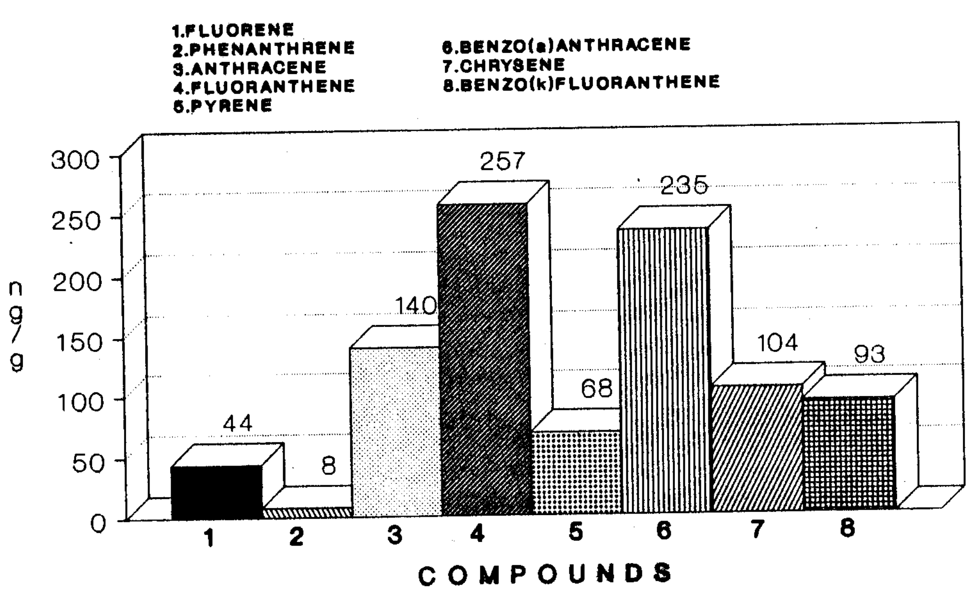
Within the Caribbean Sea information on the levels and distribution of hydrocarbons in coastal and marine sediments are more sparse. Consequently, although data is being collected, particularly in coastal areas, only a few studies have been published. Garay (1986) reported on the levels of total hydrocarbons and

PAH in sediments from Cartagena Bay with values ranging from 3 to 53 $\mu g\ g^{-1}$ (DW) for PAH and from 23 to 890 $\mu g\ g^{-1}$ for total hydrocarbons.

Table 7. Distribution of Polycyclic Aromatic Hydrocarbons in recent sediments from the continental shelf of Tabasco State, Mexico (ng g-1) dry wt.

Compounds	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Napthalene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
2,6 Dimethylanthracene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Acenaphthylene	N.D	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	39	N.D.
Acenaphthene	N.D	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Fluorene	N.D.	N.D	N.D.	N.D.	N.D.	84	68	N.D.	N.D.	87	61	66	64	69	158
Phenanthrene	N.D.	N.D	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	24	N.D.	N.D.	N.D.	89
Anthracene	149	101	100	45	158	253	262	172	112	201	128	101	50	190	79
Fluoranthene	87	151	251	305	633	98	54	70	319	310	62	61	145	41	1296
Pyrene	72	44	54	57	91	67	86	61	53	58	90	49	94	65	79
Benzo(a)anthracene	120	118	139	215	340	251	424	250	250	283	190	84	75	235	562
Chrysene	76	57	83	81	55	356	110	134	121	90	94	93	73	84	62
Benzo(b)fluoranthene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	67	N.D.	N.D.	N.D.	144
Benzo(k)fluoranthene	N.D.	N.D.	N.D.	129	162	77	92	129	137	145	121	N.D.	N.D.	141	264
Benzo(a)pyrene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	735	N.D.	N.D.	N.D.	N.D.
Benzo(ghi)perylene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	147
Indo(1,2 Cd)pyrene	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D	N.D.	130	N.D.	N.D.	N.D.	240

FIG. 6. POLYCYCLIC AROMATIC HYDROCARBONS IN RECENT SEDIMENTS FROM THE CONTINENTAL SHELF OF TABASCO STATE, MEXICO.



