ORIGINAL ARTICLE

Estimating methane emissions from mangrove area in Ranong Province, Thailand

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Abstract

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This study aimed to estimate methane emissions from the mangrove area of Ranong Province and to explore the factors affecting the emissions, as part of an attempt to evaluate methane contribution to the global methane budget. Methane was measured by using a closed chamber technique and analyzed by a gas chromatograph equipped with a flame ionization detector (FID). The results showed that the annual estimated methane emission was released at approximately 157.32 mg/m^2. The amount of methane emission from this mangrove area was lower than in other previously studied areas. Emission rates varied seasonally with the highest rate in the rainy season followed by summer and cold seasons, during which the values were 0.52, 0.27, and 0.19 mg/m^2/day, respectively. Seasonal variations of methane emission was related to several factors depending upon field conditions such as water conductivity, soil temperature, and water level.

Key words : methane, emission, mangrove, Ranong

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การประเมินการปลดปล่อยก๊าซมีเทนจากป่าชายเลนจังหวัดระนอง

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การศึกษานี้มีวัตถุประสงค์ เพื่อประเมินอัตราการปลดปล่อยก๊าซมีเทนจากพื้นที่ป่าชายเลนของจังหวัดระนอง และความสัมพันธ์ของปัจจัยทางสิ่งแวดล้อมที่เกี่ยวข้อง โดยใช้วิธีแบบกล่องปิด (closed chamber) ในการวัดก๊าซมีเทน และนำตัวอย่างก๊าซมาวิเคราะห์หาค่ามีเทนด้วยเครื่องแกสโครมาโตกราฟที่มีเครื่องตรวจจับสัญญาณ (detector) แบบ FID ผลการศึกษาพบว่า พื้นที่ดังกล่าวมีอัตราการปลดปล่อยก๊าซมีเทนโดยเฉลี่ย 157.32 มก./ตร.เมตร/ปี ซึ่งนับว่าค่อนข้างต่ำเมื่อเปรียบเทียบกับผลการศึกษาจากพื้นที่อื่น ๆ และในแต่ละฤดูกาลจะปลดปล่อยก๊าซมีเทนมากน้อยแตกต่างกัน กล่าวคือ สูงสุดในฤดูฝน รองลงมาคือ ฤดูร้อน และต่ำสุดในฤดูหนาว ในอัตรา 0.52, 0.27 และ 0.19 มก./ตร.เมตร/วัน ตามลำดับ ความผันแปรในแต่ละฤดูกาลดังกล่าวมีความสัมพันธ์กับปัจจัยต่าง ๆ มากมายที่เปลี่ยนแปลงอยู่ตลอดเวลาในสภาพพื้นที่จริง ได้แก่ ค่าการนำไฟฟ้าของน้ำทะเล, อุณหภูมิของดิน และระดับน้ำ

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Methane is one of the important greenhouse gases that contribute to a rise in global mean surface temperature due to their relatively high absorption of infrared radiation (Bouwman, 1990). Methane concentration has more than doubled since pre-industrial times, with a current globally-averaged mixing ratio of 1750 part per billion by volume (Wuebbles and Hayhoe, 2002). The increasing rate of methane emission may have significant impact on future global warming which has become a serious concern. This concern has stimulated the efforts to quantify the potential of ecosystem as sources of atmospheric methane to develop policies and plans for controlling methane emissions.

Mangroves occupy a large fraction of the tropical coastline, dominating the intertidal zone of diverse environmental settings. Mangroves are complex ecosystems with highly interactive plants, animals, and microbial lives. The high primary productivity of mangroves implies a high demand for nutrients essential to plant growth and this demand appears to be met by a highly efficient system of nutrient trapping, uptake and recycling (Aksornkoae, 1999). However, the role of mangrove as a source of atmospheric methane remains uncertain because methane emissions from various mangrove areas have been estimated with a wide range of emission. Some researchers found that methane emissions from mangroves were considered to be negligible (Giani *et al.*, 1996; Alongi *et al.*, 2001). Sotomayor and coworkers (1994) reported the methane emission at about 4-82 mg/m^2/day from mangroves along the southwestern coast of Puerto Rico. Purvaja and Ramesh (2001) presented the methane emission from unpolluted mangrove of South India ranging from 47.28 to 324.48 mg/m^2/day. Lyimo and colleagues (2002) reported the methane emission from mangrove in Tanzania ranging from 0 to 192 mg/m^2/day.

