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Abnormally high phytoplankton biomass near the lagoon mouth in the Huangyan Atoll, South China Sea

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ABSTRACT

Nutrient concentration and phytoplankton biomass were investigated in Huangyan Atoll in May 2015. The concentrations of nutrients were very low, and dissolved inorganic nitrogen was composed mainly of ammonia. Nitrogen likely was the primary limiting factor for phytoplankton growth. The spatial variation of phytoplankton biomass was significant among the lagoon, reef flats, and outer reef slopes. Extremely high chlorophyll *a* concentration and micro-phytoplankton abundance were found in the region near the lagoon mouth. This high phytoplankton biomass might be due to nutrient input from fishing vessels and phytoplankton aggregation driven by the southwestern wind. Our results indicate that phytoplankton biomass could be a reliable indicator of habitat differences in this coral reef ecosystem, and micro-phytoplankton seems to be more sensitive to nutrient input than pico-phytoplankton.

1. Introduction

Among natural ecosystems, coral reefs are known for their high biodiversity and high gross primary productivity. They also are considered to be one of the ecosystems most vulnerable to human activities and climate change (Hughes et al., 2003; Bell et al., 2014; Riegl et al., 2014). Currently coral reefs face the threats of global warming and ocean acidification combined with local disturbances such as overfishing, destructive fishing methods, and coastal anthropogenic eutrophication (Szmant, 2002; Bellwood et al., 2014; Vega Thurber et al., 2014; Hedberg et al., 2015). Many studies have shown that coral reefs around the world are declining at a fast rate (Pandolfi et al., 2011; Bellwood et al., 2014). Burke et al. (2002) estimated that over 80% of Southeast Asia's coral reefs are under threat, and Gardner et al. (2003) reported that an estimated 80% of coral cover has been lost on the Caribbean coral reefs over the past three decades. Long-term monitoring data show that hard coral covered on the Great Barrier Reef (GBR) has decreased by >70% over the past century (Bell et al., 2014). The worldwide decline of coral reefs calls for more studies of coral reefs and more effective management of coral reef ecosystems (Wilkinson, 2002; Bellwood et al., 2014).

In many coastal regions, eutrophication is considered to be a main cause of the degradation of coral reefs (Bell, 1992; Szmant, 2002; Fabricius and De'ath, 2004; D'Angelo and Wiedenmann, 2014). Eutrophication and flourishing of nuisance algae can have negative impacts on coral reefs via a number of routes, and eventually it can lead to the replacement of the coral community with attached algae, seagrasses, and detrital/filter feeders (Bell, 1992). In addition, nutrient enrichment can reduce the tolerance of corals to heat and light stress (Furnas et al., 2005; Riegl et al., 2014), decrease calcification, increase bleaching, and heighten disease susceptibility (Voss and Richardson, 2006; Vega Thurber et al., 2014). The threshold of nutrients or chlorophyll *a* (Chl *a*) for eutrophication to occur is still being debated (Lapointe, 1997; Hughes et al., 1999; McCook, 1999; Bell et al., 2014; Furnas et al., 2014). Due to environmental variation, there might not be a uniform threshold for eutrophication in worldwide coral reef ecosystems (Hughes et al., 1999; McCook, 1999). However, the effect of nutrient enrichment should be considered in the management and monitoring of coral reefs.

The South China Sea (SCS) is the largest semi-closed sea in the western tropical Pacific Ocean, and it extensively distributes well-developed coral reefs. It is considered to be one of the most diverse marine ecosystems in the world (Morton and Blackmore, 2001). Because they are generally situated far from the mainland, most coral reefs in the southern and central SCS have experienced few direct anthropogenic impacts and are still in good health with high biodiversity (Zhao et al., 2013; Zhao et al., 2016). The latest survey showed that the Yongle Atoll (the biggest atoll in the central SCS) has 2–29% of coral cover in different geomorphic habitats and its coral communities are still in a relatively healthy condition (Zhao et al., 2016). However, Shen et al. (2010) reported that eutrophication and human activities have influenced the offshore coral reefs, basing on the discovery of a brackish water phytoplankton species in the Zhubi Reef lagoon in the southern SCS. In recent years, artificial island building activities in this area have posed a great threat to these coral reef ecosystems (Larson, 2015). This reclamation

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destroyed coral reefs together with their fragile ecosystems on a large scale. Even though the SCS is an area with extensive coral reef development, coral reefs in this region are still poorly understood. Due to political complexities, few surveys of the offshore coral reefs have been conducted in the southern and central SCS. Most coral reef investigations in the SCS were conducted along the coast in the northern SCS, especially in the Luhuitou fringing reef near Sanya City, Hainan Island (Zhang et al., 2006; Li et al., 2008; Li et al., 2013; Zhang et al., 2014).