ORGANISMS

Studies on the incorporation of petroleum hydrocarbons into coastal and marine organisms of the Wider Caribbean region have been mainly gathered from benthic organisms of coastal ecosystems (Stegeman and Teal, 1973). In the US Gulf coast, the Mussel Watch Programme has provided the most recent information on the accumulation of petroleum hydrocarbons by the oyster Crassostrea virginica. The latest information for the northern Gulf of Mexico area has been provided by NOAA's Status and Trends the same conditions indicated previously for sediment sampling. A total of 18 individual PAH compounds were determined in 145 oyster samples during the first survey, the total PAH concentration in the oyster tissues ranged from 20 to 18620 µg g^{-1} (DW), with a mean value of 536 µg g^{-1} (DW). The results of the survey indicated that the concentration of PAH in both oysters and sediments was very similar. However, the distribution of PAH accumulated in oysters was different from that found in sediments. The oysters accumulated low molecular weight PAH while the sediments retained high molecular weight PAH.

Total concentration of hydrocarbons for Crassostrea virginica in the southern region of the Gulf of Mexico was also reported by Botello and Mandelli (1978), and Botello and Macko (1982). The concentration of PAH in oysters from the same area was also published by Bravo et al. (1978).

Botello and Macko (1982) reported total hydrocarbon concentrations in oysters from six coastal lagoons of the Mexico Gulf coast, the values ranged from 8 to 552 µg g^{-1} (DW) for a total number of 686 samples. In some of the sampled areas, the oysters exhibited relatively high values of hydrocarbons particularly in the Carmen-Machona and Mecoacan lagoons on the coast Tabasco, thus indicating the impact of human activities in these lagoons. The hydrocarbon levels determined in oysters were similar to those published by Farrington (1973) for Crassostrea virginica samples from Buzzard and Galveston bays, sites affected by oil spills and discharges.

Botello and Paez-Osuna (1986) also reported levels of PAH in tissues of 19 species of marine and estuarine organisms from the Coatzacoalcos river area and an adjacent coastal lagoon. Values ranged from 17 to 380 ng g^{-1} (DW). Botello et al. (1993) and Gonzalez et al. (1992) determined the presence of PAH oysters (Crassostrea virginica) and fishes (Eugerres plumieri and Centropomus undecimalis) from coastal lagoons in Tabasco State, southern the Gulf of Mexico. The study indicates that due to the filter feed habits in oysters they were capable to retain a great variety of PAH. This would be attributed to the fact that those low molecular weight PAH are more water soluble and are thus lost to the water column were they may be available for uptake by the oysters. The range of concentrations for PAH in oysters was from 27 to 2340 ng g^{-1} (DW).

For fishes the pattern of distribution was fairly different compared with the oysters and showing a very limited number of PAH. However the concentration is higher than those obtained for oysters.

Additional information about the presence of PAH in marine organisms have also been published for coastal water bodies of the Caribbean Sea. For Cartagena Bay, Garay (1986) reported PAH values reported PAH in bivalves, tunicates and echinoderms from the Kingston Harbour area, with values ranging from 1200 to 11500 ng g^{-1} (DW). The data available on the presence of hydrocarbons in coastal marine organisms of the wider Caribbean region has good coverage in the Gulf of Mexico.

Singh et al. (1992) published information on levels of hydrocarbons in fishes, crabs and mussels from the coasts of Trinidad. The results obtained shown significantly different levels of hydrocarbons in skin and muscle tissues of fishes. Thus, the levels for muscle were from 0.23 to 1.79 µg g^{-1} and for skin from 0.28 to 22.19 µg g^{-1}.

The higher levels in the skin would be explained by 1. the skin is the primary site of contact with environmental pollutants, 2. the higher lipid content of the skin and 3. the skin plays an important role in hydrocarbon metabolism.

Indeed, the data for hydrocarbons levels obtained in the gills (0.94 to 1.06 µg g^{-1}) and muscle (0.42 to 0.53 µg g^{-1}), tissues of the crabs Callinectes sapidus shown significant differences being higher in gills.

