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Estuarine abandoned channel sedimentation rates record peak fluvial discharge magnitudes

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ABSTRACT

Fluvial sediment deposits can provide useful records of integrated watershed expressions including flood event magnitudes. However, floodplain and estuarine sediment deposits evolve through the interaction of watershed/marine sediment supply and transport characteristics with the local depositional environment. Thus extraction of watershed scale signals depends upon accounting for local scale effects on sediment deposition rates and character. This study presents an examination of the balance of fluvial sediment dynamics and local scale hydro-geomorphic controls on alluviation of an abandoned channel in the Salinas River Lagoon, CA. A set of three sediment cores contained discrete flood deposits that corresponded to the largest flood events over the period of accretion from 1969 to 2007. Sedimentation rates scaled with peak flood discharge and event scale sediment flux, but were not influenced by longer scale hydro-meteorological activities such as annual precipitation and water yield. Furthermore, the particle size distributions of flood deposits showed no relationship to event magnitudes. Both the responsiveness of sedimentation and unresponsiveness of particle size distributions to hydro-sedimentological event magnitudes appear to be controlled by aspects of local geomorphology that influence the connectivity of the abandoned channel to the Salinas River mainstem. Well-developed upstream plug bar formation precluded the entrainment of coarser bedload into the abandoned channel, while Salinas River mouth conditions (open/closed) in conjunction with tidal and storm surge conditions may play a role in influencing the delivery of coarser suspended load fractions. Channel adjacent sediment deposition can be valuable records of hydro-meteorological and sedimentological regimes, but local depositional settings may dominate the character of short term (interdecadal) signatures.

1. Introduction

Fluvial sediment deposits are the product of interactions between external processes that govern sediment delivery, and internal processes that affect sediment transport, deposition and preservation. At the largest regional to continental scales, and over thousands to millions of years, sediment delivery hinges on the balance of tectonics and climate, as illustrated by landscape evolution models (Howard et al., 1994; Lane et al., 1997; Tucker and Slingerland, 1997; Armitage et al., 2011). However, at watershed to regional scales, and over decades to centuries, sediment delivery is more directly explained by annual precipitation characteristics, seasonal precipitation variability, and landscape characteristics (e.g. relief, maximum elevation, area, land cover, and land use) (Dendy and Bolton, 1976; Milliman and Syvitski, 1992; Ludwig et al., 1992; Pasternack et al., 2001; de Vente et al., 2007). At subbasin to watershed scales, and over days to years, sediment delivery is again conditioned by factors operating over larger spatio-temporal scales, such as interdecadal scale anthropogenic impacts (Gilbert, 1917; Gottschalk, 1945; Trimble, 1997; Constantine et al., 2005; Warrick and Rubin, 2007). However, short term sediment delivery is most directly explained by weather-driven transient events (Park, 1992; Warrick and Farnsworth, 2009; Mayor et al., 2011) and transient disturbances such as wildfire (Warrick and Rubin, 2007; Warrick et al., 2012). The overall goal of this study was to investigate episodic sediment delivery to an estuarine lagoon over several decades in a dry-summer subtropical climate (i.e., Mediterranean) in order to determine the major factors controlling sedimentation.

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Watersheds experiencing a Mediterranean climate exist at a metastable tipping point in terms of the genetic factors controlling water and sediment generation and export. Langbein and Schumm (1958) suggested that the semi-arid zone is a potent source of sediment flux, because rainfall is sufficient for effective erosion, but insufficient for the support of dense vegetation or well-developed soils, both of which tend to reduce runoff, resist erosion, and decrease drainage density (Thornes, 1994; Osterkamp and Friedman, 2000). This mechanism is further enhanced for the dry-summer subtropical zone by the concentration of runoff and erosion during a short period of the year and high interannual variability in total flow and flood peaks (Baker, 1977; McMahon et al., 2007).

Further precarious dynamism stems from an array of climate-related disturbance types that render semi-arid watersheds particularly vulnerable to erosion, and those in the dry-summer subtropical zone even more so. The largest, rarest floods under these climatic regimes are more extreme than for many other climates (Baker, 1977; Costa, 1987) and they account for a disproportionate amount of sediment yield (Warrick and Farnsworth, 2009; Gonzalez-Hidalgo et al., 2010; Warrick et al., 2013). For example, greater than 90% of sediment exported from many coastal central and southern California watersheds is produced during events that represent less than 1% of the hydrologic records (Farnsworth and Warrick, 2007). Wildfire recurrence interval is the shortest in these regions (Malamud et al., 2005) and recovery from fire is slow (Mayor et al., 2007), with low resilience after human-influenced vegetative conversion from shrubland to grassland (Gabet and Dunne, 2002).

