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Nutrient variations and isotopic evidences of particulate organic matter provenance in fringing reefs, South China

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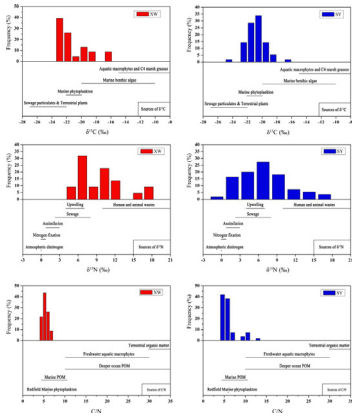
HIGHLIGHTS

- The isotope values suggest marine and terrestrial-derived nutrient sources.
- $\delta^{15}N$ values revealed terrestrial and upwelling-dominated nitrogen sources.
- Fringing coral reefs are more vulnerable to anthropogenic nutrient inputs.

GRAPHICAL ABSTRACT



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ABSTRACT

Nutrient over-enrichment is considered to be one of the causes of coral decline. Increase in traditional fishing in the Xuwen National Coral Reefs Reserve tract (XW) and tourism around the Sanya National Coral Reefs Reserve tract (SY) are causing this coral decline. This study reviews the current state of knowledge of the nutrient status of coastal fringing reefs in South China and evaluates the primary sources of nutrients using stable isotope method. Surveys of seawater nutrients showed that the seawater remained clean in both the XW and SY coastal coral reef areas. Based on the isotopic differences between anthropogenic sewage and naturally occurring aquatic nutrients, the isotopic values of particulate organic matter (POM) and the C/N ratios were successfully used to identify the presence of anthropogenic nutrients in aquatic environments. The $\delta^{13}C$, $\delta^{15}N$ and C/N compositions of POM from XW and SY (-21.18 ± 2.11‰, 10.30 ± 5.54‰, and 5.35 ± 0.69 and -20.80 ± 1.34‰, 7.06 ± 3.95‰, and 5.77 ± 2.15, respectively) showed statistically significant variations with the season. The $\delta^{13}C$ and $\delta^{15}N$ values of POM suggest marine and terrestrial-derived nutrient sources. Organic carbon is a mixture of marine phytoplankton, marine benthic algae and terrestrial-derived plants. The $\delta^{15}N$ values suggest terrestrial-derived sewage and upwelling-dominated nitrogen sources. In the presence of natural upwelling and coastal currents, coastal coral reef areas are more vulnerable to the increasing anthropogenic nutrient inputs. Anthropogenic activities might lead to large increases in the nutrient concentrations and could trigger the shift from coral- to macroalgae-dominated ecosystems, which would ultimately result in the degradation of the coastal coral reef ecosystem. These results provide some understanding of the declining coral reef ecosystem and the importance of conservation areas and coastal coral reef resource management.

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1. Introduction

Coral reefs have suffered remarkable declines of both coral cover and coral species worldwide. The area of coral reefs has declined by 19% since 1980s; 15% of reefs are seriously threatened with loss within the next 10–20 years; and 20% of reefs are under threat of loss in 20–40 years (Wilkinson, 2008). Halpem et al. (2008) indicated that 41% of the area of the ocean is strongly affected by human influences and that half of the global coral reef area experiences medium high to very high influence. Numerous human activities and natural disturbances, such as overfishing, coastal development, pollution, tourism, floods, storms, hurricanes, diseases, global warming, and acidification, are jeopardizing coral reefs (Cao and Wong, 2007; Mumby et al., 2007; Mora et al., 2011; Pandolfi et al., 2005, 2011; Palumbi et al., 2014; Dulvy and Kindsvater, 2015; Graham et al., 2015). In many areas, coral reef ecosystems are experiencing a shift from coral-dominated to macroalgal-dominated ecosystems (Done 1992; Hughes et al., 2007; Maliao et al., 2008; Cheal et al., 2010), and nutrient over-enrichment from human activities is considered to be a major cause of this degradation in spite of the sparse conclusive evidence (Hughes et al., 1999; Costanzo et al., 2001; Szmant, 2002; Yamamuro et al., 2003; Barile and Lapointe, 2005; Marion et al., 2005).

Generally, corals live in oligotrophic environments. Nitrogen is a limiting element in their growth, and high nutrient loads can have severe effects and disrupt the internal balance in the ecosystem. Thus, it is critical to determine the provenance of nutrients. Particulate organic matter (POM) is a good indicator for identifying nutrient sources. POM is composed of a variety of colloidal and particulate matter, including living and nonliving material from various sources (Volkman and Tanoue, 2002). The greatest portion of POM is composed of organic detritus that represents a complex mixture of biogenic reactivity and reflects short-term nutrient fluctuations in the water column (Libes, 1992). Considerable attention has been focused on utilizing the stable isotopic values of carbon and nitrogen in POM to determine possible nutrient sources (Saino and Hattori, 1980; Mariotti et al., 1984; Owens, 1985; Lapointe et al., 1990; Risk and Erdmann, 2000; Lamb and Swart, 2008; Briand et al., 2015; Cao et al., 2015). The simultaneous utilization of stable carbon and nitrogen isotopes and C/N ratios as natural tracers can enhance the precision of the traceability of end-member signatures.

