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Gulf of Thailand

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1. Introduction

The Gulf of Thailand is one of 21 enclosed coastal seas as identified by the International EMECS Center. The gulf locates in Southeast Asia, immediately to the west of the South China Sea. Its boarding nations, Thailand, Cambodia, Malaysia, and Vietnam. Millions of people derive their livelihoods from fish and mineral resource produced from the gulf, and millions are affected by the change in the gulf environment.

This article consists of two parts. The first part reviews the physical, chemical, and biological properties of the gulf, The second part reviews environmental issues of the gulf, including, eutrophication, mangrove conversion and destruction, coastal erosion, contamination of toxic wastes, and marine litter.

2. Physical, Chemical, and Biological Properties

The Gulf of Thailand (Figure 1) extends northwest from the southern part of the South China Sea. It is approximately 835 kilometers long on its northwest axis. The maximum width is approximately 555 kilometers. The mouth of the gulf, as indicated by the dotted line, is about 370 kilometers. The Gulf of Thailand covers an area of approximately 350,000 km^2.

Being a part of Sunda Shelf, the gulf is relatively shallow, with a mean depth of approximately 45 meters and a maximum depth of approximately 80 meters. The deepest part is located in a central basin between latitude 9°N and longitude 101° and 102°E. This deep basin extends northward to the vicinity of Ko Chang off Sattahip, Rayong province, and is separated from the South China Sea by two ridges. One of these ridges extends southwest from Cape Camau at various depths of less than 25 meters for more than 110 kilometers and the other extends northeast off the Thai-Malaysian border for a distance of 167 kilometers at various depths of less than 50 meters. Between these two ridges, there exists a deep channel with a sill depth of 67 meters (Robinson, 1974).

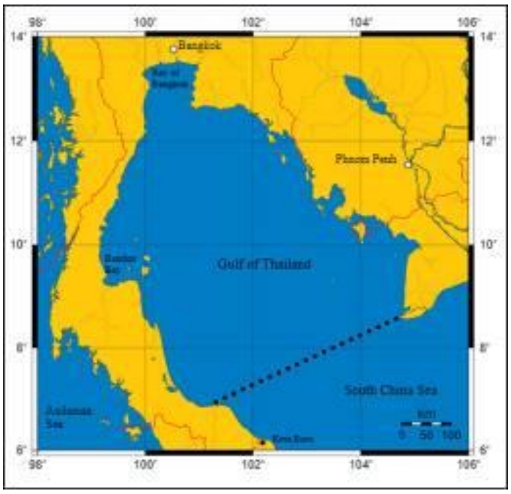

Figure 1 Gulf of Thailand.

Source:https://upload.wikimedia.org/wikipedia/commons/b/b7/Gulf_of_Thailand.svg

Another general characteristic of the gulf, which is typical of the Sunda Shelf, is the lack of an extensive distribution of coral reefs like those in Philippines waters. The corals that exist are located around some small island in the gulf, usually far from the coast.

The Gulf of Thailand is an integral part of the Asian Continent. The sediments deposited on the bottom of the shelf are largely muddy, with sandy components brought in during the Pleistocene. Studies of the sediments at different parts of the gulf during a series of exploratory trawling and resources surveys carried out by the Department of Fisheries revealed that the bottom was covered with ooze, or mud mixed with sand or shells (Pasuk, 1969 ; Ritraksa, Thamaniyom and Sittichaikasem, 1968). The bottom of the inner gulf, into which four rivers drain a considerable amount of sediment annually, is covered with loose mud. In the central basin, where the sediments are deposited, the bottom is again covered with soft mud.

Robinson (1974), in summarizing the results of the NAGA Expedition, concluded that the gulf is a two-layered shallow water estuary. This means that low salinity water which has been diluted by rainfall and freshwater runoff flows out of the gulf at the surface, while high salinity and relatively cooler water from the South China Sea flows into the gulf over the 67-meter sill at the mouth of the gulf. Various forces arising from monsoon winds, heavy precipitation and tidal currents create complex circulation in the gulf. There exists localized areas of divergence of upwelling, downwelling or convergence of waters.

