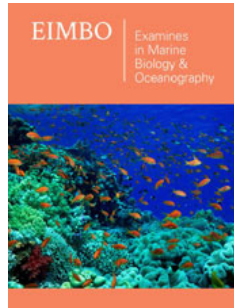



There is No Evidence that the Northern Gulf of California Has Ever Been Brackish or Estuarine During the Holocene

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Abstract

There is a long-standing belief that the Colorado River once created brackish-water estuarine conditions in the Northern Gulf of California, and that this affected the ecosystem of the Upper Gulf. However, a thorough review of the literature reveals this not to be the case. There has never been published documentation of brackish water in the Northern Gulf south of the river's mouth, at Isla Montague. (Data from multiple independent investigations have never shown brackish or estuarine conditions south of Isla Montague.) Furthermore, the average daily tidal exchange in the Upper Gulf exceeds the highest annual river discharge ever estimated, suggesting the impossibility of brackish conditions in the Northern Gulf. Species such as vaquita (*Phocoena sinus*), totoaba (*Totoaba macdonaldi*), corvina (*Cynoscion othonopterus*), and others have always lived in marine conditions

Keywords: Colorado river; Colorado delta; Upper gulf of California; Northern gulf of California; *Totoaba*, *Corvina*; Vaquita; Shrimp

Introduction

Two key archives of the Colorado River's history are Holocene tree-ring reconstructions of precipitation and the late Miocene-early Pliocene Bouse Formation, which outcrops and is also present in the subsurface along the lower Colorado River Valley of western Arizona, southern Nevada, southeastern California, and northeastern Baja California. The Bouse formation ranges from less than 10m thick in some outcrops to over 250m in subsurface drill sites. Based largely on analyses of the Bouse Formation, the Colorado River is thought to have reached the Gulf of California (far to the north of its present location) sometime between 5.3 and 4.8 million years ago [1-3]. A long chronicle of tree-ring research shows an historic mean Colorado River flow (past Lees Ferry) of $\sim 13.5 \times 10^9 \text{m}^3$ (~ 11 million acre-feet) annually. The amount reaching the U.S.-Mexico border, even with the Gila River flow included, would have been far less than that, perhaps as little as half that amount or $\sim 6.5 \times 10^9 \text{m}^3$ (~ 5.5 maf) annually. The Mississippi River discharges $554 \times 10^9 \text{m}^3$ annually to the Gulf of Mexico, and the Columbia and Fraser Rivers discharge $236 \times 10^9 \text{m}^3$ and $110 \times 10^9 \text{m}^3$ annually to the Pacific, respectively. Even Niagara River discharges $183 \times 10^9 \text{m}^3$ annually to Lake Ontario. In comparison, the Colorado's flow to its delta is almost trivial, and the concept of a "Mighty Colorado" south of the Utah-Arizona border, is no more than folklore. Exactly how much river water actually ever entered the Gulf in the past is unknown. Based on published research, the idea that, during the Holocene, the Colorado River has ever delivered enough freshwater to the Upper Gulf to create brackish or estuarine conditions appears to be a myth. The modern Delta of the Colorado River is restricted to that region north of Isla Montague (the sand island at the mouth of the river), which means species such as vaquita (*Phocoena sinus*), totoaba

(*Totoaba macdonaldi*), Corvina (*Cynoscion othonopterus*), penaeid shrimps, and others have always lived in marine conditions, not in estuarine/brackish waters.