In the coastal ecosystem, salinity and sulfate (SO_4^{-2}) are the major inhibitors of methane production by stimulating the activity of sulfate reducing bacteria, which compete with methanogens for the reduced substrates (DeLaune *et al.*, 1983; Bartlett *et al.*, 1987). The supply of organic matter is important for methane production and emission (Wang *et al.*, 1993a). Soil texture also has an effect on the net methane emission because the texture involve in transferring and trapping of methane produced in the reduced soil (Le Mer and Roger, 2001). Soil temperature is critical in determining the production and emission of methane from the subsurface to the atmosphere with optimum temperature between 25 and 30ºC (Dunfield *et al.*, 1993). These factors vary seasonally that may account for the variation of methane emission from mangrove. However, they are still questionable.

In this study, the objectives were to estimate annual rate of natural methane emission from the mangrove area of Ranong Province, a large undisturbed mangrove along the Western Coast of Southern Thailand. Measurements of methane emission were made with emphasis on the seasonal variations and environmental factors that affected methane emissions.

Materials and Methods

Study area

The study was carried out at Ranong Biosphere Reserve located at latitude 9.50ºN and longitude 98.35ºE on the Andaman coastline of Southern Thailand, Ranong province, 650-km southwest of Bangkok (Figure 1). In the area of Ranong Biosphere Reserve, the estuarine mangrove was relatively undisturbed and represented one of the best-developed mangrove forests, classified as old growth stands. The mangrove forest in Ranong Biosphere Reserve coverss about 67,506 rai or 27,002 acres (Ranong Biosphere Reserve, 2000), where *Rhizophora apiculata* is the dominant plant species. Therefore, the sampling stations were located in the vicinity of the Rhizophora trees. In this study five accessible sampling stations were selected to cover the range of mangrove-related environments within the mangrove forest, and were representative of a transect across the mangrove. These sampling stations were in the area inundation by medium high tide 50-100 m away from the Ngao canal bank; one of the major canals of the Ranong mangrove ecosystem. Two sam-

