Unsubstantiated Claims Can Lead to Tragic Conservation Outcomes

LORENZO ROJAS-BRACHO, RICHARD C. BRUSCA, SAÚL ÁLVAREZ-BORREGO, ROBERT L. BROWNELL JR., VÍCTOR CAMACHO-IBAR, GERARDO CEBALLOS, HORACIO DE LA CUEVA, JAQUELINE GARCÍA-HERNÁNDEZ, PHILIP A. HASTINGS, GUSTAVO CÁRDENAS-HINOJOSA, ARMANDO M. JARAMILLO–LEGORRETA, RODRIGO MEDELLÍN, SARAH L. MESNICK, EDWYNA NIETO-GARCÍA, JORGE URBÁN, ENRIQUETA VELARDE, OMAR VIDAL, LLOYD T. FINDLEY, AND BARBARA L. TAYLOR

**The vaquita porpoise (*Phocoena* ***sinus*) is Mexico's only endemic—and the world's most endangered—marine mammal. With a population of fewer than 30 individuals (Thomas et al. 2017, IUCN 2018), any delay in taking needed conservation actions will result in its extinction. A recent article in the journal *Sustainability* (Manjarrez-Bringas et al. 2018) reasserts, without providing any scientific evidence, the baseless claims that the vaquita is fundamentally an estuarine species and that decline in vaquita is due to reduction of freshwater flow into the Upper Gulf of California (UGC) due to damming and diversion of the Colorado River. These unsupported claims detract from the real cause of vaquita decline—deaths in gillnets, in both legal and illegal fisheries. Here, we focus on setting the record straight, again, that there is no evidence that damming of the Colorado River has affected the fate of vaquita, in the hope that management efforts can be correctly and effectively directed to protect this marine mammal. As we describe below, the Upper Gulf did not have a large, long-term, continuous river flow nor brackish-water conditions even before the damming of the Colorado River.

The Gulf of California is an arm of the Pacific Ocean, approximately 267,000 square kilometers, characterized by good tidal flushing, strong upwelling, and exchange with the open Pacific that lead to high, year-round productivity (Hidalgo-González et al. 1997, Lluch-Cota et al. 2007). The Upper Gulf experiences extreme tidal flushing and mixing and has some of the highest biological productivity of any marine region in the world (Brusca et al. 2017). At the northernmost boundary of the Upper Gulf is Montague Island, and above that is the wide expanse of the Colorado River Delta. The estuary of the river has, historically, included Montague Island and the seawaters north of it. Although predam Colorado River flows into the Gulf were not recorded, they were very low relative to other North American rivers. For example, using an average flow estimate for the Colorado River of 15×10^9 cubic meters (m^3) per year past the city of Yuma, Arizona (see the supplemental material), this discharge is small relative to the Columbia and Fraser Rivers, which discharge 236×10^9 m^3 per year and 110×10^9 m^3 per year to the Pacific, respectively. Both of these rivers have concentrations of harbor porpoise (*Phocoena phocoena*) at their mouths, but harbor porpoises are also found continuously along the coasts from California to Japan and clearly do not depend on estuarine conditions, nor do any of the other six species of porpoise (including vaquita; Read 1999). The physiology and biology of vaquita also clearly indicate it is a marine species, not an estuarine animal (see the supplemental material).

No long-term, predam salinity data exist for the Upper Gulf. However, salinities for hydrographic stations between San Felipe and El Golfo de Santa Clara recorded before damming, in March 1889, were between 35.8 and 36 parts per thousand (ppt; Roden 1958), which indicates the presence of typical marine water masses in the Upper Gulf in predam years and not brackish waters. The best assessment of predam river influence on salinity is the measured effect of a 1993 flood release (Lavín and Sánchez 1999). An estimated maximum 550 m^3 per second of river water crossed the border into Mexico during a March–April pulse release, for a total 2-month discharge of about 2.9×10^9 m^3, or an average daily flow of 47.5×10^6 m^3 during that 2-month period. That last value—47.5×10^6 m^3—is about 0.1% of the volume of the Upper Gulf. During that period, a slight drop in surface salinity extended only along the northernmost western shore of the Upper Gulf for about 70 kilometers, with salinities off San Felipe being approximately 35.4 ppt, similar to today's oceanic salinities, whereas the lowest salinity value of approximately 32.0 ppt was recorded southwest of Montague Island. The eastern side of their northernmost transect also had salinities of approximately 35.4 ppt, "typical of the surface mixed layer just outside the UGC" (Lavín and Sánchez 1999). This demonstrates that the Upper Gulf has never been estuarine or brackish (i.e., below 30 ppt) in nature, except for the area between Montague Island and the mouth of the Colorado River—where vaquita have never been reported.

