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Sources and sinks of nutrients and organic carbon during the 2014 pulse flow of the Colorado River into Mexico

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ABSTRACT

For the first time in history a short pulse of water was intentionally released for environmental purposes in April–May 2014 into the final 160 km stretch of the Colorado River, south of the Mexican border. During this pulse the sources and turnover of dissolved nutrients (nitrate, ammonium, phosphate, silicate and carbon), particulate organic matter, along with stable isotopes of suspended particulate carbon and nitrogen, were studied. The river water, as it flowed along the dry riverbed became rapidly depleted in N-NO_3 (from 21 to 0.5 μmol L^{-1}), while dissolved organic carbon of terrestrial C_3 plant origin became depleted in ^{13}C and thus more negative $\delta^{13}C_{DOC}$ values. At the confluence with the Hardy River, the pulsed water along the Colorado River mixed with perennial return flows from agriculture with high $\delta^{15}N$ values (+25‰) due to microbial uptake of NH_4 and discrimination against ^{15}N and/or volatilization of ammonia. From nutrient and isotopic evidence, no mixing of the CR water with seawater was evident, which had a typical phytoplankton $\delta^{13}C$ composition of about −20‰. However, increases of chlorophyll-*a* after the pulse ended (up to 32 mg L^{-1}) suggest a possible effect of the pulse on estuary primary productivity.

1. Introduction

For half a century no sustained water flow from the Colorado River (CR) has reached the ocean, in the upper Gulf of California, and the last time some of its water was released was in 2000 (IBWC, 2014). No reliable data are available for the nutrient fluxes in the CR across the international border prior to dam construction. However, nitrogen cycling and precipitation of phosphate in the US-reservoirs resulted in removal of nutrients (Minckley, 1979; Gloss et al., 1980). Despite this reduced nutrient input, the upper Gulf of California is still considered as an important area for marine primary productivity, with peak chlorophyll-*a* concentrations of 18.2 mg m^{-3} (Millán-Núñez et al., 1999) and averages of 1.8 mg m^{-3} between 1997 and 2007 in coastal waters near the delta (Pérez-Arvizu et al., 2013).

The upper Gulf of California hosts important fisheries of shrimp, shark, and sea bass (Valdés Casillas et al., 1998; Galindo-Bect et al., 2000, 2013a) and the rich coastal productivity is assumed to remain sustained by addition of nutrients via sediment re-suspension and surface/groundwater input from agricultural runoff drains associated wetlands, recycling of nutrients in the water column, and/or the input from the Gulf of California (Millán-Núñez et al., 1999; Orozco et al., 2015; Ramírez-León et al., 2015). Nutrient concentrations are relatively high in the estuarine waters of the CR delta. For instance, in 1990 maximum nutrient concentrations in the estuary were 68 μmol L^{-1} N-NO_2 + NO_3, 11 μmol L^{-1} P-PO_4, and 92 μmol L^{-1} Si-SiO_2 (Hernández-Ayón et al., 1993) and remained practically unchanged in 2001 (Carriquiry et al., 2011). In the upper Gulf of California nutrient concentrations were compared for 1993 with river flow (due to anomalous water release from the US dams) and 1996 without river flow (Nieto-García, 1998). Unexpectedly, NO_3 and PO_4 concentrations were higher in 1996, without river input.