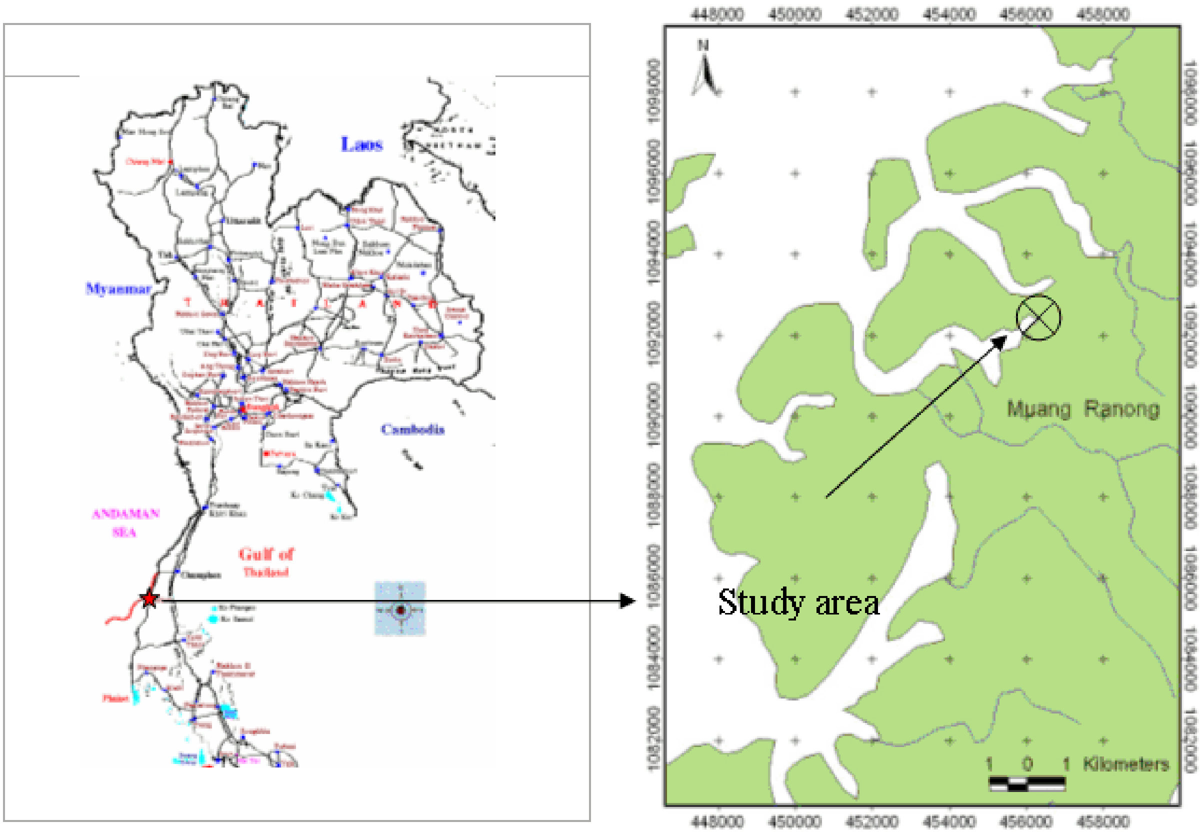

Figure 1. Study area at Ranong Biosphere Reserve (RN).

pling stations were at the edge of the Rhizophora community that was situated close to landward fringe on the non-vegetated bank adjacent to a small (ca 1 m wide) creek. Three sampling stations were in the center and at the rear of the centre of the Rhizophora community, and located between 'prop' roots of Rhizophora trees.

The seasonal separation, in this study, was considered based upon the climate pattern of Ranong Province. Ranong is a renowned as the wettest province in Thailand, which is the result of the influencing monsoon from the Andaman Sea that brings an abundant rainfall. Rainy season is from May to December whereas the cold season is in January and the summer season from February to April (Ranong Province, 2002). Tides in the Andaman coastline of Southern Thailand are semi-diurnal. During low tide the ground of the sampling station was exposed to the air while during the sampling period the mean heights of flooded water covering the sediment ranged from 0.3 to 1.5 meter depending on the lunar cycle and season.

Gas sampling and analysis

There were totally 6 samplings over a year, one time during the cold season in January 11-12, 2002, two times during summer on February 25-26 and April 17-19 and three times during the rainy season on June 10-11, July 1-2, and August 9-10. For each sampling, four gas samples were collected for each site, two during a high tide period and two during a low tide period.

The chambers were flushed with ambient air after placement following the method used by Sotomayor and coworkers (Sotomayor *et al.*, 1994). Gas sampling was conducted both on low and high tide periods during January and August 2002 using a closed chamber method. The chambers were made of acrylic glass of size 30×30×15 (length × width × height) cm^3. The top of the chamber had a glass tube fitted with silicone closed end tubing, which could be sampled via syringes, and had a thermometer for temperature measurement within the chamber. During the low tide period, the chambers were firmly pushed (1-2 cm) into the waterlogged sediment, with as little disturbance as possible, to ensure a seal against the ambient atmosphere. During the high tide period, the chambers were floated on a styrofoam plate (Figures 2a and 2b).

A polypropylene syringe was used for gas withdrawal from the headspace of the chamber immediately at intervals of 0, 20, 40, 60, 90 minutes. Samples were collected into evacuated vials fitted with rubber septa for analysis in the laboratory. Gas samples were analyzed by using a Hewlett-Packard 6890 gas chromatograph equipped with a flame ionization detector (FID) and a Poraplot Q capillary column (10 m × 0.32 mm ID). The detection limit was 0.010 ppm. The gas chromatograph was calibrated before and after each set of measurement, using 50 parts per million by volume (ppmv) CH_4 in N_2 as a primary standard. The standard was re-analyzed periodically after 20 consecutive analyses of samples and responded within the range of three standard deviations. The concentration of methane in the gas sample was interpolated by comparing chromatogram (peak area) of gas sample with a standard methane gas. Duplicate analyses for each sample were made and the limits of variability were within ± 3%.

Calculation of methane emissions was based on a linear regression analysis of an increase in concentration over time, as presented in Figure 3. The criterion for determining any leak was the coefficient of determination (r^2). The results were valid only with a coefficient of determination more than 0.6 (Sotomayor *et al.*, 1994). Low coefficient of determination may indicate the disturbance of the system during sampling, chamber-air leakage, enclosure dimensions or measurement period were not suited to the exchange rate being measured. (Livingston and Hutchinson, 1995; Sotomayor *et al.*, 1994). In this study the r^2 of greater than 0.6 was obtained which indicates the valid results (i.e., no chamber-air leakage).

