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Results of the CARIPOL Petroleum Pollution Monitoring Project in the Wider Caribbean

D. K. ATWOOD*, F. J. BURTON†, J. E. CORREDOR‡, G. R. HARVEY*, A. J. MATA-JIMENEZ‖, A. VASQUEZ-BOTELLO§ and B. A. WADE¶
**NOAA/AOML, Ocean Chemistry Division, 4301 Rickenbacker Causeway, Miami, FL 33149, USA*
†Mosquito Research and Control Unit and Natural Resources Study, P.O. Box 486, Grand Cayman, Cayman Islands
‡Department of Marine Sciences, University of Puerto Rico, Mayaguez, P.R. 00708, Puerto Rico
‖Decano, Facultad de Ciencias, Universidad de Costa Rica, 2060 San Jose (San Pedro), Costa Rica
§Inst. de Ciencias del Mar y Limnologia, Universidad Nacional Autonoma de Mexico, Apartado Postal 70-305, Mexico, 04510, D.F., Mexico
¶Petroleum Corporation of Jamaica, Box 579, Kingston, 10, Jamaica
All authors are members of the IOCARIBE/CARIPOL Steering Committee

Since 1979, about 9000 data points for tar on beaches, floating tar, and dissolved/dispersed petroleum hydrocarbons have been collected by fourteen governments in the Caribbean/Gulf of Mexico region. Analysis of these data has allowed an assessment as to the status of petroleum pollution in the region. Tar levels on windward exposed beaches are very high and impact tourist use of them. Data also indicate that dissolved/dispersed hydrocarbons in the Gulf of Mexico are much higher than that measured by the 1975–1980 MAPMOPP study in 'clean' areas of the World's oceans. Indications are that about half of the tar in the region enters by way of the prevailing current and wind regime from the North Atlantic gyre system. The remaining half comes mostly from tanker cleaning and ballast discharge in the region.

Since 1979 the Intergovernmental Oceanographic Commission's (IOC) Regional Subcommission for the Caribbean and Adjacent Regions (IOCARIBE) has conducted a project of monitoring for petroleum pollution in the area known as the Wider Caribbean, which includes the Gulf of Mexico, the Straits of Florida and the Eastern approaches to the Caribbean Sea. The project was implemented within the IOCARIBE marine pollution research and monitoring programme which is called CARIPOL and is part of a cooperative framework of programmes conducted by IOC/IOCARIBE and the United Nations Environment Programme's (UNEP) Caribbean Action Plan (CAP). The CARIPOL Programme is one of the regional marine pollution research and monitoring efforts conducted within the IOC Global Investigation of Pollution in the Marine Environment (GIPME). Projects conducted within IOC/IOCARIBE UNEP/CAP framework are also designed with input and cooperation from the United Nation's Food and Agricultural Organization's (FAO) Western Central Atlantic Fisheries Commission (WECAFC). IOCARIBE/CARIPOL programmes stem from a description of regional needs defined by CAP and a workshop of regional experts which was convened jointly by IOC, UNEP and FAO in 1976 (IOC Workshop Report No. 11, 1976). The pollution problem identified by this workshop as having the highest regional priority is petroleum pollution. Accordingly, in 1979 CARIPOL embarked on a petroleum pollution monitoring effort under the guidance of the GIPME Group of Experts on Methods Standards and Intercalibration (GEMSI). The results of this monitoring project are described in this paper.

Petroleum Pollution Parameters Monitored

Methodology used successfully in the IOC/World Meteorological Organization (WMO) Marine Pollution Monitoring Pilot Project (Petroleum) (MAPMOPP) (Levy, *et al.*, 1981) was adapted for use in the CARIPOL project. This included monitoring of the following three parameters.

Tar on beaches: Tar is collected from the water line to backbeach along 1 m transects, weighed and reported as g m^{-1} tar on beach front.

Floating tar: A 1 m wide neuston net is towed from a vessel and outside the vessel wake for a known time and vessel speed. The tar collected is weighed and reported as mg m^{-2} tar on sea surface.

Dissolved/dispersed petroleum hydrocarbons (DDPH): A 1 gallon sample is collected from a carefully cleaned, small mouth bottle suspended on a 1 m tether from a surface float. The sample is extracted twice with 50 ml aliquots of nanograde hexane and the concentration of petroleum type hydrocarbons in the hexane phase is estimated using an ultraviolet spectrofluorescence technique with chrysene as the primary standard.

The only difference between these parameters and those used in MAPMOPP is the use of hexane as the primary extractant for DDPH samples. MAPMOPP employed carbon tetrachloride as the initial extractant by adding it to the sample immediately after collection and then storing the entire sample until analysis. Although the carbon tetrachloride serves as a biocide and enables long term storage of whole samples, it interferes with the spectrofluorescence analysis, thus, MAPMOPP extracts had to be taken to dryness and redissolved in hexane. The CARIPOL steering committee opted to use hexane directly and to complete extractions as soon as possible after collection so as to simplify the procedure and minimize any loss of volatile material in an evaporation step. A comparison of the two extraction protocols was conducted by the US NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, Florida, on the behalf of GEMSI. Results of this comparison showed that in cases where the extracted sample was evaporated to dryness and redissolved there was a decline in DDPH measured. This was true for extractions with either carbon tetrachloride or hexane. At the level of less than 1 $\mu g\ l^{-1}$ this decline was greater than 50%. Thus, in the CARIPOL programme hexane is used as the extractant and the CARIPOL procedure does not involve evaporation to dryness.

