Sources of Sedimentary Organic Carbon in Mangrove Ecosystems from Ba Lat Estuary, Red River, Vietnam

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Abstract—Mangrove leaves, particulate organic matter (POM), and surface sediments were analyzed for C/N ratios and carbon stable isotope ($\delta^{13}C$) composition in order to determine the sources of sedimentary organic carbon in the mangrove ecosystems from Ba Lat Estuary, Red River, Vietnam. The average $\delta^{13}C$ value of –28.32‰ for mangrove leaves is characteristic of C_3 terrestrial plant. The $\delta^{13}C$ values of POM gradually increased from –25.41‰ at the upper estuary to –21.18‰ at the mouth of estuary, which demonstrates that the POM pool was influenced by terrestrial (phytoplankton) sources in the upper river (mouth of estuary). The $\delta^{13}C$ values of the surface sediments decreased from tidal creek (–23.43‰), through to tidal flat (–24.39‰), and to intertidal mangrove (–24.81‰). The concomitant decrease of $\delta^{13}C$ values in surface sediments may show a decrease of phytoplankton sources and increase in mangrove-derived organic carbon sources from the tidal creek to the mangrove forest.

Keywords: stable isotope, C/N ratio, mangrove, organic matter sources, Ba Lat Estuary

INTRODUCTION

Mangrove forests situate at the boundary between land and sea in the subtropics and tropics. These ecosystems play important roles for the carbon cycle in (sub)tropical coastal environments. The carbon accumulation is estimated at 0.02 Pg C/year in the mangrove sediments (Twilley *et al.*, 1992), and to be an important factor when constructing any carbon budget of the mangrove ecosystems (Twilley *et al.*, 1992; Bouillon *et al.*, 2003). Carbon stable isotope ($\delta^{13}C$) and C/N ratios have been used to understand sources and cycling of organic matter in the mangrove ecosystems (Bouillon *et al.*, 2008b), and to reconstruct the paleoenvironment and relative sea level points in the estuarine environment (Wilson *et al.*, 2005a). However, few studies provide a robust measure and description of the sources of sedimentary organic carbon (SOC) to the mangrove
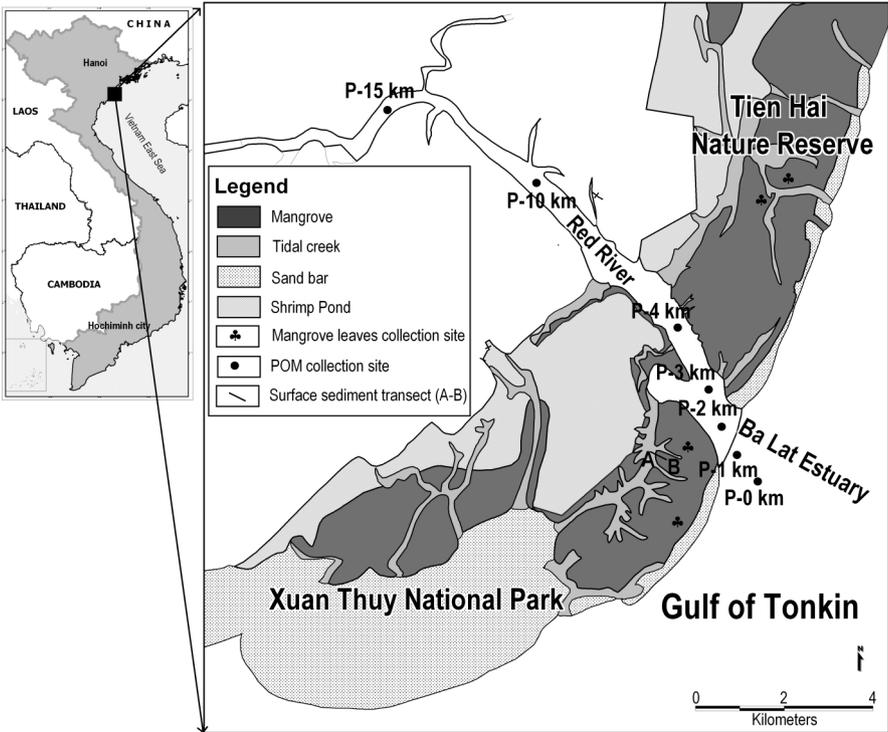
Fig. 1. Sampling sites within mangrove forests of the Ba Lat Estuary, Vietnam.

ecosystems. In this study, we examined the sources of SOC from surface sediments collected within mangrove ecosystems from the Ba Lat Estuary (BLE), Red River, Vietnam.

