Comparison of Organic Matter Distribution Patterns in the Gulf of Thailand over the Past Two Decades

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ABSTRACT

Distribution and accumulation of organic matter are key factors to understanding coastal ecosystem health, and hence long-tern monitoring of their patterns could provide useful data for appropriate coastal management. This study examines water content (WC), total organic matter (TOM), total organic carbon (TOC) and total nitrogen (TN) in the Gulf of Thailand, and then compares these values to a study from 1995. Sediments from the Gulf of Thailand were collected using a gravity corer between 14 March and 12 April 2012 from onboard a fishery research vessel (M.V. SEAFDEC). High values for TOM and WC were found for surface sediments at 0-0.5 cm depth in three major areas of the Gulf of Thailand including the eastern inner gulf near Chang Island, the western gulf near Samui Island, and the southern lower gulf. Horizontal distribution patterns of TOM in surface sediment were almost the same as in the 1995; however, average TOM content increased by 35 %. Distribution patterns of TOC and TN were similar. High values for TOC were observed in the eastern inner gulf near Chang Island and in the western area near Samui Island, while average TOC and TN content increased by 47.08 % and 1.09 %, respectively. Statistical analysis confirmed that TOC content of surface sediments in the Gulf was significantly different ($p<0.05$) between 1995 and 2012. Overall, results indicated a marked increase of TOM in sediments of the Gulf of Thailand over the past two decades, highlighting current eutrophication problems.

Keywords: Gulf of Thailand, Organic matter, Sediment, Total nitrogen, Total organic carbon

INTRODUCTION

The Gulf of Thailand is a semi-enclosed tropical sea located between latitudes 5º 00’ and 13º 30’ N and longitudes 99º 09’ and 105º 00’ E with an area of 350,000 km^2 and 1,980 km of coastline. The Gulf is continuously contaminated by both indirect and direct discharges of domestic wastes and untreated industrial wastes passing through canals and rivers within the watershed and urban areas. Four main rivers, namely the Chao Phraya, Mae Klong, Tha Chin and Bang Pakong discharge total suspended solids into the inner gulf at an estimated 6.32 million tonnes per year with sedimentation rate as high as 0.8 cm per year (Srisuksawad *et al*., 1997).

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Large areas of mangrove forests have been cleared for shrimp pond construction during the last three decades. Huge amounts of effluents from shrimp farming have been discharged into the aquatic environment and eventually reach the Gulf. This human activity has caused nutrient concentrations to increase in coastal seawater in the Gulf of Thailand. Uncontrolled discharge of organic pollutants from industries and cities have also caused marine pollution in coastal and estuarine areas, which has impacted fisheries and coastal aquaculture activities (Suvapepun, 2003). High quantities of terrestrial materials are transported into the Gulf of Thailand study area (Meksumpun *et al*., 2005).

Normally, sedimentary organic matter is derived from organic-rich wastes of human origin as well as natural sources. Sediments containing high organic matter are important food and energy sources for organisms in the Gulf. Sediments in many zones have already become a significant sink of organic matter under biological, chemical, and physical interaction processes (Bouillon *et al*., 2002). Several authors have revealed that carbon and nitrogen are the most important elements for nutrient material transfer and energy flow in sediment-vegetation systems (Chmura *et al*., 1987; Gao and Jia, 2004; Zhou *et al*., 2007). Total organic carbon (TOC) is defined as the amount of organic matter preserved within the sediment. Sediment nutrients are assessed as total nitrogen (TN) concentration with inorganic as well as organic sources. Atomic ratios of TOC and TN in sediments have been used to track sources of organic matter as well as environmental change in coastal and estuarine ecosystems (Chareonpanich and Seurungreong, 1999; Choi *et al*., 2001; Wilson *et al*., 2005a; 2005b; Lamp *et al*., 2006; Liu *et al*., 2006; Kemp *et al*., 2012). Meksumpun *et al*. (2005) revealed that total organic matter (TOM) contained in surface sediments of the Gulf of Thailand was higher than 15 $mg \cdot g^{-1}$ in the eastern inner gulf and in the western area near Samui Island. Highest TOC content (17 $mg \cdot g^{-1}$) was found in the innermost areas and eastern middle gulf, with TN (below 3.00 $mg \cdot g^{-1}$) showing a similar distribution pattern to TOC. Mean TOM was less than 10 % on dry weight basis, with a maximum of 15.4 % and minimum of 3.1 %. Organic accumulation was observed in the central inner gulf and western area near Samui Island. Water content data reflected typical bottom characteristics as mainly composed of muddy deposits in the upper half and sandy deposits in the lower half of the gulf. Shi *et al*. (2015) noted that vertical profiles of water content (WC) in almost all cores indicated a gradual decrease as depth increased.