The project was initiated in 1979 with a pilot study conducted by AOML on the beaches of the Florida peninsula and in the waters of the Gulf of Mexico and the Straits of Florida. The results of this pilot study were reported to IOCARIBE in 1980 (Romero, *et al.*, 1981) and based on its success and the experience gained, training workshops in English and Spanish were conducted in Costa Rica in 1980, during which personnel from governments throughout the region received training in the CARIPOL methods described above. Funding for the conduct of these workshops and associated travel was obtained from contributions by regional states to the IOC Trust Fund. On the basis of results from these workshops a methods manual for analysis and data submission was written in both English and Spanish and distributed to participants (CARIPOL, 1980). A data archiving system was established through cooperation of IOCARIBE with the US NOAA National Oceanographic Data Center (USNODC) in Washington, D.C. and the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami. Training of new participants was accomplished by establishing CARIPOL training centres at the University of Costa Rica in San Jose, the University of Puerto Rico in Mayaguez, and at AOML. Training was accomplished by sending prospective participants to these centres and by visits of scientists from these centres to interested regional governments. Funding for travel involved in this training was provided by UNEP through CAP. Additional training was provided through scholarships provided for attendance of CARIPOL participants at courses in marine pollution sampling and analysis methodology at the Bermuda Biological Station (BBS) in St. Georges, Bermuda. Funding for these scholarships was provided by the IOC and the BBS. Intercalibration between participants was accomplished by participation of regional personnel in a UNEP funded IOC international intercalibration exercise on the methods used, which was held at BBS in 1984. This exercise demonstrated that training for CARIPOL participants had been successful and that these participants were obtaining high quality data which was intercomparable (Knap, *et al.*, 1986).

Since 1979 the CARIPOL Petroleum Pollution Monitoring Project has generated over 9000 observations which are archived in the CARIPOL data base at NOAA/AOML in Miami. Table 1 is a summary of these data in terms of governments, training received and data submitted for each of the three parameters monitored. It is clear from the table that some did no more than accept training, however, the overall results are impressive. Figure 1 is a map of the IOCARIBE/CARIPOL region showing the locations of the countries identified in Table 1. Results from the programmes conducted by each of these were presented at a symposium conducted with UNEP/CAP funding at the Uni-

Fig. 1 Map of the IOCARIBE/CARIPOL area with countries which have participated in the CARIPOL petroleum pollution monitoring programme identified.

TABLE 1
Summary of CARIPOL Training and Data Submissions
(December 1986)

Government	Scientists Trained	Data Submissions Beach Tar	Floating Tar	DDPH	Total
Barbados	1	70	1	–	71
Belize	1	–	–	–	–
Bonaire	1	83	–	–	83
Cayman Islands	1	169	27	27	223
Colombia	10	127	–	119	246
Costa Rica	4	74	–	129	203
Cuba	1	–	–	176	176
Curacao	1	96	–	–	96
Dominican Republic	2	–	–	–	–
Grenada	1	9	–	–	9
Guatemala	2	–	–	–	–
Guayana	2	–	–	–	–
Jamaica	2	148	39	108	295
Mexico	4	218	77	610	905
Panama	3	–	–	–	–
Puerto Rico	1	75	121	97	293
St. Lucia	2	–	–	–	–
Trinidad–Tobago	2	5316	16	84	5416
U.S.A.	6	230	400	114	744
Venezuela	2	239	–	–	239
Totals	48	6854	681	1464	8999

versity of Puerto Rico (Mayaguez) in December 1985 (CARIPOL, 1987). The following is a synthesis of the results of the programme, with a regional perspective for each of the parameters monitored.