Data analysis

The daily methane emission was calculated by integrating emissions during low and high tides in proportion to the daily duration of low and high tides as the following:

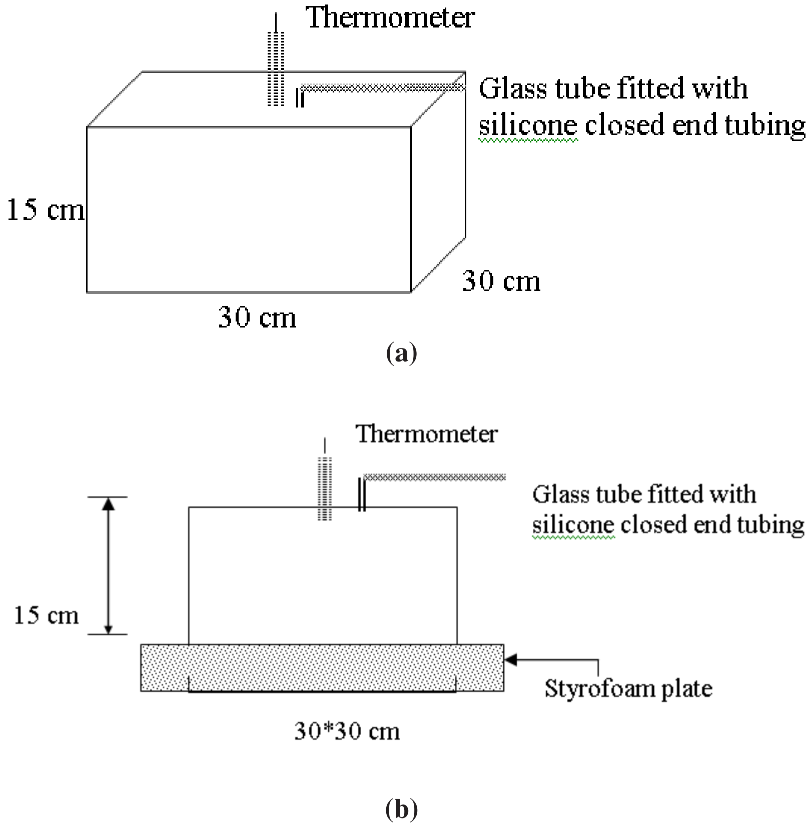

Figure 2. Static chamber (a) 30×30×15 cm^3; (b) floating chamber.

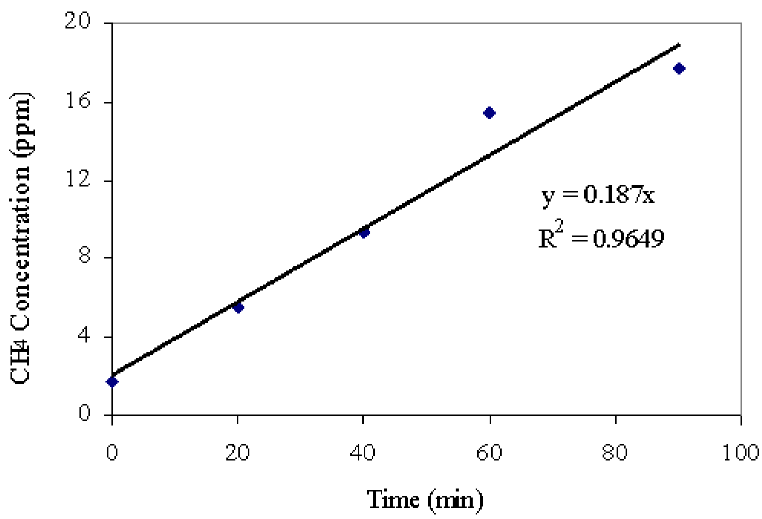

Figure 3. A linear relationship of methane concentration in the closed chamber over time.

$$Y = (X_l T_l) + (X_h T_h)$$

where Y is average daily methane emission ($\mu g/m^2$/day),
X_l is methane emission during low tide period ($\mu g/m^2$/hr),
T_l is the number of hours during low tide period = 16 hrs,
X_h is methane emission during high tide period ($\mu g/m^2$/hr),
T_h is the number of hours during high tide period = 8 hrs.

