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Effect of *Cerastoderma edule* density on near-bed hydrodynamics and stability of cohesive muddy sediments

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Abstract

Flume experiments were performed to investigate the impact of cockle density (*Cerastoderma edule* — 0, 47, 141 and 312 individuals m^{-2}) on near-bed hydrodynamics and sediment erodability. Undisturbed cohesive muddy sediment was collected by coring at an intertidal site in the Tamar estuary (SW England) and placed in the annular flumes. Cockles at the required density were added to the surface sediments, allowed to bury, and were then exposed for 24 h to sinusoidal cycles of currents (3 to 18 cm s^{-1}) which simulated 6-h tidal cycles comparable to the Tamar site. During this period the cockles adopted their usual behaviour of burrowing, suspension feeding and shell valve adductions. After 24 h, current speeds were increased from 5 to 50 cm s^{-1} in 11 steps, and current velocities, turbulent kinetic energy (TKE), and suspended sediment concentration (SSC) were measured. Current speeds decreased and turbulence increased within 3 cm of the sediment surface as a function of cockle density. Sediment resuspension increased with increasing cockle density: SSC at 0.5 m s^{-1} = 156, 574, 1045 and 2253 mg L^{-1} for 0, 47, 141 and 312 animals m^{-2} respectively. Enhanced sediment erosion was due to increased bioturbation and bed roughness. Critical erosion velocity decreased from 26 to 8 cm s^{-1} with increasing cockle density. Shear stress, measured in terms of TKE, increased at 0.5 and 1 cm above the bed for 141 and 312 animals m^{-2} and up to 2 cm above the bed for 312 animals m^{-2}, reflecting the increased bed roughness due to bioturbation. However, the critical erosion shear stress was relatively independent of cockle density (0.225 and 0.151 N m^{-2} for 0 and 312 animals m^{-2} respectively). The valve adduction frequency of the cockles was also measured in response to increasing SSC. The frequency increased from 1.2 to 16.3 adductions h^{-1} with increasing SSC from 13 to 308 mg L^{-1}. It represents a significant behavioural response, creating positive feedback with increased SSC further enhancing sediment disturbance and resuspension.

Keywords: *Cerastoderma edule*; Current velocity; Hydrodynamics; Intertidal sediments; Sediment stability; Shear stress

1. Introduction

Biota play an important role as 'ecosystem engineers' (Lawton and Jones, 1995) modifying the near-bed hydrodynamics and sediment dynamics of intertidal and subtidal habitats (Rhoads and Young, 1970; Rhoads, 1974; Widdows and Brinsley, 2002). The erodability of cohesive sediments is dependent on the interaction between physical, chemical and biological processes, particularly the balance between biostabilisation and biodestabilisation processes. Sediment stabilisation is influenced by a range of biostabilisation mechanisms, including: 1) flow and wave attenuation by macroalgae (Romano et al., 2003), seagrass (Fonseca

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and Fisher, 1986) and saltmarsh plants; 2) enhanced cohesion of sediments by benthic algal films (Paterson, 1997); and 3) physical protection and armouring of the surface sediments by epifaunal bivalves such as mussel beds and oyster reefs (Widdows et al., 1998b, 2002). Sediment disturbance and increased erodability can result from a range of biodestabilisation mechanisms including: 1) disturbance and loosening of the surface sediments by grazers such as *Hydrobia ulvae* (Orvain et al., 2004) and *Neomysis integer* (Roast et al., 2004); 2) burrowing, deposit feeding activity and bioturbation by crustaceans such as *Corophium volutator* (De Deckere et al., 2000), and bivalves such as *Macoma balthica* (Widdows et al., 1998b) and *Ruditapes philippinarum* (Sgro et al., 2005); and 3) corrasion or ballistic impact by shells (Amos et al., 2000). While the importance of biological processes on sediment stability has been demonstrated in many studies there is still inadequate understanding of the mechanisms involved and the nature of the interactions between key biota and physical processes including tidal currents, bed shear stress, wind/wave action, and intense rainfall. Quantification of these biological–physical interactions are required for improved understanding of estuarine sediment dynamics and parameterisation of numerical models.

The cockle, *Cerastoderma edule* (Mollusca: Pelecypoda), is a potentially important destabiliser of surface sediments via a range of behavioural responses including vertical and horizontal movements through the sediment, as well as shaking and rapid valve adductions (Richardson et al., 1993; Flach, 1996). Cockles are suspension feeding bivalves living buried in the top few centimetres of sediment, where they can occur at high densities (up to 1000 individuals m^{-2}; Ferns et al., 2000). Several studies have investigated the effects of increasing suspended silt and clay concentrations on filter feeding by cockles and have demonstrated a significant increase in pseudofaeces production and a decrease in the amount of algal food ingested (Navarro et al., 1992; Iglesias et al., 1996; Navarro and Widdows, 1997; Urrutia et al., 1997, 2001).

Previous experiments (Ciutat et al., 2006) have demonstrated the influence of cockles (*C. edule*) on the resuspension and deposition of contaminated sediments and associated flux of polycyclic aromatic hydrocarbons when exposed in annular flumes to simulated tidal current cycles for 7 to 9 days. The specific aims of the present study were to: (1) investigate the biological and physical processes that are responsible for increased sediment erodability with increasing cockle density when buried in cohesive muddy sediments and exposed to environmentally realistic tidal current cycles and periods of sediment resuspension; (2) quantify the influence of cockle density on near-bed currents, turbulence, shear stress and sediment resuspension; and (3) determine the impact of an increase in suspended sediment concentration (SSC) on the valve adduction frequency of cockles and the possible feedback effect of this behaviour on sediment disturbance.

2. Materials and methods

2.1. Experimental design

The first series of experiments was carried out during September and October 2004 to analyse the effect of cockle density on the hydrodynamics and the stability of muddy sediments. Four densities of cockles (*C. edule*) were studied in four successive experiments, one for each density of cockles: 0 cockles m^{-2} (no cockles added to the flume, identified as density “zero”), 47 cockles m^{-2} (8 cockles added to the flume, termed “low” density), 141 cockles m^{-2} (24 cockles added to the flume, identified as “medium” density), and 312 cockles m^{-2} (53 cockles added to the flume, referred to as “high” density). Each experiment lasted 3 days: coring of sediment from the Tamar sampling site, placement in the annular flume, addition of water, addition and burrowing of cockles on day 1, exposure of cockles to sinusoidal cycles of currents on day 2, and erosion measurements on day 3. In a second series of experiments carried out in November and December 2004 the effects of increasing suspended sediment concentration (SSC) on the valve adduction frequency of cockles were investigated. All the laboratory experiments were performed at 15 °C in a temperature-controlled room with a photoperiod of 10 h light/14 h dark. Finally, field measurements were performed on the 12th and 13th of January 2005 to determine the prevailing current speeds and SSC at the Tamar sampling site.

2.2. Cockles

C. edule were collected from the Plym estuary (Plymouth, Devon, SW England) at low tide and allowed to acclimatise to laboratory conditions for 5 days prior to the beginning of the first series of experiments. They were maintained in a system of recirculating seawater (temperature 15 °C, salinity 30) and were fed with an algal culture of *Isochrysis galbana* which was continuously added via a peristaltic pump to give a concentration of approximately 20,000 cells mL^{-1}. The four cockle densities chosen for the