These studies indicate that the only significant penetration of delta waters into the Gulf, historically, was from the mouth of the river (Montague Island) to San Felipe, only along the extreme northwest shore of the Upper Gulf and probably only during very high flow periods (normally, May–July). The assertions by Manjarrez-Bringas and colleagues (2018) that “the estuary condition of the UGC changed radically due to the severe modification of freshwater discharge” and that “in the estuary environment of the vaquita, the salinity ranges from 38–42 ppt, which are not characteristic of healthy estuary environments” and that “between 20 to 25 ppt are suitable for life adapted to estuary environments,” implying that 20–25 ppt is the healthy range for the vaquita, are completely unsubstantiated. There is no evidence that short-term salinity variability in the northwesternmost region of the Upper Gulf has affected biological productivity (Brusca et al. 2017). Over 50 vaquita necropsies have shown no emaciated animals, which might be expected if habitat degradation was an issue (Hohn et al. 1996, Vidal et al. 1999). Many studies have shown that the Upper Gulf remains one of the world’s most highly productive marine areas, with no evidence of postdam decreased productivity (reviewed in Brusca et al. 2017).

Earlier claims (Aragón-Noriega and Calderón-Aguilera 2000, Lau and Jacobs 2017) that there was a significant increase in the Upper Gulf’s salinity following the construction of Hoover Dam in 1935 have been rebutted (Brusca et al. 2017, Brusca 2018a, 2018b). Although the reduction of river flow to the Colorado River Delta’s riparian corridor has clearly been detrimental to that terrestrial habitat, the amount of water reaching the Upper Gulf has historically been too little to have any significant impact on the salinity of the region. Given the average 3.87-meter tidal range in the Upper Gulf, and the semidiurnal nature of its tides, around 25.5×10^9 m^3 of tidal water flushes into and out of the region daily (see the supplemental material), which is far more than the highest estimates of Colorado River water reaching the Upper Gulf in an entire year. Therefore, in general, the influence of the river’s discharge on salinity in the Upper Gulf had been nil. The idea of the Upper Gulf having continuous freshwater flow or being low salinity year-round in predam years or being a brackish water estuary before the building of the dams on the river is simply not supported by any scientific data.

It has been well documented, for decades, that the primary cause of death among vaquita is incidental capture in gillnets (Norris and Prescott 1961, Brownell 1983, Vidal 1995, D’Agrosa et al. 2000, Rojas-Bracho et al. 2006, Jaramillo-Legorreta et al. 2007, Rojas-Bracho and Reeves 2013, CIRVA 2016a, 2016b, 2016c). Illegal gillnets for totoaba (*Totoaba macdonaldi*), an endangered sciaenid fish endemic to the Gulf, are the deadliest fishing gear for vaquita. Of the 128 vaquitas killed in gillnets between 1985 and early 1992, 65% were in the totoaba fishery (Vidal 1995). A large, illegal totoaba fishery resumed in about 2011, fueled by high prices for their swim bladders in China (anonymous 2016, 2018). This illegal fishery resulted in the well-documented decline in vaquita numbers (Thomas et al. 2017) that today leaves fewer than 30 remaining. Nine dead vaquita were recovered since 2015 during totoaba spawning season, and the eight for which cause of death could be determined were killed by gillnets. None of those specimens showed signs of starvation attributable to a lack of food due to habitat alteration, nor did the many vaquitas killed in gillnets and necropsied from 1985 to 1995. The most recent analyses by the International Committee for Recovery of the Vaquita (CIRVA 2016a, 2016b, 2016c) also concluded that the main threat to vaquita remains mortality in gillnets. Manjarrez-Bringas and colleagues (2018) noted the gillnet problem but chose to follow the unsupported claims of Fleischer and colleagues (1996), Galindo-Bect and colleagues (2013), and Santamaría-del-Ángel and colleagues (2017), rather than this widely accepted body of evidence.

