HYDROCARBONS IN THE SOUTHERN GULF OF MEXICO

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## INTRODUCTION

Pollution by petroleum is one of the most attractive topics to the media, as a result of the catchy images of tankers spilling oil and birds and other wildlife covered with tar. There is an ongoing debate in the press of the southern Gulf of Mexico, unfortunately without scientific foundation, about the role of the oil industry in the decrease of fisheries, which is catastrophic in the case of some species.

Unfortunately, the media's interest has not been followed by an increase in the investigation on the effects of hydrocarbons on the Mexican coast. According to a review of the database of the *Aquatic Sciences and Fisheries Abstracts* (ASFA) from 1977 to 2002, only 12 papers about oil pollution in the Gulf of Mexico were published by Mexican researchers in international journals (Fig. 21.1), resulting in an average of 0.5 articles published annually. Sixty-eight papers on the subject were published by U.S. authors during the same time period. This is a very small number of studies which does not provide the well founded information that is necessary to assess the consequences of contamination and thus allow pertinent management actions to ensure the sustainable development of natural resources.

This low number of publications also gives an indication of the small number of pollution research laboratories on the Atlantic Coast of Mexico, and also of the research funding policies that do not prioritize this kind of study. It also reflects the fact that there is a large amount of information in the so called "grey literature", such as thesis and technical reports, which are not available to the public and, therefore, cannot be analyzed.

Petroleum is a complex substance formed by thousands of different compounds, primarily hydrocarbons (formed only by hydrogen and carbon), metals, sulfur, etc. It also contains heterocyclic compounds, which have nitrogen and oxygen atoms (Gold-Bouchot 2000). Oil is formed by chemical processes that transform organic material from different sources, in diverse geological environments. This results in important differences in the composition of each oil field which, in turn, make a more complex environment due to the presence of tens of refining products such as gasoline, diesel, lubricant oils, fuel oils, asphalts, etc. (Wang and Fingas 2003). Differently from other pollutants, such as pesticides, pharmaceuticals and substances of industrial origin, oil is of natural origin. For this reason many organisms are adapted to its presence, and there are even bacteria and fungi that degrade it. Oil can enter the ocean through different sources, but mainly by operations related to its transportation by ships (National Academy of Science 1985).

Once the oil reaches the sea it undergoes a series of physical, chemical and biological processes known as weathering. The main processes are the following:

- *Dispersion* – Because petroleum is formed by hydrophobic components it spreads on the surface of the ocean forming large slicks. This increases the exposure of the affected area to the sun, waves, etc.
- *Photolysis* – The sunlight, especially the ultra violet radiation, transforms the oil, primarily forming oxidation products.

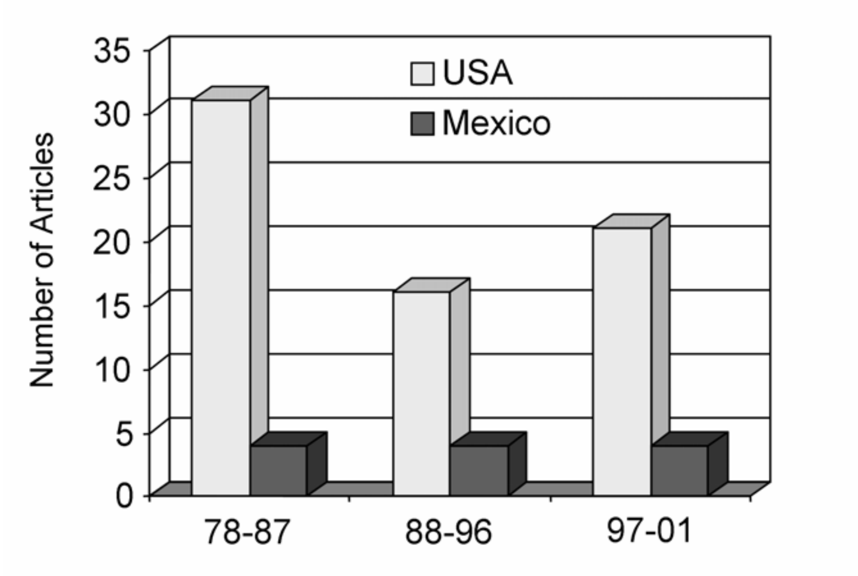


Fig. 21.1. Number of articles published on oil pollution in the Gulf of Mexico by U.S. and Mexican authors.

- *Emulsification* – The wind and the waves form an emulsion of water and oil (Fingas and Fieldhouse 2003) known as "chocolate mousse". When it reaches the shores it forms balls of tar, which are common on the whole coast of the Gulf of Mexico.
- *Evaporation* – This is a very quick process, which can detach up to half of the spilled oil in a few hours.
- *Adsorption* – Due to its hydrophobicity, petroleum tends to adsorb to both suspended sediment particles and planktonic organisms. This process enhances oil degradation (Owens and Lee 2003).
- *Sedimentation* – Oil adsorbs to suspended particles, including plankton, and eventually settles.
- *Biodegradation* – A series of organisms, especially fungi and bacteria, can degrade petroleum. In fact, an industry has developed for the use of microorganisms to degrade spilled oil.

All these processes affect the composition of petroleum in different manners, increasing its complexity which brings the need for more complex chemical and toxicological analyses. This is particularly important when trying to identify the source of a spill in order to determine possible legal responsibilities (Wang and Fingas 2003). One of the most complicated problems of analytical environmental chemistry is to determine what ship or well is the source of an oil spill, or if it is from a natural seep.

There are several analytical techniques developed in the field of geochemistry of petroleum to determine the maturity, source rock, migration, etc. of oil fields. These techniques are based on the use of molecular biomarkers such as the alkylation profiles of low molecular weight polycyclic aromatic hydrocarbons (like naphthalenes and phenanthrenes), dibenzothiophenes**,** hopanes, norhopanes, etc. (Wang and Fingas 2003). These molecular biomarkers have also been used successfully as indicators of origin of hydrocarbons in the environment, its degree of weathering, etc.

## BACKGROUND

The oil exploitation zone in the Gulf of Mexico encompasses several thousand square kilometers. Due to its visibility and the large amount of resources managed by the Mexican state owned company, Petróleos Mexicanos (PEMEX; National Mexican Petroleum Company), it has been object of big social controversy. The decrease in the catches of the main fisheries species, including the species of highest commercial value, which is the shrimp, has been attributed to PEMEX. Shrimp catch, particularly pink shrimp (*Farfantapenaeus duorarum*), has decreased dramatically in the last 20 years (Fig. 21.2). This has promoted strong social pressure to solve the problem, since this fishery employs thousands of workers, both in the fishing and packaging industries.

The mass media and the fishermen believe that oil pollution and fishing restrictions within the area of oil extraction have caused the decrease in catch. However, in the academic arena other possibilities have been suggested, such as global climate change, decrease of genetic variability, overfishing and capture of juveniles in inner waters, in what seems to be a multi-factorial problem.

A couple of review studies have been published on the problem of oil pollution in the coastal lagoons of Mexico, including the Gulf of Mexico (Vázquez-Botello *et al.* 1994) and the lagoons of the southern Gulf of Mexico (Gold-Bouchot *et al.* 1999a). This review will focus on the state of knowledge of polycyclic aromatic hydrocarbons (PAHs) and the effect of the oil activity in the southern Gulf of Mexico over 13 years (from 1990 onwards).

## HYDROCARBONS IN SEDIMENTS AND ORGANISMS OF COASTAL LAGOONS AND BAYS

Sediments are the final destination of several contaminants, particularly the hydrophobic ones. Table 21.1 shows the average concentrations of PAHs in sediments from different coastal lagoons and bays of the Atlantic coast of Mexico. As a means of comparison, it also includes concentrations in the Northern Gulf of Mexico that are considered high by the Status and Trends Program of the U.S. National Oceanic and Atmospheric Administration (NOAA) (O'Connor 1990), as well as critical concentrations reported by Long and Morgan (1990), which are the concentrations above which toxic effects to the biota are expected.

The results on Table 21.1 exhibit some striking results. Firstly, concentrations of total PAHs in several Mexican coastal lagoons and bays, especially in the state of Veracruz, exceed the value considered high (2.4 µg/g) for the northern Gulf of Mexico, according to NOAA (O'Connor 1990). Secondly, none of the average concentrations in lagoons and bays exceeds or even gets close to the critical value reported by Long and Morgan (1990) of 35.0 µg/g, suggesting that at the studied sites these compounds are not present in levels expected to be toxic to the local biota.

