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Sources and Distribution of Organic Matter in Coastal Area of Muang Chonburi District, Eastern Thailand: Using Carbon and Nitrogen Stable Isotopes

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ABSTRACT

The sources and spatial distribution of organic matter were investigated in the nearshore area receiving untreated urban wastewater and offshore areas containing bivalve mariculture in Muang Chonburi District. Content, elemental, carbon, and nitrogen isotopic analyses in particulate organic matter (POM) and surface sediments were performed. We found particulate organic carbon (POC), δ^{13}C, and δ^{15}N of POM ranging from 435.0-5,247.7 µg/L, -27.7 to -22.0‰ , and 1.7-8.6‰ , respectively, whereas total organic carbon (TOC), total nitrogen (TN), δ^{13}C and δ^{15}N in sediment were 3.5-76.9 µg/g, 0.8-8.3 µg/g, -25.7 to -22.9 ‰ and 2.6-6.0 ‰, respectively. These values show significant differences between nearshore and offshore sampling stations wherein accumulation of organic matter was high in the nearshore and decreased with greater distance offshore, with some retained in the bivalve farming area. The results from a mixing model indicated that organic matter in POM and sediment were initially derived from anthropogenic organic matter. In contrast to the offshore water which had organic matter derived from marine organic matter. This study highlights the distribution of anthropogenic organic waste released to coastal waters with plenty of bivalve farms such as green mussels and oysters. The results can be used to advise national strategies regarding bivalve aquaculture zoning and seafood safety policies going forward.

1. INTRODUCTION

Shallow coastal waters are where the biotic and abiotic components of the marine and terrestrial environments interact to form complex ecological and economic resources systems. These area are highly influenced by human activities, including housing developments, commercial industries, as well as recreation (Nordstrom, 2000). Consequently, these areas have been affected by various anthropogenic pollutants in sewage. Among the existing pollutants, the accumulation and distribution of organic matter in the shallow waters that receive urban wastewater, such as the inner Gulf of Thailand, has not been well understood.

Chonburi Province is situated on the east coast of the Inner Gulf of Thailand, covering 4,363 km^2 with a current population of more than 1.6 million. Muang Chonburi District is one of the most densely populated areas in Thailand, with more than 400,000 residents (1,490 people/km^2) (Official Statistics Registration Systems, 2021). Consequently, these vast expanses of man-made activities cause a potential risk to the survival, growth, and ecological relationship of sessile and intertidal bivalves (Thushari et al., 2017). Coastal area of the district has become a significant economic ecosystem for tourism, industry, human settlement, and bivalve shellfish farms covering 197 ha with a production of 4,200 tons per year (Department of Fisheries, 2020). Oysters, green mussels, and bloody cockle have high commercial values because they are popular seafood sources for residents and tourists in this area and nationwide.

However, coastal water along Muang Chonburi District receives untreated wastewater from several communities via small canals (Boonkhwang et al., 2010). Therefore, massive amount of anthropogenic

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pollutants, for instance, organic matter (Onpankoon et al., 2010), nutrients (Boonphakdee et al., 2008), microbial contaminants (Bussi et al., 2017), persistent organic pollutants (POPs) (Beyer et al., 2017), household chemicals and emerging contaminants of concern (Ocharoen et al., 2018) have been discharged to the coastal water of Muang Chonburi District. Organic matter and nutrient substances may cause eutrophication and eventually a red tide (Lassauque et al., 2010; Nijole et al., 2017), which creates a severe deterioration of the coastal environment and bivalve farming due to excessive oxygen consumption during the microbial respiration of the dead phytoplankton cells (Andrews et al., 1998). The low oxygen conditions may, in turn, kill fish and invertebrates, with severe consequences for the marine ecosystem (Boyer et al., 2009). Microbial contaminants, persistent organic pollutants (POPs), household chemicals, and emerging contaminants of concern may accumulate in bivalves and impact human health via consumption (Webber et al., 2021).

This study is focused on the distribution and sources of organic matter in the coastal area with an abundance of bivalve mariculture, and are receiving urban wastewater by using the stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotopes. Distribution of organic matter and its origin are essential approaches for understanding the movement and accumulation of organic matter in a coastal area. The results from this study can assist in improving a national policy for mariculture zoning and seafood safety.

2. METHODOLOGY

2.1 Study area and sampling sites

We took samples from three canals located in Muang Chonburi District, Chonburi Province; Sungkep (SK) (N13°22.437' E100°58.690'), Bangplasoy (BPS) (N13°21.697' E100°58.383') and Bangprong (BPR) (N13°18.856' E100°55.078') canals (Figure 1). These three canals receive municipal wastewater from densely populated communities in Muang Chonburi District (Sangmanee et al., 2017) before emptying into the east coast of the inner Gulf of Thailand. Stn. SK1, BPS1, and BPR1 were located at the mouth of each canal. We classified Stn. SK1-4, BPS1-4, and BPR1-4 as nearshore areas with shallow areas (depth <3.0 m). In contrast to Stn. SK5, BPS5, and BPR5 located >1,500 m. from the coastline and deeper water (>5.0 m) were determined as offshore stations. The sampling stations were approximately 300 m interval in the seaward direction along the discharging plume from the canals (Boonkhwang et al., 2010).

The bivalve mariculture area along the coast of Muang Chonburi District is shown in Figure 1, covering 197 ha with a production of 4,200 tons per year (Department of Fisheries, 2020). Bivalves cultured in this area are mainly green mussel (*Perna veridis*) in Sungkeb and Bangplasoy sites and oyster (*Saccostrea cucullate*) Bangprong site Figure 1 (a) and (b).

2.2. Sample collection and pretreatment

Water samples for marine organic matter, mangrove leaves, sewage, particulate organic matter (POM) and sediment samples were taken at Sungkep (Stn. SK1-SK5), Bangplasoy (Stn. BPS1-BPS5), and Bangprong (Stn. BPR1-BPR5) sites during 10-14 January 2016. This period is classified as a dry season (Boonphakdee et al., 2008). Water samples were collected at a depth of 0.5 m using the Kitahara water sampler. Surface sediments samples were taken by an acrylic core sampler at a depth of 0-3 cm. After sample collection, water samples were stored in labelled plastic bottles and then frozen at -4°C. Sediment samples were stored in labelled plastic bags and then transported to the laboratory for further process.

Mangrove leaves were sampled from the reserved mangrove area in Muang Chonburi District (Figure 1), whereas sewage samples were collected at sewer outlets discharging into the three canals. Marine phytoplankton samples were vertically taken by using 60 µm mesh size plankton net at Stn. SK5, BPS5, and BPR5 where salinity was >33 and used as marine organic matter (OM).