*** Note:** Numbers of hours during low and high tide periods were based on the data at The Ranong River Mouth (Pak Nam Ranong) Station obtained from Hydrographic Department Royal Thai Navy (Royal Thai Navy, 2002).

The annual methane emission from Ranong Biosphere Reserved was extrapolated from the mangrove areas by using a following equations.

$$CH_4 \text{ emission } (mg/m^2/yr) = (Y_c D_c)+(Y_s D_s)+(Y_r D_r)$$

where Y_c is average daily methane emission during cold season,
D_c is the number of days during cold season
Y_s is average daily methane emission during summer season,
D_s is the number of days during summer season
Y_r is average daily methane emission during rainy season, and
D_r is the number of days during rainy season

Cold season is considered to be in January only while summer and rainy seasons are from February to April and May to December, respectively.

$$CH_4\ (10^9\ g/yr) = CH_4 \text{ emission } (mg/m^2/yr) \times \text{area of mangrove } (m^2)/10^{12}$$

Soil sampling and analysis

Surface soil characteristics of sampling areas were supplementarily studied for a better understanding of methane emission capability so that comparison could be made with the other mangrove areas of the previous studies. Soil sampling and analysis were performed once in August 2002 after gas measurements had finished. Triplicate soil cores from the area of the sampling stations, 50-100 m away from the canal bank, were collected using PVC tubes, 5 cm in diameter and 100 cm in length. The cores were sectioned at 0-10, 10-20, 20-30 and 30-40 cm intervals and further characterized in terms of total organic carbon, total nitrogen, C:N ratio, texture, and sulfate concentrations. Total organic carbon and total nitrogen in core subsections were analyzed by FLASH EA1112: Elemental Analyzer, followed the US.EPA method 440.0. Texture was analyzed by pipette method. Sulfate concentration in the interstitial water was analyzed by Ion-Chromatograph.

During gas sampling period, soil temperature, soil pH and soil Eh (at the 5-cm depth) were also measured using a portable field pH/Eh meter. In addition, conductivity of surface water was measured using a portable field conductivity meter. The fluctuation of water level at sampling stations was monitored using a measuring tape.

Results and Discussions

Soil characteristics

The variations of total organic carbon, total nitrogen, C:N ratio and sulfate concentration with depth in soil are given in Table 1. The surface soil samples (0-10 cm) had a higher total organic carbon and total nitrogen content than the deeper samples (10-40 cm). The average of total organic carbon and total nitrogen in core subsections from 0-40 cm were 2.35±0.29% and 0.26±0.04% of the dry weight, respectively. The average C:N ratio was 9.25±1.50. The sulfate concentration for all subsamples in mmol/L was 9.42±1.24. Soil analyses indicated that the texture of soil sample was silty clay with high clay content. The percentages of sand, silt, clay in sediment were quite similar along the depth (Table 2).

Table 1. Characteristics of soil sample at various depths.

Depth (%)	Total organic carbon	Total nitrogen (%)	C:N ratio	Sulfate concentration (mmol/L)
0-10	2.58	0.32	8	7.59
10-20	2.51	0.23	11	9.76
20-30	1.94	0.24	8	10.23
30-40	2.36	0.24	10	10.11

Estimated methane emission

The variations of methane emissions during low and high tide periods are shown in Figure 4 and daily emissions of methane are showed shown in Figure 5. Daily methane emissions varied from 0.19 to 0.91 mg/m^2/day. The lowest value occurred in January and the highest emission was found in August.

It was found that methane emission rates during low tide were lower than during high tide period (Figures 4 and 5). One possible explanation is the oxidation state of soil during the low tide period, which was affected by crab burrows. Site inspection found that the sampling stations had a high crab burrow density (ocypodid crabs). This was probably due to a favorable environment of soil texture and temperature (Aksornkoae, 1999; Bunpavichit, 1979; Frith and Frith, 1977 & 1978). In this area, soil texture was silty clay with fine particles of silt and clay and lay in the shade of dense trees that stabilized the temperature. Kristensen and Coworkers (1992) reported that during the non-flooded period, drainage of water from sediment interstices (burrows and cracks) exposed the site to oxygen, which increased the area of oxic-anoxic interfaces. This sub-oxic condition results in the oxidized sediment appearance (Kristensen *et al*., 1994). Therefore, it is possible that penetration of oxygen into the crab-burrow increased the oxic area, which provided a methane oxidizing zone leading to a higher methane oxidation rate, thereby leading to a low methane emission during the low tide period.