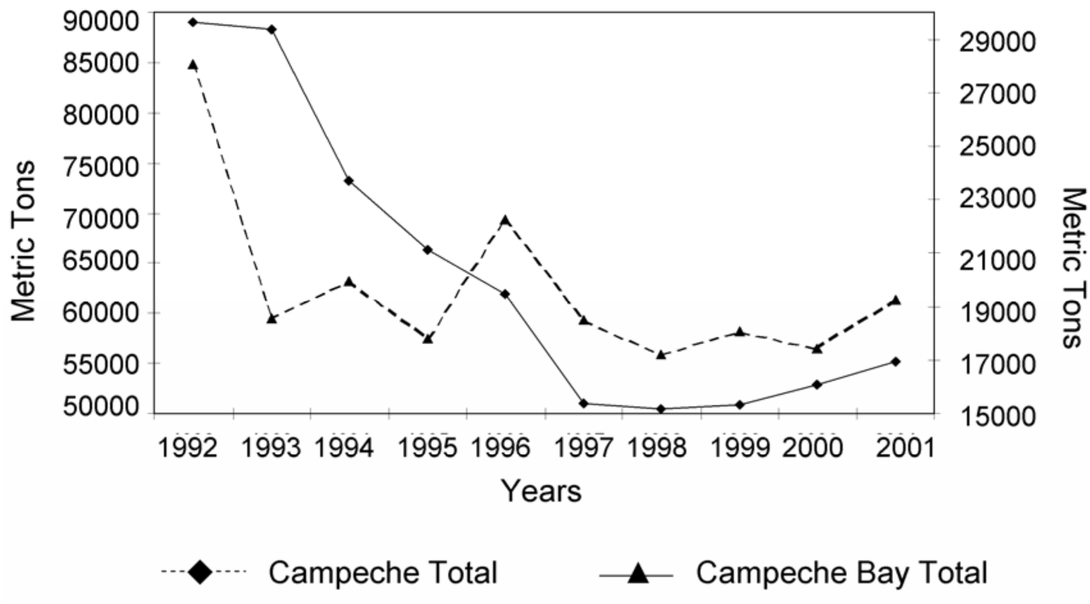


Figure 21.2. Shrimp catch in the area of Campeche from 1982 to 2001.

It is common to group PAHs according to their molecular weight to determine their origin. Thus, the concentrations of low molecular weight hydrocarbons are grouped as the sum of the hydrocarbons with two or three benzene rings (naphthalene, biphenyl, phenanthrene and anthracene, as well as their methylated derivatives). The high molecular weight PAHs are those with four or five benzene rings (pyrene, benzo(x)pyrenes, benzo(x)anthracenes, perylene, etc.). If the concentration of low molecular weight PAHs is higher than that of high molecular weight, it is considered that their source is petroleum, whereas if the opposite occurs, i.e., if high molecular weight PAHs predominate, it is considered that they originate from incomplete combustion processes (forest fires, factory chimneys, etc.), asphalts used in street paving, or oil refining products, such as motor oils (Wade *et al*. 1994; Noreña-Barroso *et al*. 1998). In all the coastal ecosystems for which there is information available, the concentration of high molecular weight PAHs exceeds that of low molecular weight PAHs. This indicates that motor oils or other compounds from incomplete combustion of organic matter, rather than petroleum, are the source of these compounds. This must be confirmed by a more detailed analysis using other geochemical biomarkers (Wang and Fingas 2003).

Other geochemical indices can be used to determine origin of the PAH, such as the degree and pattern of alkylation of naphthalene, phenanthrene and anthracene. However, since most of the environmental studies focus on the PAHs considered as priority by the U.S. Environmental Protection Agency (USEPA), it is not possible to calculate other indices, since the necessary compounds are not quantified.

Table 21.2 shows the average concentrations of PAHs in organisms from different coastal ecosystems of the Mexican Atlantic. In this table we find the average concentrations of PAHs in eastern oysters (*Crassostrea virginica*) and catfish (*Ariopsis assimilis*). The two species have important metabolic differences, and whereas oyster data are for the whole soft tissue, catfish analyses were done with liver tissue. Therefore, the data for the two species is not directly

Table 21.1. Average concentrations of total high and low molecular weight polycyclic aromatic hydrocarbons (PAHs) in coastal lagoons and bays of the Atlantic coast of Mexico. N.R.=Not reported.

| Lagoon/Bay | PAH (μg/g) | LMW[1] (μg/g) | HMW[2] (μg/g) | Reference |
|---|---|---|---|---|
| Chetumal | 2.34 | 0.27 | 2.17 | Noreña-Barroso *et al.* (1998) |
| Sian Ka'an | 1.16 | 0.55 | 0.80 | Gold-Bouchot *et al.* (1999b) |
| Salada | 6.65 | 0.21 | 6.44 | Vázquez-Botello *et al.* (2001) |
| Llano | 5.00 | 0.31 | 4.69 | Vázquez-Botello *et al.* (2001) |
| Mandinga | 5.68 | 0.80 | 4.88 | Vázquez-Botello *et al.* (2001) |
| La Mancha | 6.73 | 0.39 | 6.34 | Vázquez-Botello *et al.* (2001) |
| Pueblo Viejo | 3.81 | 1.12 | 2.08 | Vázquez-Botello *et al.* (1998) |
| Tamiahua | 3.42 | 0.88 | 2.54 | Vázquez-Botello *et al.* (1998) |
| Tampamachoco | 4.48 | 1.21 | 3.27 | Vázquez-Botello *et al.* (1998) |
| Mecoacán | 0.95 | N. R. | N. R. | Gold-Bouchot *et al.* (1997) |
| Carmen | 1.31 | N. R. | N. R. | Gold-Bouchot *et al.* (1997) |
| Machona | 1.85 | N. R. | N. R. | Gold-Bouchot *et al.* (1997) |
| "High" EUA | 2.40 | | | O'Connor (1990) |
| Critical | 35.0 | | | Long and Morgan (1990) |

[1] LMW=Low molecular weight PAHs.
[2] HMW=High molecular weight PAHs.

comparable, but is useful for illustrative purposes. Average concentrations for the same species from the Status and Trends Program of NOAA are also included.

It is remarkable that measured concentrations in catfish are much higher than those measured in oysters. In fact, a high incidence of histological lesions, including tumors, was observed in this species. The PAH concentrations in oysters are generally lower than those obtained by NOAA for the same specie in the northern Gulf of Mexico, with exception of the Laguna de Términos, where the average concentration was almost four times higher than that reported by NOAA.

The proportion between low and high molecular weight PAHs in the organisms cannot be used, because bioaccumulation and/or differential metabolism processes can affect the measured concentrations of PAHs.

Table 21.2. Average concentrations of polycyclic aromatic hydrocarbons (PAHs) in organisms of the coastal lagoons and bays of the Atlantic coast of Mexico.

| Lagoon/Bay | PAH (ng/g) | Organism | Reference |
|---|---|---|---|
| Carmen | 232 | *C. virginica* | Gold-Bouchot *et al.* (1997) |
| Machona | 404 | *C. virginica* | Gold-Bouchot *et al.* (1997) |
| Mecoacán | 219 | *C. virginica* | Gold-Bouchot *et al.* (1997) |
| Términos | 1,900 | *C. virginica* | Noreña-Barroso *et al.* (1999) |
| Chetumal | 77,000 | *A. assimilis* | Noreña-Barroso *et al.* (in press) |
| Mean *STP* | 536 | *C. virginica* | Jackson *et al.* (1994) |

## HYDROCARBONS ON CAMPECHE BANK

A panoramic view of two special scales is presented: a large scale that comprises all the southern Gulf of Mexico, and a small scale limited to the area of oil operations zone and its surroundings.

### Large Scale Affects

In the oceanographic campaign Xcambó 1, 69 stations were sampled, from the west of the mouth of the Río Coatzacoalcos to the west coast of the Yucatán Peninsula (Fig. 21.3). The spatial distribution of total hydrocarbons in the southern Gulf of Mexico can be seen in Fig. 21.4. The maximum concentration occurs in the area of oil platforms, indicating the possible impact of oil extraction activities on the marine ecosystem in the area. However, a different view of the problem arises upon an examination of the results for the most toxic fraction (PAHs).

The average concentrations of low and high molecular weight PAHs in sediments from the Xcambó Campaign in 1999, as well as from the Camarón 1 Campaign in 2002, are exhibited in Fig. 21.5. It can be observed that high molecular weight PAHs predominate in both campaigns, which indicates that the main source of these compounds is not oil, but compounds formed by incomplete combustion of organic matter, and/or refined products such as oils for motors of internal combustion.

An interesting point is that this proportion remains constant over time, which suggests that the sources of these compounds remain. An indication of the source can be observed in Fig. 21.6, which shows the spatial distribution of high molecular weight PAHs.

Unlike the total hydrocarbons, which exhibited their maximum concentration in the area of PEMEX platforms, the maximum concentrations of high molecular weight PAHs occur opposite the mouth of the Río Coatzacoalcos. This is where the main refineries of Mexico are located and it is also a very important urban area. Thus, the geochemical evidence suggests that the main source of PAHs in the southern Gulf of Mexico is not the extraction activity on Campeche Bank, but river discharges.