The BLE is the largest estuary of the Red River system, consisting of two major mangrove wetland sites (Xuan Thuy National Park and Tien Hai Nature Reserve) (Fig. 1). The mangrove forests are dominated by trees of *Sonneratia caseolaris*, *Bruguiera gymnorhiza*, *Kandelia candel*, *Aegiceras corniculatum* and *Acanthus ilicifolius*, which play important role in the filtering and containment of terrestrial-derived material and various pollutants, and as a physical buffer against erosion and surge from major storm events.

This study provides a clear indication of the sources of SOC to the mangrove ecosystems from the BLE, the largest estuarine system of the northern Vietnam. The results of this study may use to examine the importance of different primary producers to mangrove-inhabiting fauna, and to reconstruct the paleoenvironmental change through the system in the future studies.
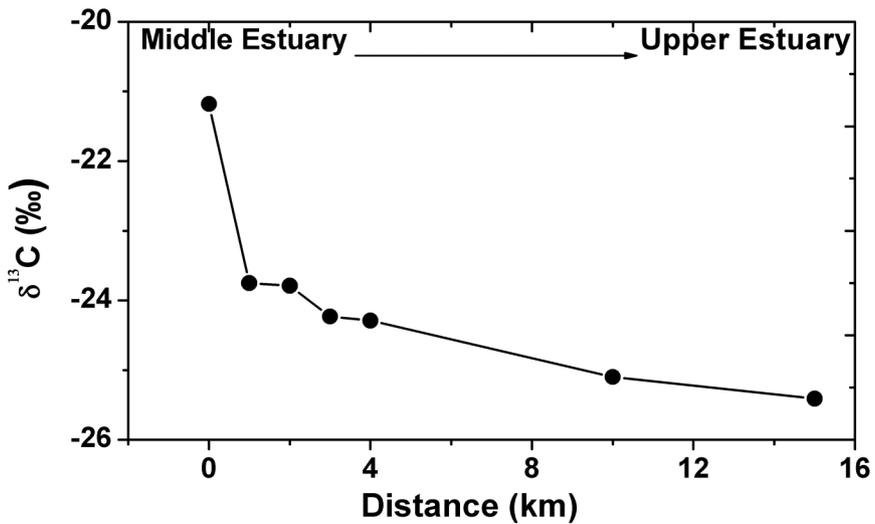
Fig. 2. Longitudinal gradients of $\delta^{13}C$ within the estuary.

MATERIALS AND METHODS

Field sampling

Mangrove leaves were sampled from 28 January to 10 February 2008. Fresh leaves were collected from mangrove trees at 13 sites (eight natural mangrove samples, five restored mangrove samples). The leaves were carefully rinsed with distilled-deionized water soon after collection for removing any potential extraneous material. And then, the leaves samples were kept on ice in a cool box.

Surface sediments and POM samples were sampled from 9 to 15 March 2010. The POM samples were collected by filtering 0.5–1.0 L of surface water (0–2 m in depth) through pre-combusted (at 550°C) 47 mm Whatman GF/F glass fiber filters. The POM samples were sampled during the flood tide and along the axis of the estuary. The POM samples were labeled by their distance from the mouth of estuary (Fig. 1). Three surface sediments were collected along the 300 m transect, which encompasses a range of ground elevation from tidal creek, through to tidal flat, and to intertidal mangrove. Surface sediments were immediately put in the plastic bags and kept in a cool box.

Sample analysis

Sediment samples, mangrove leaves, and POM samples were dried at 60°C for 48 h, and then ground to a fine powder by an agate mortar and pestle for $\delta^{13}C$, TOC, and C/N ratio analysis.

Sediment powder and POM samples were analyzed for stable isotope $\delta^{13}C$, total organic carbon (TOC), and total nitrogen (TN) by using a stable isotope mass spectrometer (ANCA-SL, PDZ Europa, Ltd.) following an *in situ* acidification procedure.

Carbon stable isotope values ($\delta^{13}C$) were expressed in ‰ (per mil) deviations from the standard value by the following equation:

$$\delta^{13}C(\text{‰}) = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) * 1000$$

where $R = {}^{13}C/{}^{12}C$, R_{sample} is the isotope ratio of the sample, and R_{standard} is the isotope ratio of a standard referenced to Pee Dee Belemnite (PDB) limestone carbonate. The analytical error was ±0.01‰ for $\delta^{13}C$.