Researchers generally use total Chl *a* concentration as the indicator of phytoplankton biomass in coral reef waters. Relatively few studies have focused on the phytoplankton community and water quality status in coral reef ecosystems of the SCS (Shen et al., 2010; Li et al., 2013). Thus, little is known about the phytoplankton community in coral reef waters and whether its composition differs from that of the adjacent ocean. However, phytoplankton community structure can provide important information for evaluating the health of coral reefs because different phytoplankton classes or species vary in relation to environmental disturbances (i.e., climate change and eutrophication) (Revelante and Gilmartin, 1982; Riegl et al., 2014). In this study, spatial distribution of nutrients, phytoplankton biomass and composition, and primary productivity were investigated in the coral reef ecosystem of the Huangyan Atoll during the southwest monsoon in May 2015. The aim of this study was to better understand the phytoplankton community and nutrient level in the offshore coral reef waters of the SCS. This study provides basic information about nutrient concentrations and phytoplankton composition and biomass in Huangyan Atoll, and it may contribute to assessing the potential impacts of human activities on coral reef ecosystems in the SCS.

2. Materials and methods

2.1. Study sites

Huangyan Atoll (117°51′E, 15°07′N), also named Democracy Reef or Scarborough Shoal, is a typical circular coral atoll in the eastern part of the Zhongsha Islands in the central SCS. It has a triangle-shaped lagoon

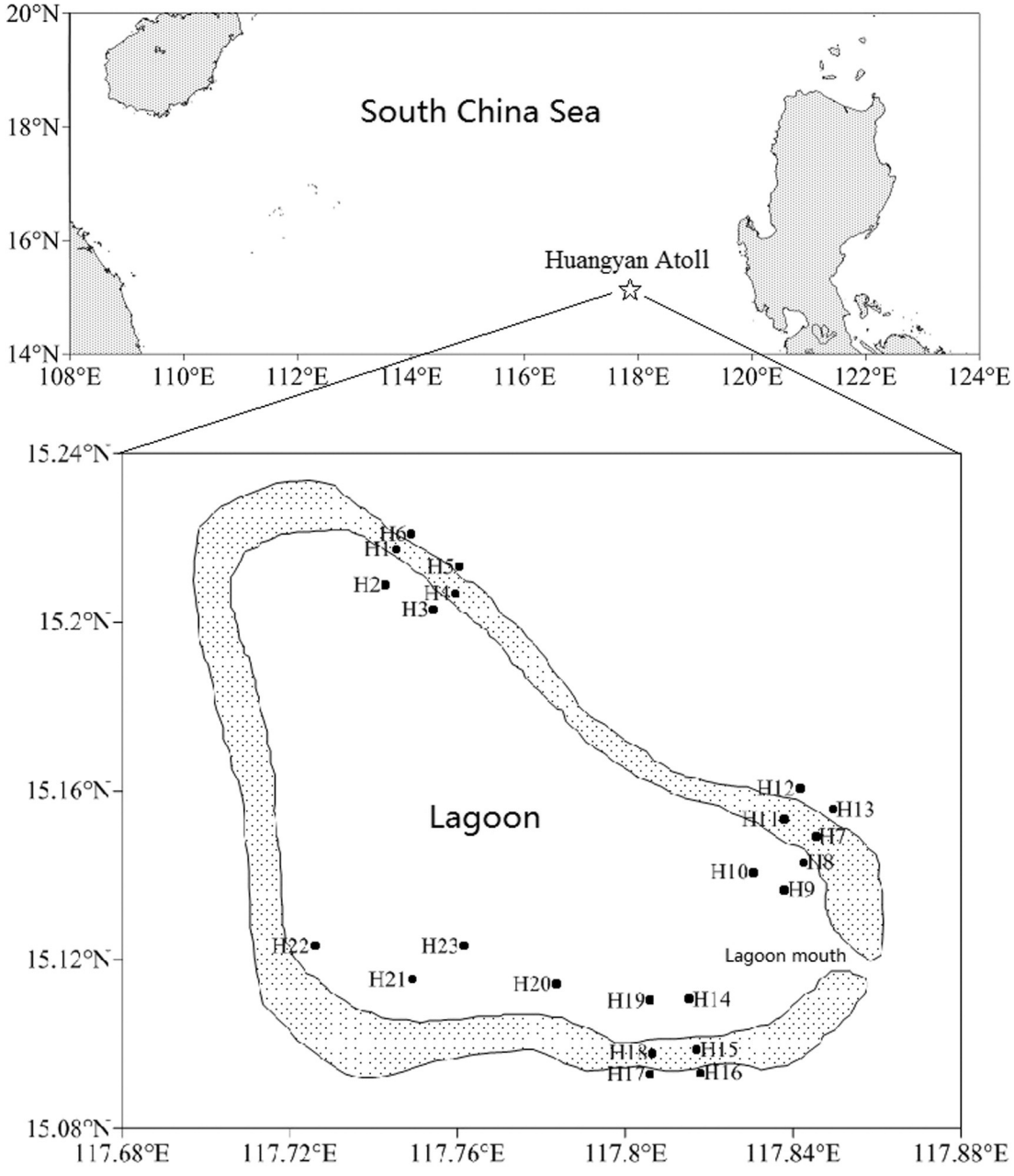

Fig. 1. Location of sampling stations in Huangyan Atoll in the central South China Sea.

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