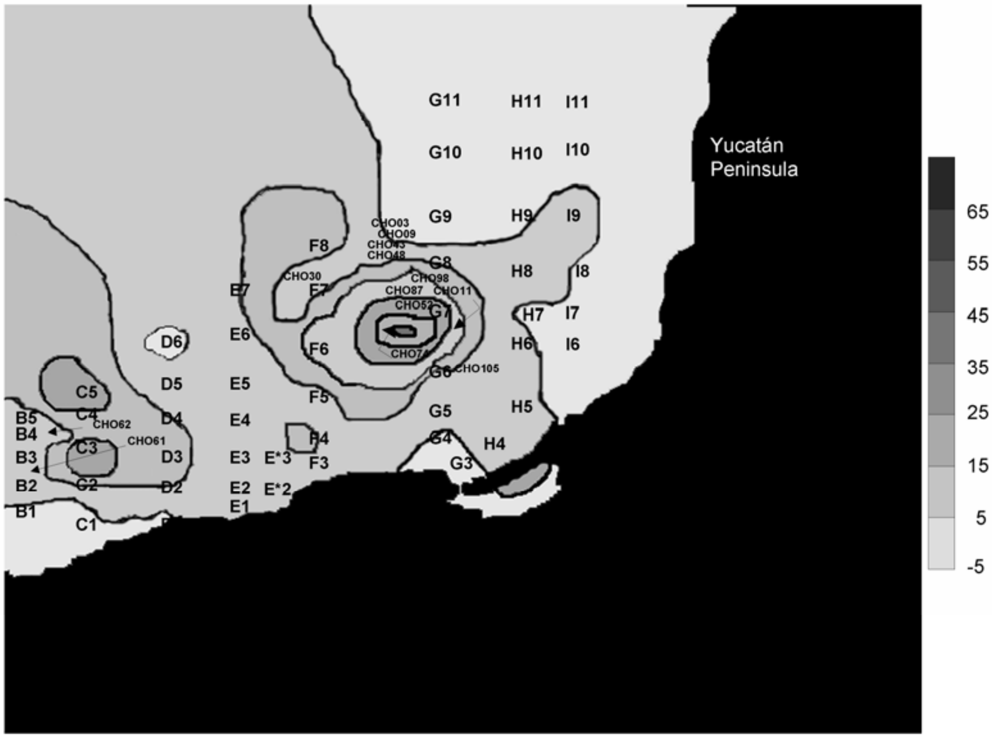


Fig. 21.3. Network of sampling stations of the Xcambó 1 oceanographic campaign.

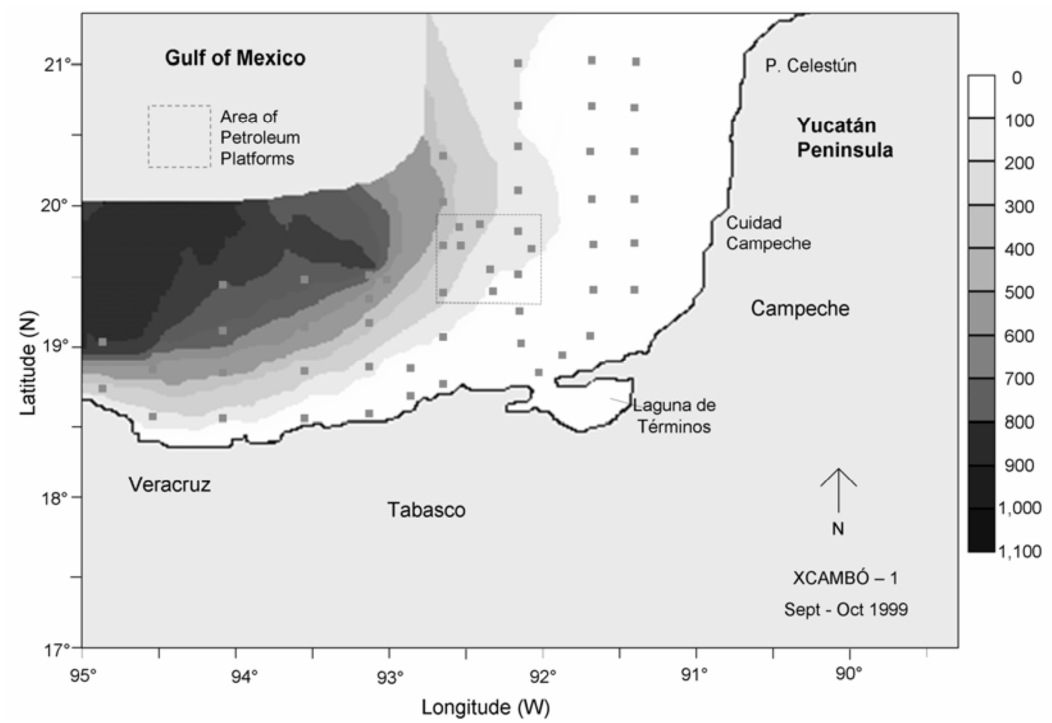


Fig. 21.4. Spatial distribution of total hydrocarbons concentrations in sediments from the southern Gulf of Mexico.

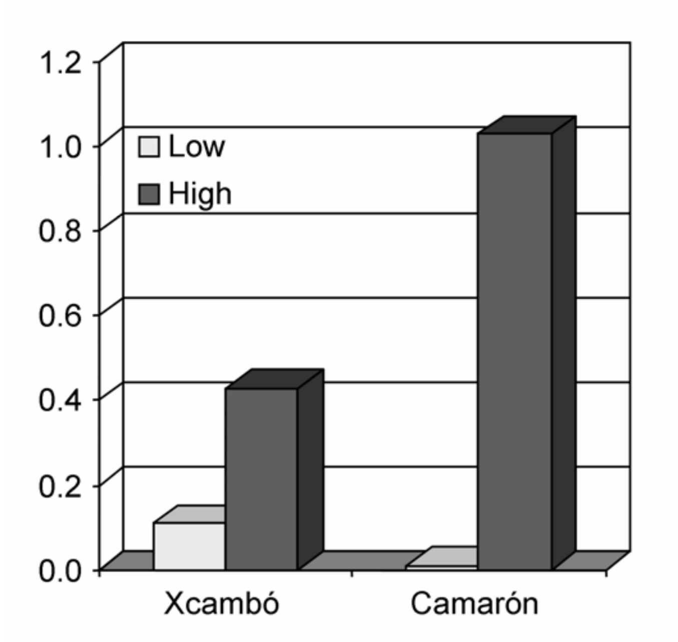


Fig. 21.5. Average concentrations of low and high molecular weight PAHs in sediments from the southern Gulf of Mexico in the campaigns of Xcambó (1999) and Camaron (2002).

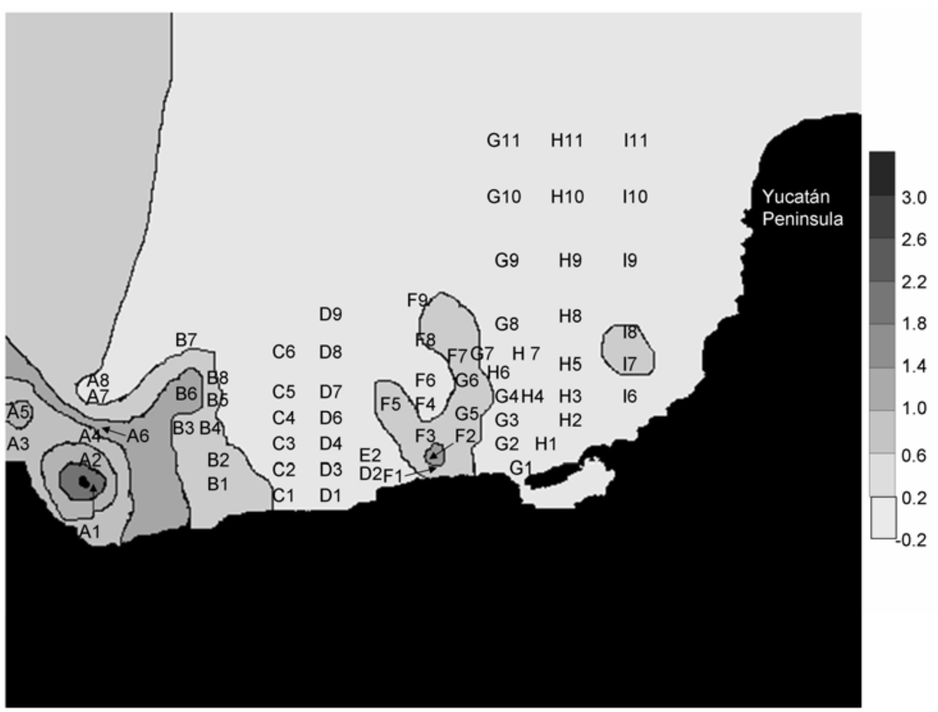


Fig. 21.6. Spatial distribution of the concentration of high molecular weight PAHs (four and five benzene rings) in sediments from the southern Gulf of Mexico during the Xcambó 1 oceanographic campaign in 1999.