Importantly, there are no empirical records of how much Colorado River water ever reached the Upper Gulf. Publications have usually used flow meter data from Lees Ferry (on the Arizona-Utah border), occasionally from a Yuma flow meter, or rarely from the Morelos Diversion Dam, built in 1950 (providing the only data on how much river water ever flowed across the border into Mexico, but not how much water actually reached the Gulf of California). Note that Morelos Dam is not a true dam; it is simply a switching station for water crossing into Mexico, diverting it to various agricultural and urban areas in the Mexicali Basin. Lees Ferry marks the legal transition from the Upper Colorado River Basin to the Lower River Basin. The river flows more than 1000km south from Lees Ferry, through the hottest and driest landscapes in the U.S., before crossing the border into Mexico. Research has shown that even the small flow crossing the border into Mexico rarely reached the Upper Gulf. Instead, it was trapped on the huge delta (8,612km²/3,225mi²), which is mostly below sea level and where many low basins have always held most of the river's water and prevented it from reaching the sea (e.g., Salton Basin, Laguna Salada Basin, Volcano Lake, Pescadero Basin, Santa Clara Basin, etc.). When filled, Laguna Salada alone covers ~1000 km². The reason most of the Colorado River Delta is below sea level is because the San Andreas Rift System is spreading at a rate of 4-5cm/yr (1.5-2in/yr), creating tectonic pull-apart basins (grabens) and causing the rift valley to continually subside (at a rate of 1-3mm/yr). The mean rate of subsidence has been greater than the mean rate of river sediment infill. The Salton Trough is 73m (240ft) below sea level and Laguna Salada is 11m (36ft) below sea level. Both are filled with primarily Colorado River sediments to 6,000m (19,685ft) thick, testimony to their capture of the Colorado River's water over the past few million years.

Since the 1970s, it has been only in the "flood years" that any water could have reached the Gulf (1978, 1982-1988, 1993, 1997-1999). 1983 to 1989 were unusually wet years in the Southwest. Extreme flood flows occurred 1984-1988 when great amounts of river water reached the Delta. However, even then most of this discharge ended up in Laguna Salada where it was lost to evaporation. During flood years the lower delta (that area north of Isla Montague) can be covered by 2,500km² of trapped, standing, fresh or brackish water (see photo). There has never been a single oceanographic measurement of brackish water (i.e., <30 ppt) in the Upper Gulf. The actual estuary is basically just the delta, north of Montague Island (i.e., only north of the island could brackish water ever have occurred).

The Published Research

There is no record of pre-dam brackish water in the upper gulf

Nineteenth century (pre-dam) oceanographic data show the upper gulf to be fully marine, never brackish [4].

Even flood years do not create brackish conditions

Lavín & Sánchez [5] took advantage of a natural experiment to assess pre-dam Colorado river influence on salinity in the upper gulf by measuring the effects of the enormous 1993 flood release on the river. An estimated maximum 550m³ per second of river water crossed the border into Mexico at Morelos Dam during a March-April pulse release, for a total 2-month discharge of about 2.9 X 10⁹m³, or an average daily flow of 47.5 X ~10⁶m³, and during this period salinities off San Felipe remained oceanic, averaging 35.4 ppt.

Pre-dam clam shells show no record of low-salinity water in the upper gulf

Based on oxygen isotopes in shell layers, estimates of pre-1935 natal salinities of "delta clam" shells (*Mulinia modesta*) show no evidence of pre-dam brackish water environment south of Isla Montague [6].

Long-term satellite data show no record of low-salinity water in upper gulf

John All (2006, 2007) used remote-sensing imagery to show that no water flowed beyond Morelos Dam (into Mexico) from 1958 to 1983, as Lakes Mead and Powell filled. During this time, all downstream riparian areas on the Delta disappeared and Lake Maquata (Laguna Salada, today) dried up. Laguna Salada/Lake Maquata was historically a large lake fished by locals (especially the Cucupá People). All (2006, 2007) used the same techniques to show that no water reached the Sea of Cortez from 1989 to 2000, even during flood years (when much of the fresh water was diverted into Laguna Salada).

Average annual salinity of the upper gulf does not change significantly between wet and dry periods

Rodríguez-Pérez et al. [7] found Upper Gulf salinity to range around 34.5ppt throughout the 1980s and 1990s, based on satellite data (i.e., no signs of hyposalinity or brackish water even during flood years).

The history of upper gulf oceanography provides no records of brackish conditions and indicates river water is mostly impounded on the delta

Brusca et al. [8] reviewed the history of oceanographic research in the Northern Gulf (~350 papers), concluding that: (1) the Upper Gulf has never been brackish; (2) the amount of river water reaching the Upper Gulf has rarely been large, often absent altogether (the river instead emptying into the Salton Basin, Laguna Salada, and other basins on the delta), and never enough to create brackish or estuarine conditions below Isla Montague; (3) primary productivity has always been very high in the Upper Gulf and there is no evidence it has decreased subsequent to building of the dams on the Colorado River. Older published work that tried to make a case for reduction in shrimp, finfish, or vaquita (*Phocoena sinus*) population size or production due to diminished Colorado River flow has been shown to be flawed [5,9-11].