Here, carbon and nitrogen content and area-specific vertical and horizontal sediment distribution patterns of TOM and WC are presented. We also determine changes in the sedimentary environment of the Gulf of Thailand from 1995 to 2012 by comparing with our previously published data. Results from our study can be used as a data resource to increase understanding of the coastal marine environment in the Gulf of Thailand and the impending problem of eutrophication.

MATERIALS AND METHODS

Study area

The Gulf of Thailand is shallow, with maximum depth of around 80 m. Sediment samples were collected at 45 stations throughout the Gulf (Figure 1). The sampling area was split into three zones: upper section with Stations 1-9, middle section with Stations 10-36, and lower section with Stations 37-45. Surface water circulation in the Gulf shows seasonal variation. During mid-summer (April), a counter-clockwise eddy current appears to the north of Samui Island, Surat Thani Province, and in the lower inner gulf, while a clockwise eddy current exists in the upper inner gulf (Anukul and Mahunnop, 1998).

Water and sediment collection

Depth of water and salinity were measured using a CTD meter (Alec ASTU-1000M). A gravity corer with core tubes 85 cm in length and 6 cm inner diameter was used to collect two sediment cores at each sampling station in the Gulf of Thailand from the M.V. SEAFDEC between 14 March and 12 April 2012. At least 10 cm of sediment was collected in each core and split into 0-0.5, 0.5-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-9 and 9-10 cm depths. All sectioned sediment samples were immediately frozen at -60 °C until required for further analysis.

Sediment analysis

Sediment samples were measured for water content (WC), total organic matter (TOM), total organic carbon (TOC) and total nitrogen (TN). To determine WC, the samples were homogenized at room temperature before weighing about 2 g of wet sediment. Samples were then freeze-dried for 48 h and WC was calculated from the following equation:

Water content of sediment sample (%) = (dry weight after freeze-drying×100) / weight before freeze-drying

Determination of TOM was performed by measuring the weight loss of dry sediment after ignition in a muffle furnace at 550-600 ºC for 3 h. After the crucible had cooled down in a desiccator, TOM was calculated from the weight loss using the following equation:

Total organic matter (% dry weight) = ((weight loss after ignition×100)/sediment weight before heating)

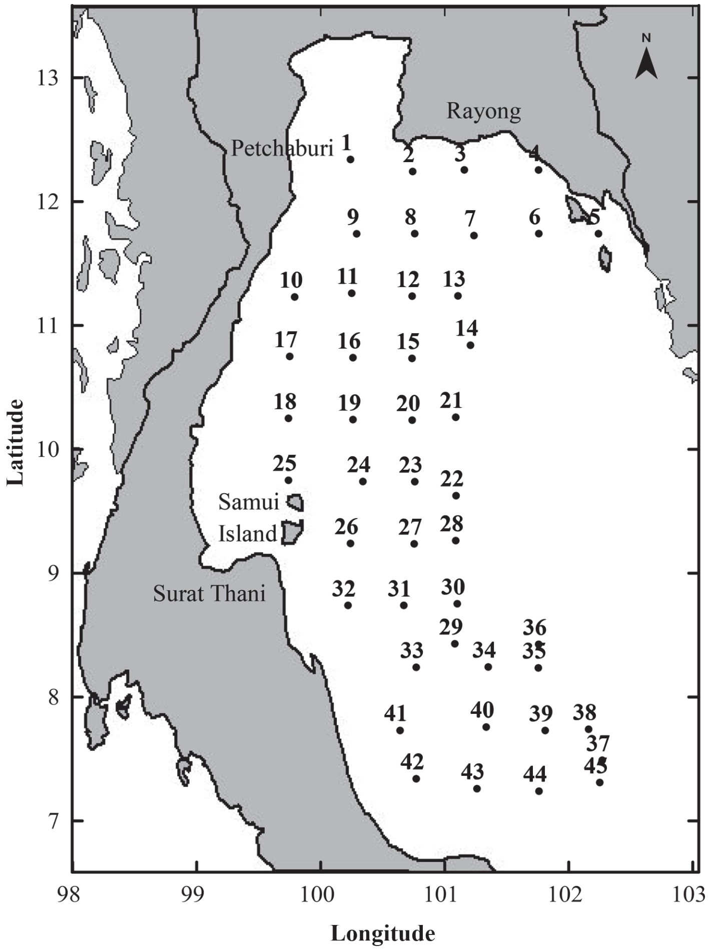

Figure 1. Sampling locations in the Gulf of Thailand.

To analyze TOC and TN content, samples of sediment were freeze-dried in the laboratory. Dried sediment samples were then ground and packed in silver cups. To remove carbonate, the sediment samples were treated with 1M HCl solution, then dried and repacked in tin cups prior to analysis. Total organic carbon and TN content were analyzed by an Element Analyzer (Carlo Erba, NA-1500). Measuring standards consisted of CO_2 gas produced from NBS 18 standard and N_2 gas produced from L-alanine.

