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Review

# Marine environmental status in the Thai waters

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**Abstract**—The marine environment in Thailand has been degraded by various pollutants arising both from land-based sources and from heavy shipping traffic, together with the accompanying accidental oil spills. Domestic wastes in the coastal waters of major cities are much evident. High levels of heavy metals in marine organisms are occasionally reported. The observed elevated mercury levels in some areas provide a warning of potential risk in the Gulf. Pesticide residues were detected in sediment and mussel samples. Low-level hydrocarbon pollution to some degree occurs most of the time in the Upper Gulf and the Eastern Sea Board. Polycyclic aromatic hydrocarbons (PAHs) were identified in the water, sediment and biota samples. Tributyltin (TBT) was also detected in water, sediment and biota samples. Gastropods collecting near major shipping lanes all had imposex characteristics. Although marine pollution levels have been reported to be acceptable in Thai waters, management measures to minimize pollutant loading are needed to reduce long-term risk to the marine environment.

**Key words:** heavy metals, tributyltin, persistent organic pollutants, polycyclic aromatic hydrocarbons, petroleum hydrocarbons, Thai waters, Gulf of Thailand

## Introduction

Thailand is situated on the South-East Asian mainland, between latitudes 5°N and 20°N and longitudes 97°E and 106°E. The total land area is approximately 513,000 $km^2$, extending about 2,500 km from north to south and 1,250 km from east to west. The country is highly dependent on its marine environment for food, raw materials and other needs for sustenance and economic development. During recent years, the country has exerted unusually high demands on its environment as a consequence of rapid population growth. This is manifested in the increased intensity of extractive and non-extractive activities in the marine areas and the undesirable consequences such as pollution and resource degradation. The associated problems have evolved into magnitudes of concern so that efforts to contain them are in order. Baseline surveys and monitoring of pollutants are undertaken in Thai waters by several government agencies, research institutions and universities, in order to assess its extent as well as to determine the nature and degree of deterioration of the ecosystem.

This paper makes an effort to summarize and to compare available information on marine pollution in the Thai waters. The paper describes the status of marine pollution and gaps in knowledge on its extent which may be used as reference for future cooperative work.

## Background Information

The seas surrounding Thailand are the Gulf of Thailand and the Andaman Sea off the West Coast of peninsular Thailand. The Gulf of Thailand, a semi-enclosed sea, covers an area of about 350,000 $km^2$. Being part of the Sundra continental shelf in the South China Sea, the Gulf is rather shallow, with an average depth of about 50 metres. The deepest part of the Gulf, 85 metres, is located between Lat. 9°N. and Long. 101°E. The Inner Gulf receives drainage from the four major rivers, the Chao Phraya, Thachin, Mae Klong and Bangpakong, with a large amount of runoff during the rainy season. These rivers flow through many cities and provinces and receive various kinds of wastes, at different volumes and concentrations, from a variety of human activities. The Upper Gulf of Thailand has thus become a final receptor for all types of waste. The pressures of both industrial development and rising populations along the coast of Thailand have significantly increased the industrial and domestic waste discharge to the Gulf. Concerns about the extent of pollution in the Gulf prompted the commencement of a series of oceanographic and water quality studies since 1974. There is also concern about the effect of pollutants discharged in coastal waters of the Lower Gulf and along the Eastern Sea Board (ESB), an increasingly industrialized coastline just east of the Upper Gulf.

The Andaman Sea is deeper than the Gulf of Thailand, with an area of about 126,000 $km^2$. It has the general features