Mean daily tidal flushing of the upper gulf exchanges more water than an entire year of river flow

Rojas-Bracho et al. [12,13] calculated the amount of oceanic water exchanged in the Upper Gulf due to the area's extreme tides. They found that the amount of river water reaching the Upper Gulf has historically been far too small to have any significant impact on the salinity of the region, and the size of the daily tidal exchange makes it physically impossible for the Upper Gulf to become brackish. Given the average 3.87-meter tidal range in the Upper Gulf, and the semidiurnal nature of its tides, a mean of over $25.5 \times 10^9 \text{ m}^3$ of oceanic tidal water flushes into and out of the region daily, which is more than the highest estimates of Colorado river water reaching the Upper Gulf in an entire year. Thus, the influence of the river's discharge on salinity in the Upper Gulf has always been trivial, pre-dam and post-dam.

Conclusion

There has never been a single record of estuarine conditions or brackish waters in the Upper Gulf of California south of Isla

Montague (at the river's mouth). Nor has there ever been a recorded measurement of how much river water actually entered the gulf. Despite this, there persists in the minds of some the idea that the river formerly poured millions of acre-feet of freshwater into the Gulf to affect its ecology. This idea, it appears, is myth. An analysis of the published research reveals no support for the idea of the Upper or Northern Gulf of California ever being brackish-water or estuarine below the mouth of the Colorado river (the sand island of Isla Montague). Nor is there any evidence that loss of Colorado river water due to dams or drought has affected the salinity or primary productivity of the Upper/Northern Gulf of California. The 1983-84 El Niño event led to "flood year" excess water releases into the Colorado river channel, filling Laguna Salada Basin and connecting it to Ciénega de Santa Clara as the delta flooded from April to June. Laguna Salada covers $\sim 1,000 \text{ km}^2$ and the total flooded area of the delta is $\sim 2,500 \text{ km}^2$. In this image, one can see that essentially all of the river's water is trapped on the lower delta behind berm-barriers to the Upper Gulf. The water eventually evaporates or infiltrates into the delta's sediments. LANDSAT images courtesy of Alejandro-Hinojosa-Corona (CICESE, Ensenada) (Figure 1).

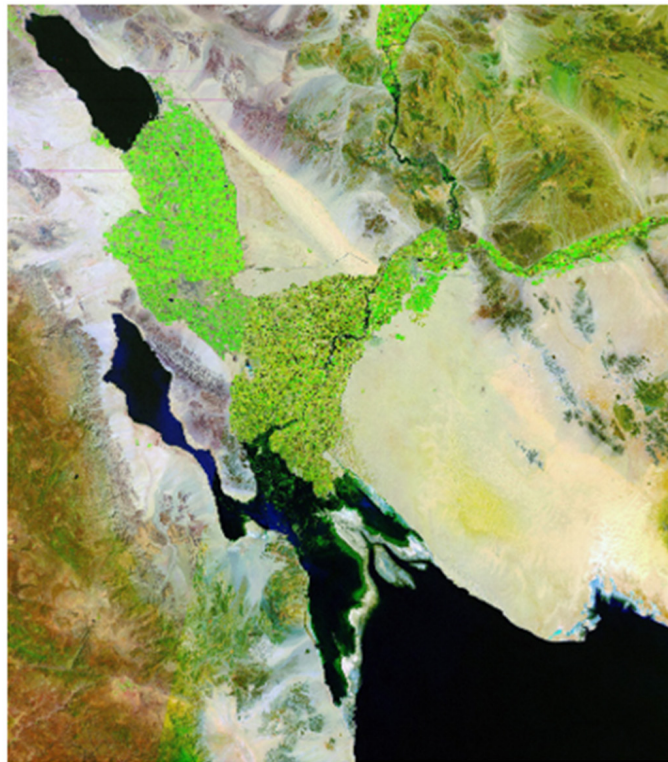


Figure 1: "The river was nowhere and everywhere." Aldo Leopold, A sand county almanac.

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