Despite a global tendency for stratigraphic preservation of delivered sediment to decrease with increasing timescale of investigation (Sadler, 1981) due to the distribution of erosional/non-deposition hiatuses (Sadler, 1999), millennial scale paleo-environmental studies in dry-summer subtropical watersheds of California have reported an opposite effect in which apparent deposition rates increase with record length (Kirchner et al., 2001; Constantine et al., 2003). This is partly explained by climatic change causing an inter-millennial decrease in event frequency and intensity relative to stormy conditions during the Pleistocene/Holocene transition (Johnson, 1977; Adam and West, 1983; Rypins et al., 1989; Grigg and Whitlock, 1998; Beaty and Taylor, 2009). An additional factor is the dominant role that rare, high-intensity floods play in the interdecadal to millennial scale flux of sediment from dry summer subtropical basins. In these systems longer time periods of observation (or sedimentation) result in greater chances for an extreme event to occur in that domain, which can dramatically increase average sedimentation rates (Schumer and Jerolmack, 2009).

Sedimentary records under event-dominated hydro-sedimentological regimes may or may not bear decipherable event scale signatures depending on the character and magnitude of local factors affecting sediment deposition and preservation. Transport, deposition and resuspension of sediments delivered to coastal marine settings are influenced by fluvial plume characteristics, delta/estuarine dynamics, coastal currents, tidal and wind-driven wave regimes (van Rijn, 1993). The resultant accreted sediments are often prone to bioturbation, which can impose event magnitude thresholds on preservation (i.e. burial depths that exceed bioturbation depths) (Wheatcroft et al., 1997). Abandoned channel bends in lowland fluvial settings can present ideal settings for event scale sediment capture (Allen, 1965). However, the character of such sedimentary deposits is also dependent in part on local geomorphic and hydrologic conditions that control hydro-sedimentological connectivity to the river mainstem (Constantine et al., 2010; Toonen et al., 2012). One consequence of the morphology of this coupling can be the imposition of dynamic event magnitude thresholds as physical inundation and sediment entrainment barriers evolve with deposition or scour (Kleinhans et al., 2013). Such variable connectivity between the zone of deposition and fluvial sediment supply can impose significant complications to paleohydrologic interpretations of abandoned channel sediment deposits.

Although coastal and estuarine depositional environments have been used extensively to record long-term average sedimentation rates worldwide, there is relatively little scientific knowledge about how episodic sediment delivery functions in dry-summer subtropical estuaries (Rich and Keller, 2012). In this study, sediment cores collected from an abandoned river channel bend located in a small estuarine lagoon at the mouth of a coastal dry summer subtropical watershed in central coastal California were examined as potential records of episodic sediment delivery over the last ~50 years. The first study objective was to quantify rates of sediment deposition and evaluate their feasibility as a proxy for watershed sediment delivery. The second study objective was to relate deposition rates to hydro-climatic activity, suspended sediment discharge, records of time-synchronous individual disturbances, and local hydro-geomorphic conditions to parse out the most important factors contributing to stratigraphic characteristics (e.g. particle size distribution) and sedimentation rates. To this end we synthesized hydro-sedimentological results from the lower Salinas River first reported in Gray et al. (2014) and stratigraphic data and results and from its estuarine lagoon first presented in Watson et al. (2013) to better understand dry-summer subtropical episodic sediment delivery. Characteristics of lagoon sediment deposits were tested for dependency on water and sediment discharge characteristics. Results were then considered in the context of the drivers of changing sediment regimes in the Salinas River watershed.

2. Background

2.1. Study area

The Salinas River is the largest watershed and water source discharging to Monterey Bay, draining 11,605 km^2 of the Central Coast Ranges of California with a mean discharge (Q_{mean}) of 11.6 $m^3 s^{-1}$ (Gray et al., 2015a). Originating in the Garcia Mountains, the Salinas River flows north-northwest for 250 km toward the Salinas River Lagoon through a central trough of valley bottomlands flanked by the Santa Lucia and Gabilan Mountains to the southwest and northeast, respectively (Fig. 1). Previously the Salinas River drained into Monterey Bay in the vicinity of Elkhorn Slough, some 6 km north of the current position in the vicinity of the Salinas River Lagoon (Watson et al., 2013). Geologic substrate is primarily Mesozoic sedimentary rock and overlying Pleistocene to Holocene alluvium (Garcia and Mahan, 2009; Rosenberg and Joseph, 2009).

The regional climate is dry-summer subtropical. Most annual precipitation falls as rain originating from winter storms, and thus the ‘water year’ in this region is defined as running from October 1 of the previous year to September 30. The largest of these storms tend to occur during strong El Niño years when high sea surface temperature anomalies in the equatorial eastern Pacific increase the likelihood of moisture advection from the tropical western Pacific (Farnsworth and Milliman, 2003; Andrews et al., 2004). A strong precipitation gradient extends from the wetter SW (~100 $cm\ yr^{-1}$) to drier NE (~30 $cm\ yr^{-1}$) region of the Salinas River watershed due to orographic forcing (Farnsworth and Milliman, 2003) and the predominant S-SW impingement of storms (Andrews et al., 2004).

The hydro-sedimentological response of the Salinas River to this