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Post-dam sediment dynamics and processes in the Colorado River estuary: Implications for habitat restoration

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ABSTRACT

River-sea connectivity is essential for restoring ecosystem services in the Colorado River delta. The mixing of river water and seawater sustains biodiversity and provides brackish-water nursery grounds for both commercially important and endangered marine species. The Colorado River no longer reaches the sea except during particularly high tides and anomalously wet years. The river's relict channel is now obstructed by an accumulation of sediments deposited during flood tides; ebb flows are not strong enough to keep the channel open. Landsat 5-TM and Landsat-7 scenes from the Colorado River delta and tide prediction tables were used to reconstruct river-sea connectivity and geomorphic processes after 50 years of extensive human manipulation of the Colorado River. Historical documentation, previous topographic surveys and sediment cores were used to estimate sedimentation rates in the lower river channel. Satellite images and tide charts show that currently the river reaches the sea or the sea reaches the river about 12 days per year, unlike 10 years ago when a year-round connection existed. Reduction in connectivity results from the evolution of a tidal sandbar located within the bedload convergence zone, about 35 km upstream from the river's mouth. Historical documentation and sediment core analyses suggest sedimentation rates in the range of 10–21 cm per year. With the current conditions prevailing, active management – dredging – is required and needs to occur once every 5–10 years to reconnect the remaining riparian wetlands in the Colorado River to the Gulf of California.

1. Introduction

The Colorado River is the most important river in the southwestern United States and it allowed for the extensive agricultural and urban development in the southwestern U.S. and northwestern Mexico. Progress in the region came at a significant environmental cost to the river's delta and estuary sections. Prior to large-scale river diversions, the 800,000 ha of the delta received 18 billion m^3 of freshwater discharge annually, forming an enormous estuary and serving as home for a diverse number of bird and fish species (Calderon-Aguilera and Flessa, 2009). During the last century, the Colorado River became one of the most managed and diverted rivers in the world (Fig. 1). Dam building projects and water management practices were implemented to provide water to more than 27 million people and more than 1.2 million ha of farmland in the rapidly developing southwest U.S. and northwestern Mexico (Barnett and Pierce, 2009). The 1944 treaty that allocated water to Mexico and the United States did not account for the water needs of the wetland and estuary ecosystems. Water consumption for human uses led to a massive decrease in the biodiversity and ecosystem services downriver on the Mexican part of the delta. At present, less than 1% of the river's water reaches the delta and the area formerly occupied by wetlands has been reduced to less than 5% of its original extent (Zamora-Arroyo and Flessa, 2009). Furthermore, the river no longer reaches the sea except during extremely wet years and during very high spring tides. Spring-season floods no longer maintain a connection to the Gulf of California by clearing away material accumulated in the river's lowermost channel restricting nursery grounds for endangered and economically valuable species (Rowell et al., 2005, 2008).

The river's relict lowermost channel is plugged by sediment accumulated during flood tides. Ebb flows are not strong enough to keep the river channel open. Spring-season floods, which used to deliver 60% of the river's flow in only three months (USGS, 1954; Harding et al., 1995), no longer reach and maintain the channel. Under these circumstances, active river management – dredging – is needed to reconnect the river and the Gulf of California. This research seeks to understand current sedimentological processes

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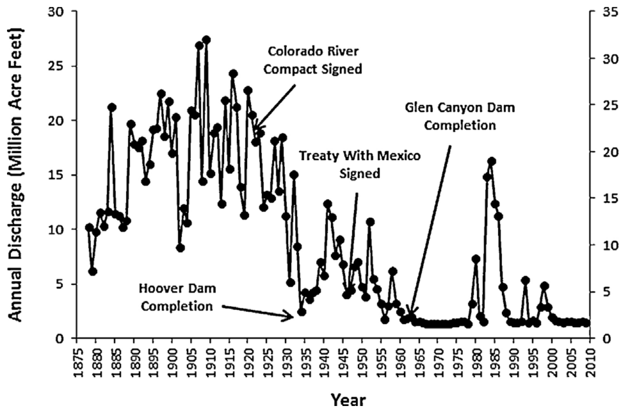