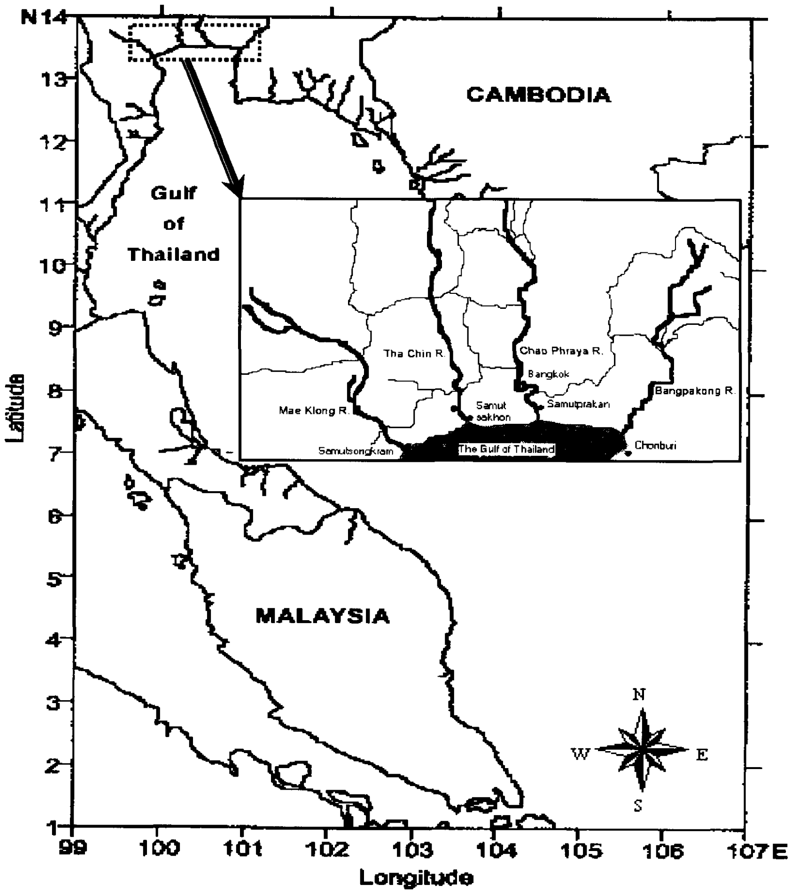


**Fig. 1.** Map of the Gulf of Thailand showing the four major rivers, the Mae Klong, Thachin, Chao Phraya and Bangpakong that flow into the inner Gulf of Thailand.

of oceanic waters. From Phuket Province northward to Ranong Province, the continental shelf is narrow and the waters are deep. Mangrove forests can be found north of Ranong and in Takua Pa District of Phang-nga Province. From Phuket Province southward to Satun Province, the continental shelf is wider than in the north, and the waters are shallower. The coastal area south of Phuket is fringed with mangrove forests and sea grass beds. In the past, tin mining in Phuket, Ranong and Phang-nga Provinces was the main cause of marine pollution, affecting the well being of coral reefs and seagrass resources. With the decline in tin mining activities in these coastal areas in recent years, the main cause of pollution is now effluents released from the steadily increasing number of houses, hotels, restaurants and expanding communities along the coast resulting from booming tourism, especially in Phuket Province.

## Marine Environmental Status in Thai Waters

The marine environment in Thailand is threatened by various pollutants arising both from land-based sources and from heavy shipping traffic, together with the accompanying accidental oil spills. Sources of coastal pollution can be grouped into several main classes: agriculture, sewage, industrial discharges, urban storm water, shipping activities, aquaculture and mining. The principal contaminant classes which may be presented in discharges from these sources are sediment, nutrients, toxic metals, pesticides, oxygen depleting substances, pathogenic organisms, larvae of exotic species, litter and other toxic chemicals. Nutrient pollution (in the form of eutrophication and algal blooms) and chemical pollution has become apparent in many areas such as the major estuaries and coastal waters. Eutrophication, mainly *Noctiluca*, occurs from place to place in the upper Gulf of Thailand, especially during the high river runoff period. The extent of phytoplankton bloom is usually limited to few tens of kilometers from major riverine discharge points.

Various universities and academic institutions have carried out marine pollution research in Thailand. The research has been focused on the following: (a) identification and characterization of sources and development of appropriate measurement techniques; (b) determination of the distribution and behavior of pollutants in various media; (c) identification of health and environmental effects; and (d) evaluation of cost-effectiveness and efficiency of pollution control methods.

Some of the relevant results of various research activities are summarized as follows:

## Heavy metals

There are a number of studies being carried out regarding heavy metal pollution in Thai waters. Most of the studies were conducted in specific areas such as estuaries, coastal area and area of extensive industrial activities. Recent studies on heavy metals in the Gulf of Thailand were carried out by Utoomprurkporn et al., (1999) and Shazili et al. (1999).