Results for Tar on Beaches

Although the CARIPOL beach tar data base presently has 6854 records in it, 5316 of these are from Trinidad and Tobago where they were collected in a programme led by the Institute of Marine Affairs in Chagaramus, Trinidad. The results of this Trinidad and Tobago project were published in 1983 (Georges & Ootsdam, 1983). Even though the sample control is heavily biased toward this Trinidad and Tobago data set, there is also substantial control through the rest of the Region. This is illustrated in Fig. 2 where each sampling location is identified by a circle, along with the average concentration at each location. Although the scale in Fig. 2 prevents good resolution of the data in many locations (especially of the 5316 data points in Trinidad and Tobago), the figure clearly indicates that *1.* there is substantial data control through much of the region (there is a noteable lack in the northern Gulf of Mexico), and *2.* the problem of beach contamination by tar is serious in many locations, with numerous beaches having average concentrations in excess of 100 g m^{-1} of shore front. Experience throughout the region indicates that when beach tar values reach 10 g m^{-1} persons using the beach commonly get tar on their feet. At values approaching 100 g m^{-1} the beaches become virtually unuseable for tourist purposes. Given the fact that many of the region's economies depend extensively on tourism, the high incidence of contamination in excess of 100 g m^{-1} is a serious problem. Of special concern are the high concentrations of tar on beaches in the Southern Bay of Campeche and the east coast of Yucatan in Mexico, the southeast coast of Florida, the Cayman Islands, the area near Kingston Harbour in Jamaica, Curacao, and beaches on the windward side of islands such as Barbados, Grenada, Trinidad, and Tobago. In fact windward coasts are seriously contaminated throughout the region as evidenced in Figs 3 (Trinidad and Tobago), 4 (Curacao and Bonaire), 5 (Grand Cayman) and 6 (the Florida Peninsula) (Romero, *et al.*, 1981). In each of these cases beaches exposed to the prevailing southeast tradewinds are significantly more contaminated than beaches on the leeward side. This is interpreted as evidence that the source of tar is upwind throughout the region and clearly the result of factors beyond the control of the individual governments involved. It is noteworthy that contamination is particularly serious in Grand Cayman where there is no domestic petroleum activity. However, that island is located in an area with very high amounts of petroleum tanker traffic which moves through the Yucatan Strait and Windward Passage (Reinberg, 1984). It is important to note that a comparison of the results of the Romero, *et al.* (1981) Florida study to previous studies in the same area (Dennis, 1959, 1974) indicates that the level of contamination on southeast Florida beaches has been about the same since 1958.

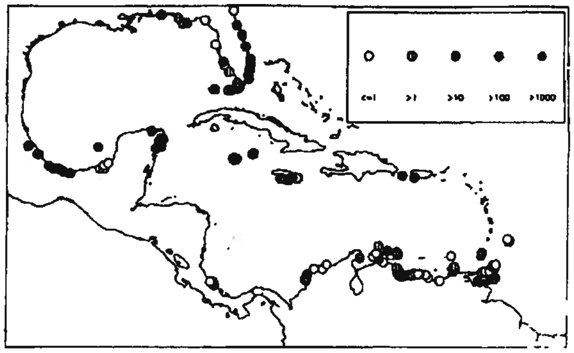

Fig. 2 Mean concentrations of beach tar (g m^{-1}) of beach front for each site sampled in the CARIPOL petroleum pollution monitoring programme.

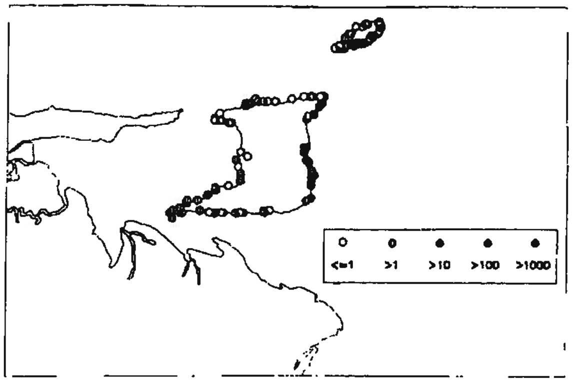

Fig. 3 Mean concentrations of beach tar (g m^{-1}) at sampling sites in Trinidad and Tobago.

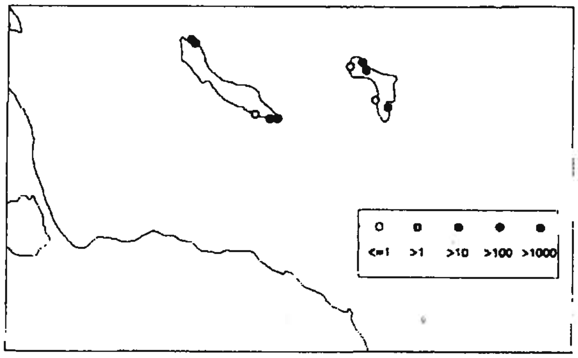

Fig. 4 Mean concentrations of beach tar (g m^{-1}) at sampling sites in Curacao (left) and Bonaire (right).

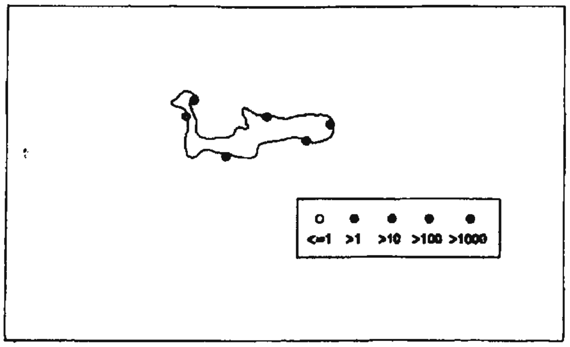

Fig. 5 Mean concentrations of beach tar (g m^{-1} at sampling sites on Grand Cayman.