Robinson (1974) further observed that the general circulation and physical properties of the water mall varied to some extent both during seasonal periods, and that the monsoon winds play a major role influencing the circulation in the Gulf of Thailand. In the inner gulf area where four major rivers drain, there is a rapid confluence of river and gulf waters.

The southwest monsoon, starting in March or April, is usually well established in May and ends in September. This wind, after having blown across the India Ocean and the Bay of Bengal, brings rainfall to Thailand, Cambodia and Vietnam between July and October. October is the lull between the southwest and the northeast monsoons. From November to February, the northeast monsoon winds, after having blown across the continent, bring low-moisture, cool air to Thailand and over the gulf. March and April are the inter-monsoon months.

In general, surface salinities in the gulf are between 30.5 and 33 parts per thousand (ppt). Salinities at the deepest part of the central basin, where South China Sea water flows in, are higher ranging, i.e., between 33 and 34 ppt or above. Low oxygen concentrations (less than 2.5 mg/l) and high salinity of surface water in certain areas indicate localized areas of divergence or upwelling. Likewise, high oxygen concentrations and low salinity found at lower depths indicate localized areas of convergence or downwelling.

From a study of horizontal charts of temperature, salinity and sigma-t, it was concluded that in October the surface water flowed into the gulf in a counter-clockwise direction, i.e., inflow along the east coast and outflow along the west coast of the gulf; while at the central part, there was sluggish circulation. During the peak of the northeast monsoon, water of low temperature and high salinity moved into the gulf around Cape Camau, but did not penetrate deep into the gulf; instead, the water flowed out of the gulf, slightly west of its mouth. During the peak of the northeast monsoon (August), there was a strong flow into the gulf along the east coast. The survey carried out during 1970 and 1971 by H.T.M.S. Chanthara of the Hydrographic office of the Royal Thai Navy indicated that there was an intrusion of water mass from the South China Sea along the western coast of the gulf and an outflow of less saline, but cooler, water along the eastern coast of the gulf (Pongsapipatt and Sapsomwong, 1973).

The circulation in the inner gulf was influenced more of less by tidal currents and the circulation of surface water was clockwise in direction at the beginning and at the end of the year (during the northeast monsoon period) and counter-clockwise in the middle of the year (southwest monsoon period). The average surface salinity was 27.1 to 29.8 ppt. In estuaries during the peak of freshwater runoff (November to December), the salinity was quite low. Oxygen concentration at the surface was more than 4 mg/l but at the bottom it was very low, being 2.9 mg/l or less. The concentration of phosphate varied from 0.1 to 0.9 g-at P/1 and of nitrite from 0.05 to O. 14 ug-at N/1. The increasing trend of biochemical oxygen demand (BOD) in this area indicated that the water quality was becoming increasingly poor.

The amount of plankton, ranging from 200 to 1,000 ml/1,000 m^3, indicated that the inner Gulf of Thailand is one of the most productive areas of the world. The peak of the abundance of plankton was found to be in December. High plankton concentration areas are located in the inner Gulf of Thailand, at the estuaries of the four rivers and along the upper west coast of the gulf. Along the west coast of the gulf, plankton was most abundant during March to August. Hence, off the west coast several species of fish spawn, and their larvae and young feed in this area until October, when they move to a new feeding ground in the inner Gulf of Thailand.

The upwellings off the west coast, especially in the gulf waters off Prachuab Kiri Khan and Chumphon province, have a very beneficial effect on fishery resources, because of the resulting high levels of nutrients in the area. The Department of Fisheries found that this area is the spawning area and larval rearing area of pla tu, or the Indo-Pacific mackerel (*Rastrelliger neglectus*), a staple item in the Thai diet.

The high productivity of the inner Gulf of Thailand was also revealed by a study on the primary production of the waters there. Luasinsap (1979) reported that the average primary production rate of sampled waters in the inner gulf was 3.15 g-C/m^2/day in 1978 and 3.45 g-C/m^2/day in 1979.

