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Mariculture pond influence on mangrove areas in south China: Significantly larger nitrogen and phosphorus loadings from sediment wash-out than from tidal water exchange

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ABSTRACT

The continued overexploitation of coastal fisheries has stimulated rapid development of coastal mariculture. Such mariculture can significantly increase nitrogen and phosphorus loadings to nearby coastal waters, but the pathways of these loadings have not been well studied. In this study, we quantified the nitrogen and phosphorus budgets in selected mariculture ponds next to two mangrove areas in south China: the Zhangjiangkou National Mangrove Nature Reserve in Fujian Province and Zhanjiang National Mangrove Nature Reserve in Guangdong Province. We also estimated the nitrogen and phosphorus loadings from crab, clam and shrimp ponds for the entire coastal region of south China. The studied mariculture ponds – crab, clam and shrimp – had a net release of dissolved inorganic nitrogen (DIN) through water exchange of −0.06, 0.31 and 1.17 kg N ha^{-1} yr^{-1}, and a net release of dissolved inorganic phosphorus (DIP) of −0.01, −0.03 and 0.40 kg P ha^{-1} yr^{-1} respectively. In contrast, pond sediment wash-out resulted in total nitrogen (TN) loading of 96.38, 375.2, and 712.84 kg N ha^{-1} yr^{-1}, and total phosphorus (TP) loading of 464.69, 488.18, and 353.86 kg P ha^{-1} yr^{-1}, respectively, 100–1000 times higher than the loading from tidal water exchange. The NH_4^+–N:NO_3^-–N ratio of the DIN during the ebb tide (mariculture output) was higher than that during the flood tide, indicating that the mariculture ponds could increase the NH_4^+–N in mangrove swamps. For the entire region of south China, about 239.5 t yr^{-1} of DIN and 42.8 t yr^{-1} of DIP were released through tidal water exchange of the mariculture ponds, while about 2.7 × 10^5 t yr^{-1} of TN and 1.7 × 10^5 t yr^{-1} of TP were released through the sediment discharge from the rearing and fodder ponds. Thus, most of the nitrogen and phosphorus loads to the nearby mangrove swamps are from sediment discharge rather than from tidal water exchange. Although preliminary results on the spatial distribution of loaded nutrients indicated that mangrove sediments could be a sink for nitrogen and phosphorus, the fates and impact of mariculture ponds discharge in the mangrove and other coastal wetlands require further investigation.

1. Introduction

With a booming world population, the demand for seafood has steadily grown, which has in turn led to the rapid decrease of global fishery resources. Aquaculture has become an important complement to the world fishery supply. China has the world's largest mariculture industry, with a total mariculture production of 20.52 million tons in 2005 that accounted for 38% of the global total aquaculture production (Sapkota et al., 2008), and has been the world's largest exporter of fishery products since 2002 (Li et al., 2013; Yu et al., 2012). According to data from the State Oceanic Administration, China (SOA), aquaculture area (including seawater, beaches and land-based aquaculture) increased from 277 × 10^3 ha to 1.695 × 10^6 ha from 1998 to 2005 (SOA, 2006). The rapid development of aquaculture industries has brought a wide variety of environmental problems, including water quality deterioration and contaminants (Hargreaves, 1998; Huang et al., 2010; Wu et al., 1994), biological invasion (Naylor et al., 2001), aquatic diseases (Bondad-Reantaso et al., 2005; Meyer, 1991), and drug residue (Grave et al., 2008; Schnick, 2001).

Aquaculture pollutants mainly consist of residual baits, animal wastes and organics from natural sources (Naylor and Burke, 2005). Excess nitrogen and phosphorus are among the pollutants of most concerned since they pose the potential risk of eutrophication in coastal waters. In south China, marine aquaculture (mariculture) ponds are often located next to mangrove wetlands or salt marshes, and some ponds are constructed simply by excavating mangroves (Feng et al.,

