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The utility of estuarine settling basins for constructing multi-decadal, high-resolution records of sedimentation

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ABSTRACT

Obtaining long-term records of sediment flux and sources to estuaries is a major challenge in coastal and estuarine research due to the dynamic processes that actively work to remove the high-resolution, long-term sediment record. Examining cores from sediment-settling basins directly adjacent to or within estuarine systems provides a potential alternative means of establishing a history of estuarine sedimentation. As a recently established settling basin with high rates of sedimentation, Cape Lookout Bight, NC presents an ideal coastal environment to capture a long-term record of sedimentation.

In 2010, a 4.6 m-long core was extracted from the deepest portion of the basin. Through lithologic description, grain-size, water content and radioisotope analysis (excess ^{210}Pb), a high-resolution geochronology of sedimentation has been established for the basin. The record begins with spit accretion that captured part of the marine shelf and formed the basin. A transition in sediment type from dominantly marine, through storm-induced overwash, to dominantly estuarine was identified in the basin. This transition reflects the increased trapping efficiency of fine estuarine mud due to the changing geomorphology of the settling basin. An abrupt increase in the rate of estuarine sedimentation occurred ~1983–1985. After careful reconstruction of basin geomorphology, this increased rate of sedimentation is not attributed to internal dynamics within the basin, but instead is interpreted to be the result of increased estuarine sediment flux through Barden's Inlet from the upper estuary. This work underscores the importance of considering changing basin physiography and sediment dynamics before interpreting the paleo-record, as those mechanisms can hide or eliminate allogenic signatures from the sediment profile.

1. Introduction

Long-term records of sediment flux and sources within estuaries are difficult to obtain, due to the dynamic physical and biological processes that remove and mix the sediment bed. Estuaries have numerous sediment sources, including riverine, direct shoreline erosion, and off-shore marine, each with unique sediment-transport processes (Dalrymple et al., 1992). The river flux generally involves uni-directional flow of freshwater and sediment to the estuary (Dyer, 1995). Estuarine shoreline erosion can increase overall sediment load and change the shape of the estuary, causing increased fetch and a feedback loop that will exacerbate shoreline retreat (Schwimmer, 2001; Cowart et al., 2011). Erosion along the shoreline also creates accommodation for additional sediment accumulation (Zaitlin et al., 1994; Cooper, 2002; Slagle et al., 2006). Marine inputs to the estuary result from episodic storm events that overwash barrier islands and form washover fans and more continuous marine-sediment delivery through the mouth of the estuary.

Sediment flux to estuaries from each of those sources outlined above is not constant through time. Episodic events such as storms result in greater sediment flux from rivers due to runoff, increased estuarine shoreline erosion from waves, remobilization of previously-deposited sediment on the estuary floor, and increased sediment influx from marine contributions (French and Spencer, 1993; Day et al., 1995; French, 2002; Yang et al., 2003; Ralston

Abbreviations: RSLR, Relative sea-level rise; CLB, Cape Lookout Bight, NC; DEM, Digital Elevation Model; CIC, Constant Initial Concentration sedimentation rate model; OGF, Open Grounds Farm.

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and Stacey, 2007; Ralston and Geyer, 2009). Daily to monthly tidal fluctuations can remobilize sediment within the estuary, and seasonal variations (e.g., spring freshet, winter/summer storms, dry and wet seasons) can increase estuarine flow regimes, turbidity and overall sediment flux to and from the estuary, causing continual erosion, transport and deposition within the estuarine basin (Allen et al., 1980; Geyer et al., 2001; Fain et al., 2001; Grabemann and Krause, 2001). Over decadal to millennial timeframes, variations in anthropogenic influences (e.g. dams, land-use and cover modifications, shoreline armoring), sea level, and climate can also affect changes in sediment flux to the estuary (Patton and Horne, 1992; Small and Cohen, 2004; Poff et al., 2006; Mattheus et al., 2009; Walling 2012).

Constructing high-resolution records of estuarine sedimentation and linking measured changes in accumulation rate to an associated change in the process of sediment transport, deposition, and/or preservation is important for coastal management, predicting estuarine response to climate change, and improving models of strata formation. Variation in sediment flux to the central basin of an estuary with low accommodation can be preserved in the sedimentary record over short time scales (storm deposition examined shortly after the event) (Olsen et al., 1978; Corbett et al., 2007); however, over scales greater than 1 year, those variations in sedimentation are much more difficult to resolve (Olsen et al., 1993). This is primarily due to the dynamic processes that control sedimentation within the estuary. Conceptual models of estuarine sedimentation emphasize a balance between the rate of accumulation and provision of accommodation by the rate of relative sea-level rise (RSLR) (Stevenson et al., 1986; Nichols, 1989; Nichols and Boon, 1994). These conceptual models show that energy dissipation through waves and currents resuspending and redistributing estuarine-bottom sediment and exporting some portion of that sediment through tidal inlets is a significant factor in determining the base level of sediment accumulation. Nichols (1989) and Simms and Rodriguez (2015) presented a significant direct relationship between the fetch and depth of estuaries arguing that estuarine accumulation rates in the central basin over decadal-millennial time scales should be in equilibrium with the rate of RSLR. Additionally, biological activity within the estuary will cause bioturbation and disturb the long-term profile. These processes make resolving long-term records of changes in sediment flux within the estuarine central basin difficult, which in turn will make identifying the forcing mechanisms that cause changes in sediment flux in and out of estuaries problematic.