3. Environmental issues

Environmental issues in the gulf area generally caused by two groups of activities, i.e. land based and sea based. Land based activities include coastal urbanization, industrial development, agriculture, aquaculture, drainage basin modification, and tourism. Sea based activities include seabed exploration and exploitation, rises of petroleum and other toxic chemical transportation.

This paper addresses 5 marine environmental issues.

(1) Eutrophication

Among the four rivers draining to the inner gulf, the Chao Phraya is the most polluted, particularly in the river estuary area, due to the urban and industrial expansion, The Ta Chin is becoming increasingly polluted due to accelerated industrial and agricultural development, as well as urban expansion from Bangkok area. The Mae Klong used to be subjected to severe water pollution problem in the past, but now the problems are being remedied by a proper management system. The Bang Pakong used to be the least affected by pollution. However, the installation of the thermal power plant at the lower reach may have altered the ecosystem of the estuarine area.

The major pollutants of the rivers are degradable organic wastes. The common effects are increased oxygen demand, input of pathogens, increased turbidity, the enrichment of nutrients or in another word "eutrophication". Since the upper gulf is semi-enclosed, the wastes drained from the mentioned rivers tend to retain and accumulated. Decomposition of the wasters results in the problem of eutrophication. Eutrophication can cause explosive bloom of algal; sometime it is called "red tides".

Noctiluca scintillans and *Trichodesmiun erythraeum* were the two species of phytoplankton which frequently bloom in the inner gulf (Suvapepant, 1995). *Noctiluca* usually changed the apparent color of water into dark green. Sometime it is called "green tides". This kind of plankton is not toxic fish and shellfish but the dense bloom can result in an anoxic condition. Besides, the decomposition of the dead cells would release large amount of ammonia into the water and affect the marine animals in the area. The bloom of *trichoesmiun* will change the apparent color of seawater into yellow-green color and later change into red-brown. Similar to *Noctiluca*, blooms of *Trichodesmium* results in anoxic condition (Suvapepant, 1995)

Bloom of diatoms could occur as a result of eutrophication. The diatom blooms recorded in the inner gulf were *Cosinodiscus*, *Rhizosolenia*, *Hemidiscus*, *Chetoceros*, and *Ceratium*. In January 2000, *Ceratium furca* bloom in the Chao Phraya estuary covered a vast area and change the apparent color into red.

According to Suvapepant (1995), 43 major red-tide were recorded during 1988-1995. Twenty-one red tides were caused by *Trichodesmium*, 17 were caused by *Noctiluca* and the rest by diatoms. It was fortunate that most of the red-tides were associated with anoxic condition. There was only one incidence of toxic condition. In May 1983, paralytic shellfish poisoning (PSP) caused illness in sixty – three people and one died after consuming the contaminated mussels in the red-tide area of Pranburi estuary. Nevertheless, the specific plankton, which was the causative agent of this PSP, could not be confirmed.

The anoxic condition of algal bloom could cause a massive fish killed. In August 1991, there was a mass fish kill in the coastal area of Chonburi. This incidence was due to a vast bloom of *Noctiluca*, covering the area from Bangsan district to Pattaya.

In order to solve the eutrophication problem in the coastal areas, the governments provide a large amount of funds for setting up waste treatment systems for coastal cities. Besides, Laws and regulation were revised and enforced. Research, development and engineering in the field of pollution control was also strengthen. Nowadays the situation is significantly improved. The "Green Tide" problems reduced to less than 10 days a year in the inner gulf.

(2) Mangrove Conversion and Destruction

Mangrove conversion and destruction has occurred in many countries. Several categories of human activities cause mangrove losses, for instance:

1. Conversion of mangrove to other uses including agriculture such as rice, coconut agriculture ponds for fish & shrimps, salt evaporation

ponds, urban sites, landfills, and industrial development.

2. Over-exploitation of mangrove for lumber, fuel wood, and charcoal.

3. Insufficient mangrove recovery or re-planting following clear-cutting for wood products.

Many of these conversion or losses are reversible through appropriate restoration. Losses due to industrial or community development and salt production are not easily reversible. Most recently, resource managers, politicians, business people and the general public become more aware of over-all mangrove values. This awareness has resulted in legislation and enforcement for mangrove protection. Emphasis is now on mangrove preservation and sustainable uses rather than on mangrove conversion. Mangrove destruction still occurs, but mangrove loss rate are much less, and in some cases have been reversed. Thailand's experience is an example of such a reversal.