Statistical analysis

Statistical analyses were preformed using the SPSS Version 11 (SPSS Inc.; Chicago, IL, USA) statistical software package. The means of sampled parameters were determined using descriptive statistics, and significant differences among sampling sites were found by analysis of variance, followed by use of the Mann-Whiney U test.

Relationships between TOM, TOC and TN in 1995 and 2012 were analyzed by using Spearman's rank correlation coefficient ($p<0.05$). Accordingly, TOM, TOC and TN in 1995 that coincided significantly with TOM, TOC and TN in 2012 were then illustrated by non-linear model using Trend Line Analysis of Excel (Version 13).

RESULTS

Water depth of the sampling area ranged between 20 and 73 m. The deepest area was at station 29, while the shallowest area was Station 25. Average depth across all sampling stations was 48.98±14.12 m. Contour lines of water depth are shown in Figure 2. Salinity ranged between 31.3 and 32.6 psu, with contour lines of salinity shown in Figure 3.

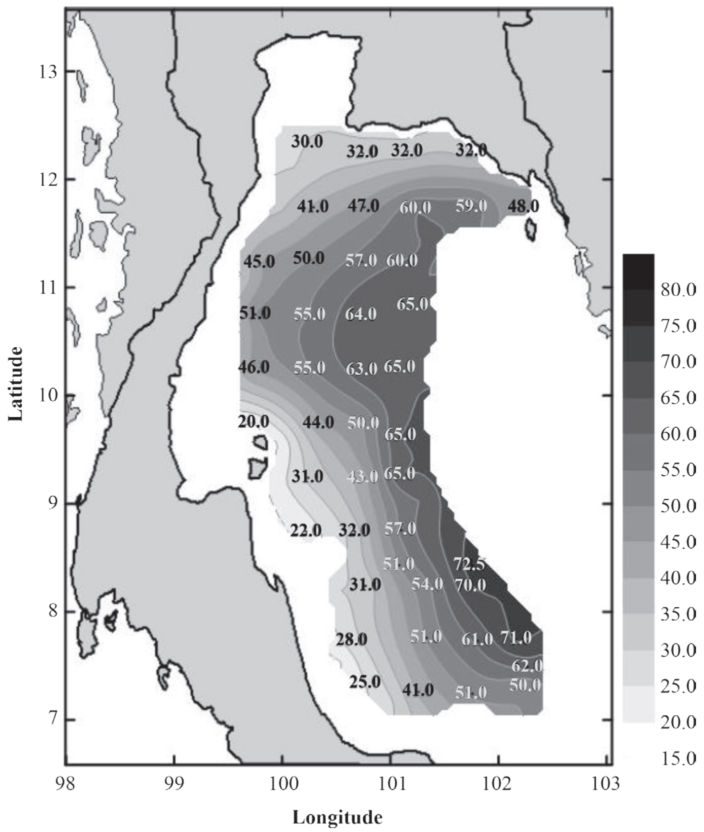

Figure 2. Depth contours (m) in the Gulf of Thailand.

Sediment characteristics

Sediment from the Gulf of Thailand was classified into two main groups, namely sandy mud (mud >50 %) and muddy sand (sand >50 %), as homogenized throughout the sediment columns. Sediments in the upper gulf (Stations 1-9) were mostly sandy mud while the most of lower gulf sediments (Stations 37-45) were muddier. Sediments in the central gulf were muddy sand with more mud than the eastern middle gulf (Stations 17-18). Sediments exhibited an oxidizing zone to a depth of 0.5 cm. Sediment around Samaesarn Island, Rayong Province (Station 3) was mainly composed of small shell fragments.

Water content

Water content in surface sediments (0-0.5 cm) in the Gulf of Thailand ranged between 34.26 and 78.02 %. Lowest WC was found at Station 2 (coastline of Chonburi Province), where the sediment was muddy sand with small shell fragments. Highest WC was found at Station 24 (near Samui Island, Surat Thani Province), where the sediment was muddy. Average WC in sediments from the Gulf was 61.33 %. Sediments in the upper gulf near the coastline of Rayong Province (Stations 4, 6, 7), central gulf (Stations 16, 17, 18, 19, 23, 24 and 25) and middle gulf near Samui Island (Stations 35, 37) all had very high WC of over 70 %.

Vertical profiles (0-10 cm) of WC in sediments at Stations 8, 24, 26 and 35 are shown in Figure 4 for comparison. Results indicated that WC in sediments at all stations gradually decreased with increasing depth to 4 cm, and three main patterns were noted in this zone among sites. Firstly, a rapid decrease in WC with sediment depth was observed for Station 35. Secondly, a slow decrease

