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Linking benthic community structure to terrestrial runoff and upwelling in the coral reefs of northeastern Hainan Island

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ABSTRACT

Near-shore coral reefs in northeastern Hainan Island are close to river mouths and aquaculture ponds, and also located at the center of the Qiongdong Upwelling (QDU). However, it is still unclear how terrestrial runoff and upwelling influence the community composition and spatial distribution of the benthos. During three cruises in 2010 and 2011 in Wenchang, northeastern Hainan Island, we determined a subset of environmental parameters in seawater (e.g. temperature, salinity, DO, dissolved inorganic nutrient (DIN), turbidity and transparency) and macroalgal $\delta^{15}N$ and investigated the benthic communities (e.g. live coral cover, coral species richness, juvenile coral density, macroalgal cover and coverage of calcified algae) by video transect and visual census techniques at 10 stations (i.e. 1S–6D). The results showed that the QDU has influenced the reef waters in Wenchang. In 2011, the upwelling started in early May, peaked in July and disappeared in September and most upwelling events lasted for 1–2 weeks between May and July. The results also demonstrated that the reef water was nutrient enriched. Stations close to the river mouth and aquaculture ponds had higher levels of DIN and a higher percentage of ammonia in DIN, and there was consistently lower live coral cover, juvenile coral density and higher macroalgal cover. At some stations in this study, live coral cover was negatively correlated with macroalgal cover (i.e. 2S–6D). Live coral cover, species richness, and juvenile coral density all increased with the distance away from the river outlet and decreased with the rise of DIN. These results suggest that terrestrial runoff and upwelling stimulate nutrient enrichment, and that overgrowing macroalgae has an important influence on the coral communities in northeastern Hainan Island.

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1. Introduction

Nutrient pollution has caused major damage to many coastal coral reefs around the world (Szmant, 2002; Fabricius, 2011; Huang et al., 2011). For example, nutrient enrichment, which is defined as an increase in nutrient concentrations (especially nitrogen or phosphorus) in a water body (Fabricius, 2011), inhibits coral fecundity, fertilization, and embryo and larval development (Fabricius, 2005) and increases coral's susceptibility to climate change (Wiedenmann et al., 2012). Moreover, nutrient enrichment induces particulate organic matter (POM) enrichment in the water column and thus reduces light availability, which decreases coral's photosynthesis and calcification (Fabricius, 2011). In areas of nutrient upwelling or in heavily polluted locations (e.g. river mouth and aquaculture effluents), chronically elevated levels of nutrients may alter the coral's physiology and calcification, causing noticeable changes in coral communities (Birkeland, 1997). In addition, as macroalgae benefit from nutrient enrichment more than corals, nutrient enrichment stimulates macroalgal overgrowth, enabling macroalgae to rapidly compete for habitat, and cover and smother living coral in areas where grazing by herbivorous fishes or invertebrates is low (Lapointe, 1997; McCook, 1999; McClanahan et al., 2002) and light is not limited (Fabricius, 2011).

Seasonal upwelling is an important factor affecting not only the physiology of corals, but also the ecology of coral communities in

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some regions. A minimum temperature of 14.7 °C was recorded on coral reefs in the upwelling season of 2001 in the Gulf of Panama, with severe coral mortality occurring (Glynn and Fong, 2006). Strong upwelling has been shown to decrease coral's growth rate (Glynn, 1977), select for species-tolerant to nutrient-rich and cold water (Brown, 1997; Schmidt et al., 2012), reduce coral recruitment (Rodriguez et al., 2009), limit reef development (Mate, 2003; Schmidt et al., 2012) and stimulate macroalgal growth, which will promote coral-algal competition for space (Szmant, 2002). Thus, coastal coral reefs in upwelling regions appear to be more susceptible to nutrient pollution, where overfishing also commonly exists. However, to date, studies have either focused on the upwelling processes or on coral reefs, with less attention to relating the upwelling processes to coral reef condition. The mechanisms affecting coral reef ecosystems in upwelling regions (e.g. benthic community interactions) are not well studied.