Results for Floating Tar

The CARIPOL data base on floating tar is the smallest of the three parameters measured, with 681 records. Most of these data were taken in the Gulf of Mexico in programmes conducted by Mexico (Universidad Autonoma de Mexico) and the USA (University of South Florida and NOAA/AOML). Figure 7 shows the data as averages for one degree squares throughout the region. A circle in the centre of each square with one or more data records depicts the average concentration for that square. Some very pertinent points can be made from this figure when considered in the light of regional current patterns. Figure 8 is a composite plot of satellite tracked buoy trajectories in the Caribbean Sea and Gulf of Mexico in 1975 and 1976 (as taken from Molinari *et al.*, 1981). Superimposed on the buoy tracks is a schematic depiction of the mean position of the major flow through the system which enters through the southeastern passes of the Lesser Antilles arc, moves through the Caribbean as the Caribbean Current, traverses the Eastern Gulf of Mexico as the Gulf Loop Current, or Loop Intrusion, and exits through the Straits of Florida (between Florida and Cuba) as the beginnings of the Gulf Stream. At times the Loop Current 'pinches off' just north of the Straits of Yucatan and becomes an eddy which moves westward through the Gulf while the major flow exits directly through the Straits of Florida until the Loop Current is 'rebuilt'. An examination of the mean floating tar concentrations in Fig. 7 reveals that concentrations are higher in the Loop Intrusion and southern Straits of Florida than in adjacent areas. There is also an indication that similar high concentrations exist in the eastern part of the Caribbean coincident with the mean position of major east–west flow in that area. Similar observations were made by Atwood *et al.* (1987) in their analysis of floating tar data collected by the USA in the Gulf of Mexico and Straits of Florida from which they concluded that floating tar concentrations are significantly higher within the Loop Intrusion and the southern Straits of Florida. It is interesting that floating tar concentrations just off the east coast of Yucatan and in the southern Bay of Campeche are quite low, whereas beaches in both of those areas are seriously contaminated.

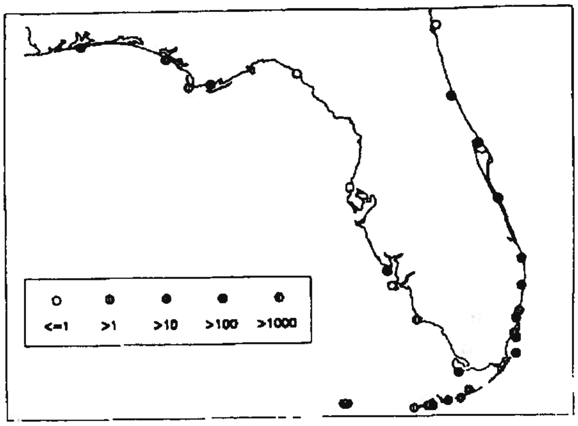

Fig. 6 Mean concentrations of beach tar (g m^{-1}) at sampling sites along the coasts of the US Florida peninsula.

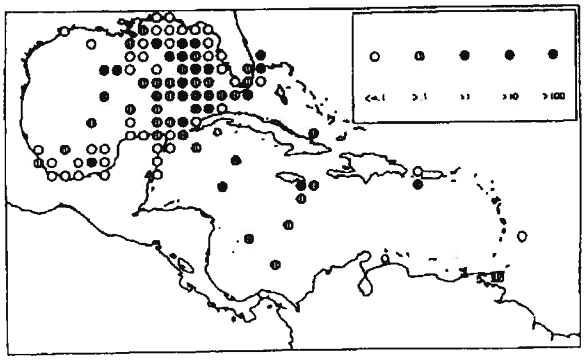

Fig. 7 Mean concentration of floating tar (mg m^{-2}) for each one degree square for which CARIPOL data exists.

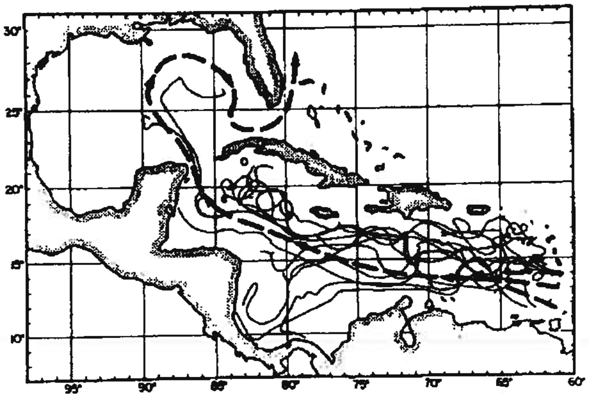

Fig. 8 Composite plot of satellite tracked buoy trajectories collected in the Caribbean Sea and Gulf of Mexico October 1975–June 1976 (after Molinari *et al.*, 1981). The heavy dashed line is a schematic representation of the major flow through the system when the Gulf Loop Current is intact in the Gulf of Mexico.