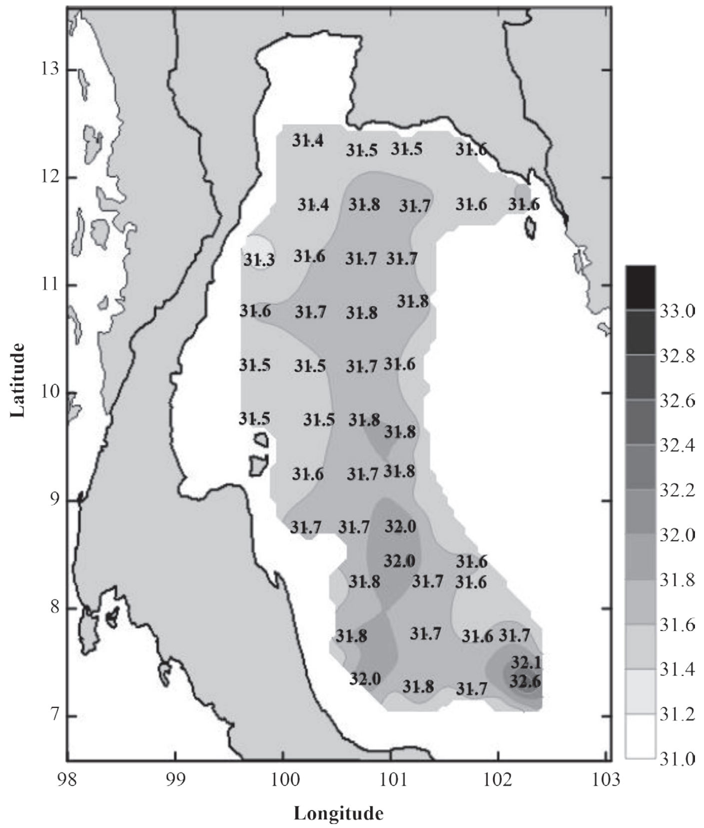

Figure 3. Salinity contours (psu) in the Gulf of Thailand.

with sediment depth was recorded for Stations 8 and 26. Lastly, WC remained almost constant with depth at Station 24.

Total organic matter

Total organic matter (TOM) in surface sediments (0-0.5 cm) in the Gulf of Thailand ranged between 4.74 and 18.55 % dry weight with average content of 11.42 %. Highest TOM was found at Station 7 (near Rayong coastline), where the sediment was muddy. Lowest TOM content was found at Station 1 (near Petchaburi coastline), where the sediment was muddy sand. Contours of TOM content in surface sediments indicated three areas higher than 15 % dry weight (Figure 5). The first was in the middle gulf near Rayong Province (Stations 6 and 7), the second was in the middle gulf near Surat Thani Province (Stations 24 and 25), while the third was in the middle gulf near the South China Sea (Stations 30 and 35).

Vertical profiles (0-10 cm) of total organic matter content at several sites are shown in Figure 6. Maximum TOM content was usually found in the top sediment layer. Vertical profiles generally showed one of three patterns of TOM content: stability throughout the entire column (64.4 % of sites), increase of TOM with increase in sediment depth (24.5 %), and decrease of TOM with increase in depth (11.1 %). Changes in TOM content of almost all sediment columns occurred between depths of 0-5 cm, and then remained relatively constant in the deeper layers.

Organic carbon and total nitrogen content

Distribution of total organic carbon content of surface sediments (0-0.5 cm) in the Gulf of Thailand is shown in Figure 7. Values for TOC ranged between 3.26 and 27.10 mg·g^{-1} dry weight, with an average of 9.46 mg·g^{-1}. However, carbon content in this area was generally higher than 15

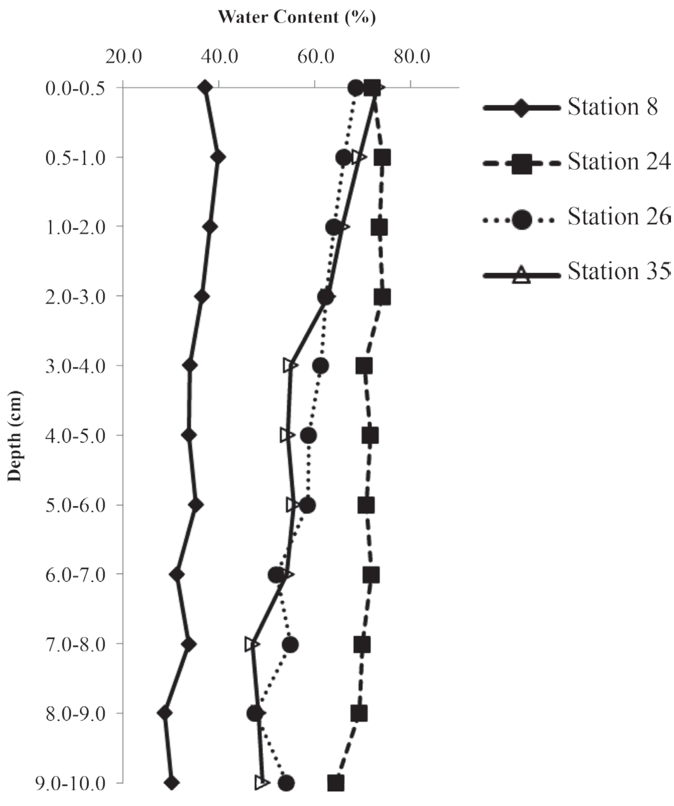

Figure 4. Vertical profiles of water content (%) in sediments at Stations 8, 24, 26 and 35.