Hainan Island is located in the tropical northern periphery of the Indo-Pacific Ocean in the South China Sea. Eastern Hainan Island is characterized by a tropical monsoon climate, with the dry season from November to April and the rainy season from May to October. It is affected by northeast wind and waves in the winter, and southerly wind and waves in the summer (Zhang et al., 2006). In the summer, the coast of eastern Hainan Island is also affected by the seasonal QDU (Jing et al., 2009). The Wenchang area is located in northeastern Hainan Island (Fig. 1). Shrimp and fishponds have expanded quickly since the 1960s at the expense of natural wetlands on the northeastern coast of Hainan Island (Herbeck et al., 2013). Historically, coral reefs were abundantly distributed in shallow waters (<10 m) in the coastal areas of Wenchang (Zhou, 2004). However, since the 1970s, at least 50% of the fringing reefs of Hainan Island have been destroyed by human activities, including overfishing, land clearing, coral mining, aquaculture expansion and pollution (Zhang et al., 2006; Hughes et al., 2013; Li et al., 2013). Unlike the well-studied coral communities in southern Hainan Island (e.g. Sanya) (Hutchings and Wu, 1987; Zhang et al., 2006; Li et al., 2013), there is currently a lack of knowledge regarding the coral species composition and spatial distribution in eastern Hainan Island. Wang et al. (2013) reported that wave energy was highly correlated with coral assemblages off Changqi Harbor in Wenchang and concluded that light intensity and wave energy are important factors regulating the coral community along a depth gradient. However, it is still unclear how terrestrial runoff (sewage or aquaculture effluents) and upwelling influence the coastal coral reef ecosystem in Wenchang (Zhang et al., 2013).

The aim of this study was to test the hypothesis that the structure of benthic communities is significantly affected by terrestrial runoff and upwelling in the coral reefs of northeastern Hainan Island. To test this, the relationships between the benthic communities and environmental parameters were examined, and a conceptual model linking terrestrial runoff and upwelling to the coral reefs was proposed. This study will contribute to our understanding of how terrestrial runoff, especially aquaculture effluents, influences coral reefs in upwelling regions, where they are considered as potential refuges in a future of rapid climate change (Riegl and Piller, 2003).

2. Materials and methods

2.1. Study site

The study sites (1S–6D) were located on the northeastern coast of Hainan Island (Fig. 1). The Wenchang and Wenjiao rivers enter Bamen Bay and then discharge into the coastal South China Sea. The study sites were about 2.5–10.1 km away from the outlet of Qinlan

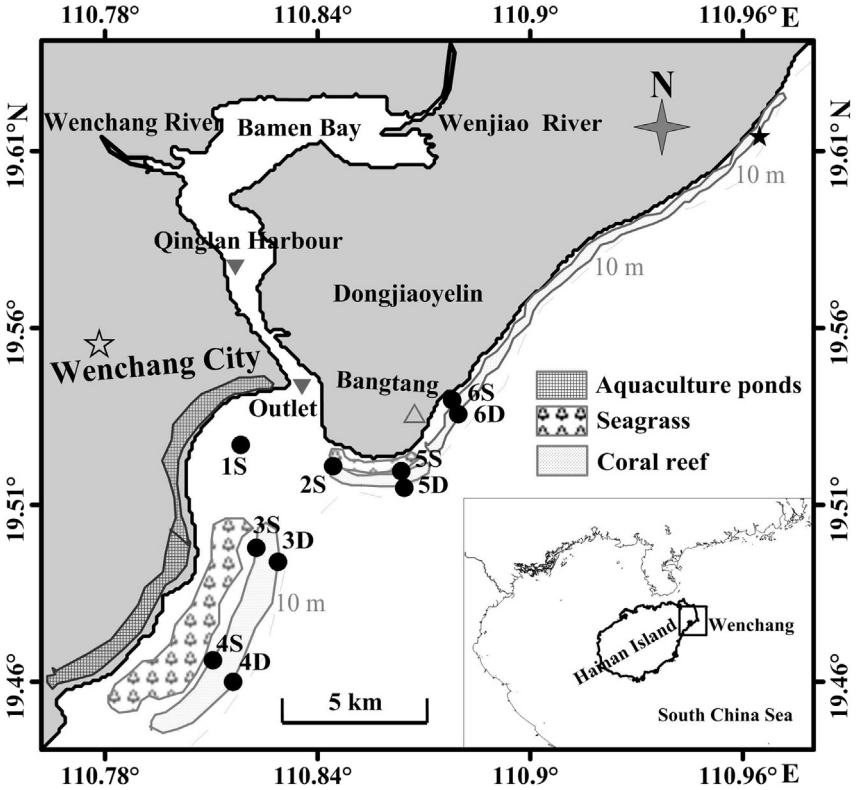

Fig. 1. Map of the 10 stations (1S–6D), shown as closed circles, near the Qinlan Harbor on the northeastern coast of Hainan Island. S: shallow back-reef at 3-m depth, D: deep fore-reef at 8-m depth. A closed five-star indicates a site where time-series logging of salinity and seawater temperature was conducted at 6-m depth in 2011.

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