RESULTS AND DISCUSSION

$\delta^{13}C$ of organic matter sources

The average $\delta^{13}C$ values of the natural mangrove leaves and restored mangrove leaves were (–27.95 ± 1.17‰, $n = 8$) and (–28.55 ± 1.05‰, $n = 5$), respectively. The overall average $\delta^{13}C$ value of –28.32 ± 1.09‰ ($n = 13$) for mangrove leaves is characteristic of C_3 terrestrial plants (Lamb *et al*., 2006) and consistent with those reported by other mangrove studies (Rodelli *et al*., 1984; Bouillon *et al*., 2008a).

Longitudinal gradients of $\delta^{13}C$ within the estuary

The $\delta^{13}C$ values of POM showed a clear difference between the upper (15 km from the sea) and the mouth of the estuary (0 km from the sea) (Fig. 2). The $\delta^{13}C$ values gradually increased from –25.41‰ at the upper estuary to –21.18‰ at the mouth of estuary. In contrast to the $\delta^{13}C$ values, C/N ratios showed little variation with distance from the mouth of BLE. C/N ratios generally varied from 7.56 to 10.37. At the upper estuary, the C/N ratios remained around 8. However, the C/N ratios varied from 7.56 to 10.37 near the mouth of estuary. The difference in $\delta^{13}C$ values of POM from the mouth to upper estuary indicates that POM had a change in constituents and sources of organic carbon. The $\delta^{13}C$ value (–21.18‰) and C/N ratio (9.79) of POM at the mouth of BLE indicate an origin of marine phytoplankton. From 1 to 5 km from the sea, gradually decrease in the $\delta^{13}C$ values and greatly variation of the C/N ratios indicate that organic carbon of POM may comprised a mixture of terrestrial organic matter and marine phytoplankton with the latter being predominant source (Wilson *et al*., 2005b). From 10 to 15 km, the $\delta^{13}C$ value was lower than that of POM at the mouth of estuary, indicating the terrestrially derived carbon (Bird *et al*., 1995). The longitudinal gradients of $\delta^{13}C$ of POM within the estuary demonstrate that the POM pool was mainly constituted by C_3 terrestrial plant sources in the upper river, and the marine phytoplankton in
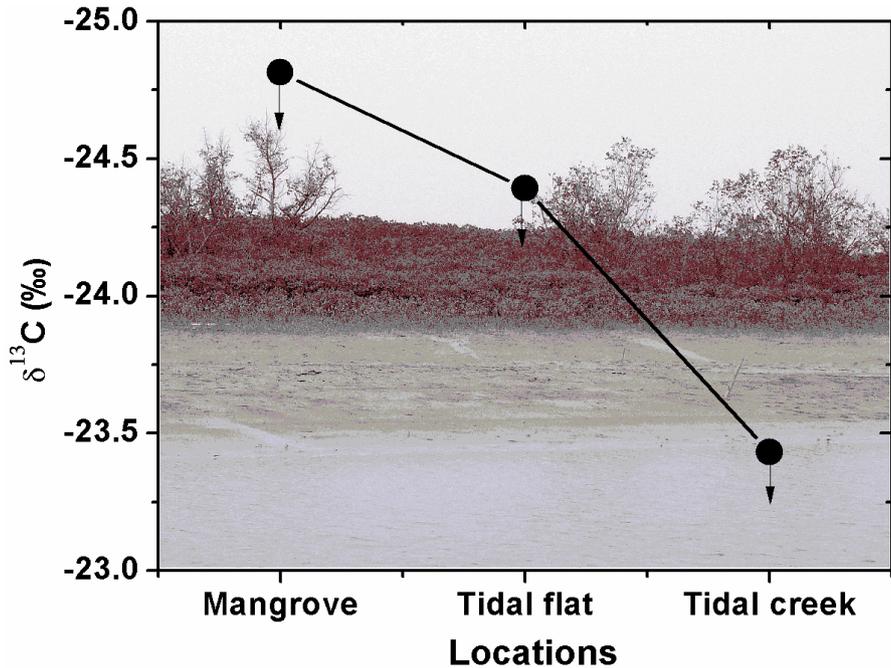
Fig. 3. Surface sediment transect of $\delta^{13}C$ in the mangrove ecosystem.

the mouth of the BLE estuary. These results may show that the marine phytoplankton production is intruded into the rivers and tidal creeks during flood tides.

