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Baseline

Maintenance of estuarine water quality by mangroves occurs during flood periods: A case study of a subtropical mangrove wetland

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ABSTRACT

Seasonal changes in water quality were measured in samples taken at various distances from shallow water across mudflat to mangroves during flood period and from mangroves across mudflat to shallow water during ebb period in a subtropical mangrove estuary (Zhangjiang Estuary, Fujian, China). The TN (total dissolved nitrogen), TP (total dissolved phosphorus), COD (chemical oxygen demand), and DOC (dissolved organic carbon) contents during the flood period were significantly higher than those during the ebb period. In contrast, the opposite was true for the POC (particulate organic carbon) content and transparency. The mangroves at Zhangjiang Estuary may trap nutrients at rates of 90.5 g N/m^2/yr, 2.2 g TP/m^2/yr, and 13.7 g C/m^2/yr in the form of DOC, and export POC at a rate of 81.8 g/m^2/yr. Our results support the hypothesis that the maintenance of estuarine water quality by mangroves occurs during flood periods.

Since mangrove ecosystems are suitable for brackish water shrimp culture, many shrimp ponds have been constructed in or adjacent to mangrove wetlands (Twilley et al., 1993; Csavas, 1994; Robertson and Phillips, 1995; Rivera-Monroy et al., 1999; Wang and Wang, 2007). This is the case of the Zhangjiang Estuary, Fujian, China (Fig. 1). Intensive shrimp aquaculture is an inefficient production system because only approximately 20% of the nitrogen of the feed input is incorporated into the shrimp harvest (Briggs and Funge-Smith, 1994; Jackson et al., 2003). Remaining nitrogen acts to fuel plankton and microbial production within ponds, often resulting in negative effects on pond water and sediment (Moriarty, 1997; Burford and Glibert, 1999). The exchange of coastal waters in shrimp aquaculture ponds is important to ensure optimal survival and high yields (Rivera-Monroy et al., 1999; Jackson et al., 2003). This exchange is also the primary means of pollutant discharge (Paez-Osuna et al., 1997; Funge-Smith and Briggs, 1998; Preston et al., 2000; Jackson et al., 2003; Shimoda et al., 2007), potentially leading to deleterious effects in receiving waters such as eutrophication if not planned and managed appropriately (Lin, 1989; Sansanayuth et al., 1996; Naylor et al., 1998). This concern has led to an increase in research on systems receiving shrimp pond effluents (McKinnon et al., 2002; and other references cited in this paper).

Mangrove ecosystems create a suitable environment for removing and transforming pollutants in waste water (Wu et al., 2008). This function is fulfilled through the processes of sedimentation, filtration, microbial activity, plant absorption, etc., when waste water passes through mangroves (Nedwell, 1975; Tam and Wong, 1993; Corredor and Morell, 1994; Wong et al., 1995; Alongi, 1996; Rivery-Monroy et al., 1999). Many studies have demonstrated that mangroves make a significant contribution to the removal of nutrients and organic matter from waste water (Sansanayuth et al., 1996; Wong et al., 1997; Chu et al., 1998; Tilley et al., 2002) and to the maintenance of estuarine water quality (Saenger, 2002). Nevertheless, most of our knowledge regarding the purification process comes from simulation experiments. In these studies, shrimp pond effluents were discharged directly into the semi-enclosed or wholly enclosed vegetated areas of mangroves (Gautier et al., 2001; Tilley et al., 2002; Huang et al., 2004; Wu et al., 2008), pond-cultured mangrove saplings (Shimoda et al., 2005a), or pot-cultivated mangrove seedlings (Chen et al., 2000), and retained for certain periods of time. On most occasions, there was no tidal flushing or cycle (Wu et al., 2008). Most shrimp ponds have been constructed in places originally occupied by mangroves (Wang and Wang, 2007). To save energy, the discharge of shrimp pond effluents is generally processed during ebb periods by gravity. These effluents ultimately find their way into the coastal areas through creeks (McKinnon et al., 2002; Costanzo et al., 2004; Mishra et al., 2008). They merge with estuarine waters before returning to the vegetated areas during flood periods (Zhang et al., 1999). Thus, the proposed method to use mangrove wetlands

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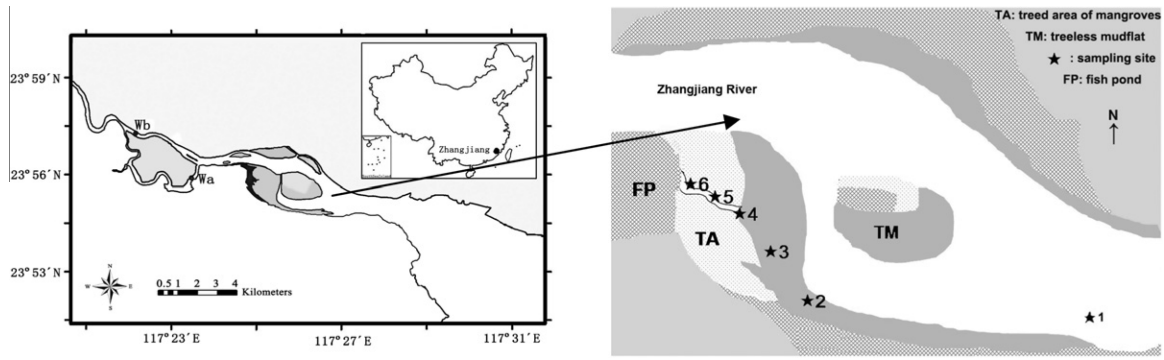

Fig. 1. Map of the coastal region of the Zhangjiang Estuary indicating the location of the sampling sites see Fig. 1.

as filters of pond discharge prior to the release of effluents to estuarine waters has not yet been tested in the field under natural conditions (Twilley et al., 1993; Csavas, 1994; Robertson and Phillips, 1995). Till now, much less is known about the fate of pond pollutants after they are discharged into estuarine water through mangroves (Grant et al., 1995; Jones et al., 2001).

