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Temporal changes in physical, chemical and biological sediment parameters in a tropical estuary after mangrove deforestation

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ABSTRACT

Dated sediment cores taken near the head and mouth of a tropical estuary, Nha-Phu/Binh Cang, in south central Viet Nam were analyzed for changes over time in physical, chemical and biological proxies potentially influenced by removal of the mangrove forest lining the estuary. A time-series of satellite images was obtained, which showed that the depletion of the mangrove forest at the head of the estuary was relatively recent. Most of the area was converted into aquaculture ponds, mainly in the late 1990's. The sediment record showed a clear increase in sedimentation rate at the head of the estuary at the time of mangrove deforestation and a change in diatom assemblages in the core from the mouth of the estuary indicating an increase in the water column turbidity of the entire estuary at the time of the mangrove deforestation. The proportion of fine-grained sediment and the $\delta^{13}C$ signal both increased with distance from the head of the estuary while the carbon content decreased. The nitrogen content and the $\delta^{15}N$ signal were more or less constant throughout the estuary. The proportion of fine-grained material and the chemical proxies were more or less stable over time in the core from the mouth while they varied synchronously over time in the core from the head of the estuary. The sediment proxies combined show that mangrove deforestation had large effects on the estuary with regard to both the physical and chemical environment with implications for the biological functioning.

1. Introduction

The area occupied globally by mangrove forests has declined by more than 35%, and most of this loss has occurred over the past 30 years, primarily due to human disturbance (Agardy et al., 2005; Bouillon et al., 2008). Loss of mangrove forests is caused by a variety of human activities, including clearing for lumber and firewood, development of rice paddies and establishment of aquaculture ponds (Valiela et al., 2001; Wilkie and Fortuna, 2003). In many places, mangrove removal occurs without regard for the role of mangrove forests in the functioning of adjacent coastal ecosystems (e.g. Alongi, 2008). Besides the function as e.g. valuable nursery and feeding grounds for a variety of invertebrate and fish species (Hong and San, 1993), mangrove forests are key sites for important biogeochemical transformations as well as exchange of organic and inorganic carbon between land, atmosphere and ocean (Dittmar et al., 2006; Kristensen et al., 2008). This is of particular concern as mangrove forests have the potential to mitigate the effects of future climate changes (Alongi, 2008; Donato et al., 2011; Mcleod et al., 2011), both by sequestering carbon, protecting neighboring estuaries from terrestrial runoff and sheltering coastlines from storm damage, (Dahdouh-Guebas et al., 2005; Granek

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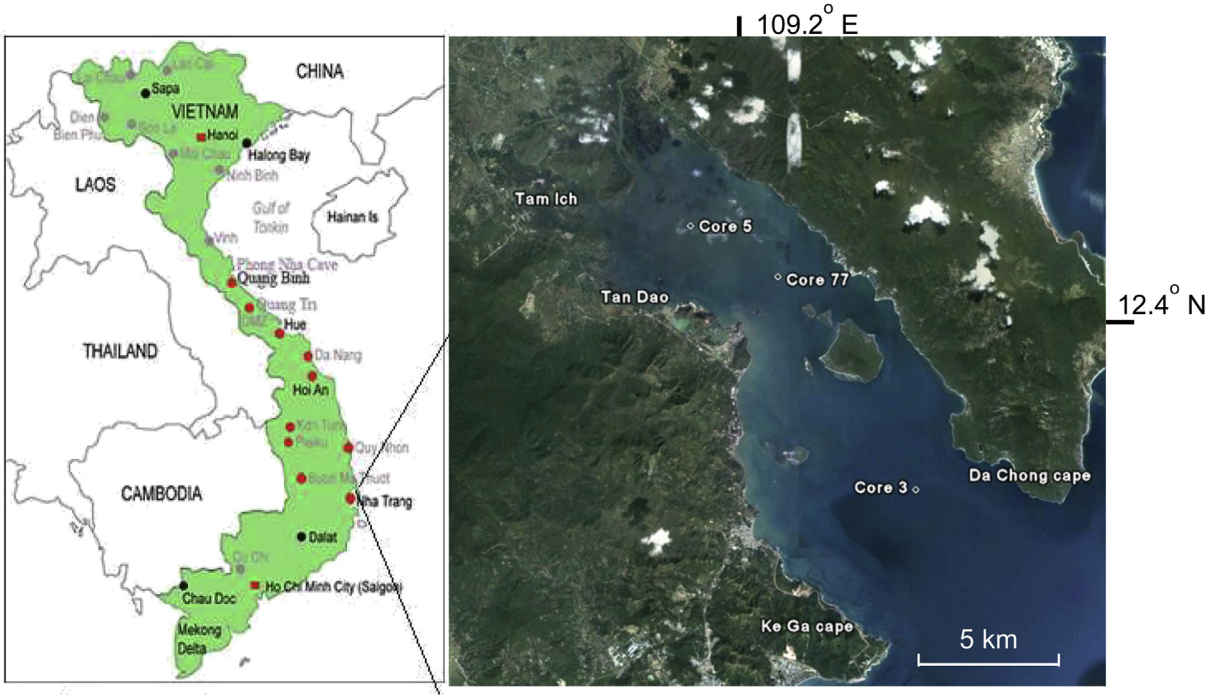