Few studies have been conducted on nutrient concentrations and their sources in coastal coral reef areas in South China. The main objectives of this study are (1) to investigate the current nutrient status of two typical coral reef tracts, (2) to describe the isotope composition of POM and their potential sources, and (3) to explore the implications for coastal coral reef protection.

2. Materials and methods

2.1. Study site descriptions

Two typical coastal coral reef areas were selected for this study. The first study area is a traditional fishing area with a sparse population in the Dengloujiao Reef tract within the Xuwen National Coral Reefs Natural Reserve (XW) (Fig. 1a). The second study area is a rapidly developing tourism area in the Luhuitou Reef tract within the Sanya National Coral Reefs Natural Reserve (SY) (Fig. 1b). Xuwen County, with a population of 714,700 and an area of 1779.63 km^2, is located in southernmost mainland China. The intertidal area is 169.33 km^2, and sewage treatment rate is 89%. Agriculture and marine fishing are the main industries in the county (Zhao et al., 2009a, b). No rivers discharge into the sampling tract at XW. Sanya City, with a population of 732,000 and an area of 1919.58 km^2, is located in southern Hainan Island. Sewage treatment rate is 84.5%, and tourism is the main industry in the city (Huang et al., 2007). The Sanya River is located to the north of the Luhuitou Reef tract; it is 31.3 km long and has an average discharge of 5.86 m^3/s (Wang et al., 2005; Zhou et al., 2009). The Dengloujiao Reef tract (~7 km long and ~300–600 m wide) is located west of Fangpo village in Xuwen county in southern Guangdong Province, north of the Qiongzhou Strait and in the eastern part of Beibu Bay (Song et al., 2007). *Acropora*, *Porites* and *Favosites* dominate this location (Lu et al., 2003; Wang et al. 2003; Zhao et al., 2008a, b; Zhang et al., 2009). The Luhuitou Reef tract (~3 km long and ~250–500 m wide) is located south of the city of Sanya in Hainan Province (Zhao et al., 2014). The dominant genera are *Acropora* and *Porites*. The two coral reefs are

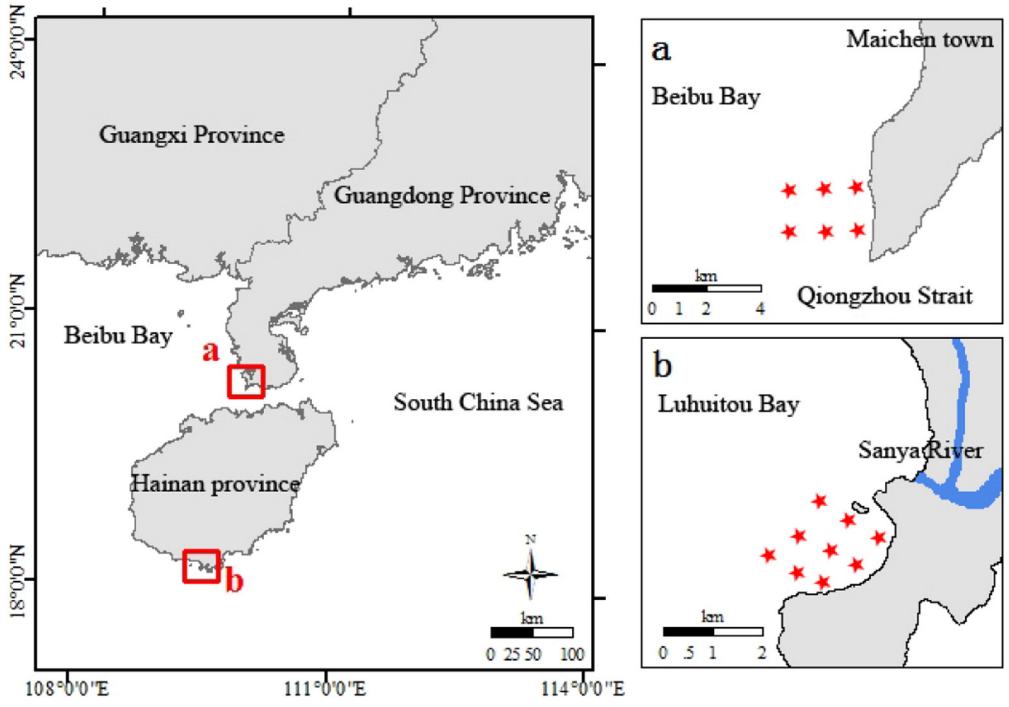

Fig. 1. Study areas XW and SY in South China. Detailed maps (a, b) showing the sampling sites at each location. The letters a and b refer to XW and SY areas respectively.