Most attentions were focused on the changes in water quality in receiving creeks (Trott and Alongi, 2000; Costanzo et al., 2004). It was proven that the symptoms of aquaculture effluent (e.g. elevated nutrient and chlorophyll concentration) were only measurable in close proximity to the discharge points (Samocha and Lawrence, 1997; McKinnon et al., 2002; Costanzo et al., 2004). Costanzo et al. (2004) found that the water quality at the month of effluent creeks was equivalent to control values (no discharge creeks), indicating that pond effluent was contained within the effluent-receiving creeks. However, there are also evidences showing that the influence of shrimp pond effluent can extend further (Jones et al., 2001; Costanzo et al., 2004).

Much effort has been invested in measuring flux of organic matter and nutrients from mangroves (Twilley, 1988). However, we still know little about mangrove-near shore exchange patterns (Werry and Lee, 2005; Sánchez-Carrillo et al., 2009). Most available reports have studied the flux of organic matter and nutrients through a small mangrove creek (Boto and Wellington, 1988; Ayukai et al., 1998; Trott et al., 2004; Rezende et al., 2007; Sánchez-Carrillo et al., 2009). Very few studies have measured the nutrient flux between creeks/mangroves and estuaries (Moran et al., 1991; Tilley et al., 2002). Thus, it is difficult to assess the potential use of mangroves in extracting nutrients from pond effluents (Rivera-Monroy et al., 1999). This lack of understanding also complicates the control of shrimp pond development in mangrove estuaries. Robertson and Phillips (1995) estimated that 2–22 ha of mangrove forest is required for complete clearance of the nitrogen load in the effluent from a 1 ha intensive shrimp pond. However, Rivera-Monroy et al. (1999) argued that the required area was 0.04–0.12 ha. Shimoda et al. (2005b) estimated that 6.2 or 8.9 ha of mangrove forest was required by 1 ha shrimp ponds to fully process the phosphorus.

In this study, we hypothesized that the maintenance of estuarine water quality by mangroves occurs during flood periods. A before-and-after sampling design was used to measure changes in water quality during a tide cycle in a subtropical mangrove estuary. We sought to provide some insight into the changes in water quality during a regular tide cycle, and to further quantify the influence of mangroves on the aquatic environment.

The study was conducted in a subtropical mangrove wetland, the Zhangjiangkou Mangrove Reserve, located on the southeast coast of China (117°24′07″–117°30′00″ E, 23°53′45″–23°56′00″ N). The estuary is semi-enclosed and opens into the Taiwan Strait. It occupies ca. 2360 ha and is fringed by 117.9 ha of mangroves. The dominant species are *Avicennia marina*, *Kandelia obovata*, and *Aegiceras corniculatum*. The average tree height is about 2.3 m, and the canopy coverage is greater than 90%. Tides are semi-diurnal, and the average tide amplitude is 2.32 m. The flood period lasts around 6–7 h and the ebb period lasts about 5 h. Annual rainfall is 1714 mm, average temperature is 21.2 °C, and average water salinity is 19‰. The depth of the water column at high tide was about 0.4 m.

There were two water locks at the uppermost distribution point of the mangroves (Wa and Wb, Fig. 1). They were closed except on rainy days. To minimize the influence of river water on our surveys, all of the samples were taken on days with no rain. Thus, the estuary received no river influx or pond effluents, but rather was influenced only by tidal action and was virtually free of any terrestrial or freshwater influences.

Before the 1990s, most mangroves of the Zhangjiang Estuary were cleared for shrimp farming. Now, nearly the whole estuary is surrounded by semi-intensive ponds (Fig. 1). This pattern is representative of mangroves in China in general (Wang and Wang, 2007). These ponds are connected to seawater by waterspouts. The spouts were only opened during water exchange (discharge of pond water or influx of fresh seawater). The discharge of pond effluent was caused by gravity during the ebb period and the effluent was discharged into the estuary through creeks in mangroves or treeless mudflats. In contrast, fresh seawater was pumped into ponds during the flood period. Effluent is periodic. The frequency and extent of water exchange from ponds varied according to the stage of the growth cycle and the water salinity, ranging from 0% in the first month after stocking to 30% volume per week in the final growth and harvesting stages.

Based on the direction of tide flow, topographic conditions, and mangrove distribution, six sites were selected for sampling (Fig. 1). These sites were distributed along the tide path at different distances from the shoreline. Site 1 was at the mouth of the estuary and farthest from the mangroves. Site 2 was closer to the mangroves and located on a treeless mudflat. Site 3 was at the edge of the mangroves. Sites 4, 5, and 6 were within the treed areas.

From June 2005 to March 2006 (June 2005, September 2005, November 2005 and March 2006), surface water samples were collected from the 6 sites. The samples were taken 10–20 cm below the water surface. All samples were taken on spring tide days due to the fact that creeks are inaccessible by boat on neap tide days. Sampling was carried out with the tide, beginning at Site 1. The same actions were carried out at Sites 2–6, and were finished before the tide started to ebb. We then waited at Site 6 until the tide turned (i.e., water refluxing), and proceeded to take samples again in the opposite direction. Salinity, pH, and DO were measured *in situ* during the sampling process at a depth of 20 cm using