For the mussel Mytella guayanensis the authors reported levels of hydrocarbons from [illegible] µg g^{-1}. This could be explained by the higher levels of hydrocarbons in the sediments where this organisms were collected.

However, within the Caribbean Sea, the information still very sparse in ascertaining the impact of oil pollution on coastal and marine organisms of that sub-region.

EFFECTS

The main effects of petroleum hydrocarbons in the Wider Caribbean region has been assessed mainly through biossays by using the water soluble fractions (WSF) either from crude oils or drilling fluids (Cabrera 1971, Lee et al. 1972, Byrne and Calder 1977, Donahue et al. 1977, Tatem et al. 1978). Most of research was aimed at quantifying toxicity thresolds with emphasis on larvae and juvenils of fishes and oysters. At the same time there was little scientific consistency, in that researchers developed their own exposure methodology and analytical preferences.

Being the Caribbean Sea one of the major for oil tankers, the spills by accidents had been impacted two important tropical ecosystems: corals and mangroves (Loya and Rinkevich, 1980, Baker et al. 1981). A compilation of effects caused by spills in these two ecosystems are presented in tables 8 and 9.

In a recent publication Klekowski et al. (1994) pointed out the frecuency of mutation in a mangrove population from Puerto Rico which was strongly correlated with the concentration of polycyclic aromatic hydrocarbons in the underlying sediments and with both acute and chronic petroleum pollution. These results

The main effects of petroleum pollution in the Wider Caribbean would be summarized in:

Direct effects

- Bioaccumulation of PAH in tissues of economic important species as oysters, shrimps crabs, lobsters and fishes.

- Tainting of commercial species affecting its comsumption and provoking loss in the economy of fishermen.

- Ecophysiological effects related mainly with enzyme systems, alteration in the respiratory system, neurological damage and alteration in ethological responses.

- Decline in reproductive success.

- Distress and death of marine life

- Alteration of the diversity and variability of biological systems

Indirect effects

- Destruction of mangrove areas by spills

- Dredging and filling of coastal areas for construction of channels, ducts, submarine lines, and water ways used by the oil industry.

- Destruction and disruption of corals and seagrass beds by petroleum during spills

- Dissapearence of benthic communities living close to oil terminals produced by chronic low-level discharges

- Loss of important recreational beaches due to the presence of tar balls

- Expensive cost to tourism boards for clean-up operations on beaches.

TABLE 8. SUMMARY OF EFFECTS OF OIL SPILLS ON CORAL REEFS IN THE WIDER CARIBBEAN

SPILL	AMOUNT SPILLED	REPORTED EFFECTS	REFERENCE
WW II, several tankers, Gulf of Mexico and Caribbean Sea			Dennis (1959), U.S. Coast Guard (1959, 1969)
WW II, Dry Tortugas		Young mangroves of 4-5 years were killed	Odum and Johannes (1975)
1967, Argea prima Puerto Rico	10,000 tons crude	Mortalities of adult and juvenile lobster, crabs, sea urchins, sea stars, sea cucumbers, gastropoda, octopus, and fish; Thalassia beds degenerated, rock y areas denuded of algae; extensive damage to mangrove swamp habitat	Díaz-Piferrer (1964)
1968 General colocotronis Installation, Eleuthera-Bahamas	4,500 tons crude		Spooner and Spooner (1968)
1968, Ocean Eagle San Juan, Puerto Rico		Many mortalities among intertidal organisms due to oil and emulsifier, including fish, mollusks, and algae recovery good	Cerame-Vives (1968)

SOURCE: After Loya and Rinkevich (1980).

