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# Human-induced and natural carbon storage in floodplains of the Central Valley of California

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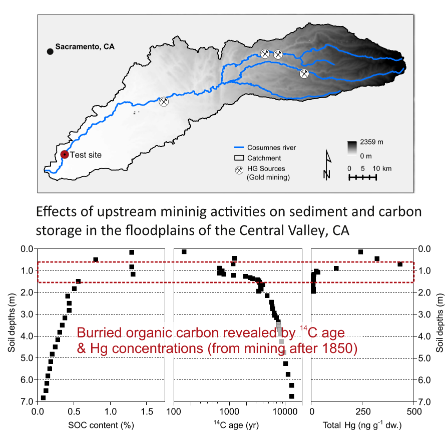
## HIGHLIGHTS

- Evaluation of depth-dependent SOC contents in a floodplain area of California
- About 60% of the entire SOC stored within the 7 m profiles found in the upper 2 m
- Radiocarbon dating and mercury analysis showed a substantial sedimentation phase.
- This phase was associated with upstream hydraulic gold mining after the 1850s.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Active floodplains can putatively store large amounts of organic carbon (SOC) in subsoils originating from catchment erosion processes with subsequent floodplain deposition. Our study focussed on the assessment of SOC pools associated with alluvial floodplain soils that are affected by human-induced changes in floodplain deposition and in situ SOC mineralisation due to land use change and drainage. We evaluated depth-dependent SOC contents based on 23 soil cores down to 3 m and 10 drillings down to 7 m in a floodplain area of the lower Cosumnes River. An estimate of 266 Mg C ha$^{-1}$ or about 59% of the entire SOC stored within the 7 m profiles was found in the upper 2 m. Most profiles (n = 25) contained discrete buried A horizons at depths of approximately 0.8 m. These profiles had up to 130% higher SOC stocks. The mean $\delta^{13}$C of all deep soil profiles clearly indicated that arable land use has already altered the stable isotopic signature in the first meter of the profile. Radiocarbon dating showed that the $^{14}$C age in the buried horizon was younger than in overlaying soils indicating a substantial sedimentation phase for the overlaying soils. An additional analysis of total mercury contents in the soil profiles indicated that this sedimentation was associated with upstream hydraulic gold mining after the 1850s. In summary, deep alluvial soils in floodplains store large amounts of SOC not yet accounted for in global carbon models. Historic data give evidence that large amounts of sediment were transported into the floodplains

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of most rivers of the Central Valley and deposited over organically rich topsoil, which promoted the stabilization of SOC, and needs to be considered to improve our understanding of the human-induced interference with C cycling.



## 1. Introduction

Riverine floodplains occupy only about 1.3% of Earth's land surface (Sutfin et al., 2016; Tockner and Stanford, 2002), but they deserve growing attention as important sinks of terrestrial carbon (Hasada and Hori, 2016; Hoffmann et al., 2009; Notebaert et al., 2014; Ricker and Lockaby, 2015; Sutfin et al., 2016). Global estimates of carbon (C) storage in floodplains vary between 1.4 and 7735 Mg C $ha^{-1}$ (Appling, 2012; Sutfin et al., 2016; Wigginton et al., 2000). There are two main reasons why floodplains store substantial amounts of organic C: (i) the in situ conditions are often favorable for C sequestration because C inputs via photosynthetic assimilation products are more or less optimal (Baldock and Skjemstad, 2000) and soil organic carbon (SOC) mineralisation is often limited by saturated conditions; (ii) floodplains receive substantial amounts of SOC associated with deposited sediments coming from the entire catchment of such floodplains (Robertson et al., 1999).