Thaler and Shiffman (2015) defined *fake science* as unsound conclusions drawn from invalid premises. Such claims can easily spread through government agencies and the lay public, especially when they enter the world of social media. A well-known example is the now-retracted Lancet paper that sparked the modern antivaccination movement (Eggertson 2010, Rao and Andrade 2011). False information can remain in the unchecked pool of common knowledge for a long time (Thaler and Shiffman 2015). Suggesting that the Colorado River’s flow caused the decline of vaquitas has been asserted and challenged for years (Rojas-Bracho and Taylor 1999, CIRVA meetings, Brusca et al. 2017), yet no scientific evidence to support the connection between vaquita and the Colorado River’s flow has been forthcoming. There are failures at many levels that have positioned the vaquita for extinction (e.g., poor fisheries management, demand for illegal products such as totoaba bladders, a culture of corruption), but a reduction of Colorado River flow is not one of them. In our opinion, Manjarrez-Bringas and colleagues (2018) created a diversion that can only result in further divisions between the collaborative efforts critically needed among fishermen, the seafood supply chain, environmental and fisheries agencies, and the conservation community seeking real solutions.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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Lorenzo Rojas-Bracho (lrojasbracho@gmail.com) is affiliated with the Comisión Nacional de Áreas Naturales Protegidas, Ensenada, Mexico. Richard C. Brusca is affiliated with the University of Arizona, in Tucson. Saúl Álvarez-Borrego is affiliated with the Departamento de Ecología Marina, at the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), in Baja California, Mexico. Robert L. Brownell Jr, Sarah L. Mesnick, and Barbara L. Taylor are affiliated with the Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, in La Jolla, California. Víctor Camacho-Ibar is affiliated with the Instituto de Investigaciones Oceanológicas, at the Universidad Autónoma de Baja California, in Ensenada, Mexico. Gerardo Ceballos and Rodrigo Medellín are affiliated with the Instituto Nacional de Ecología, at the Universidad Nacional Autónoma de México, in Mexico City. Horacio de la Cueva and Gustavo Cárdenas-Hinojosa are affiliated with the Departamento Biología de la Conservación at CICESE. Philip A. Hastings is affiliated with the Scripps Institution of Oceanography, at the University of California, in San Diego. Gustavo Cárdenas-Hinojosa, Armando M. Jaramillo-Legorreta, and Edwyna Nieto-García are affiliated with the Instituto Nacional de Ecología y Cambio Climático, in Ensenada. Jorge Urbán is affiliated with the Departamento de Ciencias Marinas y Costeras, at the Universidad Autónoma de Baja California Sur, in La Paz, Mexico. Enriqueta Velarde is affiliated with the Instituto de Ciencias Marinas y Pesquerías, at the Universidad Veracruzana, in Mexico. Omar Vidal is affiliated with Desde lo Más Alto hasta lo Más Profundo, A.C., Mexico City. Jaqueline García-Hernández and Lloyd T. Findley are affiliated with the Centro de Investigación en Alimentación y Desarrollo (CIAD)-Unidad Guaymas, in Sonora, Mexico.

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SUPPLEMENTAL MATERIAL

Unsubstantiated Scientific Claims Can Lead to Tragic Conservation Outcomes

*Lorenzo Rojas-Bracho[1], Richard C. Brusca[2], Saúl Álvarez-Borrego[3], Robert L. Brownell, Jr.[4], Víctor Camacho-Ibar[5], Gustavo Cárdenas-Hinojosa[6,7], Gerardo Ceballos[8], Horacio de la Cueva[6], Lloyd T. Findley[9], Jaqueline García- Hernández[9], Philip A. Hastings[10], Armando M. Jaramillo Legorreta[7], Rodrigo Medellín[8], Sarah L. Mesnick[4], Edwyna Nieto-García[7], Jorge Urbán[11], Enriqueta Velarde[12], Omar Vidal[13], Barbara L. Taylor[4]