Fig. 1. Colorado River Flow at U.S.–Mexico border from 1878 to 2009. IBWC (2011).

and quantify sedimentation rates in the river's lowermost channel section in order to develop a feasible plan to manage sedimentation and water flux. A healthy river-ocean interface can help restore nutrient cycling processes, improve nursery grounds for commercially valuable fish and shrimp, provide habitat for biodiversity, and flush the estuary from accumulated salts and contaminants.

2. Study area

The Colorado River delta begins near Yuma, Arizona, and extends into the states of Sonora and Baja California in Mexico south to the Gulf of California (Fig. 2). The southern delta portion and the upper Gulf of California were declared protected land under the UNESCO Biosphere Reserve program in 1993 by the Mexican government. Located between 31.5 N and 32.0 N, it is one of the warmest and driest regions in North America: average temperatures reach 40 °C during the summer and annual precipitation averages about 6.5 cm (Zamora-Arroyo et al., 2001). Two important agricultural districts are located in the region, the Imperial Valley (USA) and the Mexicali Valley (Mexico); they are both fed

Fig. 2. Study area: the Colorado River delta location between the states of Sonora and Baja California, Mexico.

Fig. 3. Study area and surrounding localities. HR: core locations in the Rio Hardy. CRE: core locations in the estuary. White dotted line marks the approximate extent of tidal influence.

by water retained in Lake Mead and Lake Powell (Graf, 1985). Little in-channel flows reached the delta after Glen Canyon Dam's completion in 1964 (Glenn et al., 2001) and prevailing drought conditions in the Colorado River Basin since 2000 have further restricted flow releases into the delta (IBWC, 2011). Downstream of the U.S.–Mexico border and Morelos Dam, the Colorado River is joined by the Hardy River, a former Colorado River channel, discharging agricultural wastewater from the Mexicali Valley, and treated wastewater from the recently artificially created Arenitas wetlands (Daesslé et al., 2009; Valdes Casillas et al., 1998). This water has helped to partially restore and sustain the few, but still important wetlands and riparian corridors that remain in the area.

3. Colorado River estuary

The Colorado River estuary is now limited to the southern section of the delta (Fig. 3). Near the river's mouth, it is characterized by a funnel-shaped channel 45 km in length with two elongated, linear tidal ridges, Montague and Pelicano Islands (Carriquiry et al., 2011). This estuarine morphology is often found in macrotidal or tide-dominated settings (see, e.g., Wright, 1977). The gentle gradient in the estuarine channel (16 cm/km) above the tidal islands (Thompson, 1968), combined with the extreme tides characteristic of the northern Gulf of California (up to 10 m) result in tidal waters reaching far upstream from the river's mouth (Payne et al., 1992).

The estuary is described as a hypersynchronous estuary, where tidal-induced currents reach maximum speeds in the upper sections due to the tidal wave convergence into a smaller cross-sectional area; these currents are ultimately dissipated by friction near the tidal limit (Allen et al., 1980; Wells, 1995). Three different energy regions receiving active river flow are found in such settings: marine-dominated, mixed energy and river-dominated (Dalrymple and Choi, 2007). Prior to massive dam operations, the Colorado River deposited large amounts of sediment, actively prograding its delta. During strong river-flow conditions the bedload convergence zone, where tidal and fluvial bedload meet, was located seaward of the river's mouth creating the characteristic tidal ridges present at the mouth (Dalrymple and Choi, 2007). Dalrymple and Choi (2007) suggest that in a tidally dominated estuary with low river influence, the bedload convergence zone will be located inland from the mouth, resulting in active transport of sediment inland from the mouth into the convergence zone. The effect of the hypersynchronous estuary coupled with the fact that in the