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Influence of suspended kelp culture on seabed sediment composition in Heini Bay, China

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ABSTRACT

Kelp aquaculture activities occupy large nearshore areas with significant effects on sediment properties, primarily caused by the influence of the suspended kelp on local hydrodynamics. Changes in sediment composition and grain-size distributions were investigated prior to and following the commencement of kelp aquaculture activities in Heini Bay in eastern China. Seabed sediment types and the particulate matter in suspension during the kelp seeding and harvesting periods, and in sediment cores, were analyzed. While suspended sediment in the kelp aquaculture area was up to 20% organic material, sediment organic content on the seabed remained at similar levels as areas lacking aquaculture. The composition of the seabed sediment in the kelp aquaculture area became finer-grained by the capture of fine particles. Within the kelp aquaculture area, the sediments are poorly sorted and positively skewed, whereas at the shoreward and seaward of the aquaculture area the sediments are relatively coarse-grained, well-sorted and nearly symmetrically distributed. Therefore, the kelp aquaculture activities not only increase the fine particulate fraction in the sediments within the aquaculture area, but also result in similar deposits seaward of it, indicating that seabed erosion and accretion is also controlled by the sediment source and the hydrodynamic conditions. The analysis of sediment cores showed that kelp culturing refines the sediment by preferentially capturing particles in the 38–40 μm size class, while having no effect on the <32 μm fractions, as evidenced by the positive skew of the surficial sediments. The captured particle size class became well mixed into the sediment, thereby changing the composition of the sediment in the uppermost layer of the core, indicating the existence of continuous and stable hydrodynamic conditions within the kelp aquaculture area. The same effect was observed in the seabed sediments seaward of the aquaculture area.

1. Introduction

Since the 1970s, the rapid development of aquaculture has raised concerns about its impacts on local environments; of particular concern is suspended and other above-bottom aquaculture, which account for approximately 85% of overall production (McKindsey et al., 2011). Previous studies have shown that macrophyte, mussel, and oyster aquaculture can reduce flow velocities, and usually lead to increased net sedimentation rates and a reduction in mean grain size on the sea bottom (Bos et al., 2007; Grant and Bacher, 2001). These changes also have local benthic impacts through increases anaerobic conditions and associated decreases in biodiversity. Partial recovery from the effects of this type of aquaculture on the physical structure of the seafloor may be possible following the cessation of farming activities, however, seafloor hydrodynamics and sediment response in such areas are slow and long-term processes. As a consequence, some impacts of aquaculture may be irreversible. This may be particularly important, in Asian countries where aquaculture in coastal environments has been a culturally accepted activity for many centuries (Costa-Pierce et al., 2005), and where aquaculture activities can occupy large nearshore areas with significant effects on sediment properties and structure. Because the impacts of such aquaculture activities are recorded in the sediment, they can be reconstructed by the analysis of sediment cores.

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A number of studies have shown that the infrastructure associated with both raft and longline suspended kelp, mussel, or oyster aquaculture can alter hydrodynamic conditions and reduce flow rates (Petersen et al., 2008; Strohmeier et al., 2005, 2008; Makita and Saeki, 2004). In mussel and oyster farming, in addition to increased sediment retention and reduced flow rates that modify depositional regimes, shell debris dropping to the seafloor can slow down near-bed water movement and thereby increase sedimentation rates (Lloyd, 2003; de Jong, 1994). Furthermore, filter-feeding bivalves repackage fine suspended material into larger biodeposits (faeces and pseudofaeces) that increase biodeposition in coastal ecosystems (Comeau et al., 2014; Walker and Grant, 2009). Similarly, the microbial mats that commonly form in muddy sedimentary environments promote sedimentation rates and stabilize sediment (Walker et al., 2014). Studies have shown that organic constituents comprise a large proportion of the resulting seafloor sedimentation. However, the changes in sediment properties and structure in kelp aquaculture are mainly caused by the influence of the suspended kelp on local hydrodynamics.

In addition to increasing sedimentation and the proportion of fine sediment deposition, suspended aquaculture can also modify deposition regimes within and adjacent to aquaculture sites by influencing the current velocity and attenuation of waves (Ottman and Sornin, 1985). Some studies modeling wave action and sediment transport have suggested that fine-scale scouring occurs around aquaculture sites (Grant, 2010; Nikodic, 1981). At the head of enclosed bays, the effects of suspended aquaculture on the surrounding sediments are also influenced by local topographic and hydrodynamic conditions (Ysebaert et al., 2009). Numerical modeling results suggest that offshore suspended kelp aquaculture, especially in small bays, can reduce current speeds and thereby affect nutrient/particle regeneration and water exchange because the vertical structure of tidal currents can be changed dramatically (Grant and Bacher, 2001; Fan et al., 2009). Although suspended kelp aquaculture are thought have no effect on the tidal prism (Zeng et al., 2015), landward tidal fluxes may be reduced by 10–70% in the upper layers of the water column during the kelp seeding to harvesting periods while increasing by 10–140% in the lower layers. Wave records have shown that the wave attenuation coefficient increases by 11–21% from non-cultivation to cultivation periods, and can increase by 72% in strong wind conditions (Liu, 2012). As a result of the effects of suspended kelp aquaculture on the flow structure and waves, the properties and patterns of the bottom layers and associated sediments may show corresponding changes.