Corresponding Author: lrojasbracho@gmail.com

1. Comisión Nacional de Áreas Naturales Protegidas, Ensenada, BC, México
2. University of Arizona, Tucson, Arizona, USA
3. Departamento de Ecología Marina, CICESE, Ensenada, BC, México
4. Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, La Jolla, California, USA
5. Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, Ensenada, BC, México
6. Departamento de Biología de La Conservación, CICESE, Ensenada, BC, México
7. Instituto Nacional de Ecología y Cambio Climático, Ensenada, BC, México
8. Instituto de Ecología, Universidad Nacional Autónoma de México, Ciudad de México
9. Centro de Investigación en Alimentación y Desarrollo (CIAD)-Unidad Guaymas, Sonora, México
10. Scripps Institution of Oceanography, University of California, San Diego, CA, USA
11. Departamento de Ciencias Marinas y Costeras, Universidad Autónoma de Baja California Sur, La Paz, BCS, México
12. Instituto de Ciencias Marinas y Pesquerías, Universidad Veracruzana, México
13. Desde lo Más Alto hasta lo Más Profundo, AC, Ciudad de México

Colorado River Water Flow to the Upper Gulf: Detailed Account

Manjarrez-Bringas et al. (2018) claim that prior to construction of Hoover Dam the Colorado River carried 20.7 X 10^9 m^3 $year^{-1}$ to the Upper Gulf, citing a lay book as their source for this information (Fradkin 1981, updated and republished 1996). However, this is not what Fradkin wrote, nor is it an accurate figure based on the scholarly literature. Fradkin (1996) states that, from 1922 (when the River Compact was signed) to 1976, the flow past Lees Ferry was 17.15 X 10^9 m^3 yr^{-1}; he does not cite his source for these data. The scientific literature, however, consistently indicates that, since flow has been measured at Lees Ferry, the river has averaged around 15.2 X 10^9 m^3 yr^{-1} (Harding et al. 1995, Tarboton 1995). Deep-time reconstructions of flow at Lees Ferry, based on tree-ring studies and going back hundreds of years, suggest the long-term mean flow has been around 13.5 X 10^9 m^3 yr^{-1} (Stockton and Jacoby 1976, Powell 1995, Woodhouse et al. 2006, Meko et al. 2007). However, the Lees Ferry flow gauge (and tree-ring estimates) measure river water leaving the Upper Colorado River Basin, not the river's flow over a thousand kilometers south, where it meets the Gulf of California. Between Lees Ferry and the head of the Gulf, the river meanders through one of the driest and hottest stretches of land in North America, past Las Vegas, Lake Havasu, Blythe, Yuma, and San Luís Río Colorado. The river's flow is diminished in this 1075 km final stretch by evaporation, movement into permeable soils, and uptake by plants. Annual flow is also very uneven, with 70 percent typically occurring in just three months, May through July.

The Colorado River watershed is also characterized by long periods of draught. An example is the 22-year drought of 1943 to 1964, when the flow past Lees Ferry averaged 13.4 X 10^9 m^3 yr^{-1}

(Tarboton 1995). Tree-ring reconstructions of flows at Lees Ferry show that droughts have been much larger than that, and frequent, one of the most severe so-far discovered occurring from 1579 to 1598, when flow past Lees Ferry is estimated to have been just 10.95 X 10^9 m^3 yr^{-1} (Meko et al. 1995).

In addition, before the channeling of the Colorado River across the delta in Mexico, the river frequently met natural diversions, flowing entirely into the Salton Basin for periods of years, or into other below-sea-level sinks south of the border (reviewed in Brusca et al. 2017). Thus, even when the river crossed the border, it frequently did not reach the sea or only a portion of it did.