Another contaminant commonly associated to oil extraction is barium, which was used in the form of barite in drilling fluids. This material was deposited around the wells and later was dispersed all over the area by currents and waves. Fig. 21.7 shows the spatial distribution of barium in sediments in the southern Gulf of Mexico. The highest concentration occurred in the area of oil platforms, confirming that it originated from drilling fluids. It is important to mention that barite is not used anymore in oil drilling in Mexico.

Small Scale Effects

This section is based on the results of Hernández-Arana (2003) and Hernández-Arana *et al.* (2005). Two oceanographic campaigns were undertaken in 1999 and 2000, using a sampling design composed of four transects with 12 stations each (Fig. 21.8). Two transects were parallel to the coast, to observe the change in sediments in the transition zone between the carbonated and terrigenous provinces of the Gulf of Mexico. The other two transects are perpendicular to the coast to analyze the effects of depth. The concentration of hydrocarbons increases notoriously across the transects in the area of platforms (Fig. 21.9). The barium concentration also increases (Fig. 21.10), which indicates that its source were the platform drilling activities.

This argument is strengthened by observing the direct linear correlation between total hydrocarbons and barium concentrations (Fig. 21.11). The available geochemical evidence points out that the high concentrations of barium on Campeche Bank come from drilling activities undertaken some time ago. The concentration of other metals, such as chromium (Fig. 21.12) and nickel also increase in the area of the platforms. This suggests that its source is also oil drilling and hydrocarbon extraction activities.

Other geochemical techniques are available to determine the source of the metals. If their origin is the sediment matrix, there should be a correlation between the concentration of metals in the sediments and iron or aluminum. Figure 21.13 shows a linear correlation between magnesium, zinc and copper with iron, but not with barium, nickel and chromium, which indicates that the latter come from platforms activities. The concentration of hydrocarbons, barium, nickel and chromium decreases relative to the distance from the platforms, which confirms that the platforms are the source. However, with the information available, it is not possible to determine if these contaminants continue to be added to the environment, or if cleaner technologies have ceased their discharge.

Figure 21.14 exemplifies, for hydrocarbons and barium, the relationship between the distance from the platforms and the concentration of contaminants. The concentration decreases with increased distance from the platforms, suggesting that these structures are the source of these contaminants. The decrease is relatively mild and, at considerable distances (more than 10 km), the measured concentrations were high relative to values measured farther away. This differs from observations in the North Sea, and the coasts of Louisiana and Texas, where the concentrations decrease at 3 km or less from the platforms.

Biological Effects

There are very few studies on the biological effects of petroleum hydrocarbons or other substances derived from petroleum activities in Mexico. This section focuses on field studies or those that evaluate the effect of oil activities using environmental samples. Due to space limitations, studies performed with single chemicals will not be discussed.

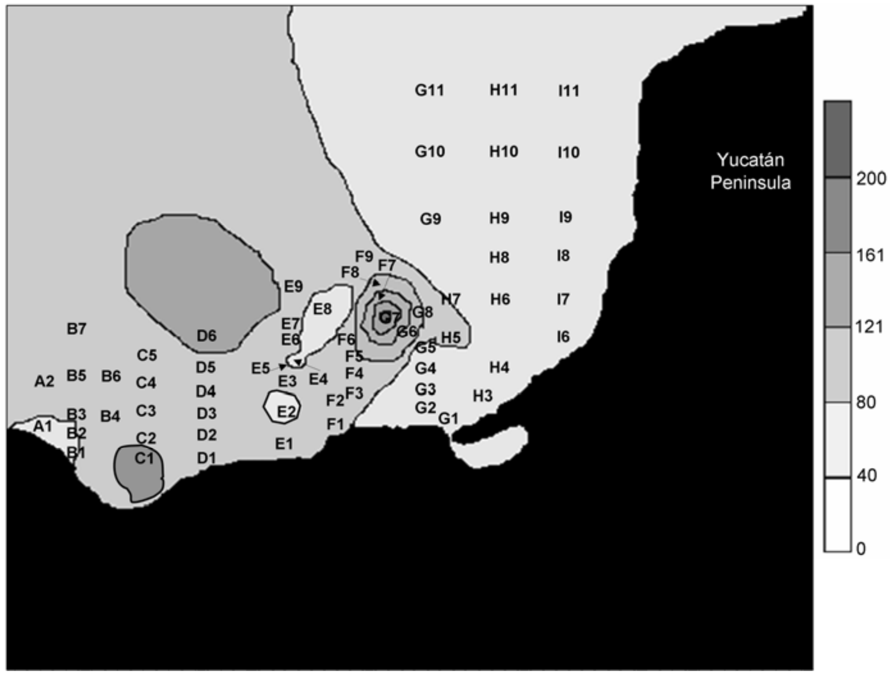


Fig. 21.7. Spatial distribution of barium in sediments collected during the Xcambó oceanographic campaign in 1999.

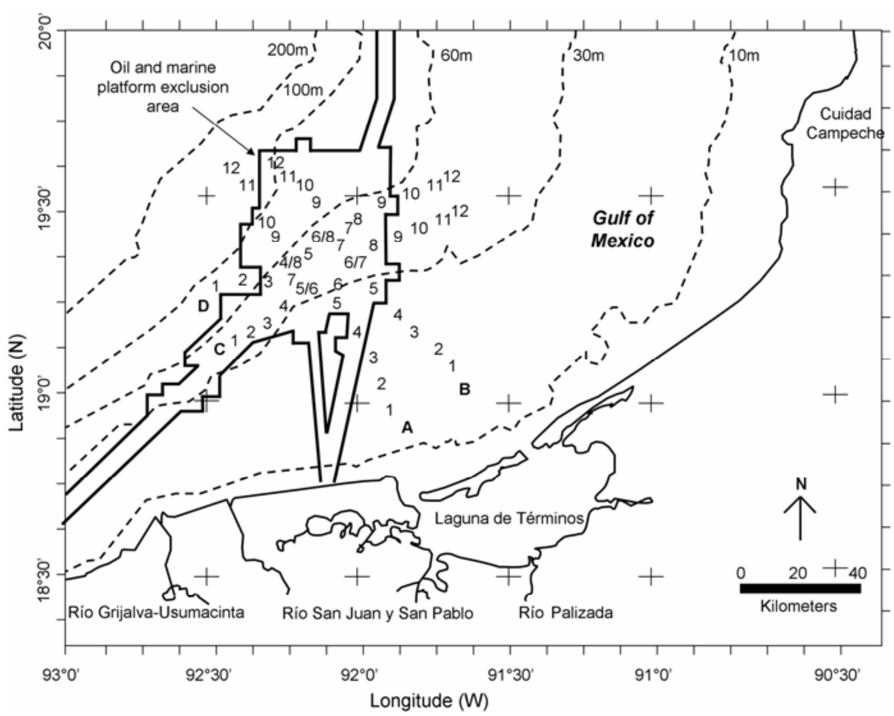


Fig. 21.8. Sampling stations of the oceanographic campaigns of 1999 and 2000, with four transects across the platforms zone.

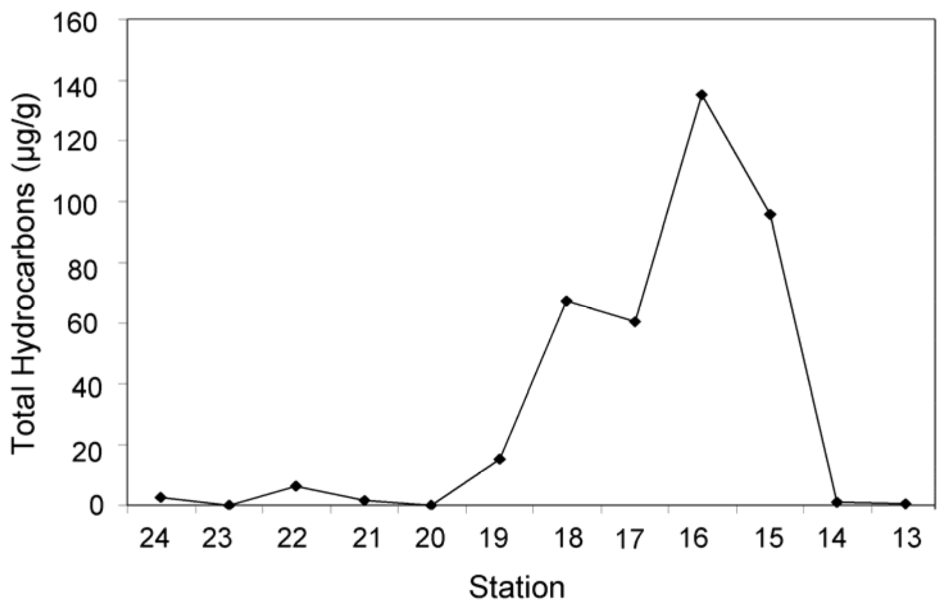


Fig. 21.9. Concentration of hydrocarbons in Campeche Bank.