After being transferred to the laboratory, water samples were filtered through pre-combusted (550°C, 2 h) GF/F Whatman glass fiber. The filtered samples were dried in an oven at 60°C for 24 h and decarbonated by HCl fumes for 6 h. After that, samples were rinsed with distilled water and stored at -20°C for elemental and isotopic analysis. The sediment samples were dried at 60°C for 48 h and then ground to a fine powder and homogenized. Powder sediment samples were acidified with 5 N HCl to remove inorganic carbon and washed with distilled water. Finally, sediment samples were dried at 60°C for 48 h and kept in a desiccator for further elemental and isotopic determination (Boonphakdee et al., 2008). Total organic matter was determined using the ignition loss procedure (Verardo et al., 1990). The organic carbon and nitrogen contents were determined using a CHN elemental analyzer. We conducted a t-test using SPSS software (Version 20) to check the differences in $\delta^{13}C$, $\delta^{15}N$, and C/N ratio values among samples.

The contents of organic carbon and nitrogen were determined using a CHN elemental analyzer. We conducted a t-test using SPSS software (Version 20) to check the differences in $\delta^{13}C$, $\delta^{15}N$, and C/N ratio values among samples.

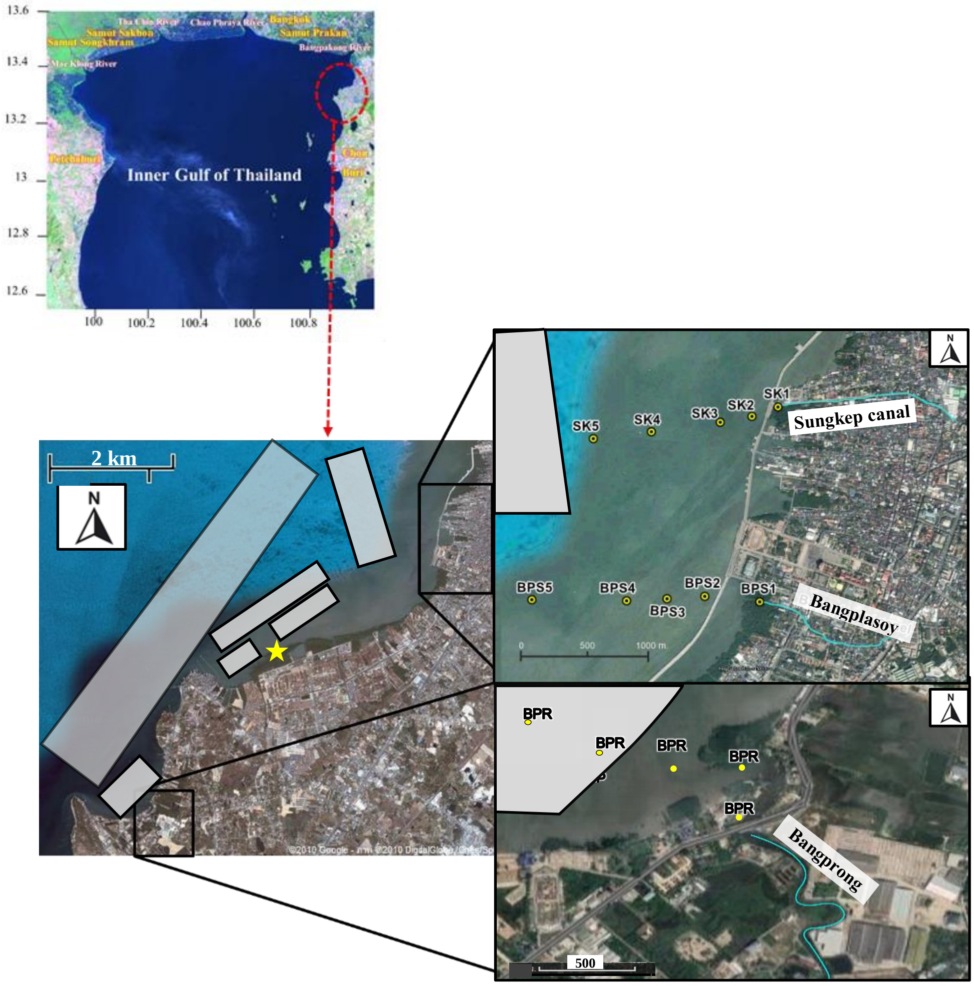

Figure 1. Map of sampling sites and stations in (a) Sungkep (Stn. SK1-5) and Bangplasoy (Stn. BPS1-5) and (b) Bangprong (Stn. BPR1-5) canals in Muang Chonburi District, Eastern Thailand. A star symbol indicates a sampling point for mangrove leaves. Grey areas illustrate bivalve mariculture in Muang Chonburi District (Department of Fisheries, 2021).

2.3 Stable isotope analysis

Stable isotopes were analyzed by a Thermo Finnigan Delta V advantage Isotope Ratio Mass Spectrometer Analyzer at Cornell Isotope Laboratory, Cornell University, USA. Carbon and nitrogen isotopic signatures were expressed as the relative differences between the isotopic ratio in the sample and conventional standards ($^{13}C/^{12}C$ or $^{15}N/^{14}N$), using the standard equation:

$$\delta^{13}C \text{ or } \delta^{15}N\ (‰) = [(R_{sample}/R_{reference}) - 1] \times 1{,}000$$

In this expression, R_{sample} and $R_{reference}$ are the isotopic ratios of the sample and reference, respectively. The carbon standard is Peedee Belemnite (PDB), and the nitrogen standard is atmospheric N_2. All samples were analyzed twice. Reproducibility was better than ±0.1‰ of absolute difference for both $\delta^{13}C$ and $\delta^{15}N$.

3. RESULTS AND DISCUSSION

3.1 Compositions of organic matter in POM and sediment

3.1.1 Particulates organic matter (POM)

The values of particulate organic carbon (POC), particulate organic nitrogen (PON), C:N ratio, $\delta^{13}C$ and $\delta^{15}N$ of POM ranged from 435.0-5,247.4 µg/L, 85.1 to 927.5 µg/L, 2.6-10.1, -27.7 to -22.0 ‰, and 1.7-8.6 ‰, respectively (Table 1). Concentrations of POC and PON were significantly different ($p<0.05$)

among the three sampling sites. Spatial variations in PON and POC were observed with a similar pattern showing the high values in nearshore, especially in canal mouth stations (Stn. SK1, BPS1, and BPR1) and decreased seaward to low values at offshore stations (Stn. SK5, BPS5 and BPR5) (Table 1 and Figure 2(a)).

Table 1 . Compositions of organic matter in coastal waters of Muang Chonburi District.