Figure 9 is another analysis of CARIPOL floating tar data with histograms of sample concentrations shown as percent of samples collected in the eastern Caribbean, southwestern Gulf of Mexico, eastern Gulf of Mexico, and Straits of Florida. Each of these areas has a statistically reasonable data set except the southwestern Caribbean which has only three records. Most of the areas are dominated by observations of floating tar in the range of 0–0.1 mg m^2 of sea surface. However, the Straits of Florida are clearly different, with the concentrations shifted upward, the 0–0.1 and 1.0–10.0 ranges having an equivalent number of observations, i.e., each with 35% of the total for the area. The eastern Gulf of Mexico also shows an upward shift in concentrations as evidenced by the fact that it contains the next lowest percentage of samples in the 0–0.1 mg m^2 range (58% as compared to >70% in the other areas) and that there is a significant increase in percent of samples in the 0.1–1.0 (24%) and 1.0–10.0 (13%) ranges. These higher concentrations in the eastern Gulf are a result of the higher levels of floating tar in the Loop Current as shown in Fig. 7. The Bay of Campeche has the lowest floating tar values of any of the areas, which emphasizes the apparent contradiction (mentioned above) between these low values and the high beach tar values observed adjacent to it.

Comparison of floating tar concentrations in the CARIPOL data base to those observed in the MAP-

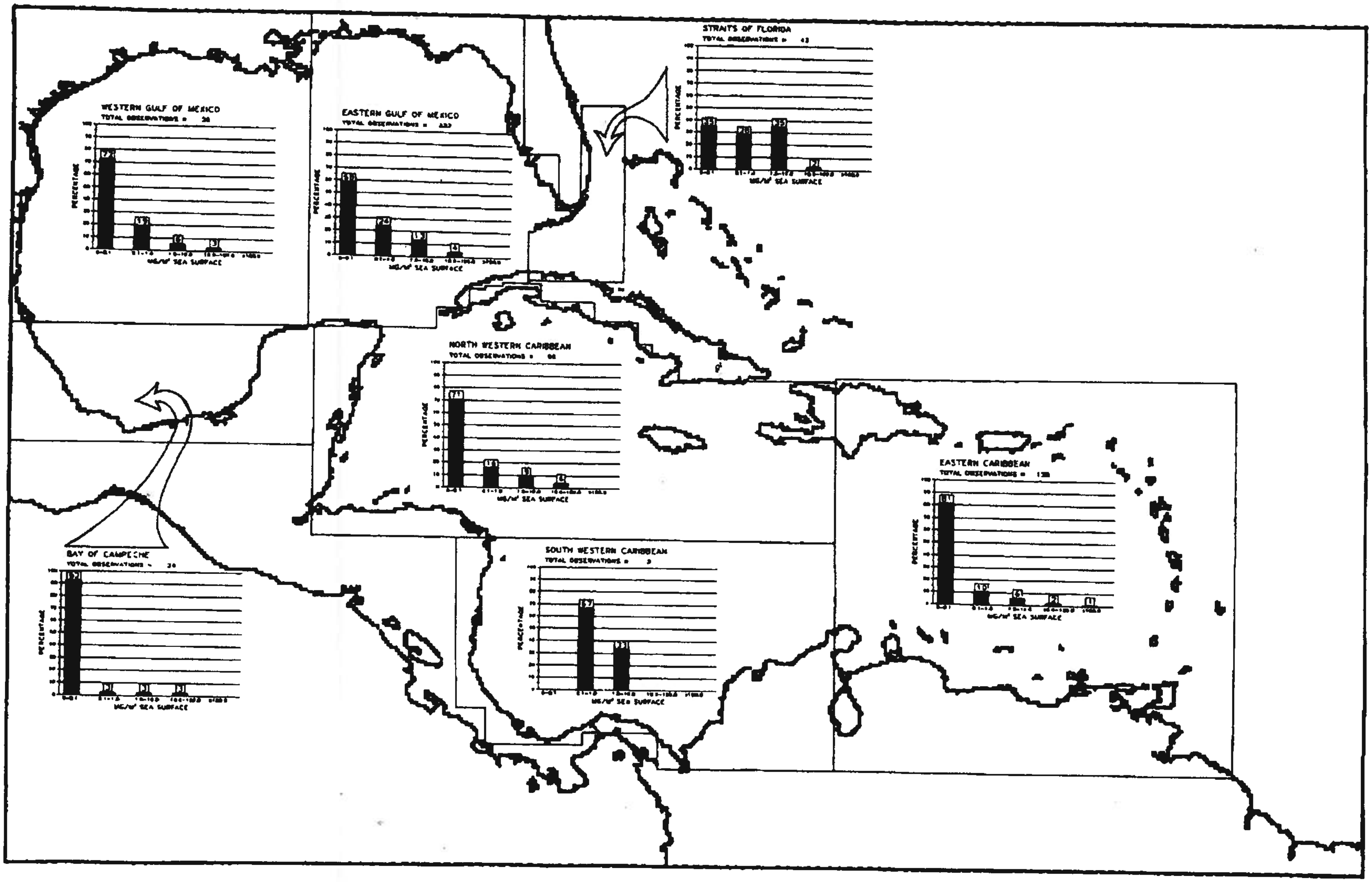

Fig. 9 Histograms of floating tar concentrations (mg m^{-2}) for each of seven areas in the CARIPOL area.

MOPP study (Levy *et al.*, 1981) show that where overlap occurs with the relatively sparse MAPMOPP data in the region, mean concentrations are very similar.