Seasonal variations were observed during the measurements. The highest emission rate occurred in the rainy season with a mean of 0.52 mg/m^2/day (averaged from data collected during June to August only) and the lowest emission rate was in the cold season (January) with the mean of 0.19 mg/m^2/day. By extrapolation, the annual methane emission flux was calculated to be 157.32 mg/m^2 (Table 3) or equivalent to the amount of methane emitted from the Ranong Biosphere Reserve of 0.017×10^9 g/yr.

The methane emissions as found in this study were lower than the values obtained in other

Table 2. Fractions of sand, silt, clay at various depths in soil.

	Fraction		
Depth	Sand (%)	Silt (%)	Clay (%)
0-10	3.02	45.89	51.09
10-20	5.60	63.92	30.48
20-30	1.34	42.45	56.20
30-40	4.95	44.03	51.02
Texture		Silty Clay	

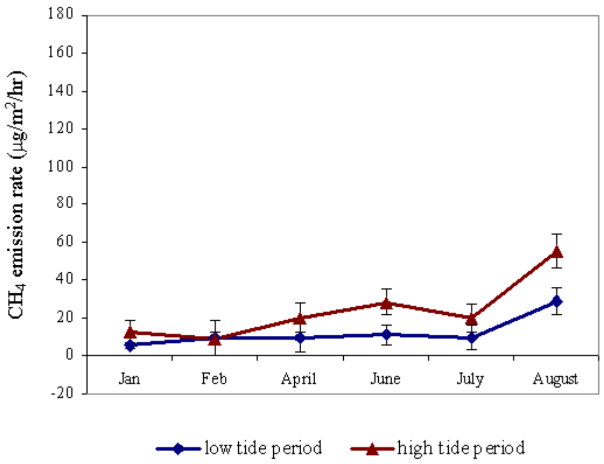

Figure 4. The variation of methane emission during low and high tides period.

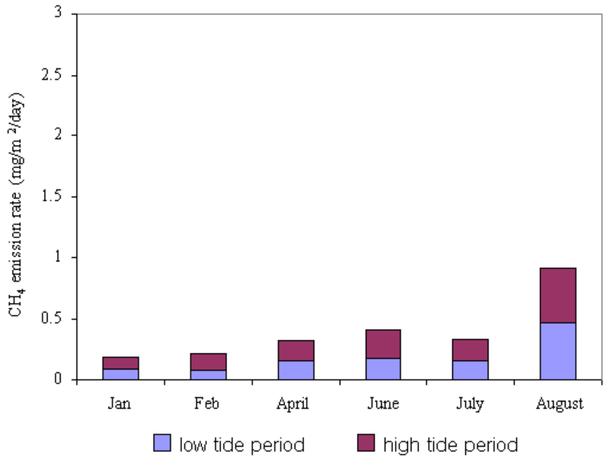

Figure 5. Daily methane emission rate: the summation of emissions during high and low tide periods.

mangrove areas (Sotomayor *et al.*, 1994; Purvaja and Ramesh, 2001). This was partly due to the organic carbon content of soil within Ranong Biosphere Reserve which was found to be 1.94-2.58% of dry weight, whereas organic carbon content of mangrove soil along the southwestern coast of Puerto Rico and South India were 6.5-16.3% and 5.7-8.3%, respectively. (Sotomayor *et al.*, 1994; Purvaja and Ramesh, 2001). According to a stoichiometric reaction, one can expected that methane emission could be more or less proportional to the input of organic carbon. Nevertheless, there may be other factors as well which were unable to establish within the context of this study.

Seasonal methane emission and influencing factors

Attempts were made to correlate the methane emission with various influencing factors including soil pH, temperature, and redox potential, water level and water conductivity. Nevertheless, only the correlation trend was reported due to a limited data available in a number of factors. As a result, no regression coefficient is reported.

Table 3. Estimation of annual methane emission (mg/m²/year).