The average concentrations of dissolved metals (Cd, Cu, Fe, Ni, and Pb) were within the normal range found in coastal seawater elsewhere. Horizontal distributions of trace metals in the Gulf, particularly Cd, Cu, Fe and Pb, indicated the importance of land-based sources (*via* river inputs). Cd, Cu and Ni in river water draining into the Gulf were dominated by dissolved form whereas those of Fe and Pb were in suspended particulate form. Vertical profiles of trace metals in the Gulf showed some high concentrations at bottom layer near the Upper Gulf, which may be an indication of the release of metals from bottom sediment.

**Table 1.** Concentrations of dissolved metals in the Gulf of Thailand (Utoomprurkporn et al., 1999).

| Metal | | Sept. 1995 | April 1996 | n |
|---|---|---|---|---|
| Cd (ng/L) | surface | 1.0–4.8 | 0.1–11.1 | 81 |
| | bottom | 2.1–7.8 | 3.3–18.5 | |
| Pb (μg/L) | surface | 0.01–0.15 | 0.01–0.18 | 81 |
| | bottom | 0.01–0.44 | 0.01–0.19 | |
| Ni (μg/L) | surface | 0.1–0.5 | 0.1–0.5 | 81 |
| | bottom | 0.1–1.0 | 0.1–0.7 | |
| Cu (μg/L) | surface | 0.1–0.9 | 0.1–0.6 | 81 |
| | bottom | 0.1–1.3 | 0.1–0.5 | |
| Fe (μg/L) | surface | 0.5–4.9 | 0.4–3.0 | 81 |
| | bottom | 0.6–4.5 | 0.3–3.0 | |

**Table 2.** Mean concentration of metals (μg/g dry wt.) in sediments from the Gulf of Thailand (Shazili et al., 1999).

| Metal | Sept. 1995 | April 1996 | N |
|---|---|---|---|
| Al | 4.38 | 5.34 | 80 |
| Fe | 2.13 | 1.22 | 80 |
| Cd | 0.42 | 0.35 | 80 |
| Cr | 85.0 | 62.7 | 80 |
| Cu | 19.7 | 25.7 | 80 |
| Pb | 16.2 | 29.9 | 80 |
| Zn | 61.0 | 51.6 | 80 |

The Pollution Control Department has monitored mercury in seawater along the coast of Thailand and the Andaman Sea since 1992. The results (Table 3) showed mercury concentrations ranged from <0.01 to 0.54 μg/L, with average values of 0.03–0.6 μg/L. Most concentrations found were within the National Coastal Water Quality Standard Limit of 0.1 μg/L. High concentrations were found in areas associated with port activities, industrial discharges as well as discharges from gas exploration platforms.

Total mercury concentrations in coastal sediments ranged from 0.05 to 2.13 μg/g dry wt., with an average of 0.14 μg/g dry wt. The high concentrations were found in sediments from stations near river mouths, suggesting accumulation from anthropogenic (industrial) discharges. The observed elevated mercury levels provide a warning of potential risk in the Gulf indicating that management measures to minimize mercury loading are needed to reduce long-term risk to the marine environment.

Monitoring of selected heavy metals, using the mussel watch approach, has been conducted by the Department of Environmental Quality Promotion since 1990. Green mussels were collected from 13 locations along the coastal area of the Gulf of Thailand and the Andaman Sea (Table 4). Most metals showed variable trends of accumulation, except chromium, which showed a trend of increasing accumulation in mussel tissues. However, the concentrations of trace metals in green mussel were found to be within the acceptable limits set by the National Public Health Standards of Thailand.

A survey on arsenic accumulation in biological tissues was carried out in Pak Phanang Bay, near the tin mining area in Nakhon Si Thammarat Province. Despite the high arsenic contaminated area of Ron Phibun District upstream of the Bay, the study showed that arsenic levels in biological samples were not seriously affected by such high concentrations.