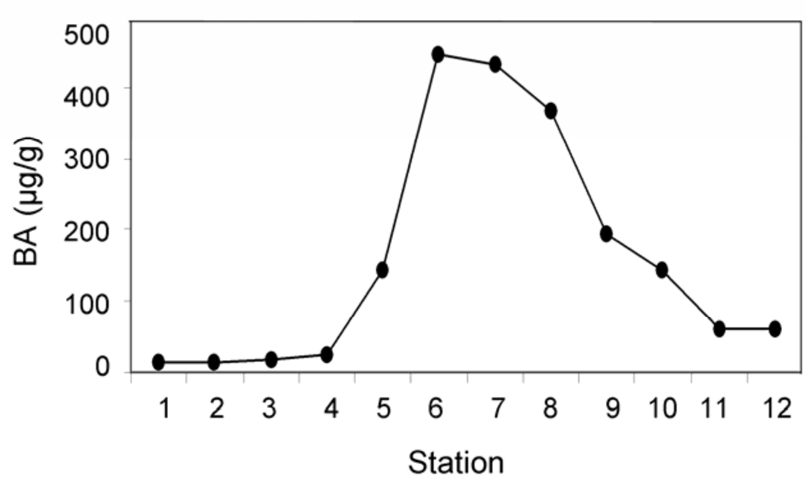


Fig. 21.10. Concentrations of barium in sediments from the oil platforms zone of sedimentsfrom the oil platforms zone of Campeche Bank.

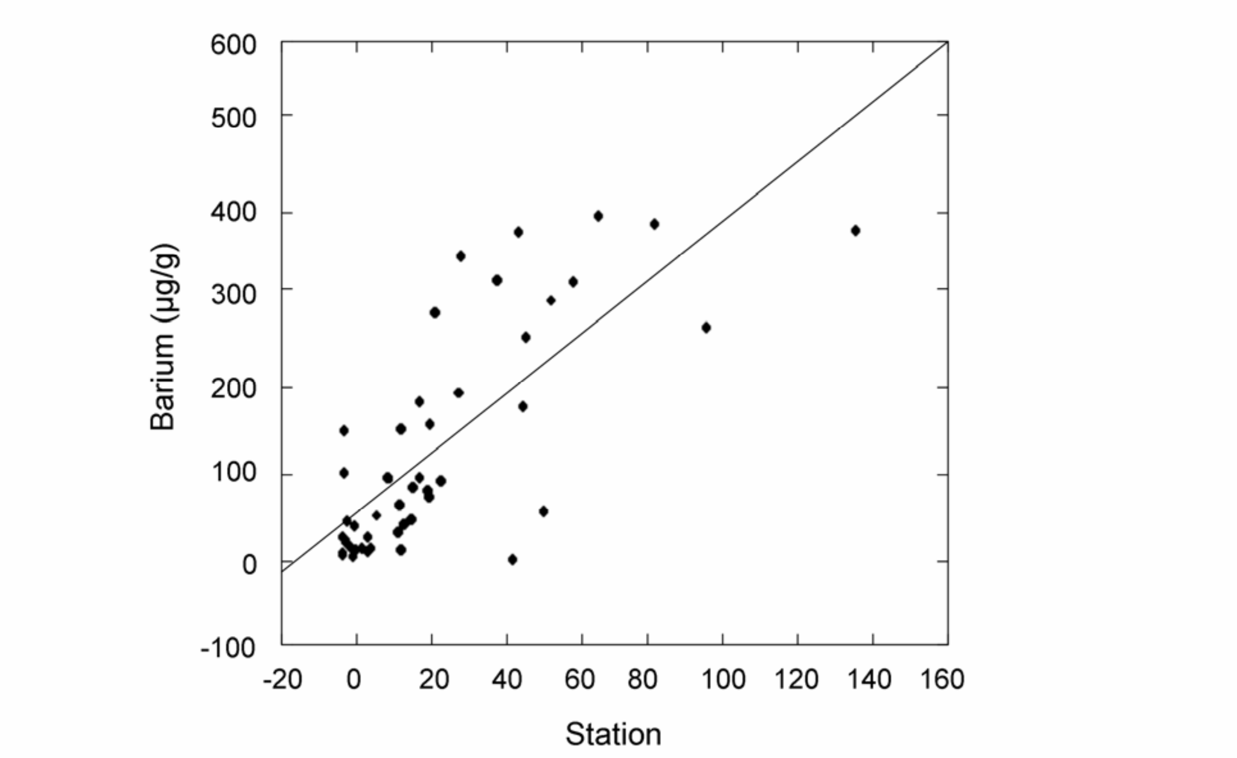


Figure 21.11. Correlation between the concentration of total hydrocarbons and barium in the oil platforms zone of Campeche Bank.

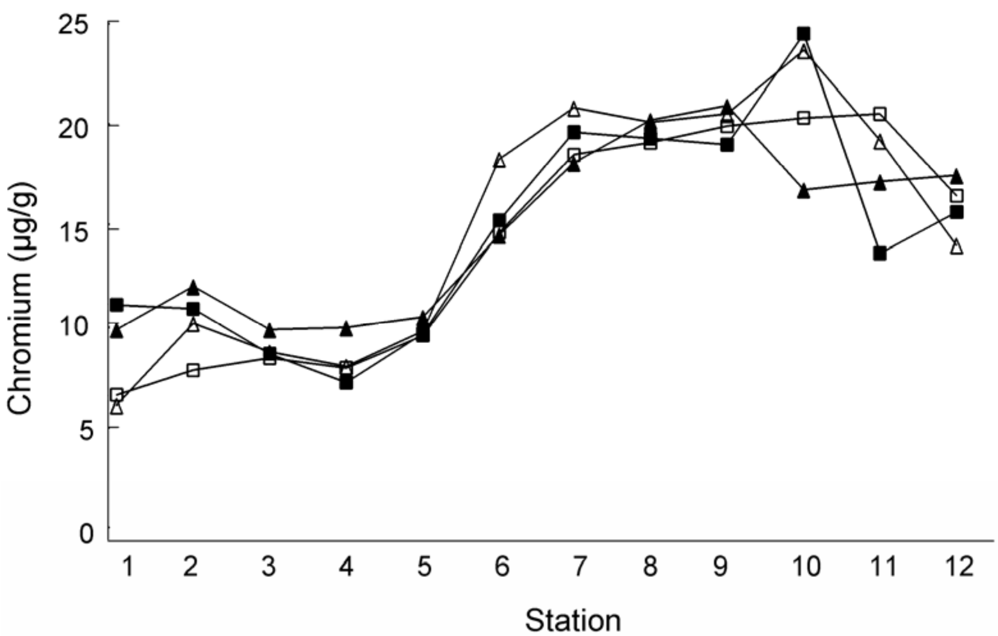


Figure 21.12. Concentration of chromium in sediments from the four transects across the oil platforms zone of Campeche Bank.

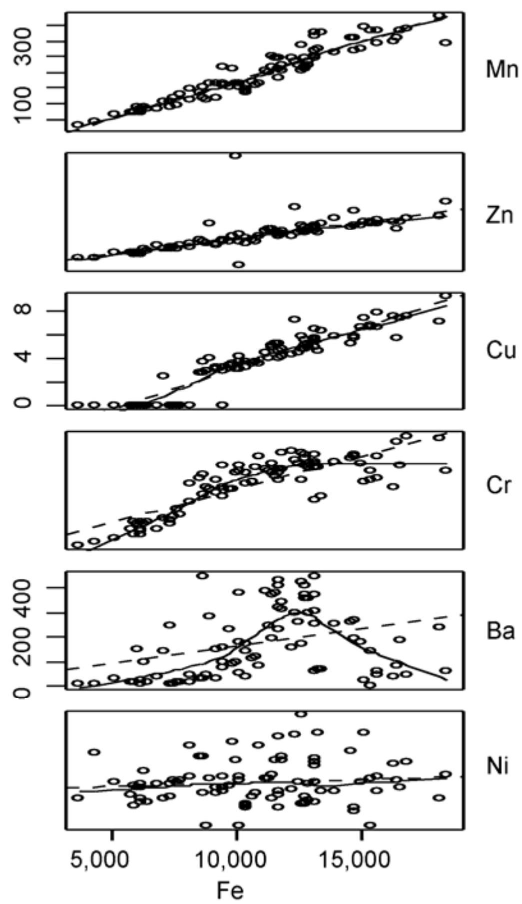


Fig. 21.13. Correlation between metals and iron in sediments from the oil platform zone of Campeche Bank.