Season	Methane emission rate (mg/m²/day)[a]	Number of days[b]	Annual methane emission (mg/m²/year)[a×b]
Cold	0.19	31	5.89
Summer	0.27	89	24.03
Rainy	0.52	245	127.40
	Total	365	157.32

Table 4. The seasonal methane emissions as related to the environmental factors.

Season	Methane emission (mg/m²/day)	Soil (ºC) temperature	Soil pH	Soil Eh (mV)	Water level (cm)	Water conductivity (mS/cm)
Cold	0.19	26.7	7.05	-233	30.0	47.40
Summer	0.27	27.7	6.90	-181	41.5	45.39
Rainy	0.52	28.4	6.93	-194	104.7	26.68

Mean soil temperature in all seasons fluctuated slightly from 26.7 to 28.4ºC (Table 4). These temperature are in the optimum range as found by Dunfield *et al.* (1993) who reported that methane production depended on temperature, with optima between 25 and 30ºC. A positive correlation between soil temperature and methane emission was observed. The highest methane emission occurred in the rainy season when soil temperature was the highest while the lowest emission was detected in the cold season.

Soil pH year-round ranged from 6.90 to 7.05 (Table 4). Most methanogens grow over a relatively narrow pH range, about 6-8, and the optimal pH is about 7 (Oremland, 1988). Thus, in this study, soil pH remained in the optimum pH range. However, change in soil pH did not relate to seasonal variation of methane emission. It indicated that soil pH might not be responsible for low or high methane emissions in different seasons at this mangrove area.

Soil redox potentials were consistently low, in the range of -181 to -233 mV (Table 4). Wang and his associates (1993b) reported that critical soil redox potential for initiation of methane production was lower than -150 mV. Thus, soil environment of this area would favor of methanogenesis and could lead to a high methane emission. However, there was no correlation between variation of soil redox potential and methane emission. This implieds that soil Eh might not be responsible for low or high emission rates of methane for different seasons in the area.

During the period of study, mean height of flooded water was measured and it covered the sediment ranging from 30 to 105 cm (Table 4). Water level was the highest in the rainy season due to the effect of monsoon raining and the highest emission coincided with the highest water level in the rainy season. Increased methane emission was well correlated with the increased water level. This result might due to the dense growth of Rhizophora trees. Thus the shade of trees prevented sunlight from penetrating into the great depth of flooded water, leading to darkness within the water body. The water darkness was one of the prerequisites for development of anoxic sediment surface and for the consequent inhibition of aerobic methane oxidation and increasing methane release into the water (Heyer and Berger, 2000).

Water conductivity was measured to represent the salinity of the water. Water conductivity ranged from 26.68 to 47.40 mS/cm (Table 4). There was significant variation of water conductivity in a year especially in rainy season when a lower value was observed as compared to other seasons. This might due to the topography of the study area that is estuarine mangrove farther from the sea. Its water quality was affected by fresh-water discharging from uplands thus resulting in decreased conductivity during the rainy season. The results revealed that conductivity was inversely correlated with methane emission. The highest methane emission occurred during rainy season when water conductivity was the lowest. This agrees with DeLaune *et al*. (1983) who reported that methane emission was inversely related to salinity.

However, seasonal variation of methane emission from mangrove was also related to other factors such as vegetative cycles (Kelly *et al*., 1995), in particular, duration of flowering, fruit formation and maturity of mangrove plant, including litter fall and decomposition rates (Giani *et al*., 1996). Besides these factors, seasonal change involved the tidal fluctuation resulted from monsoon rains. All of these factors controlled sediment metabolism, quantity and quality of organic carbon input and activity of microbial in mangrove ecosystems. These various factors consistently changed in the field conditions.

Conclusions

Estimated methane emission rate from mangrove areas in Ranong ranged from 0.19 to 0.52 $mg/m^2/day$. The estimated annual emission was approximately 157.3 mg/m^2. Methane emission from this mangrove was lower than those reported from other mangroves. This could be mainly due to the low organic carbon content of soil within Ranong Biosphere Reserve as compared to other mangrove areas. Methane emission varied seasonally. The lowest methane emission occurred during the cold season whereas the highest emission was found in the rainy season. Seasonal variations of methane emission was related to several factors that varied depending upon field conditions. Methane emission rate possessed a negative correlation with water conductivity, but was well correlated with soil temperature and water level. No correlation could be established for soil pH and soil Eh.

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