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Catchment clearing accelerates the infilling of a shallow subtropical bay in east coast Australia

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ABSTRACT

Understanding processes that govern the transport and distribution of terrestrial sediments to and within bays is critical for interpreting the drivers of long-term changes in these ecosystems. On the east coast of Australia increased soil erosion and sediment delivery following extensive land clearing in the contributing catchments, associated with European settlement, is highlighted as a key driver of the decline of numerous nearshore habitats including seagrass meadows and in-shore coral reefs. Here we use optical, radiocarbon and radionuclide dating to estimate mass accumulation rates and type of terrestrial sedimentation in central Moreton Bay during the Holocene. We compare the long-term rates of infilling within the central basin with the recent past and show a 3–9 fold increase in sediment accretion over the last 100 years compared to the long term (last ~ 1500 to 3000 yrs) average. Infilling during the Holocene is not spatially uniform, with preferential deposition occurring within the now submerged palaeochannels of the Brisbane and Pine rivers. We suggest that modern turbidity regimes in Moreton Bay are the result of the compounded effect of both a historical increase in fine sediment supply and a rapid decline in the effective storage capacity of the basin.

1. Introduction

River deltas and estuaries are subject to both riverine and marine processes, and as such are sensitive to disturbances caused by changes in climate, land use, sea level and river flows (Dalrymple et al., 1992; Carter and Woodroffe, 1994; Pye, 1996; Meire et al., 2005; Ericson et al., 2006; Estrany and Grimalt, 2014). The characteristics and physical form of estuaries and nearshore environments often represent the culmination of a long history, driven by both gradual and episodic processes. These processes, both physical and chemical, determine the distribution of habitats (Edgar et al., 2000; Roy et al., 2001). Knowledge of the physical evolution of estuaries and nearshore environments allows for the prediction of both their geomorphic responses to indirect and direct disturbances and also the associated ecological changes.

Human disturbances to river catchments exert significant controls on the quantity of sediment transported downstream. This is observed as both increases in sediment transport, driven by catchment disturbance, through land-clearing, agriculture, urban development, and mining (Pasternack et al., 2001; Syvitski et al., 2005; Ruiz-Fernandez et al., 2009) and decreases resulting from impoundment construction and increased sediment trapping within catchments (Vorosmarty et al., 2003; Blum and Roberts, 2009; Schoelhammer et al., 2014). Climate variability has also been shown to exert controls on sediment entrainment and transport within small river catchments (Inman and Jenkins, 1999; Andrews and Antweiler, 2012). In many parts of Australia vegetation clearing associated with European settlement resulted in an increase in channel and hillslope erosion (Prosser et al., 2001). Using sediment delivery models, it has been shown that this erosion increased the total yield of sediments to east coast Australia (Neil et al., 2002; McKergow et al., 2005; Kroon et al., 2012). This increase has been noted as a primary contributor to the historical decline of inshore reefs within the Great Barrier Reef (GBR) (Fabricius and De'ath, 2001; Fabricius et al., 2003, 2005). Nutrients and contaminants associated with fine sediments can also lead to increased eutrophication and pollution of coastal environments (Wolanski and Spagnol, 2000; Wolanski and Duke, 2002; Brodie et al., 2011). Coral proxies have indicated increased sediment flux to the GBR lagoon following European settlement (McCulloch et al.,

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2003). However, few studies have empirically demonstrated an increase in sedimentation and turbidity downstream of disturbances since European settlement (Bartley et al., 2014). This has remained a challenge due to the difficulties in accounting for complex cycles of erosion, deposition, and storage across the river-estuary continuum in expansive east coast Australian catchments (Douglas et al., 2010).

While much research has focused on the controls and processes of sediment erosion and transport in river catchments, less is known about the response of nearshore depositional environments to variations in sediment supply. In particular, whether these apparent increases and decreases of sediment loads of rivers owing to different catchment disturbances (natural or anthropogenic) are represented in fluvial-marine sedimentary environments. Furthermore, the estuarine zone itself can impart significant controls on sediment flux within the river-marine continuum, modifying both the quantity and grain size of sediments delivered further offshore (Bryce et al., 1998; Bostock et al., 2007). Regional oceanographic conditions (i.e. waves, wind and currents) also have a strong influence on how sediments are transported and redistributed within coastal regions (Larcombe et al., 1995; Lambeck and Woolfe, 2000; Orpin and Ridd, 2012; Delandmeter et al., 2015). Therefore, ongoing research on the physical evolution of the fluvial marine interface is critical for understanding the impact of human disturbances in river catchments on quantities and types of sediments received by nearshore coastal waters.

Here we examine the sedimentation rates in the shallow subtropical Moreton Bay on the east-coast of Australia. A series of off-shore dune barrier islands restrict the flow of oceanic water into the bay making it lagoonal. Consequently, sediments derived from the largely cleared 21,220 km^2 catchment which drains into the 1523 km^2 bay are generally trapped. Optical, radiocarbon, ^{210}Pb, ^{137}Cs and trace metal dating techniques are applied to sediment cores (1.5 m–4.4 m in depth) collected from the Central Bay area to determine the rates, and type of sediment deposition in the bay during the Holocene. This information is used to investigate the response of this fluvial marine sedimentary environment to historical human disturbance within the catchments draining into the bay.