Mangrove forest area in Thailand decreased sharply during 1961-1986. Since then, the rate start to slow down. The reversal started after 1996. At present, the percentage increase from 1996 is 51%. (Table 1).

Year	Mangrove Area (Ha)	Change in Mangrove Area Percentage (Period)
1961	367,900.00	-
1975	312,700.00	-15.00
1979	287,308.00	-08.12
1986	196,453.84	-31.62
1989	180,559.04	-08.09
1991	173,820.96	-03.74
1993	168,682.96	-02.96
1996	167,366.88	-00.78
2000	252,726.24	+51.00
2004	233,307.84	-07.68
2009	244,441.76	+04.77
2014	245,533.44	+00.45

Table 1. Mangrove areas in Thailand between 1961 – 2014. Sources : Fast and Menasveta (2003) and Department of Marine and Coastal Resources (2017)

There was a reason to believe that shrimp farm might be one of the important causes for mangrove conversion during 1961-1986 because extensive shrimp farming was practiced. This method for farming required large pond area without seeding and feeding. Since 1986 we introduced intensive shrimp farming with seed stocking, feeding, and aeration, requiring smaller ponds. The pond could be constructed behind mangrove area. This resulted in higher shrimp production but less use of mangrove area. So shrimp production increased concurrently with the mangrove area. (Figure 2).

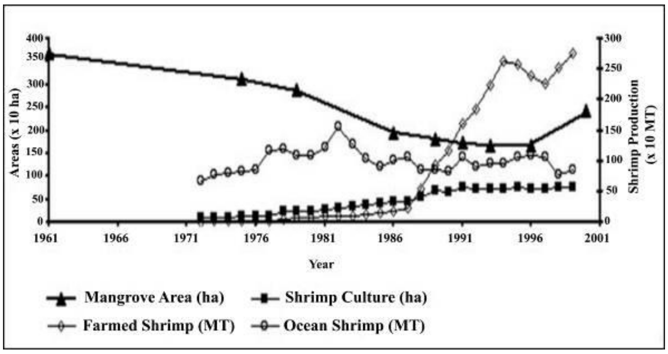

Figure 2 Total mangrove areas, shrimp pond area, ocean-caught production and farmed shrimp production in Thailand during 1961 and 2001.
Soure: Fast and Menasveta (2003)

Increase of mangrove area was due to public awareness that mangrove value extend beyond the mangrove themselves, and that further mangrove destruction is unacceptable. This public awareness is reflected in Thailand's legislation and enforcement of laws and regulation concerning mangrove uses. As an outgrowth of public awareness and legislation, there have been active programs of mangrove reforestations by public and private sectors.

(3) Persistent Chemicals

A number of studies on the distribution and concentration of persistent chemicals like organochlorines and heavy metal were documented. Most of them were still within the acceptable limits except two heavy metals namely lead (Pb) and mercury (Hg).

Lead was reported to heavily contaminate biota in the upper gulf during late 70 decade (Polprasert et al. 1979; Menasveta and Cheevaparanapiwat, 1981). The Contamination was presumably due to contaminated run off. Approximately one ton of lead per day was released into the atmosphere of Bangkok through car exhausts. The problem was resolved after the government ban the use of leaded – gasoline.

Fishes in the off shore area in the vicinity of natural gas platforms in the middle of the gulf exhibited higher mercury concentration (ARRI, 1998). Between 5-10% of fishes at Erawan and Funan platforms had mercury concentration higher than 0.5 ug g^{-1}. This concentration is the maximum permissible concentration in fish set by the FAO. The biological magnification of mercury was reported by several researchers (Menasvera, 1976; Cheevaparanapiwat and Menasveta 1979; Boonyachotmongkol *et al.*, 1987). Fish of the higher trophic levels bore higher residue than those in the lower trophic levels. This suggested that mercury might be concentrated in the same manner as organic compounds such as organochlorines compounds, i.e. passed through and amplified by the food chain.