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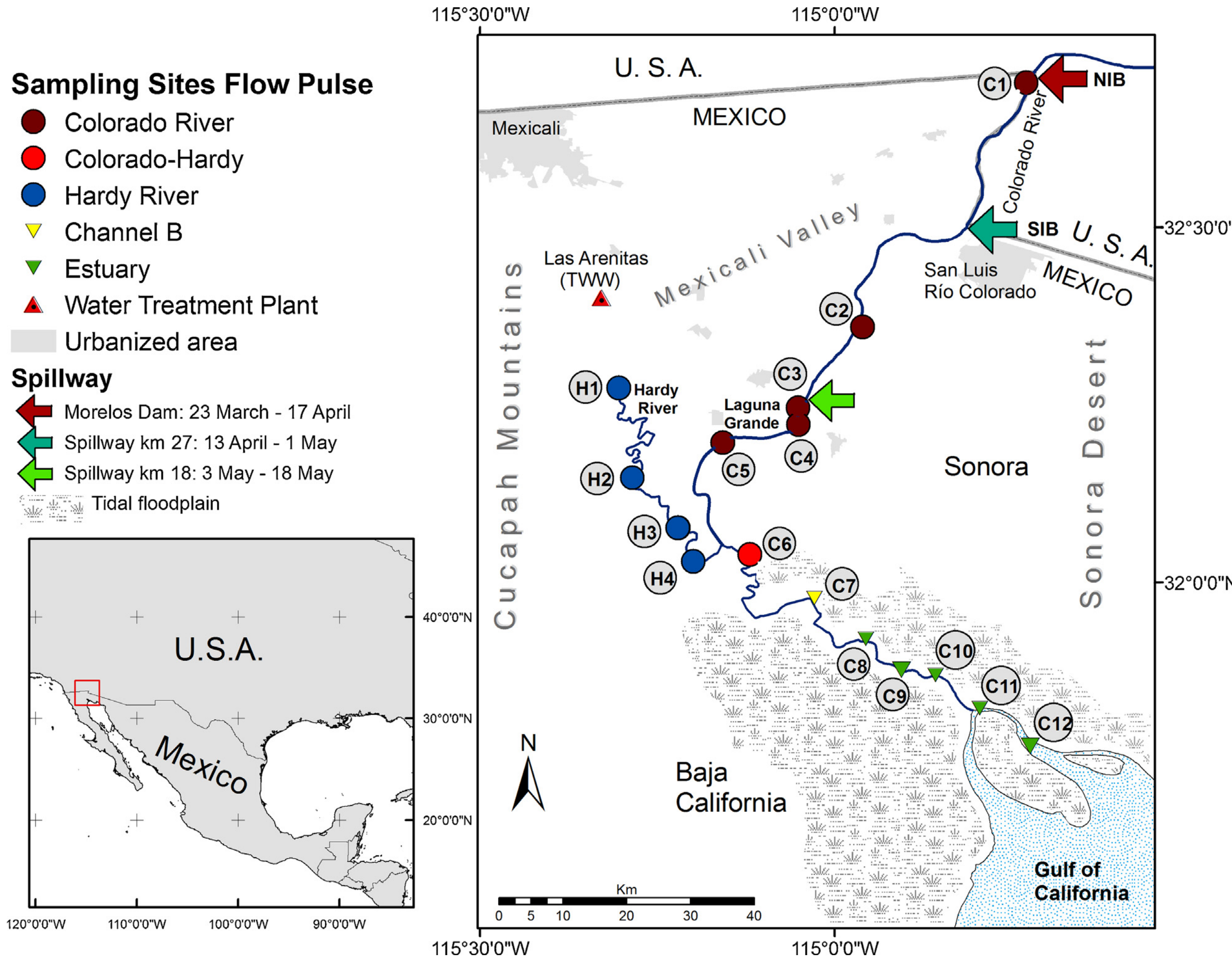

Fig. 1. Location and sampling sites along the Colorado River (CR), Hardy River (HR), and main estuary channel, showing the locations of the three different water-release sites and their dates.
Figure modified from Daesslé et al. (2016).

The study of the biogeochemistry of nutrients and carbon, and the stable isotopes of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) in riverine and estuarine ecosystems is important to understand the productivity and biological sustainability of these environments, and also serves to assess the sources and budgets of organic matter, as well as anthropogenic effects that may affect these aquatic systems (Galindo-Bect et al., 2013b). For example, agricultural return-flows to the lower CR basin derived from cultivated farmlands in Mexico. Locally, agricultural drains and effluents flow toward coastal wetlands adjacent to vast tidal mudflats. They can contain as much as 469 $\mu mol\,L^{-1}$ of N-NO_3 (Orozco et al., 2015).

In the Mexicali Valley, fresh surface water is limited to irrigation and drainage channels, a few wetlands are supported by drainage and wastewater flows. However, the main Colorado riverbed remains mostly dry along its course to the estuary. This only changed briefly during spring 2014 when a programmed pulse-flow of $130 \times 10^6\,m^3$ was released directly into the CR course through the international border over an eight-week period (Flessa et al., 2013; IBWC, 2014; Witze, 2014). The purpose of this experiment was to evaluate the ecosystem responses (hydrological and biological) by generating water flows to the riparian ecosystem.

The aim of this work is to assess the sources and sinks of nutrients and carbon along the river course during the water pulse starting from Morelos Dam at the northern international border (NIB) to the main tidal channel of the estuary (Fig. 1). The event offered a unique opportunity of fresh nutrient availability and possible associated carbon cycling in a re-activated riverbed that had seen no water for decades. This investigation helps to answer important questions of how nutrient and carbon cycling can be activated in an arid environment. With the application of stable carbon isotopes ($\delta^{13}C_{DOC}$ and $\delta^{13}C_{POC}$) and of nitrogen in particulate matter ($\delta^{15}N_{PN}$), we discuss the sources and sinks of nutrients along the CR during this short water pulse. With these parameters we also tested if the pulse had any effect on the estuary's primary productivity.

2. Methodology

2.1. Field work

The pulse flow experiment was divided into three stages in which water was released from three sites from North to South of the riverbed: (a) $102 \times 10^6\,m^3$ on 23 March–17 April at the Northern International Border (NIB) via Morelos Dam, (b) $21 \times 10^6\,m^3$ on 13 April–1 May, 36.8 km downstream of Morelos Dam at spillway km 27 of Canal Reforma and (c) $9 \times 10^6\,m^3$ on 3–18 May, 78 km downstream Morelos Dam at spillway km 18 of Canal Barrote (Fig. 1). River water was sampled along its course including "Channel B", which is a 5 m wide man-made pilot channel built in 2012 to facilitate river discharge into the estuary (Nelson et al., 2013). Water samples were taken at different sites before, during and after the pulse on 20 March, 24 April, and 14, 20 and 29 May. Samples