Gold-Bouchot and Herrera-Rodríguez (1996) evaluated the effects of hydrocarbons and other environmental variables, such as depth, grain size distribution and organic matter content on the structure of free living benthic nematode communities on Campeche Bank during four oceanographic campaigns. A cluster analysis of the abundance of nematodes showed them mostly in three groups of geographically contiguous stations. The results were confirmed through a non-metric multidimensional scaling (NMDS) analysis. An attempt to "explain" the grouping of the stations was done with a discriminants analysis of multiple components. Depth and organic matter content were the variables that best explained the obtained grouping for the four cruises, whereas in three of the four, the concentration of total hydrocarbons was also an explanatory variable. This means that the hydrocarbons play a role in the structuring of the free living nematode community, in addition to the environmental variables.

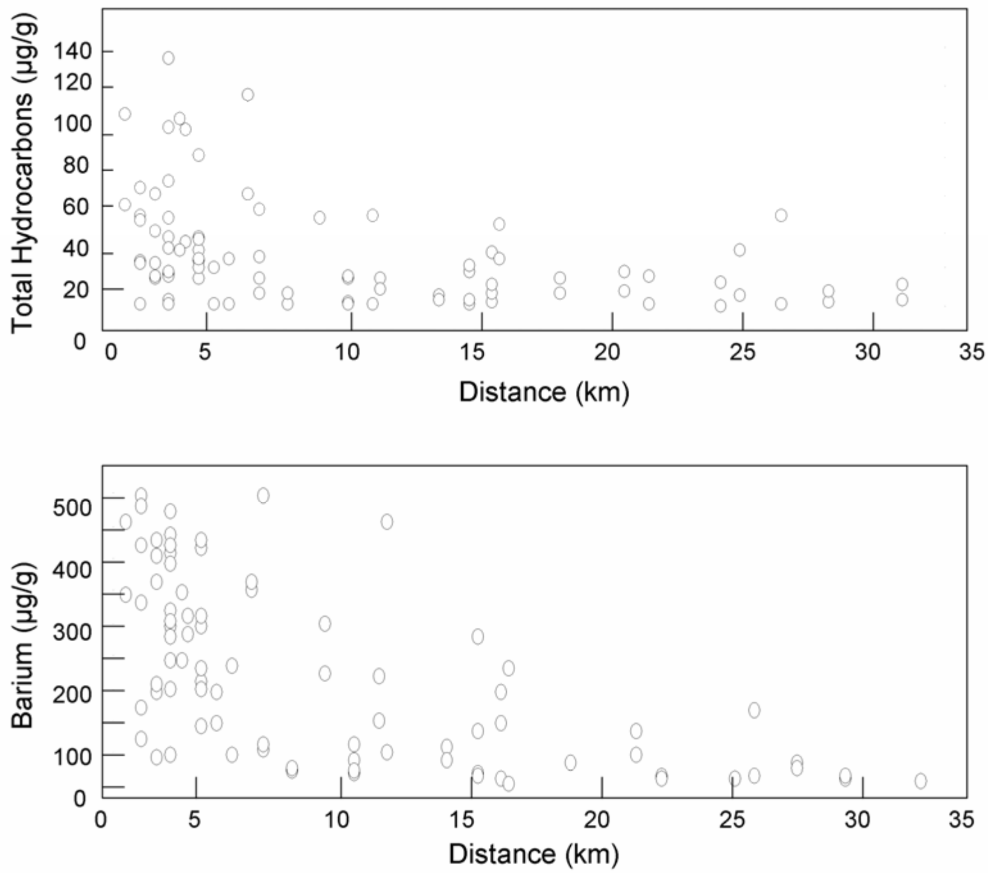


Fig. 21.14. Correlation between the concentrations of total hydrocarbons and barium in sediments, relative to the distance from oil platforms in Campeche Bank.

Gold-Bouchot *et al.* (1995b) reported that some fractions of hydrocarbons and metals, such as cadmium, are associated with the presence of histological lesions in the soft tissues of eastern oysters in Carmen, Machona and Meocacán lagoons in the state of Tabasco. They also observed that the condition index of oysters decreased with the concentration of contaminants, particularly metals (Marín-Mézquita *et al.* 1997).

Rodríguez-Fuentes and Gold-Bouchot (2000) observed that sediment extracts from the lagoons El Yucateco and Santa Anita in the state of Tabasco inhibited acetylcholinesterase in the brain of the Nile tilapia (*Oreochromis niloticus*). This inhibition was significantly correlated with the concentration of hydrocarbons in the sediments and was higher in the rainy season than in the dry season.

The catfish (*A. assimilis*) of Bahía Chetumal presented histological lesions and, of even higher concern, hepatic tumors, which were associated to the concentration of organic pollutants such as PAHs and pesticides in the liver (Noreña-Barroso *et al*. 2004). Additionally, Zapata-Pérez *et al*. (2000) showed that sediments of the bay are toxic. These two studies are particularly distressing because Bahía Chetumal is a critical ecosystem, which has been declared a protected zone because it is a reproduction area for manatees. It is also an ecosystem shared by Mexico and

Belize, and one of the priority areas of the Mesoamerican Reef Program along with the Golfo de Honduras.

Hernández-Arana (2003) and Hernández-Arana *et al.* (2005) found that the contaminants associated with oil activity have affected the structure of the benthic macrofauna on Campeche Bank. This effect is difficult to detect over the high variability of the structure of the benthic macrofauna due to both seasonal changes and the discharge of rivers (Hernández-Arana *et al.* 2003).

In the beginning of the 1990s both oyster fishermen and the authorities of the then Secretaría de Pesca (SEPESCA; Secretariat of Fisheries) attributed an alleged eastern oyster mortality in the coastal lagoons of the state of Tabasco to the concentrations of hydrocarbons. An interesting point is that the hydrocarbon concentrations in Laguna de Términos Lagoon (Gold-Bouchot *et al.* 1995a) were higher than those measured in Carmen, Machona and Mecoacán lagoons (Gold-Bouchot *et al.*1995b), without massive mortalities reported. The PAH concentrations are also higher in Laguna de Términos than in the lagoons of Tabasco (see Table 21.2). The prevalence of the parasite *Perkinsus marinus* was much greater in the lagoons of Tabasco than in Laguna de Términos Lagoon, which could explain the different mortality in these lagoons (Dr. Leopoldina Aguirre Macedo, CINVESTAV, pers. comm.). Álvarez-Legorreta *et al.* (1994) reported very high hydrocarbon concentrations in clams (*Rangia cuneata* and *Polymesoda carolineana*) of Laguna de Pom, in Campeche. If the differences in bioaccumulation between clams and oysters are taken into account, the concentrations found in Laguna de Pom are several times higher than those found in the oysters of the lagoons of Tabasco or in Laguna de Términos.

Nipper and Carr (2001) observed that about 80% of the sediments sampled in the Sian Ka'an Biosphere Reserve were toxic. It was not possible to identify the cause of toxicity, but sediments of this reserve have 70% higher concentrations of total hydrocarbons and similar concentrations of some pesticides, such as hexachlorocyclohexanes and chlordanes, than Bahía Chetumal (Gold-Bouchot *et al.* 1999b), which is considered a highly affected ecosystem. This is worrisome since Sian Ka'an is a protected zone, distant from agricultural or industrial areas.

The results obtained by Mexican researchers on Campeche Bank differ from those obtained recently in the oil extraction area of the North Sea (Grant and Briggs 2002). In the latter, the metals did not have toxic effects, and sediment toxicity was fully explained by the hydrocarbons present in the sediment. One possible explanation for this difference is that in the North Sea sediments were collected very close to the oil platforms, from the center of the platform up to a few hundred meters away, whereas in Mexico studies were always performed at much farther distances, of several kilometers. Another factor is that the research done in Mexico was not designed to distinguish which contaminants produce the toxic effect.

In a recent review of the consequences of oil extraction activities on the ecological processes of temperate and tropical ecosystems, Holdway (2002) concluded that 10 to 20 years of studies are necessary to establish the chronic and sub lethal impact of wastes from oil extraction activities in the ocean. It is of concern that Mexico lacks monitoring programs of concentrations of toxic contaminants on its coasts. Therefore, long term studies cannot be expected. It is necessary to seek mechanisms for the implementation of monitoring and research programs to observe long term trends, eliminating the variability induced by climate and biological cycles.

The few studies done in Mexico show that oil activities can have negative effects on coastal organisms. However, the available information is not sufficient to allow the conclusion that the magnitude of the observed effects, i.e., decrease in fisheries catches and other environmental degradation often attributed to PEMEX, are a result of the influence of petroleum activities. Among other reasons, this is due to the fact that there is no long term information to quantify the effects of natural variability on biological responses.

## MONITORING

As far as it is publicly known, there is no systematic monitoring program for hydrocarbons, or any other toxic contaminant, in the Gulf of Mexico. The only program known by the author is done in Punta Venado, Quintana Roo by the company Calicas Industriales del Carmen, S.A. (Fig. 21.15). This monitoring started on an irregular basis in 1988, but has been reasonably constant since 1995.