Under natural conditions floodplains seem to be a continuous long-term carbon sink, as shown by Hoffmann et al. (2009) quantifying the SOC storage in the floodplains of the River Rhine in the entire Holocene. However, human-induced changes like river management, land use along rivers and land use patterns of the catchment have altered an increasing number of floodplains and their catchments (Poff et al., 2007). For instance, along European rivers as much as 79% of the riparian areas are intensively cultivated compared to 46% for North American rivers (excluding Alaska and northern Canada) and 11% for African rivers (Tockner and Stanford, 2002). Anthropogenic changes affecting floodplain SOC storage are complex as in situ changes often are intertwined with changes within the entire catchment. Historically, floodplains with natural riparian vegetation were often converted into arable land following river regulation (i.e., flood control dyking) and wetland drainage (Zedler and Kercher, 2005). Moreover, river regulation fundamentally alters the natural flow regime often resulting in the reduction of floodwater magnitude, duration and frequency, which in turn alters biogeochemical cycling (Poff et al., 1997). The net effect of land conversion, including loss of riparian vegetation and the drainage of floodplains, coupled with flow alteration and its reduction in floodwater inundation and sediment deposition, or in some sites, cessation of peat formation and peat decay, is a reduced C sequestration potential in alluvial soils. However, it is important to note that despite the globally pervasive and persistent decline in natural floodplain areas, there are also efforts underway to restore natural floodplain systems (Bullinger-Weber et al., 2014; D'Elia et al., 2017; Florsheim and Mount, 2003; Schiemer et al., 1999). In contrast to the loss of C due to in situ changes in drainage and use of floodplain soils, these areas might gain more C via lateral input from catchments, in cases where human induced land use change in the upper catchment leads to accelerated erosion and hence sediment input into the floodplains. The importance of this C input was underlined by a recent study of Wang et al. (2017) estimating that globally about 1/3 of eroded SOC due to land use change was stored in colluvial and especially alluvial soils during the last centuries to millennia.

Studying human impacts on C sequestration in floodplains is difficult as these impacts are mostly long lasting, weakly documented and occurring diffusely along the rivers and within the catchments. The Central Valley of California represents a specific situation, which partly allows to unravel the human impact and compare it to natural conditions. Until the 1850s the human impact in the region was relatively minor. This changed with the onset of the Californian Gold Rush, leading to a substantial change in the headwater catchments of the Sierra Nevada. By the mid-1850s and onwards, the headwater catchments were affected by hydraulic mining as the most cost-effective method to recover large amounts of gold in areas with sufficient surface water (Alpers et al., 2005; Gilbert, 1917; James, 2005). This powerful method delivered significant amounts of sediment to the floodplains of the Central Valley, with an estimate of 260 × $10^6$ $m^3$ of mining debris reaching the San Pablo Bay in the northern part of San Francisco Estuary between 1856 and 1887 (Jaffe et al., 2007). Due to the utilization of mercury (Hg) in processing gold, these sediments were heavily Hg contaminated (Alpers et al., 2005; Drexler et al., 2009; Hornberger et al., 1999). Parallel to the gold mining activities, millions of hectares of wetlands were granted by the newly founded government of California to encourage the drainage of lands (Robinson et al., 2016). Levees were built to constrain anastomosing rivers to single channels and to separate wetlands from tidal waters restraining floods that historically filled the basins. Dense stands of tule (*Schoenoplectus acutus*) and willows (*Salix* spp.) were flattened or burned to make way for farmland and contributed as non-mining waste to sediment loads to the Central Valley (van Geen et al., 1999). By 1930, the majority of the land was virtually entirely cultivated (Whipple et al., 2012).

The major objective of this study is to analyze the human-induced effects of changing river sediment dynamics and land use on carbon storage in relation to the natural processes of SOC storage within a floodplain of the Cosumnes River, California.

## 2. Materials and methods

### 2.1. Sampling site

The study area was located approximately 30 km south of Sacramento, California, and north of a restored floodplain-riparian habitat, the Cosumnes River Preserve (38°17′49″N, 121°23′10″W; 5–6 m a.s.l.). In the last 150 years, the site was used for agricultural production (most recently for a variety of row crops) and associated with a significant degradation of the floodplain ecosystem. Prior to this anthropogenic disturbance, the lower Cosumnes River was an anastomosing channel network with perennial floodplain lakes (Constantine et al., 2003; Florsheim and Mount, 2003) (Fig. 1). The Cosumnes River, a tributary to the Sacramento – San Joaquin Delta, drains a 2460 $km^2$ watershed and is the last major river draining the western Sierra Nevada without any large regulating dams, and as such it rapidly responds to precipitation events (Nichols and Viers, 2017). Basin headwaters are located at an elevation of approximately 2400 m a.s.l. within a complex assemblage of granitic, andesitic, and metamorphic rocks that are part of the Sierra Nevada geomorphic province. The lower Cosumnes River ultimately enters the Great Valley geomorphic province with Pleistocene alluvium and river terraces generated during multiple Plio-Pleistocene episodes of valley incision and filling (Nichols and Viers, 2017). Floodplain restoration efforts have been implemented at the site since fall 2011 with the overall objective to hydrologically restore much of the multichannel system and the associated vegetation (D'Elia et al., 2017).

The Mediterranean climate in the Cosumnes River catchment is characterized by cool wet winters and hot dry summers (mean annual temperature 16 °C). The majority of precipitation occurs as rain in the winter and spring months (between December and March; annual