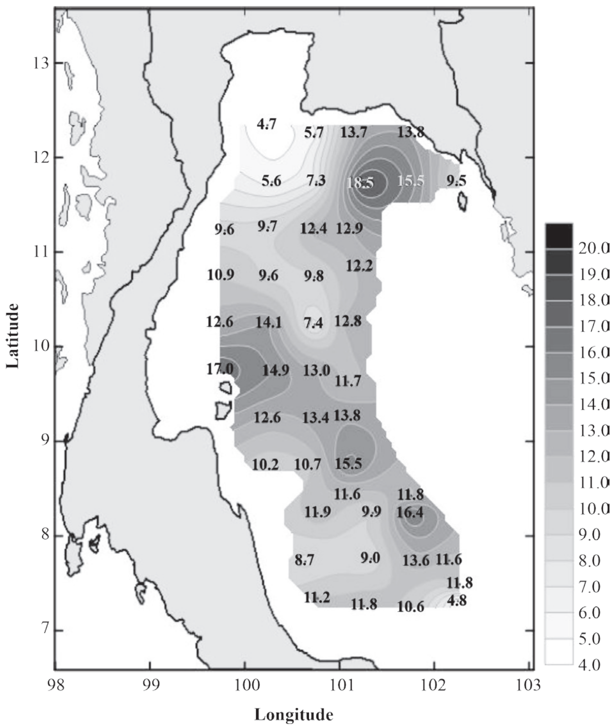

Figure 5. Contours of total organic matter (TOM) content (% dry weight) of surface sediment (0-0.5 cm) in the Gulf of Thailand.

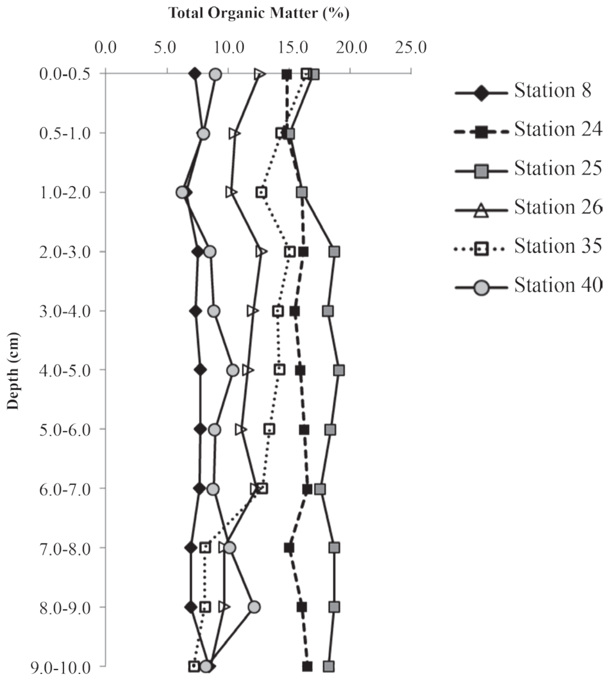

Figure 6. Vertical profiles of total organic matter (TOM) content (%) of sediments in the Gulf of Thailand.

mg·g^{-1}. Maximum TOC content occurred at Station 4 (near the coastline of Rayong Province), while the lowest value was found at Station 8 (middle of the gulf). Levels of TOC less than 5 mg·g^{-1} were found at Stations 1, 2, 8 and 9 along the western gulf, while levels higher than 20 mg·g^{-1} were found at Stations 3, 4 and 6 in the eastern upper gulf, and at Station 32 in the middle gulf.

Measurements of total nitrogen content of surface sediments (0-0.5 cm) in the Gulf of Thailand ranged between 0.18 and 2.96 mg·g^{-1} dry weight (Figure 8). Distribution of TN content in surface sediments showed a similar pattern to TOC content. Average TN content was 0.92 mg·g^{-1} dry weight. The maximum value was found at Station 4 (near the coastline of Rayong Province), where the highest TOC was also observed. The lowest value was recorded at Station 1 (upper gulf).

DISCUSSION

Water content and total organic matter

Results from the horizontal distribution of water content levels in sediments of the Gulf of Thailand indicated that WC was closely related to total organic matter. Both values were high in areas near Samui and Chang Islands, where the sediments were muddy. Distribution patterns of TOM in the Gulf were similar to those reported in 1995 (Meksumpun *et al*., 2005), implying that sedimentation patterns had not changed during the previous two decades. High water content in sediments was related to abundance of fine-grained mud. The highest content of TOM (18.55 % dry weight) recorded in our study was almost the same as that found in coastal sediments of the West Pacific Ocean, reported by Munoz *et al*.