More than 500 analyses of dissolved/dispersed hydrocarbons in waters of the Mexican Caribbean and the Gulf of Mexico have been done in the Laboratorio de Geoquímica Marina del Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional Unidad Mérida (CINVESTAV-IPN; Center for Advanced Studies and Research of the National Polytechnic Institute Marine Geochemistry Laboratory) using the same analytical techniques, thus giving comparable results. Surprisingly, the frequency distribution of the results is not lognormal (Fig. 21.16). A logarithmic transformation of the data results in a Gaussian frequency distribution (Fig. 21.17), with an mean of 11.55 ± 2.5 µg/L. Based on these results, a reference concentration of 16.5 µg/L is proposed as a management measure, i.e., the average plus two standard deviations, since this would leave out approximately 65% of the measurements.

A series of hydrocarbons concentrations has been reported for sediments from the southern Gulf of Mexico, although not as part of a systematic monitoring program. These data have to be considered with caution since the study areas, as well as the analytical techniques, are not identical. However they give an idea of the long term situation in the region. Figure 21.18 shows the total hydrocarbons concentrations from 1978 to date.

It seems that there is a temporal tendency to the decrease of concentrations. This may be due to growing attention and social pressure, and to the implementation of better environmental regulations that have given impulse to better operations of oil installations.

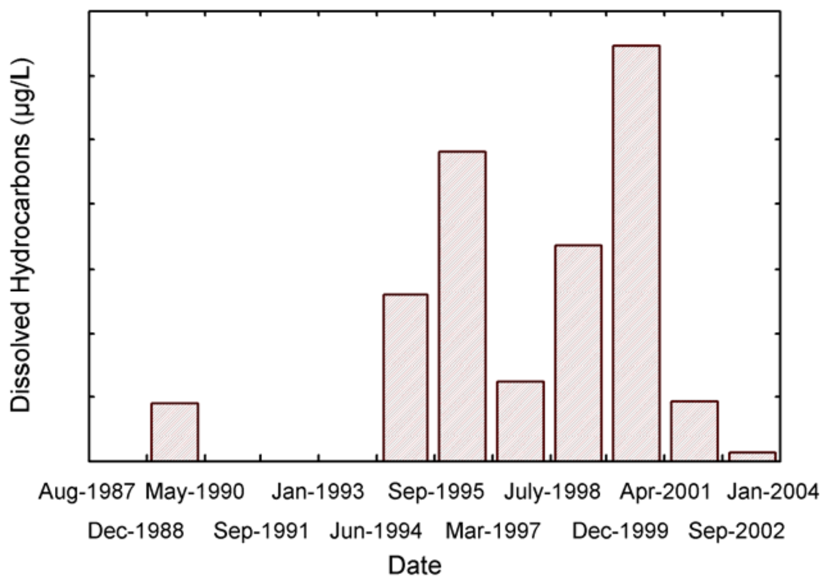

Fig. 21.15. Mean concentration of dissolved/dispersed hydrocarbons in Punta Venado, Quintana Roo, from 1988 to 2004.

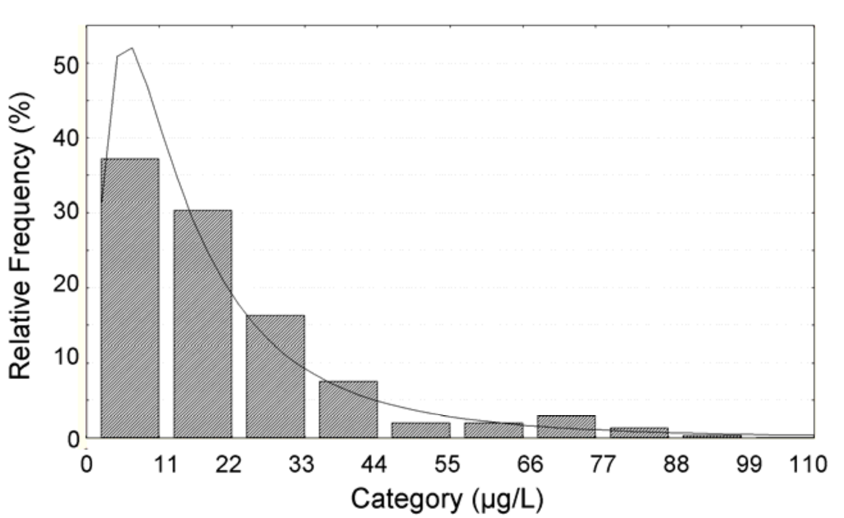


Fig. 21.16. Frequency distribution of the total dissolved/dispersed hydrocarbons concentrations (µg/L) in the Mexican Caribbean and the Gulf of Mexico.

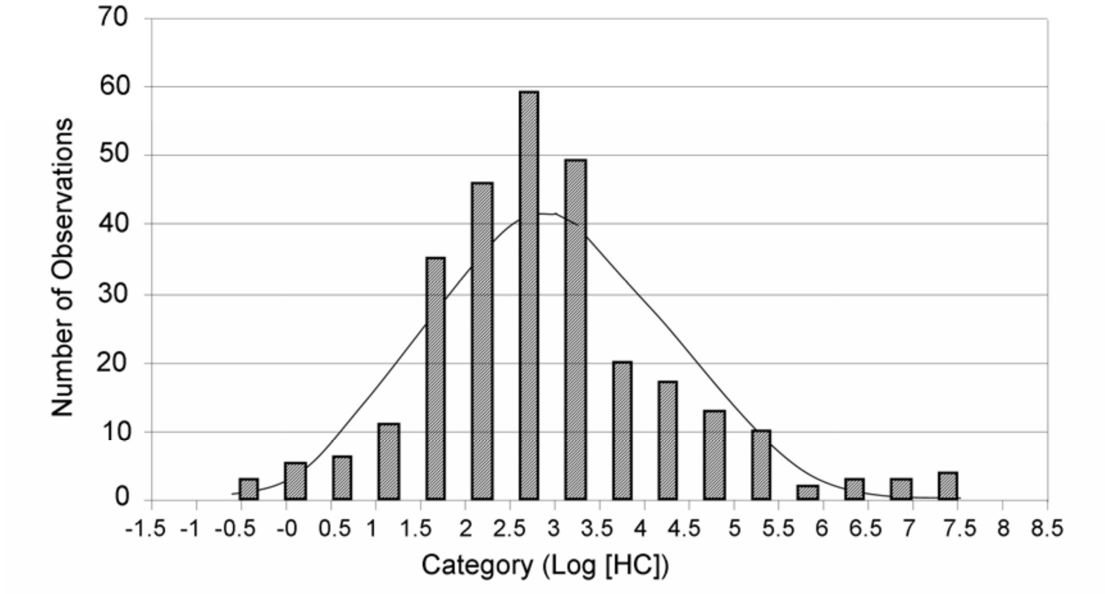


Fig. 21.17. Frequency distribution of the total dissolved/dispersed hydrocarbons concentrations (log $X_1$) in the Mexican Caribbean and the Gulf of Mexico.

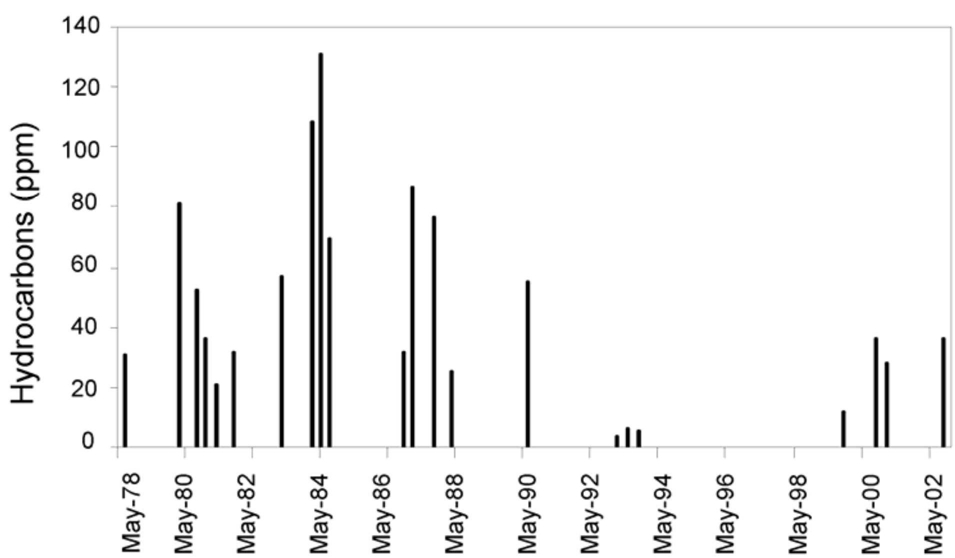


Figure 21.18. Mean concentrations of total hydrocarbons (μg/g) in sediments from different oceanographic campaigns from 1978 to 2002.