Results for Dissolved/Dispersed Petroleum Hydrocarbons

The CARIPOL data base contains 1464 records for dissolved/dispersed petroleum hydrocarbons (DDPH). The data are plotted in Fig. 10 as mean values for all one degree squares in which records exist. Results of the 1984 BBS intercalibration (Knap *et al.*, 1986) indicate that blank values for this parameter are about 0.1 μg l^{-1}, and only values of greater than this can be considered significant. Based on experience within the IOCARIBE region, including experience in the Bay of Campeche during the 1979 IXTOC-1 oil well blowout (Atwood & Ferguson, 1982), the background level for DDPH in the Gulf of Mexico seems to be 1–10 μg l^{-1}. This is borne out by Fig. 10 where the majority of the means shown are $>$ 1.0 μg l^{-1} with many values near Yucatan and in the Gulf of Mexico $>$ 10 μg l^{-1}. This Gulf of Mexico background level is more than an order of magnitude higher than the 0.1–0.2 μg l^{-1} observed during MAPMOPP (Levy *et al.*, 1981) for areas which were not obviously contaminated and for which a reasonable statistical sampling existed, e.g., the western Pacific and parts of the Mediterranean. We have no reason to doubt the validity of the MAPMOPP data sets, except as regards the difference between GEMSI sponsored comparison of the MAPMOPP carbon tetrachloride method (which requires evaporation to dryness) and the CARIPOL hexane method (see above). However, even if we assume that the MAPMOPP data is low by a factor of two, we still must conclude that the Gulf of Mexico is significantly contaminated with DDPH relative to 'clean' areas sampled in the MAPMOPP study. This is particularly true in the numerous locations where mean values exceed 10 μg l^{-1}. DDPH contamination is not obvious for the Caribbean Sea itself from the CARIPOL data set, except for the east coast of Yucatan and the area near Kingston Harbour in Jamaica, however, the extent of CARIPOL sample coverage for the Caribbean is sparse.

Figure 11 shows histograms of sample frequency, expressed as percent of samples for the area in question, versus DDPH concentration in the same areas, as was done for floating tar (above). Histograms for the areas in the Gulf of Mexico and Straits of Florida are dominated by concentrations in the range of 1.0–10.0 μg l^{-1} with significant numbers $>$ 10 μg l^{-1}, again illustrating the contamination of that area relative to the non-polluted means of 0.1–0.2 μg l^{-1} in the MAPMOPP data. Dominant frequencies occur at generally lower concentrations in the Caribbean, i.e., 0.1–1.0 μg l^{-1} with very few samples with concentrations $>$ 10 μg l^{-1}.

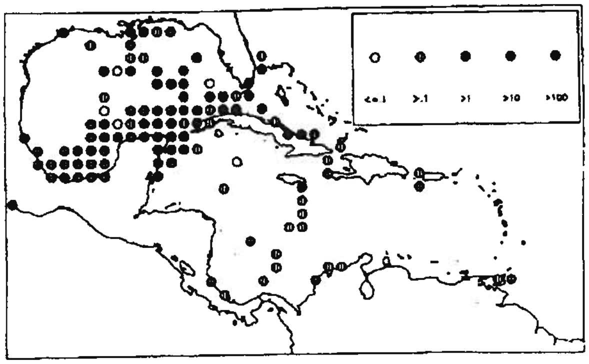

Fig. 10 Mean concentration (μg l^{-1}) of dissolved/dispersed petroleum hydrocarbons (DDPH) for each one degree square for which CARIPOL data exists.

Atwood *et al.* (1987) in their analysis of US floating tar and DDPH data for the Gulf of Mexico and Straits of Florida showed significantly higher DDPH values for the Southern Straits of Florida just as they had for floating tar (see above). They also showed that the means of DDPH and floating tar covaried for the regions they examined.

It has been well documented that ocean waters contain incipient populations of bacteria capable of metabolizing petroleum, which, when presented with quantities of petroleum hydrocarbons, rapidly grow and consume the oil (Atwood & Ferguson, 1982). Thus, the high level of DDPH contamination in the Gulf of Mexico is an indication that these bacteria are not able to remove it faster than it is replenished, which in turn indicates that there is a constant, fresh input of soluble DDPH to this area.

Probable Sources of Observed Petroleum Contamination

In an effort to identify probable sources of the petroleum contamination documented above for the Wider Caribbean it is beneficial to review major observations made in the regional monitoring of beach tar, floating tar, and DDPH. They are as follows.

Windward exposed beaches throughout the region from Barbados to Florida are heavily contaminated with tar relative to leeward exposures.

Surface waters of the major east to west flow in the region, i.e., the Caribbean Current, the Gulf Loop Intrusion, and the Straits of Florida contain significantly more floating tar than adjacent areas.

Waters of the Gulf of Mexico and those south of the Yucatan Strait are chronically contaminated with DDPH at a level an order of magnitude higher than that measured in uncontaminated areas during MAPMOPP. This chronic, high level of DDPH is an indication that there is a constant, fresh input of petroleum to these waters.

Highest levels of petroleum contamination in the region exist within and adjacent to waters with extensive petroleum tanker traffic, e.g., the Cayman Islands and the Straits of Florida.

In addition to these regional observations we can add some very pertinent findings from individual country programmes as reported at the CARIPOL Petroleum Pollution Monitoring Symposium held in La Parguera, Puerto Rico in December 1985. These are as follows.