Nevertheless, determining changes in sediment flux to the estuary, which could be due to changes in discharge, shoreline erosion rates, or changes in estuarine hydrodynamics from changing the configuration of the estuary (e.g. changes in the width or number of tidal inlets) may be possible in estuarine sediment-settling basins or deep portions of the estuary (e.g. harbors, sinkholes, mining pits, etc.) that are capable of capturing sediment below the regional sedimentation base level (Van Rijn, 2005). Deep and extensive settling basins are not affected by sediment resuspension and redistribution in the same way as adjacent more shallow areas, due to the greater sediment accommodation within. A settling basin with these characteristics should contain a continuous sedimentary record of changes in the source of sediment and/or process of sedimentation and can be scaled and used as a proxy of sediment flux. This study examines the potential of using the sedimentary record preserved in the Cape Lookout Bight (CLB), North Carolina estuarine settling basin, placed in context with changes in the coastal geomorphology of the basin, as a proxy to identify changes in the rate of sedimentation and relative contribution of various sediment sources and sedimentation processes through time.

2. Study area and background

CLB is a well-studied estuarine settling basin, shown to have high rates of sediment accumulation (Martens, 1976; Bartlett, 1981; Chanton et al., 1983; Martens and Klump, 1984; Wells, 1988; Canuel et al., 1990). The basin is 7.5-m deep, located near the southern Outer Banks chain of barrier islands and is centered at the apex of two previously connected barrier islands, Shackleford Banks that trends east-west, and Core Banks that trends north-south (Fig. 1). A hurricane in 1933 formed an inlet between these two barriers, which has been maintained by dredging as Barden's Inlet. Upon formation of Barden's Inlet in 1933, a rubble-stone groin, previously placed along Core Banks in 1915 to enlarge the barrier, helped to facilitate rapid north-northwest spit migration. Recurved-spit growth created the deep basin-like sink for sediment, which will be referred to as an estuarine settling basin in this paper, and formed a second inlet, the Western Inlet, between Core Banks and Shackleford Banks. The Western Inlet is the entrance where marine water enters the semi-enclosed CLB basin northwest of Cape Lookout over what used to be the shoreface and inner continental shelf (Fig. 1). The formation of this basin created an effective sediment trap for fine-grained material moving through Barden's Inlet from Core Sound and North River Estuaries (Chanton et al., 1983; Wells, 1988; Canuel et al., 1990).

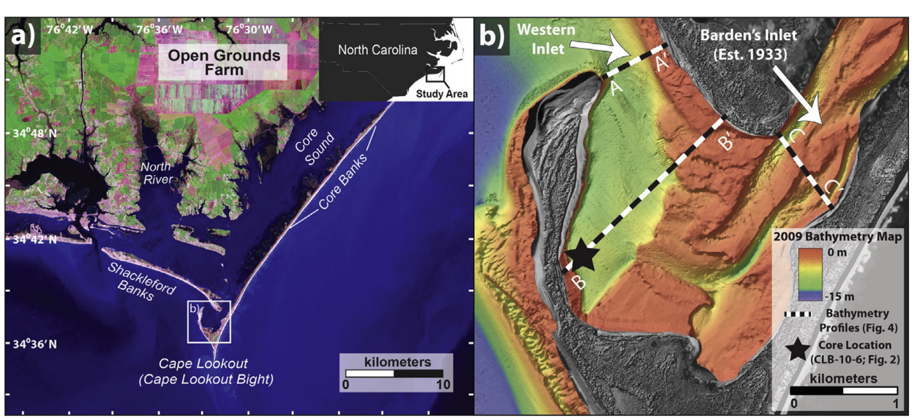

Fig. 1. Study area map showing a) location of Cape Lookout Bight, NC (CLB) and surrounding estuary (USGS Landsat image) and b) closer view of CLB with location of core CLB-10-6 (34° 37.184′N, 76° 32.965′W; Fig. 2) and bathymetry transects (Fig. 4) overlain on 2009 high resolution multi-beam bathymetry survey (Geodynamics Group).