A positive linear relation between size and mercury content of fish is well documented (Cheevaparanapiwat and Menasveta 1979; Menasveta 1990). However, for low levels of mercury in fish (below 0.2 μg g^{-1}) no increase, or a very moderate increase in mercury content was found to occur as fish weight increased. As the level of mercury increased, the mercury level in relation to the weight increased noticeably. At extremely high levels of mercury, caused by manifest contamination, no relation to age or weight was found. This indicates that there is a threshold level of mercury in the environment, above which fish cannot eliminate mercury from their muscular tissues faster than it is incorporated and accumulation thus occured. This relationship also indicates that fish are adapted to a mercury concentration of less than 0.2 μg g^{-1}. All past data indicated that the maximum natural concentration in fish is 0.2 μg g^{-1} or less. It should be noted that 23.3% of fishes caught in the vicinity of the natural gas platform in the Gulf of Thailand had mercury above 0.2 μg g^{-1} (ARRI, 1998).

In order to prove that mercury contamination in the middle of the outer gulf was due to natural gas production, an investigation was made by comparing mercury in fish caught from the natural gas production area and the coastal areas, including from the Andaman Sea. It was found that mercury in cobia (*Rachycentron canadus*) in the area of the natural gas production was significantly higher than the concentrations detected in cobia of the coastal areas and the Andaman Sea (Pongplutong, 1999).

With the formentioned finding, Thailand Environmental Authority asked the concessional company to make a corrective measure and a long-term monitoring program. The company set up the hydro-cyclone device to separated mercury from the brine before discharging the brine into the sea. Furthermore the deep well injection of the contaminated brine into the spent wells at the seafloor was practiced. Monitoring results after the control measure was exercised showed a gradual decrease of mercury concentration in fishes near to the baseline level of 0.2 μg g^{-1}. The percentage of fish having mercury concentration exceed the safety limit of 0.5 μg g^{-1} were also decreasing.

(4) Coastal Erosion

The coast at the head of the upper Gulf of Thailand which is approximately 150 kilometer long, comprises the coast of Samut Songkram, province, Samut Sakhon province, Bangkok, Samut Prakan province, and Chacheng Sao province. The coastal zone in these areas contain sediment from the four major rivers and form a soft and muddy shore. Some part of it is subjected to severe erosion and resulting in the loss of land area. The overlay technique has been used in the study to determine the areas of accretion and erosion by comparing the historic shoreline from the topographic map and the Landsat TM data of the year 1976, 1987 and 1997 which represents the condition of the shoreline of each periods (Jarupongsakul, 2005a). The results of the study revealed that there were many evidences of the coastal impact along the upper Gulf of Thailand. Very severe erosion with rates of more than 25m per year occurs on the west coast of the Chao Phraya river mouth. High erosion with rate between 10-25 m per year occured on both sides of the Chao Phraya river mouth. The shoreline at the head of the upper gulf was suffered from the attack my waves from the south with the maximum eroded distance of

Figure 3. Coastal erosion along the coast of the upper Gulf of Thailand. (units: meter per year).

1 kilometer from 1967 to 1997 in the west coast of Chao Phraya river mouth. Human intervention affecting coastal erosion in the upper Gulf of Thailand has taken place over the past 30 years. The wide scale land subsidence increased the severity of coastal erosion along the upper Gulf of Thailand. (Jarupongsakul, 2005b). Rising sea level is another factor than increase the erosion. The problem of coastal erosion is still growing.