Morell & Corredor (1987) reported a time series of floating tar observations off the southwest coast of

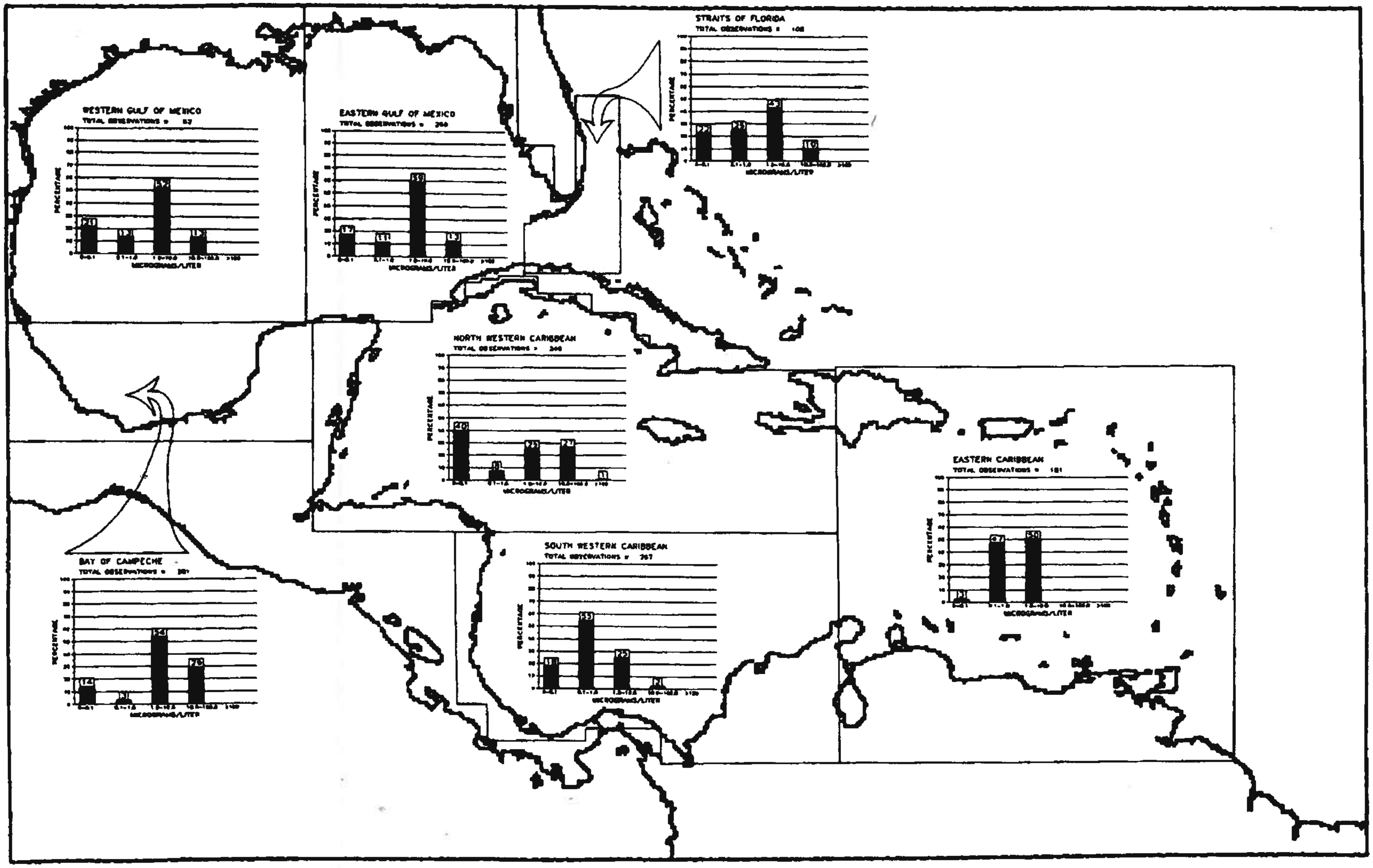

Fig. 11 Histograms of DDPH concentrations (μg l⁻¹) for each of seven areas in the CARIPOL area.

Puerto Rico in which the level of contamination dropped significantly as tanker traffic from a nearby petroleum refining complex declined. The authors conclude that at least 50% of the variability in their data can be explained by variations in tanker-traffic.

Burton (1987) reported the high levels of contamination on and near Grand Cayman, Cayman Brac, and Little Cayman, islands which are all adjacent to major tanker routes (Reinberg, 1984). UV fluorescence excitation/emission and glass capillary GC examination of tar found on beaches of these islands indicated that 80% of the samples examined had a crude oil source with spectra similar to Arabian and/or Alaskan crudes in the API-EPA Standard Oils. In cooperation with local airline pilots, Burton also documented the existence of slicks near the Cayman Islands. Twelve such slicks were documented. All were narrow (about 0.5 km wide) and long (up to 100 km). In three cases these slicks were observed as being released from ships two of which were tankers either cleaning tanks (February 1982), or discharging ballast (October 1985). All twelve slicks were sighted in the early hours of daylight, indicating that releases were occurring at night. Additionally a decline of beach contamination on Cayman Brac and Little Cayman was noted when oil transhipment operations near these islands virtually ceased in 1982.