Sites/stations	$\delta^{13}C_{POM}$ (‰)	$\delta^{15}N_{POM}$ (‰)	POC (µg/L)	$C:N_{POM}$	$\delta^{13}C_{sed}$ (‰)	$\delta^{15}N_{sed}$ (‰)	TOC_{sed} (mg/g)	TN_{sed} (mg/g)	$C:N_{Sed}$
Sungkep									
SK1	-27.0	3.4	6,352.0	10.1	-25.2	4.6	76.9	8.3	7.9
SK2	-26.0	2.3	5,114.5	8.9	-23.6	5.0	33.4	4.5	6.4
SK3	-24.5	2.5	3,970.7	7.2	-23.4	5.5	13.3	2.7	6.7
SK4	-23.4	3.0	3,734.2	6.7	-23.2	5.3	19.4	2.5	6.2
SK5	-23.3	3.0	1,849.8	5.7	-22.4	5.8	23.5	3.2	5.6
Bangplasoy									
BPS1	-27.7	2.5	3,887.2	9.7	-25.7	6.0	33.3	2.8	9.3
BPS2	-27.4	5.7	2,897.8	8.8	-24.3	2.7	8.3	1.1	7.9
BPS3	-26.9	4.7	1,414.7	6.2	-23.4	4.5	6.2	0.9	7.6
BPS4	-24.9	5.3	1,289.9	6.0	-23.6	2.6	3.5	0.8	6.0
BPS5	-23.2	5.9	1,479.4	6.1	-23.0	5.3	7.7	2.1	5.9
Bangprong									
BPR1	-24.7	1.7	5,247.4	5.7	-23.9	5.3	34.2	3.2	9.2
BPR2	-23.2	8.6	1,021.4	5.5	-22.8	4.5	8.4	1.0	7.2
BPR3	-22.9	8.5	925.4	5.5	-22.3	5.0	4.3	0.5	7.4
BPR4	-22.9	7.2	492.9	5.5	-22.0	5.9	28.4	2.6	6.4
BPR5	-22.5	7.0	436.0	5.4	-20.9	5.8	4.1	0.5	6.0

This indicates organic matter released from the municipal communities contributing to coastal water and was influenced by resuspension of bottom sediment in shallow water (Lamb and Swart, 2008). The values of POC:Chla at the canal mouth (SK1, BPS1, and BPR1) and nearshore stations of Sunkep and Bangplasoy canals (Stn.SK2-4 and BPS2-4) were higher (>200) than those of the offshore stations (<100) (Figure 2(b)), indicating a strong distribution of anthropogenic organic matter (Maksymowska et al., 2000; Boonphakdee et al., 2008; Nijole et al., 2017). This coincides with the lowest δ^{13}C at all canal mouth stations (-27.0, -27.7, and -24.7‰ for Stn. SK1, BPS1, and BPR1, respectively). The low δ^{13}C values (approx. -27‰) were close to that of sewage (Wu et al., 2003; Rumolo et al., 2011), indicating high anthropogenic input at Stn. SK1 and BPS1. Higher δ^{13}C value at BPR1 implies more contribution of marine OM at this station (Table 1). Values of δ^{13}C increased in seaward direction with the highest values (lower negative) at offshore stations (SK5, BPS5, and BPR5) (Figure 2(c)), which are close to -21.5‰ determining marine OM (Boonphakdee et al., 2008).

The values of δ^{13}C, δ^{15}N, total organic carbon (TOC), total nitrogen (TN) and C:N ratio of sediment ranged from -25.7 to -22.9 ‰, 2.6-6.0 ‰, 3.5-76.9 mg/g, 0.8-8.3 mg/g and 1.0-9.3, respectively (Table 1). Comparing with TOC and TN concentrations in sediments from worldwide coastal waters (Gu et al., 2017 and references therein), we found TOC and TON in this study were comparable to those from Bohai Bay, China. The spatial distribution of TOC and TN showed similar patterns (Figures 3(a-b)) to those in POM, with higher concentrations at the canal mouth and lower values in nearshore and offshore stations.

The values of TOC and TN in sediment were high at the canal mouth and nearshore stations and decreased with an increase in seaward distance (Figures 3(a-b)). These results imply that an increased organic matter falls to the bottom, and the benthic environment is transformed from one of oxidation to reducibility, leading to decreased benthic diversity and increased adverse biological effects on marine organisms (MPI, 2013). Fine-grained sediment in the nearshore also provides good binding for organic matter adsorbed on fine particles (Onpankoon and Boonpakdee, 2012; Gu et al., 2017). Generally, sedimentary organic matter is closely associated with fine-grained sediments undisturbed by human activities (Gao et al., 2012).

The relationship between TOC and TN in sediment was high with R^2=0.85 (Figure 4(b)), showing a single source of organic matter in sediment (Pastene et al., 2019). The values of $\delta^{13}C$ in sediment showed similar patterns to $\delta^{13}C$ in POM. The low values of $\delta^{13}C$ in sediment were at the canal mouth and nearshore (-23.5 to -25.7‰), whereas the higher values were found in samples from the offshore stations at all sampling sites (-21 to -23‰) (Figure 3(c)). This suggests that the distribution of sediment organic matter in this study area was influenced by large amounts of organic waste from human waste.