## CONCLUSIONS

- There are few studies published in the scientific literature. Most information is in the grey literature, particularly technical reports and thesis that are not publicly available.
- The concentrations of total hydrocarbons in the southern Gulf of Mexico tended to decrease from the end of the 1970s to this date.
- There are urban and industrial sources of pyrogenic hydrocarbons in coastal lagoons and bays. Information on these is available, for example, for Campeche Bank.
- Some metals (Ba, Cr, Ni, V) are associated to oil activities in areas near oil platforms.
- Effects from oil activities have been detected on the biota: free living nematodes, benthic macrofauna, eastern oysters (*C. virginica*) and catfish (*A. assimilis*). This does not necessarily mean that large scale effects, such as the decline in fisheries, are caused by the oil industry.

## LITERATURE CITED


Álvarez-Legorreta, T., G. Gold-Bouchot, and O. Zapata-Pérez. 1994. Hydrocarbon concentrations in sediments and clams (*Rangia cuneata*) in Laguna de Pom, Mexico. *Bulletin of Environmental Contamination and Toxicology* 52:39-45.

Fingas, M., and B. Fieldhouse. 2003. Studies of the formation process of water-in-oil emulsions. *Marine Pollution Bulletin* 47:369-396.

Gold-Bouchot, G. 2000. El petróleo: Características e impacto ambiental. Pp. 23-38 in A. R. Payán, F. X. Salazar and L. H. Álvarez (eds.). *Petróleo, Medio Ambiente y Sociedad*. México, D.F.: Senado de la República.

________ and M. Herrera-Rodríguez. 1996. Efectos de los hidrocarburos sobre la comunidad de nemátodos bénticos de la Sonda de Campeche, México. Pp. 279-296 in A. V. Botello, J. L. Rojas-Galaviz, J. A. Benítez and D. Zárate (eds.), *Golfo de México. Contaminación e Impacto Ambiental: Diagnóstico y Tendencias*. EPOMEX Serie Científica 5. Campeche, México: Universidad Autónoma de Campeche.

________, E. Noreña-Barroso, and O. Zapata-Pérez. 1995a. Hydrocarbon concentrations in the American oyster (*Crassostrea virginica*) in Laguna de Términos, Campeche, Mexico. *Bulletin of Environmental Contamination and Toxicology* 53:222-227.

________, R. Simá-Alvarez, O. Zapata-Pérez, and J. Guemez-Ricalde. 1995b. Histopathological effects of petroleum hydrocarbons and heavy metals on the American oyster, *Crassostrea virginica*, from Tabasco, Mexico. *Marine Pollution Bulletin* 31(4-12):439-445.

________, O. Zapata-Pérez, V. Ceja-Moreno, and M. del Río. 1999b. *Concentraciones de Compuestos Organoclorados (Plaguicidas y PCBs) e Hidrocarburos en Sedimentos de la Reserva de Sian Ka'an, Quintana Roo*. Report to the Sian Ka'an Biosphere Reserve. Mérida, Yucatán, México: CINVESTAV, Unidad Mérida.

________, M. Zavala-Coral, O. Zapata-Pérez, and V. Ceja-Moreno. 1997. Hydrocarbon concentrations in oysters (*Crassostrea virginica*) and recent sediments from three coastal lagoons in Tabasco, Mexico. *Bulletin of Environmental Contamination and Toxicology* 59:430-437.

________, O. Zapata-Pérez, M. Herrera-Rodríguez, V. Ceja-Moreno, E. Noreña-Barroso, and M. Zavala-Coral. 1999a. Oil Pollution in the Southern Gulf of Mexico. Pp. 372-382 in H. Kumpf, K. Steidinger, and K. Sherman (eds.). *The Gulf of Mexico Large Marine*

*Ecosystem. Assessment, Sustainability and Management*. Malden, Massasschusetts: Blackwell Scientific.

Grant, A., and A.D. Briggs. 2002. Toxicity of Sediments from around a North Sea oil platform: are metals or hydrocarbons responsible for ecological impacts? *Marine Environmental Research* 53:95-116.

Hernández-Arana, H. 2003. Influence of natural and anthropogenic disturbance on the soft bottom macrobenthic community of the Campeche Bank, Mexico. Ph.D. diss., University of Plymouth, Plymouth, U.K. 211 pp.

Hernández-Arana, H., M. J. Attrill, and G. Gold-Bouchot. 2003. Large-scale environmental influences on the benthic macroinfauna of the southern Gulf of Mexico. *Estuarine and Coastal Shelf Science* 58: 825-841.

________, R. M. Warwick, M. J. Attrill, A. A. Rowden, and G. Gold-Bouchot. 2005. Impact of oil related activities on benthic macroinfauna assemblages of the Campeche shelf, southern Gulf of Mexico. *Marine Ecology Progress Series* 289: 89-107.

Holdway, D. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. *Marine Pollution Bulletin* 44:185-203.

Jackson, T., T. L. Wade, T. J. McDonald, D. L. Wilkinson, and J. M. Brooks. 1994. Polynuclear aromatic hydrocarbon contaminants in oysters from the Gulf of Mexico (1986-1990). *Environmental Pollution* 83:291-298.

Long, E., and L .G. Morgan. 1991. *The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program*. NOAA Technical Memorandum NOS OMA 52. Seattle, Washington: National Oceanic and Atmospheric Administration, Office of Oceanography and Marine Assessment, Ocean Assessment Division. 175 pp.

Marín-Mézquita, L., L. Baeza, O. Zapata-Pérez, and G. Gold-Bouchot. 1997. Trace metals in the American oyster, C*rassostrea virginica*, and sediments from the coastal lagoons Mecoacan, Carmen and Machona, Tabasco, Mexico. *Chemosphere* 34:2437-2450.

National Academy of Science. 1985. *Oil in the Sea: Inputs, Fates and Effects*. Washington, DC: The National Academies Press. 601 pp.

Nipper, M., and R. Carr. 2001. Porewater toxicity testing: a novel approach for assessing contaminant impacts in the vicinity of coral reefs. *Bulletin of Marine Science* 69:407-420.

Noreña-Barroso, E., G. Gold-Bouchot, O. Zapata-Pérez, and J. L. Sericano. 1999. Polynuclear aromatic hydrocarbons in American oysters (*Crassostrea virginica*) from the Términos Lagoon, Campeche, México. *Marine Pollution Bulletin* 38:637-645.

________, R. Simá-Alvarez, G. Gold-Bouchot, and O. Zapata-Pérez. 2004. Persistent organic pollutants and histological lesions in Mayan catfish *Ariopsis assimilis* from Bay of Chetumal, Mexico. *Marine Pollution Bulletin* 48: 263-269.

________, O. Zapata-Pérez, V. Ceja-Moreno, and G. Gold-Bouchot. 1998. Hydrocarbons and organochlorine compounds in sediments from Bay of Chetumal, Mexico. *Bulletin of Environmental Contamination and Toxicology* 61:80-87.

O'Connor, T. 1990. *Coastal Environmental Quality in the United States, 1990: Chemical Contamination in Sediment and Tissues*. Rockville, Maryland: National Oceanic and Atmospheric Administration. 34 pp.

Owens, E., and K. Lee. 2003. Interaction of oil and mineral fines on shorelines: review and assessment. *Marine Pollution Bulletin* 47:397-405.

Rodríguez-Fuentes, G., and G. Gold-Bouchot. 2000. Environmental monitoring using acetylcholinesterase inhibition in vitro. a case study in two Mexican lagoons. *Marine Environmental Research* 50:357-360.

Vázquez-Botello, A., and L .G. Calva. 1998. Polycyclic aromatic hydrocarbons in sediments from Pueblo Viejo, Tamiahua and Tampamachoco Lagoons in the southern Gulf of Mexico. *Bulletin of Environmental Contamination and Toxicology* 60:96-103.

________,________, and G. Ponce. 2001. Polycyclic aromatic hydrocarbons in sediments from coastal lagoons of Veracruz State, Gulf of Mexico. *Bulletin of Environmental Contamination and Toxicology* 67:889-897.

________, G. Ponce, S. Villanueva, and L. Rueda. 1994. Contaminación. Pp. 445-470 in G. de la Lanza Espino and C. Cáceres Martínez (eds.), *Lagunas Costeras y el Litoral Mexicano.* La Paz, Baja California Sur, México: Universidad Autónoma de Baja California Sur.

Wade, T., D. J. Velinsky, and J. Rainharz. 1994. Tidal river sediments in the Washington D.C. area. II: distribution and sources of organic contaminants. *Estuaries* 17:321-333.

Wang, Z., and M. F. Fingas. 2003. Development of oil fingerprinting and identification techniques. *Marine Pollution Bulletin* 47:423-452.

Zapata-Pérez, O., R. Simá-Alvarez, E. Noreña-Barroso, J. Guemez-Ricalde, G. Gold-Bouchot, A. Ortega, and A. Albores-Medina. 2000. Toxicity of sediments from Bahia de Chetumal, Mexico, as assessed by hepatic EROD induction and histology in Nile Tilapia, *Oreochromis niloticus*. *Marine Environmental Research* 50:385-391.