Wade *et al.* (1987) used UV fluorescence excitation/emission spectra to demonstrate that most contaminating oil found on the south coast of Jamaica was similar to Venezuelan crude oil, which is the crude most commonly imported into Jamaica. Interestingly oil on Jamaican beaches with a northeast exposure did not exhibit these characteristics. The rate of tar arrival on south coast beaches was estimated at 1.4 g m^{-1} d^{-1}, but at times of 'documented near shore tanker washing' this could reach 400 g m^{-1} d^{-1}. The authors conclude that the principal source of tar contamination is illegal ballast washing and discharge from tankers.

Van Vleet *et al.* (1983a,b, 1984) demonstrated that pelagic tar levels in the Eastern Gulf of Mexico and Straits of Florida were substantially higher than in most other areas of the world and that as much as 50% of this tar entered those areas from the Caribbean through the Yucatan Strait. Gas chromatographic analyses of this pelagic tar showed that 50% of the floating tar showed a bimodal n-alkane distribution diagnostic of tanker ballast washings. This lead to the conclusion that 50% of the pelagic tar in these areas was from tanker ballast discharges.

Given the above observations we conclude the following as regards probable sources of petroleum contamination documented in the Wider Caribbean. As much as 50% of the floating tar and beach tar throughout the region comes from the adjacent North Atlantic gyre system and is carried to and through the region by the prevailing winds and currents. The fact that the MAPMOPP data (Levy *et al.*, 1981) shows high floating tar concentrations in the adjacent North Atlantic supports this conclusion. However, there is obviously significant fresh input of petroleum directly in the region as evidenced by the chronically high DDPH levels. Correlation of high floating tar and beach tar levels with petroleum tanker operations and the unique GC profiles of 50% of the floating tar in the Eastern Gulf of Mexico and Straits of Florida, shows that most of this fresh input is from petroleum tanker ballast washings. The remainder is probably from petroleum drilling and production operations, e.g., the PEMEX operations in the Bay of Campeche, as well as from natural seeps.

Effects of Petroleum Contamination in the Wider Caribbean

There are clearly adverse effects from the petroleum contamination existent in the Wider Caribbean. One obvious effect is the serious soiling of beaches in an area where tourist use of these beaches is important to state economies. This is a problem throughout the region. In southeast Florida beaches are continually cleaned to allow tourist usage with a secondary result of increased beach erosion. It is clear that any tourist development on windward exposed beaches in the region will have a significant tar problem with which to contend.

There is also clear evidence that floating tar has adverse effects other than that it is blown ashore on beaches. Van Vleet & Pauley (1987) have shown that analysis of internal organs and faeces from dead and live, threatened and endangered marine turtles captured around Florida, indicates that these turtles feed on floating oil and that this oil may remain in the turtles' digestive tracts for several days. Tar scraped from the mouths of many of these turtles had the same bimodal distribution of n-alkanes as that of tanker ballast washings. Interestingly the highest incidence of stranding of dead sea turtles in Florida is along the southeast Florida coast, i.e., adjacent to the heavily contaminated Florida Straits and coincident with the highest concentrations of beach tar in the entire Florida peninsula (Romero *et al.*, 1981).

The effects of DDPH are not as readily documented. The IXTOC-1 blowout experience showed that the gross contamination from that event was largely assimilated by the system through such processes as bacterial degradation and photo-oxidation (Atwood & Ferguson, 1982). However, then, as now, it was observed that the Gulf of Mexico background of DDPH was in the range of 1–10 μg l^{-1}, i.e., at least an order of magnitude greater than that observed in uncontaminated areas during MAPMOPP (Levy *et al.*, 1981). This is equivalent to a chronic exposure of about 0.04–0.05 μM polycyclic aromatic hydrocarbon (PAH or PNAH) based on chrysene. Numerous studies have been made on mixed function oxygenase (MFO) enzyme system response to PAH exposures (e.g., Capuzzo *et al.*, 1984), but these studies were usually conducted at exposures of one to three orders of magnitude higher than that observed as chronic here. One recent study by Davies *et al.* (1984) looked at the MFO response (in terms of an aryl hydrocarbon hydroxylase, AHH, which functions by oxidizing ingested hydrocarbons to a more soluble and excretable form) in fish caught at various distances from

North Sea oil drilling operations, where oil base muds were used and drill cuttings discarded over the side at the drilling sites. Sediments within 1.0 km of these sites had total PAH concentrations of about 10exp4 µg l^{-1} which we estimate would cause water column exposures no greater than that observed in the Gulf of Mexico. Their results show a statistically significant enhancement of AHH activity in two fish species (cod and haddock) caught in sediment contaminated areas as opposed to clean areas. The authors interpret this result as evidence that the contaminating oil is biochemically available to these fish resulting in a response of the fish MFO systems. They point out that such MFO response has been inversely correlated with fertilization success in flatfish along the coast of California (Spies *et al.*, 1984).

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