(5) Marine Litter

Marine debris has long been a problem, and has grown out of control since the introduction of packaging in the middle of 20th century (STAP 2011). Every year, 280 million tonnes of plastics is produced globally, and more than 10 to 20 million tonnes of plastics is finding its way into the oceans (UNEP 2016). Only small percentage is recycled (UNEP 2016). The problems of marine debris are now recognized internationally along with other major global issues such as global warming, coastal erosion, overfishing (STAP 2011; UNEP 2016). Marine debris can cause impact on ecosystems, fisheries, aquaculture, human health, and food safety. Incidents of entanglement and ingestion have been widely reported for a variety of marine mammals, reptiles, and birds that lead to chronic injury and death (Allen et al 2012; Campani et al 2013; Thevenon et al, 2014). Marine debris is also obviously found in shallow coral reefs through the influence of winds and tidal currents, which cause the extensive damage to reefs (Valderrama Ballesteros et al 2018). In Thailand, varieties of coastal debris can be found along the coastlines, and the coastal debris distribution is related to economic activities in the areas (Thushari et al 2017a). Majority of coastal debris found include plastic bottles, caps, lids, food and beverage containers, rubber bands, and cigarette buds (Thushari et al 2017a). At present, unfortunately, Thailand has been ranked as the sixth worst contributors of marine debris in the world (Jambeck et al 2015). Jambeck et al (2015) estimated that top contributors to plastic marine littler were from middle-income countries.

Another emergent issue related to marine debris is microplastics. Microplastics are small pieces of floating plastics in the ocean (sizes range between 1 nm to < 5 mm) (GESAMP 2015). Microplastics can be divided into primary and secondary microplastics. Primary microplastics include micro-beads and nanoparticles used in a variety of industrial processes and household wastewater while secondary microplastics result from the fragmentation and weathering of larger plastic items (GESAMP 2015). Recently, microplastics have been observed in many commercial fishery species including fish, mussels, clams, crabs, and shrimps (Li et al 2015; Rochman et al 2015; Thushari et al 2017b). In Thailand, there was a report of accumulations of microplastics in oysters, barnacles, and snails, but the concentrations were not as high as other countries yet (Thushari et al 2017b). However, the presences of microplastics in seafood can pose a threat to food safety (GESAMP 2015; Thushari et al 2017b).

At present, awareness and implementation of the best practices in addressing the causes and solutions of marine debris and microplastics are focused by both governmental and non-governmental sectors. At Special ASEAN Ministerial Meeting on Marine Debris in March 2019 in Bangkok, the government of Thailand has made a commitment to reduce marine debris by at least 50% by 2027. The government has also established Plastic Material Flow Database throughout the country. In addition, reduction of marine debris has been added for 20-year plan (2017-2036) for marine ecosystem management in Thailand.

Effective management programs for the plastic pollution are urgently needed in Thailand. In addition, monitoring of microplastic accumulation in marine organisms and seafood in Thailand should be carried out to ensure the safety conditions of environmental and human health. Moreover, effective training and educational tools for disseminating marine debris and plastic pollution awareness in Thailand needs to be implemented. To accomplish and reduce marine waste, a strategic framework and management plan to change behaviours of local people to reduce plastic source pollution and reduce their consumption of single-use plastics and recycling plastics will also be necessary.

4. Conclusion

The Gulf of Thailand is one of the 21 enclosed coastal seas as identified by the International EMECS Center. The gulf locates in Southeast Asia, immediately to the west of South China Sea. Its bordering nations, Thailand, Cambodia, Malaysia, and Vietnam. The gulf is roughly triangular and may be divided into two sections, i.e. the "inner gulf" and the "Gulf". The inner gulf is a small apex of the Gulf of Thailand. The average depth of the inner gulf and the gulf is 20 m. and 45 m, respectively. The water circulation of the gulf is influenced by the flux from South China Sea and the monsoon winds. The Gulf of Thailand is one of the most productive areas of the world.

During the past four decades, there have been a number of environmental issues mostly occurred in the inner gulf. These issues are, for instance eutrophication, mangrove conversion and destruction, coastal erosion, contamination of toxic wastes, and marine litter. Eutrophication used to be a problem during 1978 – 1983. At present the problem was alleviated. Mangrove forest area decreased sharply during 1961-1986. Since then the rate start to slow down. The reversal started after 1996 due to a big restoration campaign. At present, the percent increase from 1996 is 51%. The problem of coastal erosion is still growing. One important factor to this problem is the rising sea level, the global issue. Contamination of toxic wastes especially lead (Pb) and mercury (Hg) used to be a problem, but now it is under controlled. Marine litter has received a lot of attention recently, especially the plastic debris. Several campaigns have been exercised for the clean-up.

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