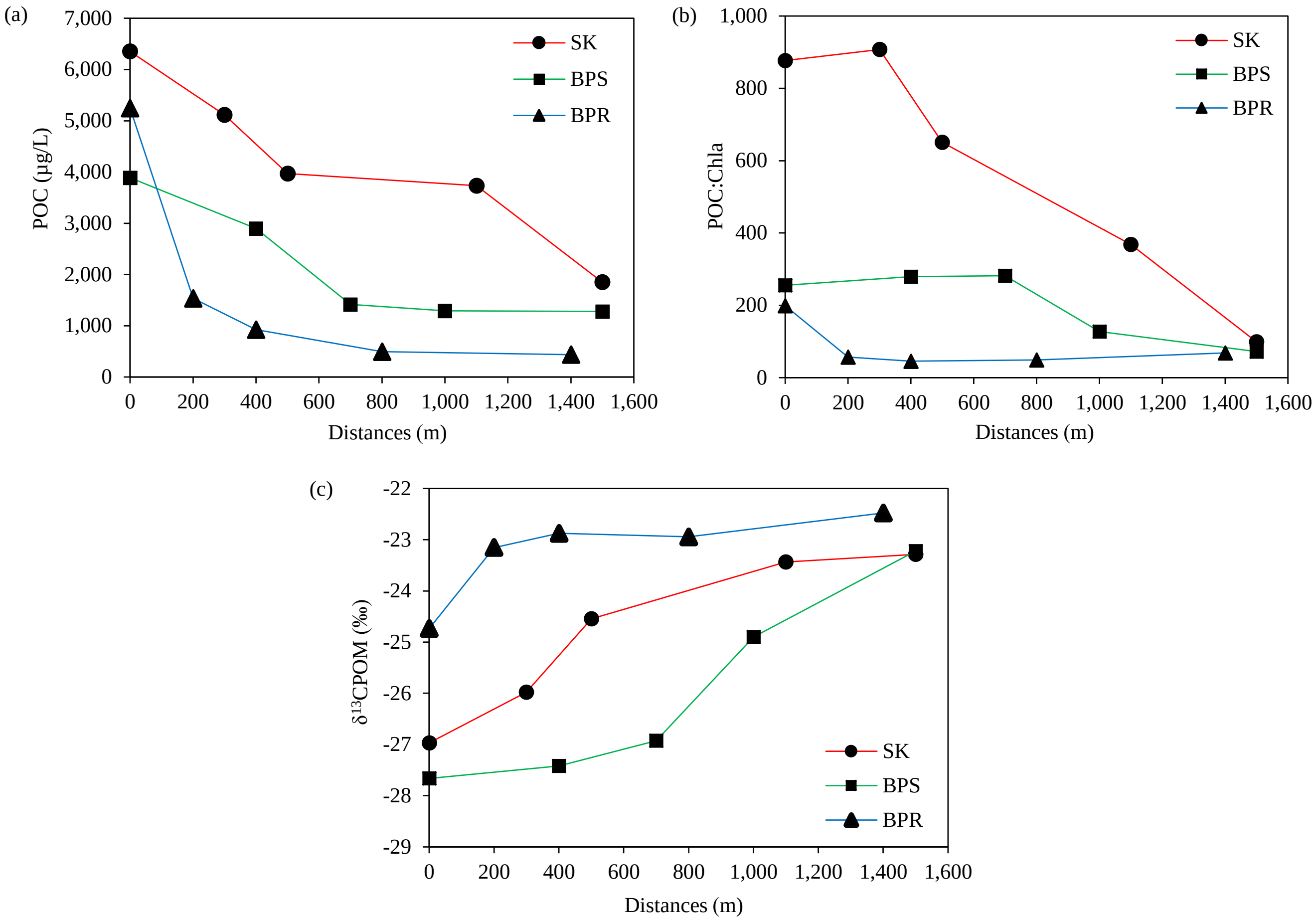

Figure 2. Values of (a) POC, (b) POC:Chla ratio, and (c) $\delta^{13}C$ in POM of SK, BPS, and BPR sampling sites. Positive distances indicate seaward direction.

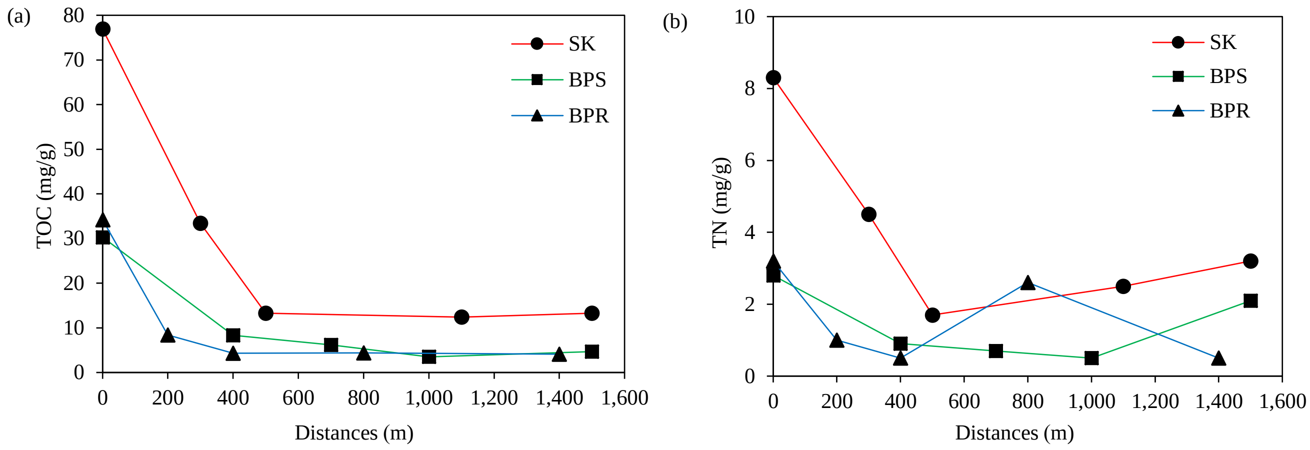

Figure 3. Values of (a) TOC, (b) TN, and (c) $\delta^{13}C$ in surface sediments of SK, BPS, and BPR sampling sites. Positive distances indicate seaward direction.

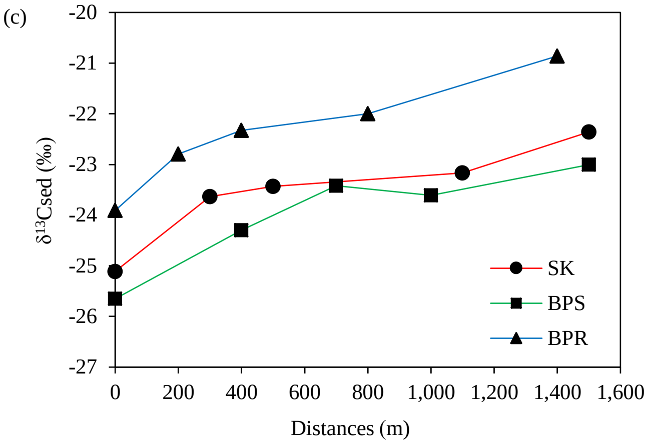

Figure 3. Values of (a) TOC, (b) TN, and (c) δ^{13}C in surface sediments of SK, BPS, and BPR sampling sites. Positive distances indicate seaward direction (cont.).

3.2 Sources of organic matter in POM and sediment

Significant linear relationships (r^2=0.75, $p<0.001$) between POC and PON were observed (Figure 4(a)) with highly strong correlation (r^2>0.95, $p<0.001$) at each study site (Table 1), suggesting they are derived from the same source (Gu et al., 2017). C/N ratios, δ^{13}C, and δ^{15}N values have been widely used as markers to effectively discriminate sources of organic matter in aquatic ecosystems (Boonphakdee et al., 2008; Holtgrieve et al., 2011; Kikumoto et al., 2014; Li et al., 2016). Marine phytoplankton derived organic matter typically has C/N ratios between 4 and 7 (Gu et al., 2010), whereas terrestrial C_3 plants have C/N ratios typically higher than 12 (Ogrinc et al., 2005; Boonphakdee et al., 2008). In this study, C/N ratios in POM and sediment varied from 5.4 to 10.1 and from 5.6 to 9.3 with an average of 6.8±1.7 and 7.0±1.2, respectively. These results indicate a mix of terrigenous or anthropogenic and marine sources. To confirm the source of organic matter in our study, we, therefore, analyzed δ^{13}C and δ^{15}N values. The δ^{13}C and δ^{15}N values derived from marine organic matter ranging from -22‰ to -18‰, and 3‰ to 12‰, respectively (Boonphakdee et al., 2008; Gao et al., 2012). Terrestrial C_3 and C_4 plants generally have δ^{13}C values ranging from -33‰ to -21‰ and -17‰ to -9‰, respectively. (Lamb et al., 2006; Boonphakdee et al., 2008; Yu et al., 2010).

