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Effect of nutrient enrichment on the source and composition of sediment organic carbon in tropical seagrass beds in the South China Sea

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ABSTRACT

To assess the effect of nutrient enrichment on the source and composition of sediment organic carbon (SOC) beneath *Thalassia hemprichii* and *Enhalus acoroides* in tropical seagrass beds, Xincun Bay, South China Sea, intertidal sediment, primary producers, and seawater samples were collected. No significant differences on sediment $\delta^{13}C$, SOC, and microbial biomass carbon (MBC) were observed between *T. hemprichii* and *E. acoroides*. SOC was mainly of autochthonous origin, while the contribution of seagrass to SOC was less than that of suspended particulate organic matter, macroalgae and epiphytes. High nutrient concentrations contributed substantially to SOC of seagrass, macroalgae, and epiphytes. The SOC, MBC, and MBC/SOC ratio in the nearest transect to fish farming were the highest. This suggested a more labile composition of SOC and shorter turnover times in higher nutrient regions. Therefore, the research indicates that nutrient enrichment could enhance plant-derived contributions to SOC and microbial use efficiency.

1. Introduction

Seagrasses develop organic-rich sediment composed of both autochthonous and allochthonous organic carbon (Kennedy et al., 2010; Fourqurean et al., 2012). Higher sediment organic carbon (SOC) concentrations have been observed in the sediment of seagrass beds compared to bare sediment (Boschker et al., 2000; Holmer and Frederiksen, 2007; Marbà et al., 2015). Seagrass, epiphyte, macroalgae, and suspended particulate organic matter (SPOM) trapped from the water column (Agawin and Duarte, 2002; Gacia et al., 2003) can be important sources of sediment organic carbon in seagrass beds (Kennedy et al., 2004; Papadimitriou et al., 2005; Volkman et al., 2008; Dubois et al., 2012; Miyajima et al., 2015). Kennedy et al. (2010) summarized the average contribution of seagrass to SOC to be about 50% according to a worldwide database of $\delta^{13}C$. The most active fraction of SOC is labile organic carbon (LOC), which is important in controlling ecosystem productivity and understanding the carbon transformation and biogeochemistry cycle (Cheng et al., 2008; Dodla et al., 2012). Microbial biomass carbon (MBC) is a vital fraction of LOC (Fang et al., 2005; Dodla et al., 2012; Yang et al., 2013) and serves as a sensitive indicator of change and future trends in sediment organic matter (Hicks, 2007; Yang et al., 2013).

The rapid expansion of aquaculture in global coastal zones has induced various environmental problems (Primavera, 2006; Grigorakis and Rigos, 2011; Ferriss et al., 2016). The exponential increase of aquaculture along the China coast over the last two decades has intensified the risk for degradation of sensitive marine habitats, such as mangrove, coral reef, and seagrass beds. For example, fish farming in Xincun Bay (an almost entirely closed bay and key aquaculture area in China), Hainan Island, and the South China Sea has generated a considerable amount of particulate organic waste and soluble inorganic waste that has led to the proliferation of macroalgae and epiphytes, and the decline of seagrass. As we know, there are distinct differences for the quality and quantity of organic carbon among seagrass, epiphyte, macroalgae, and SPOM (Cebrian, 1999; Banta et al., 2004). Does this alteration of primary community structure induced by nutrient loading affect the SOC sources and the LOC composition in tropical seagrass beds in Xincun Bay? Further research is required to address this question.

Seagrass species have been highlighted as factors inducing variability of sedimentary carbon stocks of seagrass beds (Lavery et al., 2013). The seagrass bed in Xincun Bay is a mixed seagrass community, with *Thalassia hemprichii* and *Enhalus acoroides* as the dominant species (Huang et al., 2006). In comparison, leaves of *E. acoroides* are wider and taller than those of *T. hemprichii*. New shoots of *T. hemprichii* stem form vertically from the creeping rhizome as short lateral branches, while *E. acoroides* has no lateral branches (Rollón, 1998). Do these differences in leaf morphology lead to significant difference on the source

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and composition of SOC between *T. hemprichii* and *E. acoroides* in Xincun Bay?

Consequently, focusing on tropical seagrass beds, the aim of this study was to examine the sources of SOC and its LOC composition beneath *T. hemprichii* and *E. acoroides* along the nutrient gradient in Xincun Bay. The results may help to elucidate the source and composition of SOC in tropical seagrass beds in the South China Sea and their controlling factors. Our data could help to predict the response of carbon biogeochemistry to anthropogenic stress in a nearly closed bay and provide policy makers along the Indo-Pacific with the knowledge needed to improve ecosystem-based management of these environmentally important marine angiosperms. This is the first report on the effect of nutrient loading on sediment LOC in seagrass beds.