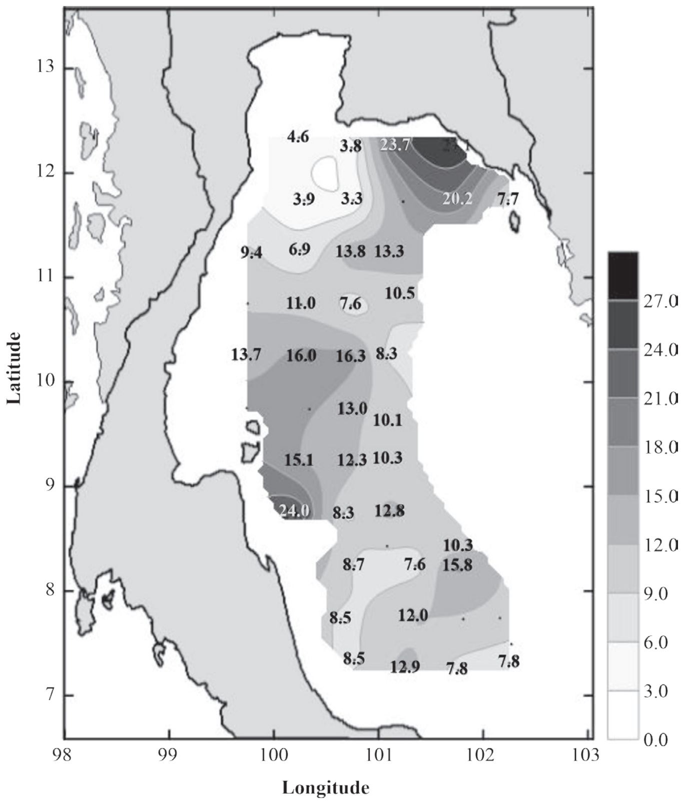

Figure 7. Contours of total organic carbon (TOC) content (mg·g^{-1} dry weight) of surface sediments (0-0.5 cm) in the Gulf of Thailand.

(2012). Our results indicated that fine-grained mud accumulated more in the western area the Gulf of Thailand, where current velocities were lower than areas outside the gulf. Sediments containing low WC (lower than 70 %) were composed of fine sand. However, the correlation of TOM content in sediments between 1995 and 2012 (Figure 9) indicated that TOM content had increased by approximately 35 % from 1995 to 2012. This phenomenon is a result of increasing nutrients in the water column of the Gulf of Thailand. Ariztegui *et al*. (2001) suggested that increasing TOM content in the sediments depended on sedimentation rate, bio-productivity, and input of organic matter. Human activities have potential to induce surface water eutrophication, and are a key source for organic matter accumulation in sediment cores. Several authors have demonstrated that sedimentary organic matter derives from autochthonous primary production and allochthonous terrestrial materials (Hanisch *et al*., 2003; Wang *et al*., 2013; Athena *et al*., 2015). Levels of TOM in sediments are known to be related to organic matter and pollutants that retain fine particles (Gingele *et al*., 2001; Morgan and Quinton, 2001; Akysoy and Kavvas, 2005). As the main component of fine-grained sediment, clays can be carried over long distances to places far from their source area, especially when re-transported in the other layer (Sionneau *et al*., 2008).

Vertical profiles of WC and TOM content in sediments of the Gulf showed various patterns indicating human impact. Normally, surface sediments are well-sorted deposits with higher WC compared to deeper layers. As sediment compacts, WC decreases with depth of sediment. Our results indicated that WC in most of the sediment cores remained constant throughout column depth, and only 42 % showed a decrease in WC with increasing

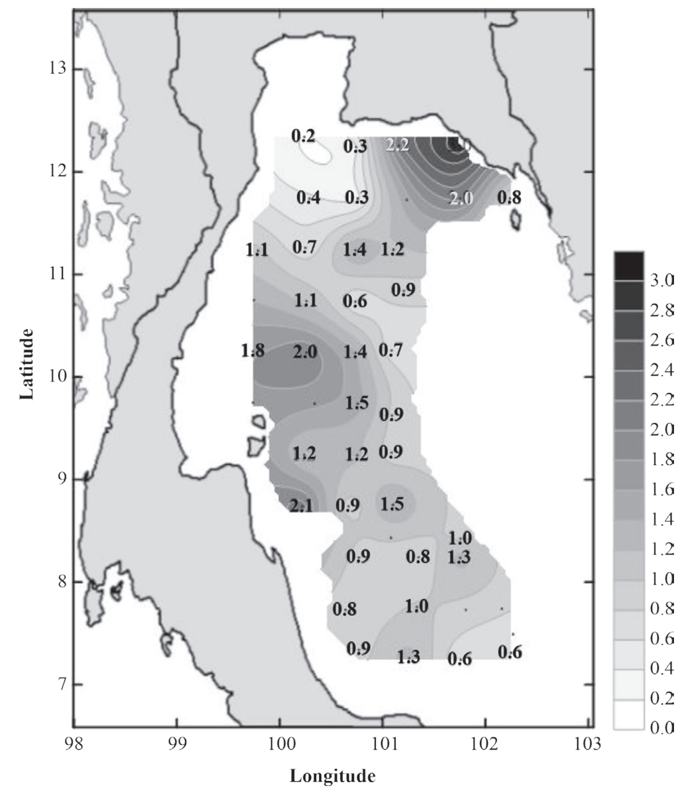

Figure 8. Contours of total nitrogen (TN) content (mg·g^{-1} dry weight) of surface sediments (0-0.5 cm) in the Gulf of Thailand.