Surface sediment transect of $\delta^{13}C$ in the mangrove ecosystem

   In the BLE, because of high turbidity and sedimentation, aquatic macrophytes and seagrasses were entirely absent. As a result, main sources of local primary production within the estuary are from mangroves and benthic microalgae (autochthonous), river-transported terrestrial material and marine phytoplankton (allochthonous), which together contributed to SOC of the mangrove ecosystems. Moreover, benthic microalgae production is usually very low within mangrove forests, due to light limitation but also from inhibition by soluble tannins (Robertson and Alongi, 1992). In this study, benthic microalgae production was therefore not considered to be a major source of the SOC.

   The $\delta^{13}C$ values of the surface sediment transect are summarized in Fig. 3. The $\delta^{13}C$ decreased from tidal creek (–23.43‰), through to tidal flat (–24.39‰), and to intertidal mangrove (–24.81‰). The $\delta^{13}C$ value of tidal creek sediment suggests that the phytoplankton production was a dominant source of SOC. A concomitant decrease in $\delta^{13}C$ may show a decrease of phytoplankton constituent

and an increase in mangrove-derived organic carbon in the tidal flat sediment. The δ^{13}C value of mangrove sediment is about 4‰ higher than that of mangrove leaves, which indicates that the mangrove sediments contained a mixture of phytoplankton production and mangrove litters, with the latter being predominant (Bouillon *et al.*, 2002; Kristensen *et al.*, 2008). These results demonstrate that the bulk δ^{13}C of surface sediment appears to be associated with ground elevation with tidal frame. The δ^{13}C values of sediments suggest that the tidal amplitudes may be an important factor controlling the sources of SOC in the mangrove ecosystems. The similar results were also reported in the mangrove ecosystems of Sri Lanka and India (Bouillon *et al.*, 2003). Moreover, Wilson *et al.*, (2005b) found a relationship between bulk sediment δ^{13}C and ground elevation within the tidal frame in the saltmarsh of the Mersey Estuary, UK. They also emphasized that the relationship may be more suitably applied in detecting changes in relative sea level rise. Therefore, the association of δ^{13}C with ground elevation in the mangrove ecosystems of BLE may be used to reconstruct the paleoenvironment change in the future studies.

A simple mixing model was applied to calculate the relative contribution of each of two sources C_3 mangrove plants and marine phytoplankton to the SOC of samples from tidal creek, tidal flat, and mangrove forest. The equation used is as follows:

$$\delta^{13}C_{sed} = f_t^* \delta^{13}C_t + f_m^* \delta^{13}C_m^{(*)}$$

$$f_t + f_m = 1$$

or

$$f_m = 1 - f_t.$$

Substitution the f_m value in equation (*), we have:

$$f_t(\%) = \frac{\delta^{13}C_{sed} - \delta^{13}C_m}{\delta^{13}C_t - \delta^{13}C_m} * 100$$

where f_t, f_m are the relative contribution of C_3 mangrove plants, marine phytoplankton sources (%), respectively; $\delta^{13}C_{sed}$, $\delta^{13}C_t$, $\delta^{13}C_m$ are the carbon stable isotope values of sediment, C_3 mangrove plants, and marine phytoplankton sources, respectively.

In this study, the average δ^{13}C value of mangrove leaves was –28.32‰, which can be considered as the value $\delta^{13}C_t$ of C_3 mangrove plants, and the δ^{13}C value of POM at the mouth of the BLE estuary (0 km) was –21.18‰, which is similar with the δ^{13}C values of seston from offshore the Matang mangrove swamp, Malaysia (Chong *et al.*, 2001). Thus, the δ^{13}C value of POM is a

reasonable value for marine production. The estimated relative proportions of the mangrove litters to the SOC of tidal creek, tidal flat, and mangrove forest are 31.5, 45, and 51%, respectively. This result confirmed that the contribution of mangrove litter to sediments decreased from mangrove forest, though to tidal flat, and to tidal creek. Therefore, the present study illustrates that the mangrove forest floor was the principal factor controlling the relative contribution of organic carbon in the surface sediments from the overlying mangrove plants and suspended matter intruded with flood tide from tidal creeks.

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