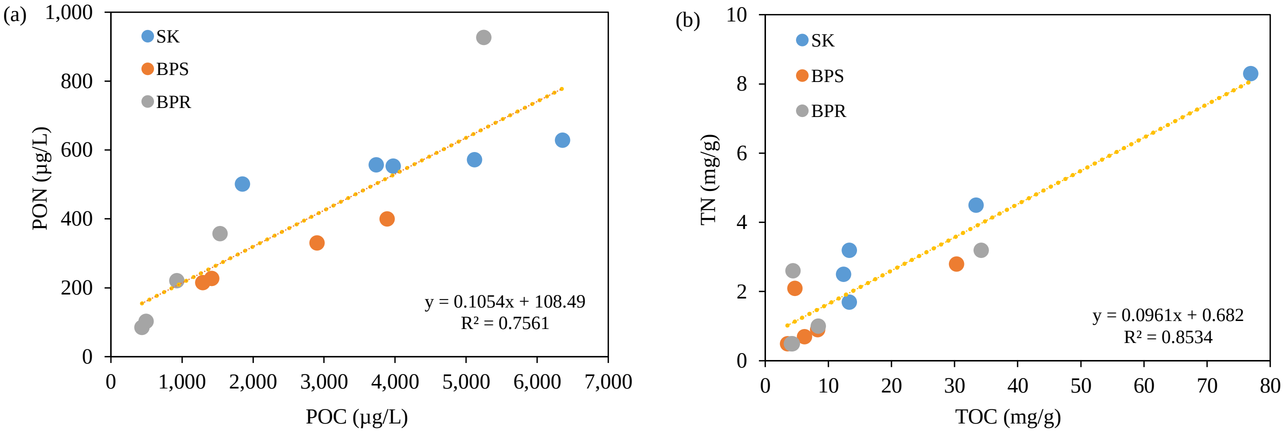

Figure 4. The relationships of (a) POC vs. PON and (b) TN vs. TOC in surface sediment of SK, BPS, and BPR sampling sites.

The δ^{15}N values in terrestrial organic matter varied from -10‰ to 10‰ (Li et al., 2016), and from 0.67‰ to 7.67‰ in terrestrial vegetations (Wei et al., 2010). The elevated δ^{15}N signature of untreated sewage (0-5‰) distinguished it from other nitrogen sources (e.g., inorganic fertilizers 0 ‰) and treated sewage (10-15‰) (Anderson and Cabana, 2006; Finlay and Kendall, 2007). However, identifying sources of nitrogen to aquatic ecosystems, some overlap may exist in isotope values of sewage and terrestrial organic matter (Diebel and Zanden, 2009).

The δ^{13}C and δ^{15}N distribution (Figures 3(c) and Figure 5) show that POM and sediment in the nearshore stations, located within 800 m from the shore, were close to those in sewage. In contrast, stations located further than 1,000 m. from the shoreline had values of δ^{13}C and δ^{15}N similar to those in marine OM. This suggests that organic matter in POM and sediment represents a mixture of continentally derived sewage and marine material (Figure 2(c) and Figure 3(c)). However, higher values of δ^{13}C of POM and sediment in the BPR site indicate low sewage origin contribution (Ogrinc et al.,2005). We measured values of δ^{13}C, δ^{15}N, and C:N ratio of potential organic matter sources, as shown in Table 2. However, low values of δ15N (<3‰) in some POM and sediment samples (Figures 5(a-b)) indicate the possibility of another source, which may be autochthonous organic matter such as benthic diatom (Sugimoto et al., 2006) or detritus derived organic matter (Sampaio et al., 2010). Therefore, further investigation is needed.

Table 2. Values of δ^{13}C, δ^{15}N, and C:N ratios of potential sources in coastal waters of Muang Chonburi District

Potential sources	δ^{13}C (‰)		δ^{15}N (‰)		C:N	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Sewage	-28.6±0.3	-28.3 to -28.8	5.2±1.2	4.6-5.7	10.6±0.8	10.0-11.2
Marine POM	-19.5±0.6	-19.0 to -21.4	7.0±0.6	5.2-9.4	5.4±1.0	4.2-6.5
Mangrove leaves	-30.7±2.5	-21.9 to -32.9	7.2±1.7	3.7-9.5	15.4±3.3	14.9-19.8

3.3 Contribution of sewage and marine organic matter

To understand the sources of organic matter in the POM and sediment in this coastal environment, we applied a mixing model based on two end-member of δ^{13}C. This two-end-member mixing model was applied to quantify the portion of organic origin considered terrigenous (sewage) and marine OM. This model has been demonstrated to effectively assess the relative proportions of terrigenous and marine organic matter in coastal waters (Goni et al., 2003; Boonphakdee et al., 2008; Gu et al., 2017; Sasmito et al., 2020).

In this study, we used δ^{13}C values of -19.5‰ and 26.80 ‰ for marine end-member ($\delta^{13}C_{marine}$) and sewage end-member ($\delta^{13}C_{sewage}$), respectively. Even though our previous works implemented terrigenous C_3 plants (mangrove leaves) as a potential source of organic matter in larger and open waters such as the Banpakong river estuary (Boonphakdee et al., 2008) and the inner Gulf of Thailand (Onpankoon et al., 2010) where terrigenous C_3 plant was the main contributor of organic matter. However, in our study sites, mangroves were available in narrow patches along the coastline and there was no terrestrial organic input from other water sources during the dry season. This coincides with values of δ^{15}N and C:N ratios of sewage that are closer to POM and sediment than those of mangrove (Figure 5(b) and Tables (1-2)). Therefore, in this study, we determined sewage as the main potential source of terrigenous organic matter.