depth. Diagenesis in the sediment column plays an important role in the resulting vertical profile pattern of TOM. Decreasing TOM content with depth is the most typical pattern. Here, over 60 % of the vertical profiles remained stable throughout the core column. This implied that fishing activities have impacted the vertical sediment profiles of TOM. Shi *et al*. (2015) suggested that WC levels could be utilized as a parameter to determine granulometric components of the seabed. Water content data also reflected bottom characteristics, which were mainly composed of muddy deposits in the upper half and sandy deposits in the lower half of the gulf.

Organic carbon content and total nitrogen

Our results demonstrated that distribution patterns of organic carbon content in surface sediments (0-0.5 cm) of the Gulf were similar to TN and TOM. Distribution patterns of TOC and TN in surface sediments concurred with results of Meksumpun *et al*. (2005). High content of TOC and TN was observed in coastal areas of Rayong Province and neighboring areas of Samui Island, Surat Thani Province. However, average values for TOC and TN in surface sediments of the Gulf in 2012 were higher than those recorded in 1995, with ranges of 2.3-17.3 and 0.3-2.2 $mg \cdot g^{-1}$ dry weight, respectively, in 1995, and 3.26-27.10 and 0.18-2.96 $mg \cdot g^{-1}$ dry weight in 2012. Nomaki *et al*. (2016) reported that the TOC content of small-grained sediment (60 µm) in the North Pacific Ocean ranged between 5.3 and 22.0 $mg \cdot g^{-1}$. Jabir *et al*. (2018) reported that the TOC of Sothern Arabian Sea sediments ranged between 7.2 and 82.9 $mg \cdot g^{-1}$. Our results indicated that the TOC of surface sediments were significantly different ($p<0.05$) between 1995 and 2012. Figure 10 shows the correlation between TOC of surface sediments in 1995 and 2012, implying an increase of 40 % during the 17-year period, while Figure 11 shows that TN in surface sediments increased by 13 % during the same period. Our present study indicates that the average amounts (±SD) of TOC and TN in TOM of sediments in the Gulf of Thailand were only 10.47±3.80 % and 1.00±0.38 %, respectively. The percentage of TOC in TOM seems to be low compared to several previous studies (Jimenez and Garcia, 1992; Lanza-Espino and Soto, 1999; Dianto *et al*., 2020). However, Agah *et al*. (2013) reported that the percentage of TOC in TOM in sediment of some areas in the Persian Gulf ranged from 11.67 to 12.82 %. Differences among these studies are likely due to the different sediment sources, characteristics and geographic regions. Nomaki *et al*. (2016) suggested that TOC content increased with increasing grain size of sediment.

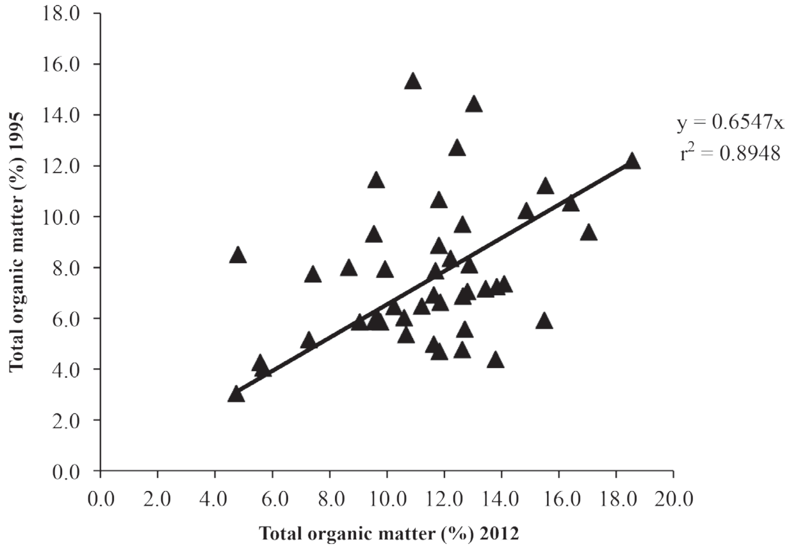

Figure 9. Relationship of total organic matter content of sediments in the Gulf of Thailand between 1995 and 2012.