The Pollution Control Department studied the accumulation of mercury in biological samples in 1998. Total mercury concentrations in fish were found to be 0.02–1.57 μg/g dry weight. Most samples were found to contain mercury at

**Table 3.** Total mercury (μg/L) in Thai waters (Adapted from Chongprasith and Wilairatanadilok, 1999).

| Location | Range | Mean | n | Sampling periods |
|---|---|---|---|---|
| Gulf of Thailand and Andaman Sea | | | | |
| (coastal waters) | <0.01–0.54 | 0.03 | 767 | 1997–1998 |
| Coastal industrial area | | | | |
| —Map Taphut | 0.01–0.48 | 0.06 | 121 | 1995–1998 |
| —Laem Chabang | <0.01–0.16 | 0.06 | 38 | 1995–1996 |
| Gulf of Thailand (Upper Gulf) | <0.01–0.51 | 0.05 | 296 | 1995–1998 |

**Table 4.** Average concentration of trace metals in green mussel tissues from the Thai waters (Boonchalermkit et al., 1999).

| Metal | Average concentration (μg/g dry weight) | | | | |
|---|---|---|---|---|---|
| | 1990 | 1994 | 1995 | 1996 | 1997 |
| Cd | 3.99 | 1.38 | 1.88 | 1.65 | 1.95 |
| Cr | 2.44 | 4.05 | 5.23 | 7.53 | 8.18 |
| Cu | 5.91 | n.d. | 2.70 | 3.16 | 3.71 |
| Mn | 55.4 | 44.7 | 71.4 | 57.9 | 73.5 |
| Ni | 5.32 | 4.39 | 5.14 | 3.16 | 4.87 |
| Pb | n.d. | 0.49 | 0.77 | 0.76 | 0.79 |

**Table 5.** Total arsenic concentration (ng/g dry wt.) in biological samples from Pak Phanang Bay (Boonchalermkit et al., 1997).

| Organism | Mean | Range | n |
|---|---|---|---|
| Pelagic fish | 0.97 | n.d.–5.25 | 14 |
| Demersal fish | 0.45 | n.d.–11.0 | 27 |
| Crab | 1.1 | 0.38–32.3 | 6 |
| Shrimp | 2.23 | 0.11–12.8 | 9 |
| Mussel | 5.92 | 0.32–25.2 | 20 |

**Table 6.** Total mercury in tissues (μg/g dry wt.) collected in June 1998 (Chongprasith and Wilairatanadilok, 1999).

| Sample | Range | Mean | n |
|---|---|---|---|
| Pelagic fish | 0.02–0.96 | 0.16 | 48 |
| Demersal fish | 0.04–1.57 | 0.28 | 30 |
| Crab | 0.18–1.44 | 0.54 | 4 |
| Shrimp | 0.06–0.31 | 0.17 | 7 |
| Scallop | 0.06–0.10 | 0.08 | 5 |
| Squid | 0.04–0.35 | 0.13 | 25 |

**Table 7.** Mean and range concentrations of butyltin compounds (ng/g wet wt.) in green mussel (*Perna viridis*) collected from coastal waters of Thailand (Kan-Atireklap et al., 1997).

| Year | n | MBT | DBT | TBT | BTs |
|---|---|---|---|---|---|
| 1994 | 7 | 21 | 17 | 64 | 96 |
| | | (3–45) | (1–66) | (7–200) | (9–310) |
| 1995 | 14 | 9 | 11 | 90 | 110 |
| | | (<3–42) | (1–80) | (3–680) | (4–800) |

n=number of locations; figures in parentheses indicate range
BTs=MBT+DBT+TBT

much lower concentration than the Standard of the USA Food and Drug Administration (1.25 μg/g dry weight). Hence, samples analyzed were found to be safe in terms of mercury contamination.

Concern is growing over contamination of fish around the natural gas exploration platforms in the Gulf of Thailand. Effluent water produced from the processing platforms has been found to be the primary potential source of mercury released from production operations. Improved water treatment technologies are being installed to reduce mercury discharges from gas production activities. Total mercury was measured in over 500 fish tissue samples that were collected between 1990 and 2001. On average, fish caught near the platforms have mercury concentrations similar to those measured in the Gulf of Thailand and other parts of the world.