We took sewage samples from the main sewer outlets flowing to the three canals. The value of -26.80‰ was close to that of untreated raw sewage reported by Anderson and Cabana (2006) and Finlay and Kendall (2007). The relative percentage contributions of sewage organic matter (SOM) and marine OM in POM and sediment samples were calculated using Equations (1) and (2).

$$\mathrm{SOM}(\%) = \frac{\delta^{13}C_{marine} - \delta^{13}C_{sample}}{\delta^{13}C_{marine} - \delta^{13}C_{sewage}} \times 100 \qquad (1)$$

$$\text{Marine OM } (\%) = 100 - \mathrm{SOC} \qquad (2)$$

The estimated contributions of sewage and marine OM indicate spatial variation in organic sources in all sampling sites (Figure 6). Accumulation of derived anthropogenic organic from the municipal wastewater was the majority in canal mouth stations with >80% and >60% for POM and sediment, respectively, decreasing with greater distance in a seaward direction (Ogrinc et al., 2005). In contrast to the offshore station, marine OM was the main contributor (Sampaio et al., 2010). However, we found that the percentage of the anthropogenic OM was higher in POM than that in sediment. This was due to the high biodegradation rate of anthropogenic POM, which typically occurs in shallow water (Zhou et al., 2021). In addition, marine OM mainly derived from marine phytoplankton has short lifetimes, and the heavier isotopic carbon weight could accumulate.

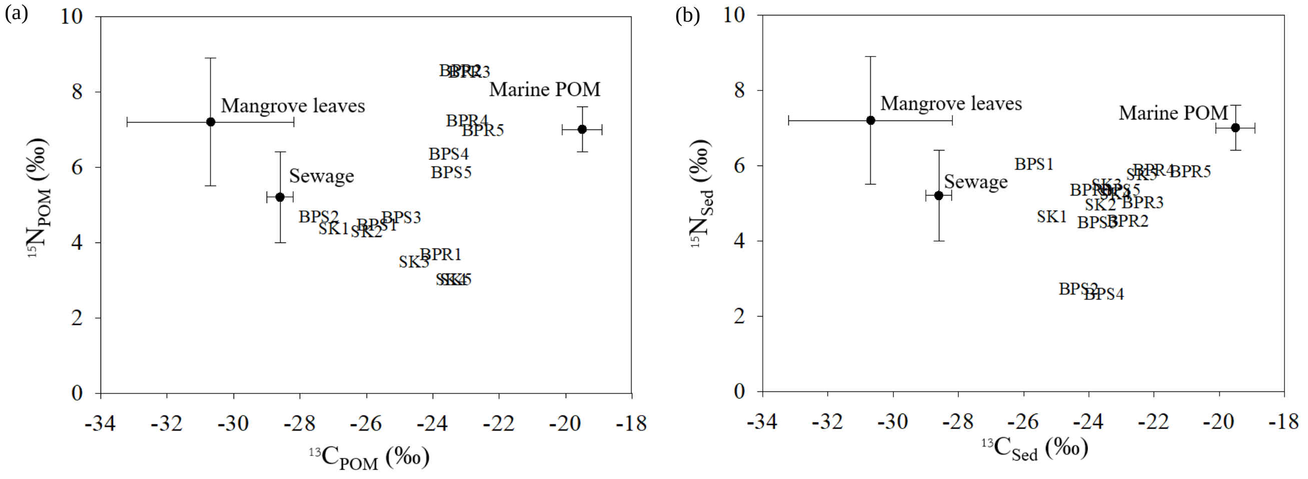

Figure 5. Scatter plots of $\delta^{13}C$ vs. $\delta^{15}N$ in (a) POM and (b) surface sediment samples, and their potential sources (mangrove leaves, marine POM and sewage).

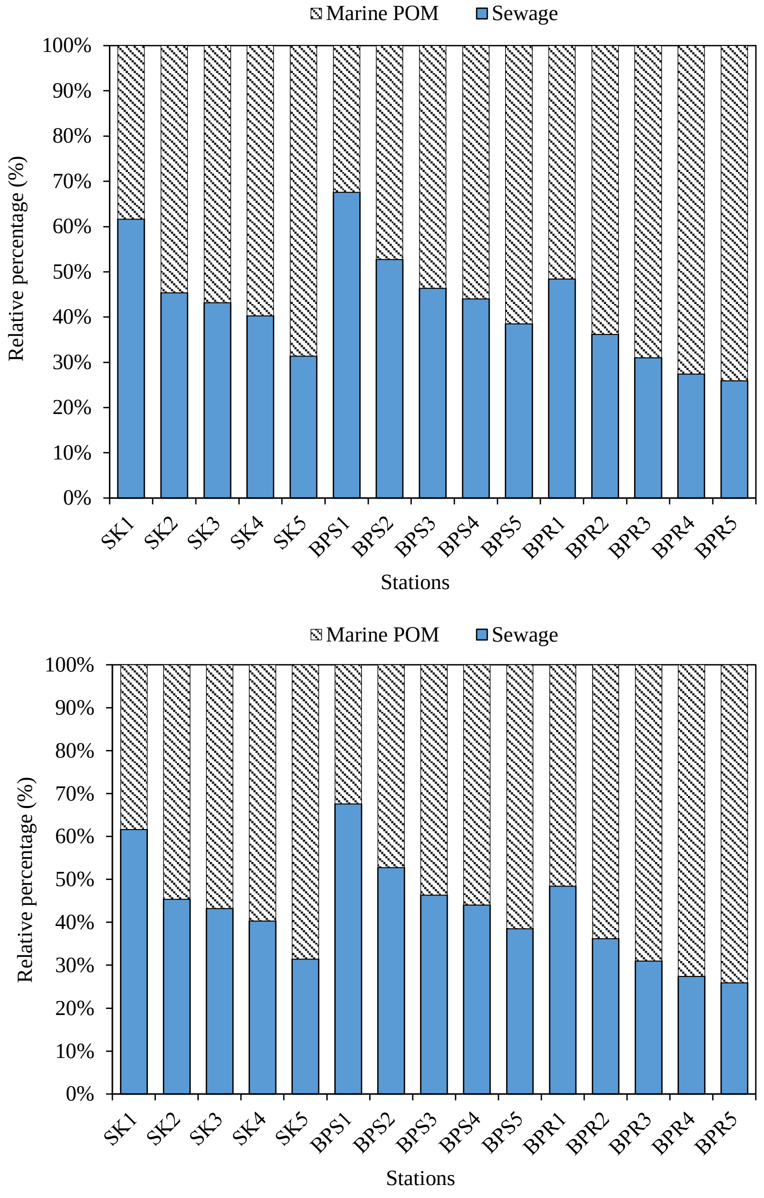

Figure 6. The relative percentage of sewage and marine OM in (a) POM and (b) surface sediment based on $\delta^{13}C$ two end-member mixing model

A higher percentage of marine OM was observed in the bivalve farming area (Stn. BPR 4-5), as shown in Figures 2 and 6. In this area, the primary farmed bivalve species was oysters that preferentially makes use of benthic diatoms (Richard et al., 1997). Uneaten natural food and cultivated bivalve feces can contribute to the accumulation of marine OM in the surface sediments of Oyster farming areas. In addition, Peng et al. (2014) and Gu and Lin (2016) reported that relatively higher nutrient levels in the seawater of the mariculture area promote algal blooms. As algae blooms subside, their major components are retained in the sediments.