Fig. 1. Map of NP-BC showing the locations of the three sampling stations 5, 77and 3 as well as the approximate location of two villages, Tam Ich and Tan Dao (referred to in the discussion).

and Ruttenberg, 2008). Viet Nam is very dependent on the functioning of its coastal ecosystems because of its approx. 3260 km long coastline with large areas of lowland including large delta regions in the south (Mekong Delta) and north (Red River Delta). There are over 250 large and small estuaries along the Vietnamese coast and most of these were previously lined with dense mangrove forests. However, much of this mangrove area has now been logged (Hong and San, 1993).

The Nha Phu-Binh Cang estuary (NP-BC) is located in south-central Viet Nam. The head of this estuary was formerly covered by dense forests with dominance of the mangrove genera *Rhizophora*, *Avicennia*, and *Sonneratia* (Nguyen et al., 2006). However, this area and the mouths of two rivers entering the estuary are now dominated by aquaculture ponds and the mangrove forests have mostly disappeared. The exact timing of the large-scale reduction of the mangrove forest was previously unknown and the associated effects were recognized only from anecdotal evidence.

Although mangrove forests have great influence on the estuaries they line, relatively little is known about the consequences of mangrove deforestation for species distribution and ecosystem functioning of the estuaries. This study aimed at describing changes over time in physical, chemical and biological sediment parameters associated with mangrove deforestation in the NP-BC estuary by exploring the sedimentary archive at stations located at the head and mouth of the estuary. As mangrove forests often act as filters for e.g. nutrients and sediment from river run-off (Prasad and Ramanathan, 2008; Twilley and Rivera-Monroy, 2009), we would expect to see changes in e.g. terrestrial input, turbidity and nutrients. To determine such long-term developments, the parameters explored included temporal changes in sedimentation rate, grain size distribution, carbon and nitrogen content as well as stable isotope ($\delta^{13}C$, $\delta^{15}N$) signatures and diatom community composition. The age–depth profiles of these proxies were related to the timing of the mangrove forest disappearance and other anthropogenic activities in the area, such as constructions on the rivers entering the head of the estuary.

2. Materials and methods

2.1. Site description

The Nha Phu-Binh Cang (NP-BC) estuary is located in south-central Viet Nam, about 15 km north of Nha Trang city (Fig. 1). It is about 20 km long and 5–6 km wide. The head of the estuary consists of a shallow area with a maximum depth of 2 whereas the mouth of the estuary at station 3 is ca. 12 m deep. The depth increases to more than 30 m within 10 km of the head of the estuary. Two larger rivers with a drainage area of about 1200 km^2 discharge into the estuary. A base-flow of 60 $m^3\ s^{-1}$ was measured in one of these rivers, the Dinh River, during the rainy season (Lund-Hansen et al., 2013). The residence time of water in the estuary is about 5–6 days (Lund-Hansen et al., 2010).

2.2. Satellite images of mangrove distribution

Maps of the head of NP-BC were obtained and analyzed to determine the timing of mangrove conversion into shrimp ponds. The maps were based on satellite imagery obtained from the Landsat MSS (1973 and 1983), MOS-1 (1989, 1993, and 1996), and Landsat ETM (1999) with spatial resolutions of 60, 50, and 30 m respectively. Four spectral bands were used from the Landsat MSS, and MOS-1, and 6 bands from the Landsat ETM. The GIS software package ENVI 4.4 was used for data processing and generation of thematic maps. A time-series of selected years between 1973 and 1999 covering the head of the estuary is used to demonstrate the changes.

2.3. Sampling

Three sampling stations, station 5 (12.4264 N 109.1826 E), station 77 (12.4117 N 109.2089 E) and station 3 (12.3500 N 109.2500 E), were established at the head and the mouth of the estuary. They are henceforth termed the head of the estuary (station 5 in the inner and 77 in the outer of the shallow part of the