## Tributyltin

The aquatic pollution by tributyltin arising from antifouling paints has been of great concern due to their effect of shell malformation in oysters, mortality of the larvae of mussels and imposex in gastropods, which occur at a very few nanogram per liter of aqueous TBT concentrations. Butyltin compounds were detected in most mussel samples analyzed; ranging from 4 to 800 ng/g wet weight (as total). The composition of butyltin derivatives was in the order of TBT>DBT>MBT (Table 7). The results indicated that butyltin contamination was widespread, particularly in high boating areas and in coastal aquaculture facilities.

Contamination by butyltin was also observed in sediments collected from coastal areas of Thailand (Table 8). High TBT concentrations were associated with large commercial or offshore vessel harbors. Although the usage of butyltin in Thailand is still unclear, the presence of detectable TBT in sediments in all locations suggests its widespread contamination.

Imposex in gastropods was reported by Swennen et al. (1997) (Table 9). In the northernmost area gastropods sampled in the eastern part of the inner Gulf of Thailand, near the major shipping route to Bangkok and near an oil terminal and a berthing place showed high imposex incidence (80–100%) in the species found. The very low shipping density in the western part was reflected by no findings of imposex.

## Persistent Organic Pollutants (POPs)

Thailand is basically an agricultural country. While the use of modern technology in agriculture, particularly the use of chemical inputs, has increased yields, the hazards of excessive and unregulated usage are becoming apparent. Residues of POPs have been detected in marine waters and organisms in the country. POPs are organic compounds that resist photolytic, biological and chemical degradation. Included in this group of substances are some older chlorinated pesticides like DDT and the chlordanes, polychlorinated biphenyls, polychlorinated benzenes, and polychlorinated dioxins and furans. Organochlorine pesticides were widely used in Thailand for pest control in agriculture as well as for public health purposes. Their extensive usage has resulted in severe environmental problems and human health hazards. The spatial differences in organochlorine residue levels in *P. viridis* collected from several locations along the coastal wa-

**Table 8.** Butyltin concentrations (ng/g dry weight) in sediments collected from coastal areas of Thailand in 1995 (Kan-Atireklap et al., 1997).

| Location | n | MBT | DBT | TBT | BTs |
|---|---|---|---|---|---|
| Coastal mariculture sites | 3 | 33 | 12 | 39 | 84 |
| | | (17–77) | (2–21) | (4–81) | (13–130) |
| Fishing boat piers/ports | 11 | 93 | 94 | 233 | 420 |
| | | (9–300) | (9–450) | (9–880) | (30–1,630) |
| Fishing boats/mariculture sites | 2 | 16 | 34 | 50 | 100 |
| | | (8–24) | (2–66) | (7–93) | (17–183) |
| Offshore vessel harbors | 4 | 254 | 930 | 3,009 | 4,193 |
| | | (7–410) | (9–1,900) | (36–4,500) | (52–6,500) |

n=number of sampling sites; figures in parentheses indicate range
BTs=MBT+DBT+TBT

**Table 9.** Imposex in gastropods from the Upper Gulf of Thailand ( Swennen et al., 1997).

| Location | Distance to nearest shipping route (miles) | Gastropods species | % Imposex |
|---|---|---|---|
| Ban Ampur, Chonburi | 13 | Murex sp. | 17 |
| (12°48'N, 100°53'E) | | *Hemifusus ternatanus* | 86 |
| | | *Babylonia areolata* | 87 |
| Tumbon NaJam, Chonburi (12°51'N, 100°53'E) | 14 | *Murex* sp. | 100 |
| | | *Cymbiola nobilis* | 27 |
| Bang Lamung, Chonburi (12°58'N, 100°48'E) | 7 | *Murex trapa* | 100 |
| Si Racha, Chonburi (13°10'N, 100°54'E) | 8 | *Bursa rana* | 100 |
| | | *Murex spo* | 100 |
| | | Nassarius livescens | 100 |
| Ko Sichang, Chonburi (13°11'N, 100°45'E) | 3 | *Phalium bisulcatum* | 33 |
| | | *Bursa rana* | 0 |
| | | *Murex trapa* | 100 |
| Ang Sila, Chonburi (13°20'N, 100°53'E) | 8 | *Murex trapa* | 94 |
| | | *Hemifusus ternatanus* | 60 |
| Samut Sakhon (13°17'N, 100°13'E) | 33 | *Babylonia areolata* | 0 |
| Cha-Am, Prachuap Khirikhan (12°46'N, 100°08'E) | 31 | *Babylonia areolata* | 0 |
| | | *Murex* sp. | 0 |

ters of Thailand suggested that these compounds were widely used in the country (Siriwong et al. 1991, Ruangwises et al. 1994, Kan-atireklap et al. 1997a). Although the agricultural usage of organochlorine pesticides, such as DDT and HCH, has been banned in Thailand, their current sources still remain in the aquatic environment.