3.4 Sewage and bivalve mariculture

This study demonstrates that sewage derived organic matter can reach bivalve mariculture area, such as the BPR site. This is particularly the case with filter feeding bivalves, which can accumulate significant amounts of contaminants from the water. Many chemical contaminants in sewage include persistent organic pollutants (Beyer et al., 2017) endocrine disrupting chemicals (Ocharoen et al., 2018), metals (Green et al., 2021), biocides, pesticides (Watts et al., 2017), veterinary and human medicines (Webber et al., 2021) all of which can be bio-transformed and bio-magnified to human via bivalves. Therefore, to assess the sustainability of the shellfish farming industry and/or seafood safety policy, we have to identify a range of future aquaculture management scenarios pertinent to future development and the sustainability of bivalve mariculture in Thailand.

4. CONCLUSION

This study has revealed the distribution of organic matter in coastal waters receiving municipal wastewater. It clearly shows that anthropogenic organic matter released from the coastal municipality accumulates in the nearshore with a decrease in a seaward direction. A mixing model indicated that the POM and organic matter in the nearshore sediment were initially derived from anthropogenic organic matter whist the source of offshore organic matter was marine phytoplankton. These results can be used to inform policies regarding bivalve mariculture zoning as well as general seafood safety regulations on a regional and national level.

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REFERENCES

Anderson C, Cabana G. Does delta N-15 in river food webs reflect the intensity and origin of N loads from the watershed. Science of the Total Environment 2006;367:968-78.

Andrews JE, Greenaway AM, Dennis PF. Combined carbon isotope and C/N ratios as indicators of source and fate of organic matter in a poorly flushed, tropical estuary: Hunts Bay, Kingston Harbour, Jamaica. Estuarine, Coastal and Shelf Science 1998;46:743-56.

Beyer J, Green NW, Brooks S, Allan IJ, Ruus A, Gomes T, et al. Blue mussels (*Mytilus edulis* spp.) as sentinel organisms in coastal pollution monitoring: A review. Marine Environmental Research 2017;130:338-65.

Boonkhwang N, Sutthasom N, Boonphakdee T. Role of small rivers in nitrogen transport to the Inner Gulf of Thailand. Proceedings of the 8th Conference of Science and Technology and Technology for Development Social Happy; 2010 Mar 19; Thammasat University, Rangsit Campus: Thailand; 2010.

Boonphakdee T, Kasai A, Fujiwara T, Sawangwong P. Combined stable carbon isotope and C/N ratios as indicators of source and fate of organic matter in the Bangpakong River estuary, Thailand. EnvironmentAsia 2008;1:28-36.

Boyer JN, Kelble CR, Ortner PB, Rudnick DT. Phytoplankton bloom status: Chlorophyll a biomass as an indicator of water quality condition in the southern estuaries of Florida, USA. Ecological Indicators 2009;9:56-67.

Bussi G, Whitehead PG, Thomas ARC, Masante D, Jones L, Jack Cosby B, et al. Climate and land use change impact on fecal indicator bacteria in a temperate maritime catchment (the River Conwy, Wales). Journal of Hydrology 2017;553:248-61.

Department of Fisheries. Statistics of Marine Shellfish Culture Report Number 14/2020. Bangkok, Thailand: Ministry of Agriculture and Cooperatives; 2020. (in Thai).

Department of Fisheries. Map of controlled shellfish mariculture area [Internet]. 2021 [cited 2022 Feb 20]. Available from: https://gisportal.fisheries.go.th/portal/apps/webappviewer/index.html?id=61050ffe668b408bb9e8e39f4e187a4a.

Diebel MW, Zanden MJV. Nitrogen stable isotopes in streams: Effects of agricultural sources and transformations. Ecological Applications 2009;19:1127-34.

Finlay JC, Kendall C. Stable isotope tracing of temporal and spatial variability in organic matter sources to freshwater ecosystems. In: Michener R, Lajtha K, editors. Stable Isotope in Ecology and Environmental Science. New Jersey, USA: Blackwell Publishing; 2007.

Gao XL, Yang YW, Wang CY. Geochemistry of organic carbon and nitrogen in surface sediments of coastal Bohai Bay inferred from their ratios and stable isotopic signatures. Marine Pollution Bulletin 2012;64:1148-55.

Goni M, Teixeira M, Perkey D. Sources and distribution of organic matter in a river-dominated estuary (Winyah Bay, SC, USA). Estuarine Coastal and Shelf Science 2003;57:1023-48.

Green N, Pettersen R, Ruus A, Beyer J, Green NW. Proposed Environmental Quality Standards (EQSs) for blue mussel (*Mytilus edulis*) [internet]. 2021 [cited 2022 Feb 8]. Available from: https://niva.brage.unit.no/niva-xmlui/handle/11250/2731548.

Gu YG, Wang ZH, Lv SH, Yang YF, Feng J, Fang J, et al. Distribution of biogenic elements and potential contamination assessment in surface sediments from western Guangdong coasts. Journal of Shenzhen University Science and Engineering 2010;27:347-53.

Gu YG, Lin Q. Trace metals in a sediment core from the largest mariculture base of the eastern Guangdong coast, South China: Vertical distribution, speciation, and biological risk. Marine Pollution Bulletin 2016;113:520-5.

Gu YG, Ouyang J, Ning JJ, Wang ZH. Distribution and sources of organic carbon, nitrogen and their isotopes in surface sediments from the largest mariculture zone of the eastern Guangdong coast, South China. Marine Pollution Bulletin 2017;120:286-91.

Holtgrieve GW, Schindler DE, Hobbs WO, Leavitt PR, Ward EJ, Bunting L, et al. A coherent signature of anthropogenic nitrogen deposition to remote watersheds of the northern hemisphere. Science 2011;334:1545-8.

Kikumoto R, Tahata M, Nishizawa M, Sawaki Y, Maruyama S, Shu D, et al. Nitrogen isotope chemostratigraphy of the Ediacaran and Early Cambrian platform sequence at Three Gorges, South China. Gondwana Research 2014;25:1057-69.

Lamb AL, Wilson GP, Leng MJ. A review of coastal palaeoclimate and relative sea-level reconstructions using δ^{13}C and C/N ratios in organic material. Earth-Science Reviews 2006;75:29-57.

Lamb K, Swart PK. The carbon and nitrogen isotopic values of particulate organic material from the Florida Keys: A temporal and spatial study. Coral Reefs 2008;27:351-62.