There are no historic, pre-dam measurements of Colorado River water actually reaching the Upper Gulf, nor even crossing the US-Mexico border, nor of pre-dam salinities in the Upper Gulf. The first permanent flow gauge where the river crosses into Mexico was installed when Morelos Dam was built, in 1950, 15 years after Hoover Dam's construction. Prior to that, the closest long-term flow gauges were in Yuma (Arizona), where the U.S. Geological Survey (USGS) has had a gauge since around 1895 and, for some years, the Southern Pacific Railroad had one below its Yuma river-crossing bridge (installed in 1878). Cory (1913) published data from these gauges for the period, 1894 to 1911 and mean flow, which included several flood years, was 15.3 X 10^9 m^3 $year^{-1}$. Thomson et al. (1969) also reported on pre-1935, USGS data on river flow from the Yuma gauge, calculating average flow for these years 1902 to 1934 at 18.6 X 10^9 m^3 $year^{-1}$. These data suggest an average of around 17 X 10^9 m^3 $year^{-1}$ flow past Yuma from 1894 to 1934. However, this was an unusually wet period. It was from this higher-than-average precipitation period that the 1922 Water Compact allotments were calculated, a situation later discovered to be problematic because there was more water allocated than generally exists in the river (Brusca and Bryner 2004). If the long-term flow past Lees Ferry averages 15.2 X 10^9 m^3 yr^{-1}, the average flowing past Yuma is less than that, and the amount reaching the Gulf of California (another 140 km downstream) still less.

Even using an average flow estimate of 15 X 10^9 m^3 $year^{-1}$ past the city of Yuma, it is obvious that the amount of water the Colorado River could provide to the Upper Gulf pales in comparison to other large American rivers. For example, the Mississippi River discharges 530 X 10^9 m^3 $year^{-1}$ to the Gulf of Mexico, and the Columbia and Fraser Rivers discharge 236 X 10^9 m^3 $year^{-1}$ and 110 X 10^9 m^3 $year^{-1}$ to the Pacific, respectively. Even Niagara River discharges 183 X 10^9 m^3 $year^{-1}$ to Lake Ontario, and the lowly Snake River discharges 51 X 10^9 m^3 $year^{-1}$ (Oxford 2009; USGS 2018). The Lower Colorado River’s flow is practically insignificant in comparison. And as Sykes (1937), Brusca et al. (2017), and others have shown, the actual amount of this water reaching the sea was historically far less than that passing through the Yuma gauge, due to numerous natural diversions and sinks.

Salinities in the Upper Gulf of California

Oceanographic conditions, especially extreme daily tidal flushing, upwelling, and mixing, indicate that the historic flow, largely restricted to the season of spring snowmelt (May to July), had little effect on the salinity of the Upper Gulf (Bray and Robles 1991; Álvarez-Borrego 2001; Lavín and Marinone 2003; Lluch-Cota et al. 2007, Brusca et al. 2017).

Carbajal et al. (1997) modeled the region of fresh water influence of the Colorado River, but they used a constant discharge of 2,000 m3/s for the simulation. The model produced fresh to brackish conditions only in the water layer between 0-10 m depth, north of San Felipe, after 52 days. However, USGS pre-dam flux data for the Colorado River at Yuma (1 October 1903 to 30 September 1931) averaged just 650 m^3/s. Over this period of time, a flow rate of 2,000 m^3/s or more occurred on average just 23 days of the year, and only in June (historically the highest pre-dam flow month of year). Thus, the model was run under an extreme condition, and typical river flows would not be capable of creating the brackish conditions Carbajal et al. (1997) modeled. Further, the brackish conditions in the model were produced in only a portion of the known current vaquita distribution. Montes et al. (2015) speculated that inverse estuary conditions in the Upper Gulf are driven by damming of the Colorado River, high evaporation rate, and almost nil precipitation. However, their work focused on modeling heat and salt balances, which resulted in the characterization of the Upper Gulf as a net exporter of both, salt and heat. The authors provided no explanation of the contribution or role of the reduced Colorado River water in the functioning of the salt and heat balances, and the alleged connection between flow and salt balance was simply speculation.