Besides being used in industries, one of the major PCB sources in Thailand is transformers and capacitors imported by the Electricity Generation Authority of Thailand. Watanabe et al. (1996) documented PCB pollution in the dumping site of transformers and capacitors located at suburb Bangkok (nearby the Chao Phraya River estuary). This fact raises a concern on the possible increase of PCB pollution in Thailand. The recent analysis of POPs in mussels is shown in Table 10.

## Petroleum hydrocarbons

A number of oil spill incidents have occurred in Thai waters since 1970's. Oil accumulation and contamination in the Gulf of Thailand is noticed mostly in waters near densely populated areas such as big cities, rural developments and coastal-based industries, which discharge effluents containing oily wastes. Oil transport by ships may also have direct effects on marine and coastal resources. Marine oil pollution from tankers is due to operational discharge of oily ballast water and/or tanker washings, and tanker accidents like groundings or collisions.

Wattayakorn (1997 and 1998) reported chronic petroleum hydrocarbon contamination in coastal waters. Pollution was believed to originate primary from the discharge of oil from small coastal boats, *via* urban, industrial, refinery and sewage effluent. Additional oil contamination could also originate from maritime transportation of crude and refined

**Table 10.** Mean and range concentrations of organochlorine residues (ng/g wet wt.) in green mussel (*Perna viridis*) collected from Thailand coastal waters (Kan-atireklap et al., 1997a).

| Year | n | PCBs | DDTs | CHLs | HCHs | HCB |
|---|---|---|---|---|---|---|
| 1994 | 7 | 4.1 | 8.7 | 1.7 | 0.08 | 0.06 |
| | | (0.17–12) | (1.3–38) | (0.3–5.9) | (<0.01–0.22) | (<0.01–0.09) |
| 1995 | 14 | 2.2 | 4.1 | 0.97 | 0.17 | 0.05 |
| | | (<0.01–20) | (1.2–14) | (0.25–3.5) | (<0.01–0.33) | (<0.01–0.12) |

n=number of sampling sites

**Table 11.** Dissolved/dispersed petroleum hydrocarbons (DDPH) in coastal waters ((g/L chrysene equivalents).

| Year | Area | Range | Mean | s.d. | N | References |
|---|---|---|---|---|---|---|
| 1994 | Upper Gulf | 0.20–8.26 | 3.07 | 2.99 | 16 | |
| | ESB | 0.05–11.8 | 1.38 | 1.68 | 162 | |
| 1995 | Upper Gulf | | | | | |
| | −500 m | 0.07–76.2 | 3.00 | 12.0 | 42 | Wattayakorn et al., 1998 |
| | −3000 m | 0.12–25.3 | 1.97 | 5.33 | 40 | |
| | ESB | 0.14–10.0 | 1.37 | 1.72 | 36 | |
| | Lower Gulf | 0.01–12.0 | 2.45 | 3.38 | 16 | |
| | Andaman Sea | 0.06–2.64 | 0.25 | 0.51 | 26 | |
| 1996 | Lower Gulf (offshore) | 0.05–4.13 | 0.68 | 1.08 | 77 | Wongnapapan et al., 1999 |

oil through the region, as a result of the discharge of ballast water from tankers. The overall mean for DDPH in the Gulf of Thailand was 1.54 $\mu$g/L in 1994 and 2.1 $\mu$g/L in 1995 (Wattayakorn et al. 1998). The background value of DDPH, using upper quartile as the threshold limit of natural variation, was found to be 1.2 $\mu$g/L, which already reflects permanent contamination of the Upper Gulf. Thus, low-level hydrocarbon pollution to some degree occurs all the time in the Upper Gulf and the Eastern Sea Board. In these areas 75% of the time low-level oil contamination occurred at the coastal sampling stations and about 25% of the stations showed evidence of chronic pollution. Additionally there were occasional acute pollution events. The Upper Gulf and the Eastern Sea Board coastal waters are thus measurably affected by oil pollution.