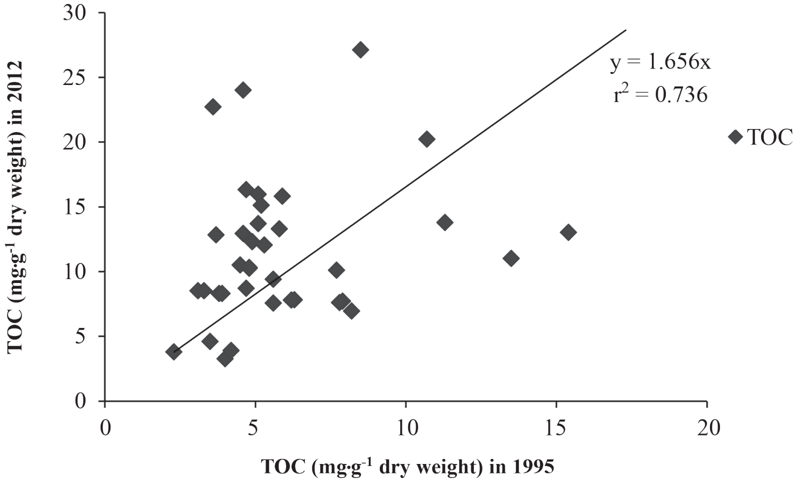

Figure 10. Relationship of total organic carbon content ($mg \cdot g^{-1}$ dry weight) of sediments in the Gulf of Thailand between 1995 and 2012.

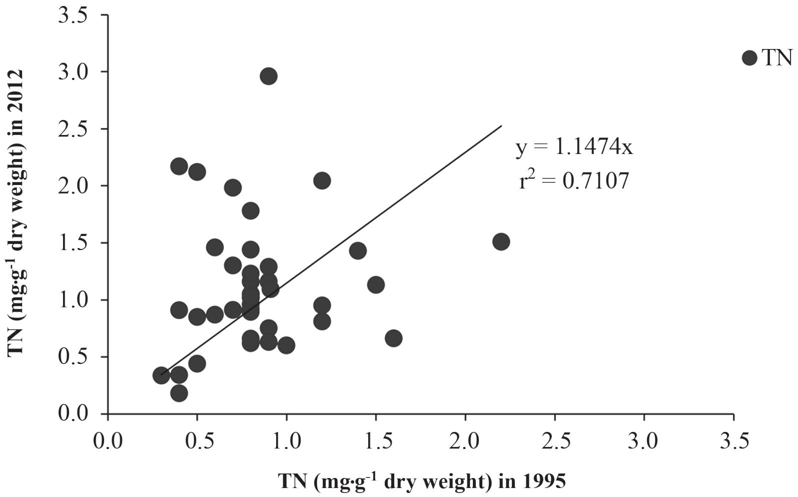

Figure 11. Relationship of total nitrogen content ($mg \cdot g^{-1}$ dry weight) of sediments in the Gulf of Thailand between 1995 and 2012.

Normally, accumulation patterns of TOC and TN depend on the distribution of water masses and currents (Meksumpun and Meksumpun, 2002). Surface current velocity and wind direction in the Gulf of Thailand are greatly impacted by the monsoon rains, and accumulation patterns of TOC and TN are directly controlled by monsoon-induced currents over the whole study area (Meksumpun *et al*., 2005). Fine-grained substances have a large surface area and can absorb and preserve more carbon and nitrogen elements (Alverez *et al*., 2003; Xiang *et al*., 2014). Our results concurred with previous findings that particle size was not the main factor controlling TOC and TN sediment content, which also had a relatively close correlation with clay content (Xiang *et al*., 2014). High concentrations of organic materials deposited in the Gulf of Thailand support high fishery production in this area. Our study results clearly demonstrated that although accumulation patterns of organic matter in surface sediments of the Gulf of Thailand had not changed over the 17 years from 2005 to 2012, the amount of organic matter significantly increased. Such a rapidly increasing rate of organic matter deposition in sediment can cause an increase of advection of nutrients into the water column, which in turn are likely to cause eutrophication of the Gulf. Eutrophication and related environmental phenomena, especially red tide incidents, have now become serious problems in the region.

CONCLUSION

Our results clearly demonstrate that distribution patterns of water content, total organic matter, total organic carbon and total nitrogen in surface sediments of the Gulf of Thailand were similar. High organic carbon and nitrogen content was found in two major areas, namely the eastern inner gulf near Chang Island and the western area near Samui Island. Accumulation patterns of TOM, WC, TOC and TN in surface sediments resulted from movement of water masses induced by currents. TOM in surface sediments increased by 35 % from 1995 to 2012. As with TOC and TN, high TOM and WC were found in areas near Chang Island and also in the southern Gulf (Samui Island). TOC and TN content of surface sediments in the Gulf of Thailand increased by 40 % and 13 %, respectively, from 1995 to 2012.

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