Based on oxygen isotopes in shells of the clam *Mulinia modesta* Dall, 1894 (cited as *Mulinia coloradoensis*), Cintra-Buenrostro et al. (2012) reconstructed pre-dam salinity conditions in the Upper Gulf, estimating minimum salinities ranging 30-38 at Campo Don Abel, about 40 km south of Montague Island, showing that, even under pre-dam river flows, the Upper Gulf's waters were not brackish (i.e., <30 PSU) and hypersaline conditions could be present. However, these estimates should be viewed with caution because *M. modesta* is a small, light bivalve with shells that are easily transported by waves (Rodriguez et al. 2001; RCB pers. obsv.) and also likely moved by storms, the prevailing cyclonic current, and extreme tidal flows of the Upper Gulf over the hundreds of years since their death. Thus, the "low salinity" clam shells sampled in the beach cheniers by Kowalewski et al. (2000), Rodriguez et al. (2001), and Cintra-Buenrostro et al. (2012) might have originated in the estuary of Colorado River, near Isla Montague.

Based on the bathymetric chart in Álvarez et al. (2009) and coastline measurements by INEGI (2017), we computed an approximate volume for the Upper Gulf California, using as its southern boundary an imaginary line connecting Punta Borrascosa on the Sonora coast to Punta Machorro on the Baja California coast. At mean sea level, the Upper Gulf has a surface area of $3.3 \text{ X } 10^9$ m^2 and a volume of $48.5 \text{ X } 10^9$ m^3. Thus, even with an annual mean flow as high as $20 \text{ X } 10^9$ m^3, in a single day the input of fresh water from the river to the ocean basin would be just 0.12% of the total volume of the Upper Gulf. (Note the close approximation of this estimate to the actual flood release measurement of 0.1% of Upper Gulf volume daily, in Lavín and Sánchez, 1999). The average depth of the Upper Gulf is about 14.7 meters. Thus, the daily input of fresh water would create, at best, a surface layer of 1.7 cm. Over an entire year, the input of fresh water would represent a hypothetical layer of only 6.2 meters. In terms of salinity, this would result in a decrease of only 0.1%, averaged over a full year. However, the average tidal range in the Upper Gulf is about 3.87 meters. This means that tidal forces alone move a volume of water (about $25.5 \text{ X } 10^9$ m^3) similar to the entire annual freshwater input every single day, and it does this about 700 times per year. Clearly, historical freshwater input has been trivial in comparison to the Upper Gulf's volume and its tidal flows.

The differences noticed by Lavín and Sanchez (1999), about 3 PSU, are because fresh water, being less dense, rests on the uppermost layer of the water column until mixed. The data in sections E and W (in Lavín and Sanchez 1999) indicate this surface effect near Montague Island, with salinity increasing quickly with depth.

The Vaquita is Not an Estuarine Species

Although Manjarrez-Bringas et al. (2018) claim that vaquita is an estuarine species, requiring environments of 20 to 25 PSU, nowhere in their paper do they explain how they came to that erroneous conclusion. Vaquita have never been reported from such low-salinity environments. In fact, no phocoenid is an estuarine species. The ecophysiology (including osmoregulation) of whales, porpoise and dolphin is well known. When marine cetaceans evolved from their terrestrial ancestors, they adapted to the high salinity of their new marine environment. They have two kidneys, with multiple renules, and a smaller bladder than their land-dwelling ancestors, to help them filter and quickly eliminate the high amount of salt in their oceanic habitats. All marine mammals examined to date produce urine that is at least as concentrated as seawater (1000 mosM), and most can do substantially better than this (Costa 2018). Vaquita is no exception. The vaquita diet also informs us about their habitat. The vaquita is a versatile, non-selective, opportunistic predator that feeds on at least 21 species of fish and squid. Its prey are pelagic and benthic-demersal marine species, none of which are restricted to estuarine habitats. L. T. Findley and J. M. Nava (pers. obsv.) dissected stomachs of 24 vaquita and found the five most important prey to be three fish and two squid species: *Isopisthus altipinnis*

(Sciaenidae), *Porichthys mimeticus* (Batrachoididae), *Cetengraulis mysticetus* (Engraulidae), *Lolliguncula panamensis* (Loliginidae), *Loliolopsis diomedeae* (Loliginidae). Pérez-Cortés Moreno et al. (1996) and Vidal et al. (1999) also reported sciaenids, ophidiids, engraulids, and squid (Loliginidae) from vaquita stomachs. There is only one conservation action that will save the vaquita from extinction, and it is an effective ban and removal of all gillnets from the Upper Gulf of California.

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