In this context, the purpose of the present study was to investigate the effect of suspended kelp aquaculture on sediment composition and depositional patterns. Field observations were conducted in Heini Bay, China, which is on the western margin of the Yellow Sea and has been an active area for suspended kelp aquaculture since the 1980s. The processes and properties of the sediment were explored using particle size distribution data from short sediment cores, and surface sediment samples. Suspended samples were also collected in and around the kelp culture area, during both cultivation and non-cultivation periods. Grain-size parameters were analyzed to assess spatial and temporal variations in order to identify sediment compositional changes in the presence of suspended kelp aquaculture. Local sediment deposition patterns were assessed on the basis of differences in the sediment type of the kelp region in 2006 and that prior to 1984 (before cultivation commenced); the latter was measured during the Coastal Zone Survey Project in 1984 (SPSTC, 1991) and in numerical hydrodynamic simulations.

2. Study area

Heini Bay (southeast Shandong Province) is one the largest kelp cultivation sites in China (Fig. 1), and has been an area of aquaculture since the 1980s. The water depth ranges from 5 to 20 m, and the geomorphic structure of the coastal area is comprised of headlands and coves. The prominent headlands to the south and north of Heini Bay separate it from other bays, and create a relatively independent sedimentary cell. Sungo Bay is located on the northern side of Heini Bay, separated by the Chu Island Cape; the entire bay is dominated by suspended kelp and scallop (*Chlamys farreri*) aquaculture (Zeng et al., 2015; Fan et al., 2009; Grant and Bacher, 2001). Shidao Bay is located on the southern side of Heini Bay, separated by the Moye Island Cape and is occupied by kelp farming (Fig. 1). Tombolos and lagoons have developed in the coves, and erosion occurs mainly around the capes (SPSTC, 1991). There is a large inshore reef in the center of the bay, creating a steep slope eastward to the 10 m isobath. The reef encroaches on the coast and separates the bay into two parts (the northern cove and the southern cove), each with a smooth slope gradient from the 0.5–20 m depth, beyond which there are a series of steep submarine slopes (Yang and Liu, 2007; Liu et al., 2004).

The study site has irregular semidiurnal tidal components with obviously diurnal inequality with the depth-averaged velocity of the flood current greater than the ebb current by a difference of 10–20 cm s^{-1}. The flood current generally flows towards the SW and the ebb current towards the NE (SPSTC, 1991). The normal wave directions is S to SW in summer and N to NW in winter; strong waves occur towards the S, SE, SSE, and NNE, with maximum wave heights of 4–7 m and an average wave height of 0.6–1.2 m. The Yellow Sea coastal current flows through the nearshore area from N to S (Liu et al., 2009). The fringing intertidal flat is predominantly composed of silty sand with mean particle sizes of 163–365 μm. Most of the Heini Bay seabed is dominated by muddy silts (Hu et al., 2013). Coarse sand and gravel predominate between the 20 and 30 m water depths from Chu Island southward.

3. Materials and methods

3.1. Field sample collection

To document changes in the sediment composition and texture resulting from suspended kelp aquaculture, short sediment cores were collected from two sites thought to have been subject to deposition over the past century. In June 2006, a sediment core was collected from each of the two coves, core HN01 (48 cm in length) from the northern cove and core HN02 (42 cm in length) from the southern cove, using a hand-driven gouge corer (1 m long and 10 cm in diameter; Fig. 1). The cores were split, described, and photographed prior to removing samples for analysis. The sediment column was manually subsectioned into 1 cm sections using a fine metal blade and plastic forceps. Each interval was subsampled and homogenized for organic content and grain-size analyses.

Surface sediment samples (85) were collected in the kelp farming area and to the landward and seaward directions (Fig. 1) in December 2010. These were used for analysis of the impacts of aquaculture activities on the surficial sediment composition. To explore the size variation of the suspended particulate matter during the cultivation and non-cultivation periods, approximately 400 vertically distributed samples of suspended particulate matter were collected from 2 m to 25 m depths during the growth of kelp in the winter (November 2004) and following harvest in the summer (May 2006); the water-column sampling stations were in