2. Study area

Moreton Bay is a semi-enclosed sub-tropical estuarine embayment situated adjacent to the metropolitan city of Brisbane in Southeast Queensland, Australia (Fig. 1). The bay is shallow, with an average depth of 6.8 m. To its east the bay is bordered by two dune barrier islands (Moreton Island and North Stradbroke Island), which act to confine bay waters and limit oceanic mixing (Dennison and Abal, 1999). Moreton Bay's catchment consists of four major river systems (Brisbane, Logan, Pine, and Caboolture rivers) and the Pumicestone Passage, with the Brisbane River catchment being the largest (13,100 km^2). The watershed of Moreton Bay has experienced severe alteration following European settlement, beginning in the 1840s in the form of widespread clearing of native vegetation (Capelin et al., 1998). Today only ~25% of the original native vegetation remains (Powell, 1998). Catchment erosion models have been used to describe the rate of increase in sediment input into Moreton Bay following catchment clearing, and typically suggest a 3–4 fold increase (Neil and Yu, 1996; Neil et al., 2002).

As a shallow enclosed embayment with long water residence times (up to 60 days), sediment and nutrient laden river water discharges typically have pronounced, long-lasting effects (Dennison and Abal, 1999). Increased sediment input to the Brisbane River as a result of increased erosion is noted as a primary cause of the degradation of habitats of Moreton Bay including seagrass meadows (Dennison and Abal, 1999) and coral communities (Neil, 1998). Increased turbidity following flood events in Moreton Bay is known to have caused coral mortality (Slack-Smith, 1959; Johnson and Neil, 1998), and reduced seagrass cover (Hanington et al., 2015).

Evidence of ecosystem sensitivity to regional environmental disturbances is not limited to the historical era. Mid-late Holocene records of coral growth and reef accretion in Moreton Bay show the occurrence of repeated phases of coral colonization, reef growth and demise across the bay (Flood, 1978; Lybolt et al., 2011; Leonard et al., 2013). These millennial scale changes are driven by relative sea-level change and freshwater discharge from the Brisbane River. Also, a significant shift in the dominant taxa within the bay is coincident with the arrival of Europeans (Lybolt et al., 2011). This shift is suggested to be a response to a decrease in water clarity and increased nutrient loading throughout the bay, following the onset of catchment clearing. The current dominant family of coral (*Faviidae*) is known to be tolerant to poor quality water and low salinity (Johnson and Neil, 1998; Lybolt et al., 2011). As a system liable to relatively rapid geomorphic change, this is an ideal environment to investigate the sensitivity of fluvial-marine sedimentary environments to historical land use changes. To do this, a firm understanding of the Quaternary evolution of the bay's sedimentary environments and the natural variability of the system prior to human disturbance is required.

2.1. Quaternary sediments of the Brisbane River Delta

Previously, seismic profiling, boreholes, and sediment grab sampling have been used to characterize the modern sediment and the Quaternary depositional environments of the region (Hekel et al., 1979; Evans et al., 1992; Lang and Herdy, 1997; Brooke et al., 2008). This research shows that Moreton Bay is a drowned river valley. Accordingly, post glacial sea-level change is the major driver of the architectural components of Quaternary sediments within the Bay. Evans et al. (1992) used extensive seismic surveying and borehole data to describe the Holocene fill of sediments directly offshore from the modern fluvial delta front, following the marine transgression ~ 8 ka (Lewis et al., 2013). These units include; 1) Pleistocene valley floors and incised palaeochannels at the last glacial maximum (LGM) ~18 ka; 2) transgressive fine muds and estuarine deposits beginning at ~10 ka; 3) Holocene stillstand deposits consisting of pro-deltaic muds and delta-front sands beginning at ~6.5 ka. Lang and Herdy (1997) refined our understanding of the modern delta front describing a series of sediment lobes downlapping on the high-stand maximum flooding surface consisting of muddy laminated estuarine deposits. Beyond the delta-front sands, laminated pro-delta muds extend into Moreton Bay. This depocenter is a product of the Bay's circulation patterns and antecedent basin-like topography, an artefact of the convergence of the Pine and Brisbane River palaeochannels during the last glacial maximum (18 ka) (Evans et al., 1992). These two factors act to focus newly exported sediment in this area and it reaches a maximum depth of ~10 m in the Central Bay (Evans et al., 1992).

Surface sediment surveying in the 1970s (Day et al., 1983) identified six major facies; 1) tidal delta sands, occupying eastern Moreton Bay within the north and south passages and extending along the western coast of Moreton Island; 2) marine basin sediments, comprised of carbonate rich material occupying central to southern Moreton Bay with low sedimentation rates; 3) pro-delta muds, extending north-east from the Brisbane River mouth; 4) fluvial delta sands; 5) shoreface/fringing coral reef; and 6) fringing fossil and remnant coral reefs (Fig. 1). Since initial surveying, significant changes in the distribution of types of surficial sediments in Moreton Bay have been observed, primarily an expansion of mud