Lassauque J, Lepoint G, Thibaut T, Francour P, Meinesz A. Tracing sewage and natural freshwater input in a Northwest Mediterranean Bay: Evidence obtained from isotopic ratios in marine organisms. Marine Pollution Bulletin 2010;60:843-51.

Li Y, Zhang HB, Tu C, Fu CC, Xue Y, Luo YM. Sources and fate of organic carbon and nitrogen from land to ocean: Identified by coupling stable isotopes with C/N ratio, Estuarine. Coastal and Shelf Science 2016;181:114-22.

Maksymowska D, Richard P, Piekarek-Jankowska H, Riera P. Chemical and isotopic composition of the organic matter source in the Gulf of Gdansk (Southern Baltic sea). Estuarine, Coastal and Shelf Science 2000;51:585-98.

Ministry for Primary Industries (MPI). Overview of Ecological Effects of Aquaculture. New Zealand: Ministry for Primary Industries; 2013.

Nijole RN, Galina L, Vitalijus M, Ruta B, Mindaugas Z, Irma VL, et al. Assessing nature and dynamics of POM in transitional environment (the Curonian Lagoon, SE Baltic Sea) using a stable isotope approach. Ecological Indicators 2017;82: 217-26.

Nordstrom KF. Beaches and Dunes on Developed Coasts. Cambridge, UK: Cambridge University Press; 2000.

Ocharoen Y, Boonphakdeea C, Boonphakdee T, Shinn AP, Moonmangmee S. High levels of the endocrine disruptors bisphenol-A and 17β-estradiol detected in populations of green mussel, *Perna viridis*, cultured in the Gulf of Thailand. Aquaculture 2018;497:348-56.

Official Statistics Registration Systems. Population and house statistics report [Internet]. 2021 [cited 2021 Oct 10]. Available from: http://stat.bora.dopa.go.th/stat/statnew /statTDD /views/showDistrictData.php?rcode=20&statType=1&year=63.

Ogrinc N, Fontolan G, Faganeli J, Covelli S. Carbon and nitrogen isotope composition of organic matter in coastal marine sediment (the Gulf of Trieste, N Adriatic Sea): Indicators of sources and preservation. Marine Chemistry 2005;95:163-81.

Onpankoon S, Sutthasom N, Boonphakdee T. An importance of small rivers on phosphorus and suspended solid transportation from Chonburi Municipality to the Inner Gulf of Thailand. Proceedings of the 8th Conference on Science and Technology and Technology for Development Social Happy; 2010 Mar 19; Thammasat University, Rangsit Campus: Thailand; 2010. (in Thai).

Onpankoon S, Boonphakdee T. Chemical and sources of organic matter in sediment from the Inner Gulf of Thailand. Proceedings of the Marine Sciences Conference; 2012 Oct 17-19; The Tawanna Bangkok Hotel: Thailand; 2012. (in Thai).

Pastene M, Quirogab E, Hurtadob CF. Stable isotopes and geochemical indicators in marine sediments as proxies for anthropogenic impact: A baseline for coastal environments of central Chile (33°S). Marine Pollution Bulletin 2019;142:76-84.

Peng X, Ma SW, Chen HG, Zhang Z, Zhou YB, Cai WG. Spatial distribution and assessment of nutrients in marine ranching in Zhelin Bay-Nanao Island in summer, South China. Fisheries Science 2014;10:27-35.

Richard P, Riera P, Galois R. Temporal variations in the chemical and carbon isotope compositions of marine and terrestrial organic inputs in the Bay of Marennes-Oleron (France). Journal of Coastal Research 1997;13(3):879-89.

Rumolo P, Barra M, Gherardi S, Marsella E, Sprovieri M. Stable isotopes and C/N ratios in marine sediments as a tool for discriminating anthropogenic impact. Journal of Environmental Monitoring 2011;13:3399-408.

Sampaio L, Freitas R, Mangus C, Rodringues A, Quintino V. Coastal sediments under the influence of multiple organic enrichment sources: An evaluation using carbon and nitrogen stable isotopes. Marine Pollution Bulletin 2010;60:272-82.

Sangmanee P, Boonphakdee T, Boonkhwang, N. An application of geographic information systems for wastewater management based on land use characteristic in Chonburi Province. EnvironmentAsia 2017;1:626-35.

Sasmito SD, Kuzyakov Y, Lubis AA, Murdiyarso D, Hutley LB, Bachri S, et al. Organic carbon burial and sources in soils of coastal mudflat and mangrove ecosystems. Catena 2020; 87:104-14.

Sugimoto R, Kasai A, Yamao S, Fujiwara T, Kimura T. Short-term variation in behavior of allochthonous particulate organic matter accompanying changes of river discharge in Ise Bay, Japan. Estuarine, Coastal and Shelf Science 2006;66:267-79.

Thushari GGN, Senevirathna JDM, Yakupitiyage A, Chavanich S. Effects of microplastics on sessile invertebrates in the eastern coast of Thailand: An approach to coastal zone conservation. Marine Pollution Bulletin 2017;124:349-55.

Verardo JD, Froelich PN, McIntyre A. Determination of organic carbon and nitrogen in marine sediments using the Carlo Erba NA-1500 analyzer. Deep Sea Research 1990;37:157-65.

Watts JEM, Schreier HJ, Lanska L, Hale MS. The rising tide of antimicrobial resistance in aquaculture: Sources, sinks and solutions. Marine Drugs 2017;15(6):Article No. 158.

Webber JL, Tyler CR, Carless D, Jackson B, Tingley D, Stewart-Sinclair P, et al. Impacts of land use on water quality and the viability of bivalve shellfish mariculture in the UK: A case study and review for SW England. Environmental Science and Policy 2021;126:122-31.

Wei XG, Zhuo MN, Guo ZX, Zhu LA. Carbon and nitrogen stable isotope composition of soil, vegetation and suspended sediment in Dongjiang River Basin. International Journal of Ecology and Environmental Sciences 2010;19:1186-90.

Wu Y, Zuang J, Li DJ, Wei H, Lu RX. Isotope variability of particulate organic matter at the PN Section in the East China Sea. Biologeochemistry 2003;65:31-49.

Yu FL, Zong YQ, Lloyd JM, Huang GQ, Leng MJ, Kendrick C, et al. Bulk organic $\delta^{13}C$ and C/N as indicators for sediment sources in the Pearl River delta and estuary, southern China, Estuarine. Coastal and Shelf Science 2010;87:618-30.

Zhou B, Yuan H, Song J, Li X, Li N, Duan L, et al. Source, transformation and degradation of particulate organic matter and its connection to microbial processes in Jiaozhou Bay, North China. Estuarine, Coastal and Shelf Science 2021;260:Article No. 107501.