Sediment samples along the coastal areas showed n-alkanes ranging from $C_{15}$–$C_{33}$. The patterns of n-alkane distributions and other indices i.e. pristane/phytane, Unresolved Complex Mixture (UCM) and Carbon Preference Index (CPI) indicated that aliphatic hydrocarbon accumulation in the sediments were from both natural and anthropogenic origins.

**Polycyclic aromatic hydrocarbons (PAHs)**

Oil is a major source of PAHs, a class of chemical carcinogens, mutagens, and teratogens suspected of being significantly toxic to estuarine and marine organisms. PAH compounds also originate from a number of other anthropogenic sources, such as municipal and industrial wastewaters, urban and suburban runoff, fossil fuel combustion and waste incineration as well as creosote and asphalt production. Atmospheric deposition of PAH compounds derived from incomplete combustion of organic matter, especially in the high temperature range, is also an important input to the marine environment. PAHs were studied in sediments from the Gulf of Thailand (Suthanruk 1991, Sarin 1994, Tappatat 1995, Chumchuchan et al. 1999, Wongnapapan et al. 1999). The data indicated that the levels found were not high when compared to other contaminated regions of the world, though some hot spots were found near port and harbor areas (Table 12). Dominant PAHs found included naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, pyrene, benzo(a) pyrene, chrysene, dibenzothiophene, 2-methylphenanthrene, benzo(ghi)perylene. Analyses have also confirmed the widespread occurrence of PAHs in estuarine and coastal marine organisms of Thailand (Table 13).

## Conclusion

The marine environmental problems face by Thailand is very similar to that face in other parts of South-east Asia. Population growth, watershed development, and industrial expansion have all contributed significantly to the array of environmental problems in the Thai waters. However, marine pollution levels have been reported to be acceptable despite

**Table 12.** Total PAH concentrations in surface sediments from the Gulf of Thailand.

| | |
|---|---|
| Estuaries: | range: 263–4,710 ng/g DW<br>mean: 1,535 ng/g |
| Coastal areas: | range: 11–1,992 ng/g DW<br>mean: 506 ng/g |
| Offshore areas: | |
| · Upper Gulf | range: 39–95 ng/g DW<br>mean: 70 ng/g |
| · Eastern Seaboard | range: 11–324 ng/g DW<br>mean : 79 ng/g |
| · Lower Gulf | range: 14–67 ng/g DW<br>mean: 51 ng/g |

**Table 13.** Total PAHs in estuarine and coastal marine organisms of Thailand.

| | |
|---|---|
| Green mussel (*Perna viridis*): | range: 24–61 ng/g DW<br>mean: 34 ng/g |
| Oyster (*Ostrea plicatula*): | range: 3–16 ng/g DW<br>mean: 7 ng/g |
| Scallop (*Amussium pleenronectes*): | range: 3–8 ng/g DW<br>mean: 5 ng/g |
| Beach clam (*Donax* sp.): | range: 1–124 ng/g DW<br>mean: 43 ng/g |

the large population of people and the intensity of usage. The studies indicated that the pollutant levels found were not high when compared to other contaminated regions of the world, though some hot spots were found near industrial sites, port and harbor areas. Although marine pollution levels have been reported to be acceptable in Thai waters, management measures to minimize pollutant loading are needed to reduce long-term risk to the marine environment. Additionally, there are significant data gaps that must be filled to improve scientific understanding of the system, such as information on certain coastal and estuarine processes and the cumulative environmental effects of pollutant loadings on these processes. Additional data are also needed on the acute and chronic effects of contaminated sediments on benthic communities and other organisms, so that ecological risk assessment in coastal and estuarine environments can be achieved. Uncertainties about biological responses to various pollutants limit the effectiveness of future management controls on the coastal and estuarine systems.

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