2. Materials and methods

2.1. Study site

The study was performed at Xincun Bay (18°24′34″N–18°24′42″N, 109°57′42″E–109°57′58″E), located in southeastern Hainan Island, South China Sea. Xincun Bay is an almost entirely closed bay with only one narrow channel connecting to the open sea in the southwest (Fig. 1). The substrate was mainly composed of medium-sized sand (China's bay compilation committee, 1999). Dominant seagrass species of *T. hemprichii* and *E. acoroides* occupy an area of approximately 200 ha in the shallow waters in the south of the bay (Huang et al., 2006). In recent years, cage aquaculture has developed rapidly, so that more than 450 floating cage units are located near the entrance of the bay (Zhang et al., 2014).

2.2. Field sample collection

Our sampling sites are shown in Fig. 1. According to the distance to the fish cage culture area, three transects were selected. Transect 1 was located near the bay's entrance and at a distance of about 800 m from the fish cage culture systems, while transect 3 was located far from (about 3 km) the fish cage culture systems. Transect 2 was between them. The distance between the two transects was about 1 km. Three sampling positions were selected in each transect.

Seawater samples were collected to analyze inorganic nutrients in 2012 (December) and in 2013 (August and December). We used the Ruttner 11.004 organic glass hydrophore (KC Denmark A/S. Co., Denmark) to collect water samples 50 cm below the surface during the high tide period (water depths about 1.0–1.5 m). In December 2013, *T. hemprichii* and *E. acoroides* shoot densities were determined by counting the abundance of shoots of the different species present in six quadrats (0.25 m^2) within each transect during low tide (water depths about 0–0.3 m). After that, all the seagrass plants in the quadrats were collected for subsequent analysis. In addition, macroalgae (*Ulva pertusa* and *Hypnea boergeseni*) were also collected in six quadrats (0.25 m^2) within each transect. Meanwhile, duplicated sediment (0–3 cm) samples were also collected in each sampling position where *T. hemprichii* and *E. acoroides* grew in these three transects. These sediment and macrophyte samples were stored in plastic bags. All the samples were stored in an ice chest immediately after sampling until being transported to the laboratory within a few hours.

2.3. Sample preparation and analysis

The seawater was filtrated onto pre-combusted GF/F filters (Whatman, 450 °C, 3 h). Filters were immediately packaged in tin foil and stored in plastic bags for subsequent SPOM analysis. The filtered seawater was analyzed for dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP) using an AQ-2 Automated Discrete Analyzer (Seal Analytical Inc.).

For each sampling point, a sediment subsample was freeze-dried, composited by plot and sieved through a 500 μm screen to remove coarse materials. The samples were then ground and homogenized with a mortar and pestle, acidified (1 N HCl) overnight at room temperature to remove carbonate, followed by washing with distilled water and drying at 40 °C in an oven. Seagrass leaves, rhizomes, and macroalgae were cleaned by distilled water to remove detritus and attached animals. Epiphytes were removed from seagrass leaves using a scalpel blade and transferred to watch-glasses. The seagrass leaves, rhizomes, epiphytes, and macroalgae were dried at 60 °C for 24 h and weighed. The average

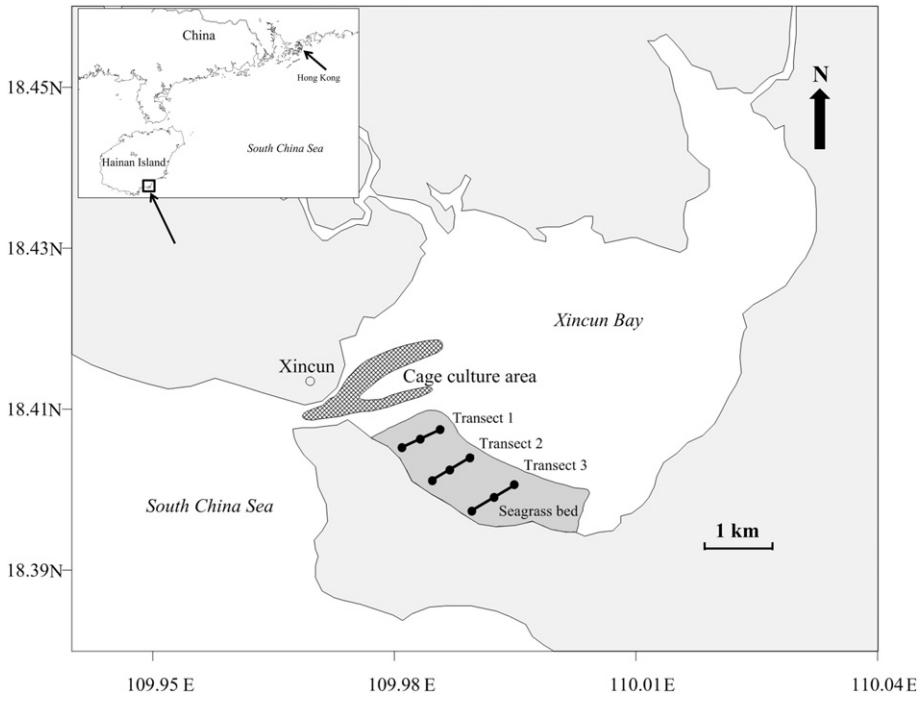

Fig. 1. Sampling sites in Xincun Bay, Hainan Island, South China Sea.