TABLE 9. COMPARISON OF THE IMPACT OF SOME OIL SPILLS ON MANGROVE IN THE WIDER CARIBBEAN

SPILL	AMOUNT SPILLED	MANGROVE SPECIES AFFECTED	REPORTED IMPACT	REFERENCE
1962 Argea prima Guanica, Puero Rico	10,000 tons crude	unidentified	Virtual destruction of habitat (reportedly rediscovered in mid 1970; Teas, personal communication)	Díaz-Piferrer (1964)
1968 Witwater, Galeta Island, Panama	20,000 bbls diesel oil and Bunker C	Rhizophora mangle Avicennia sp.	Death of young mangroves, loss of sessile animals and algae on prop roots (loss visible 66 months after spill)	Rutzler and Sterrer (1970), Birkeland et al. (1976)
1975 Garbis, Florida Keys	1500-3000 bbls crude oil	R. mangle, A. germinans (nitida)	Death of young red mangrove seedlings and some dwarf black mangroves	Chan (1976, 1977), VAST/TRC (1975)
1973 Zoe colocotroni, Cabo Rojo, Puerto Rico	37000 bbls Venezuelan crude	R. mangle and A. germinans	Death of adult trees (red and black) over 1.0-2.7 hectare area within 3 years	Tosteson et al. (1977), Nadeau and Berguist (1977), Page et al.(1979), Gilfillan et al. (1981)
1976 Pipeline rupture, Corpus Christi, Texas	377 bbls crude	A. germinans	Mangroves burned to remove oiled uncleaned trees; recovered after minor defoliation	Holt et al. (1978)
1977 unidentified vessel, Guayanilla Bay, Puerto Rico	1000 bbls Venezuelan crude	R. mangle	Damage to mangrove root community; trees survived	Lopez (1978)
1971 Santa augusta, St. Croix, U.S. Virgin I.	12.5 million liters crude	R. mangle	5 hectares completely destroyed; little or no recolonization after 7 years	R.R. Lewis (1979a,b), R.R. Lewis and Haines (1980)
1978 Pack slip barge, Puerto Rico	440-460000 gallons Bunker C	R. mangle	significantly affected mangrove crabs, snail, and epiphyte population	Gundlach et al. (1979), Robinson (1979), Getter et al. (1981)
[illegible]	[illegible] and 80% Bunker C	[illegible] L. racemosa	[illegible] polychaetes; root abnormalities	[illegible] (1980, 1981), Snedaker et al. (1981)

SOURCE: Adapted from Lewis (1980c) and Baker et al. (1981).

CONCLUSIONS

In summary, petroleum oil spills and related stressors (such as dispersants) affects the Caribbean coastal ecosystems indirectly by affecting individual ecosystem components (such as plants, animals or microbes) and directly by interfering with such ecosystem level processes as photosynthesis, respiration and mineral cycling. All impacts of petroleum pollution, regardless of the ecosystem type, must be evaluated within the context of the environmental conditions under which the ecosystem is termed its energy signature and it is this energy signature that determines if the ecosystem will be susceptible or tolarant to petroleum pollution. The energy signature is composed of energy inputs (subsidies) and energy drains (stressors) and each ecosystem is a product of and is adapted to a specific energy signature. Oil and dispersants act as disruptive forces (stressors). The magnitude of the strees they cause is dependent upon their duration (acute or chronic). In addition, oil and dispersants interact and this represents an additional energy drain to the ecosystem, which must also cope with other natural stressors such as soil salinities (in the case of mangroves) or desiccation and high temperatures (coral reffs, beaches and grass beds).

Countering stressors are the auxiliary energy sources or subsidies available to the ecosystem. In case of oil spills we have said that tidal, wave, and current energies mitigate the negative effects of oil and dispersants, because they tend to aerate and flush the system and remove toxic substances. Other auxiliary energies such as solar energy, nutrients and freshwater inputs improve ecosystem tolerance to stressors by increasing productivity or providing energy reserves needed to overcome stressors. If the balance of inputs and drains to an ecosystem is favorable, survival of the oil spill is the likely result, even if there are sublethal effects.

However, if disruptive drains exceed the incoming subsidies, then the ecosystem can survive only as long as its energy storages last and mortality, followed by succesional replacement, is the likely result.

Understanding the environmental forces acting on any particular ecosystem is then a necessary antecedent to evaluating ecosystem response to oil spills, or to any other environmental stressor.

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