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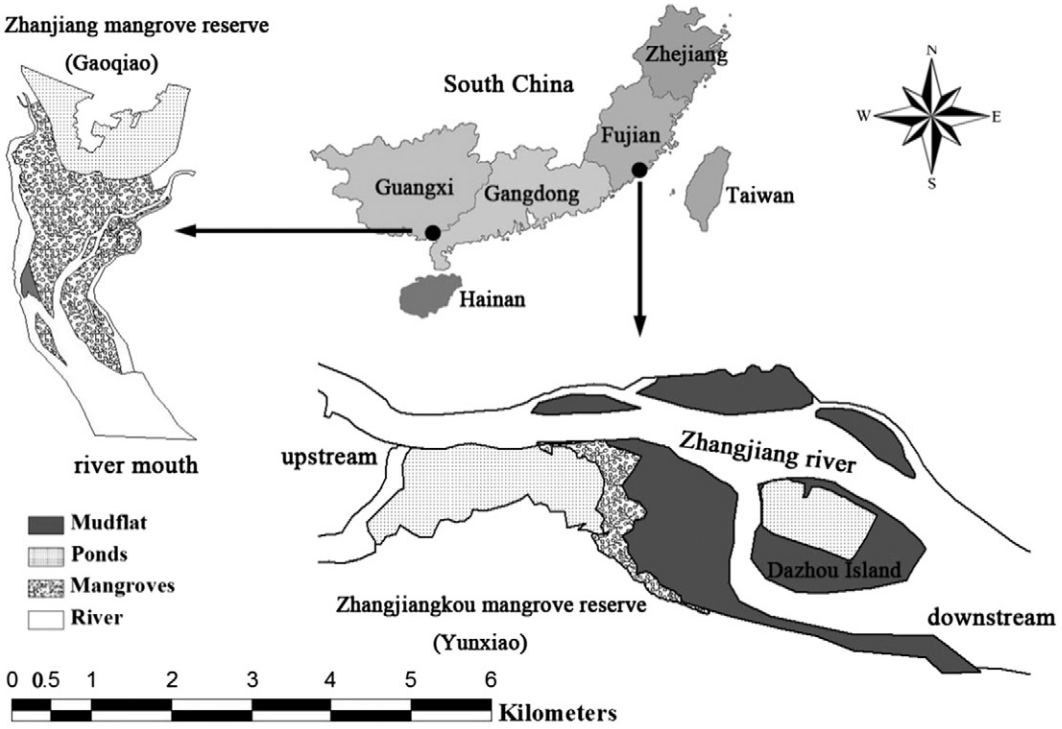

Fig. 1. Locations of study sites in south China.

2004). During mariculture, nutrients and pathogenic bacteria accumulate in pond sediments, which can be harmful to the animals intended to be cultured (Chavez-Crooker and Obreque-Contreras, 2010). Therefore, completely cleaning the pond sediments is necessary at the end of each mariculture rotation (Wang and Wang, 2007). During this process, large quantities of sediment with high nutrient levels are washed out and discharged into the adjacent mangrove swamps in a very short period, often three to four weeks. This concentrated sediment influx can rapidly alter the water quality of nearby mangrove swamps. For example, the demand for oxygen results in localized hypoxia or anoxia (Gray et al., 2002). Under anoxic conditions, ammonia, hydrogen sulfide and methane are released from the loaded sediments, posing a serious threat to fish, shellfish, and other marine organisms (Feng et al., 2004; Graslund et al., 2003).

Eutrophication caused by aquaculture pond effluents is among the most common complaints of mariculture impacts, and this concern has attracted the greatest public attention in many countries (Boyd, 2003). Most attention has been focused on changes in water quality of receiving creeks (Costanzo et al., 2004; Trott and Alongi, 2000). However, the pathways for nitrogen and phosphorus loadings from mariculture ponds, especially through sediments washout process to nearby mangrove wetlands, have not been well studied (Das et al., 2004; Gautier et al., 2001; Vaiphasa et al., 2007). It has been shown that the symptoms of aquaculture effluent (e.g., elevated nutrient and chlorophyll concentration) are only measurable in close proximity to the discharge source. Very few studies have measured the nutrient flux between creeks/mangroves and estuaries (Costanzo et al., 2004; McKinnon et al., 2002). As of yet, no studies have shown the transportation distance of pond waste in the estuary. More studies are needed to investigate the fate of pond waste in the estuary ecosystem.

The objectives of this study were to 1) evaluate the cycling of nutrient exchange between mariculture ponds and mangrove wetlands, 2) quantify the fluxes of nutrient effluents from mariculture ponds in south China, and 3) trace the fate of the exporting nutrients from mariculture ponds to adjacent mangrove swamps.

2. Materials and methods

2.1. Study areas

This study was conducted in Zhangjiangkou National Mangrove Nature Reserve in Yunxiao (YX), Fujian Province (23°55′47″N; 117°24′30″E) and Zhanjiang National Mangrove Nature Reserve in Gaoqiao (GQ), Guangdong Province (21°34′27″N; 109°45′18″E) (Fig. 1). The selected parameters of mariculture ponds at the YX and GQ sites are shown in Table 1. Based on data from Google Earth, the areas of the

Table 1
Selected parameters for the three major types of mariculture ponds at the study sites.

Parameters	Unit	Crab ponds (Yunxiao)		Clam ponds (Yunxiao)		Shrimp ponds (Gaoqiao)	
		Range	Mean	Range	Mean	Range	Mean
pH	–	7.83–9.29	8.43	7.37–9.67	8.40	7.92–9.13	8.51
DO	mg L^{-1}	5.03–9.96	7.57	5.67–11.3	7.68	5.98–11.90	8.46
Salinity	ppt	5.70–16.00	9.74	4.50–16.6	10.34	16.8–25	20.77
TSM*	mg L^{-1}	39.6–51.6	44.7	28.8–72.4	54.3	13–93.3	72.6
Clay	%	1.30–4.20	2.03	4.30–6.00	5.10	0.31–2.46	1.06
Silt	%	27.50–69.30	56.29	62.80–80.10	69.24	7.17–64.1	24.33
Sand	%	29.30–71.30	41.69	13.90–32.60	25.65	34.55–92.51	74.61

TSM: Total Suspended Matter.