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Lateral and longitudinal patterns of water physico-chemistry and trace metal distribution and partitioning in a large river floodplain

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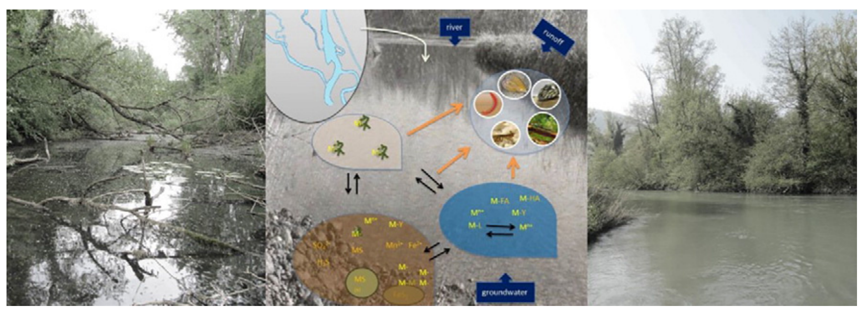
HIGHLIGHTS

- Distribution of trace metals in different floodplain water bodies is not well known.
- Water, sediment, SPM and invertebrates from different types of water bodies were analyzed.
- Trace metal partitioning varied between connected and disconnected sites.
- Lateral gradient was more important than the longitudinal gradient.
- Observed differences need to be considered in floodplain management.

GRAPHICAL ABSTRACT



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ABSTRACT

Floodplain water bodies provide habitat to diversified ecological communities. Floodplains are also among the most impacted aquatic ecosystems. While the link between the lateral connectivity of floodplain sites to the main channel and their plant, fish and invertebrate communities has been well established, detailed information on chemical characteristics and particularly on trace metal spatial distribution and partitioning is scarce. The aim of this study was to examine the link between the lateral connectivity and physico-chemical variables, their trace metal concentrations and partitioning as well as the upstream-downstream gradient of these parameters. In connected and disconnected water bodies of the Rhône River upstream and downstream of the city of Lyon, we measured major ions, dissolved organic carbon, trace metal concentrations (Al, Cr, Ni, Cu, Zn, Cd, Pb and U) in water, suspended particulate matter (SPM) and sediment. The results revealed a clear difference between connected and disconnected water bodies. pH, SPM, Na^{+}, and NO_3^{-} concentrations were lower in disconnected sites while conductivity, DOC, Ca^{2+} and Mg^{2+} were higher. Conductivity and a part of the major ion concentrations increased in the downstream sections. Trace metal concentrations and partitioning varied between connected and disconnected sites. In the dissolved fraction, trace metal concentrations were higher in connected sites. In the surface sediment, concentrations were higher in disconnected sites for the majority of metals. The upstream-downstream gradient was less important than the connected-disconnected gradient. Only three metals in the dissolved fraction (Cu, Cd and Pb) showed a clear increase in downstream sections. Overall, the study shows that the functioning of floodplains produces strong spatial patterns concerning the concentrations and partitioning of trace metals. These findings improve our understanding of trace metal biogeochemistry in floodplains and have important applications for floodplain restoration projects.

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1. Introduction

Large river floodplains sustain a mosaic of terrestrial and aquatic landscape patches that provide habitat to diversified ecological communities (Amoros and Bornette, 2002; Dziock et al., 2006; Godreau et al., 1999). However, a majority of European floodplains has been modified by human actions (Tockner and Stanford, 2002), and rivers are considered to be among the most heavily modified aquatic ecosystems (Carpenter et al., 2011). The value of free flowing rivers for biodiversity and ecosystem services has been widely recognized (Auerbach et al., 2014; Poff et al., 2010). Nonetheless, large rivers, and particularly large river floodplains remain less studied than lakes and streams.

Floodplain water bodies are influenced by their connection to the main river, which affects the physical and chemical site characteristics but also biotic communities. In their pristine state, cut-off and secondary channels are connected to the main channels at varying frequencies during the hydrological cycle. The frequency and duration of connection and the resulting shear stress and water turnover are the main drivers for physico-chemical characteristics in floodplain waterbodies. Secondary channels with a permanent connection to the mainstem are characterised by coarse mineral sediment, mineral suspended particulate matter (SPM), relatively low conductivity and dissolved organic carbon (DOC) and higher nutrient levels. Cut-off channels with no permanent connection are characterised by fine organic sediment, mostly organic SPM, higher conductivity due to groundwater inputs, higher DOC due to phytoplankton, and lower nutrients (Amoros and Bornette, 2002; Carrel and Juget, 1987; Hein et al., 2004; Tockner et al., 1999). While connected sites are strongly influenced by the mainstem and show comparable characteristics (Obolewski et al., 2015), disconnected sites are also influenced by local factors such as surrounding land-use or the hillslope aquifer.

These differences are likely to influence the lateral distribution of trace metals. As metals can originate from geogenic inputs, from industry and from agriculture, trace metals linked to different sources could show different patterns in the floodplain. Nonetheless, an exact delineation from concentration patterns alone remains difficult because most metals have different sources (e.g., metals associated with agriculture comprise most metals considered in this study). Moreover, metals often show contrasting trends in water and sediments (De Vos et al., 2006).

The lateral connectivity to the main channel also influences all biotic communities in floodplain sites. Studies looking for main drivers of community changes in floodplains invariably found hydrological variables describing the connection, respectively the isolation from the main channel to be the most important factors (e.g., bacteria (Lew et al., 2016), phytoplankton (Grabowska et al., 2014), macrophytes (Keruzoré et al., 2013), macroinvertebrates (Castella et al., 2015; Paillex et al., 2007), and fish (Daufresne et al., 2015)). However, hydrological connections were often modified by anthropogenic interventions affecting floodplains and large rivers (e.g., Olivier et al., 2009a; Tockner and Stanford, 2002). The re-connection of the floodplain with the main river is often a major aim in river restoration projects (Gregory, 2006; Lamouroux et al., 2015; Muhar et al., 2016). Such reconnections influence water chemistry (Obolewski and Glińska-Lewczuk, 2011) but their influence on trace metal mobilization is not well studied. As the quality of water and sediment have been described to play a role in the success of river restoration projects (Bednarek, 2001), the characterization of physico-chemical parameters and trace metal distribution and partitioning along gradients of lateral and longitudinal connectivity is expected to provide valuable insights into the general geochemistry of floodplains and carries potential implications for river restoration.

The aim of the present study is to characterize the distribution and variations of selected trace metals in floodplain sites of different lateral connectivity and in different sections of a river. The Rhône River is particularly suitable as a test site because of two main features: (i) its longitudinal contrast with a more human activity - impacted lower part downstream of the city of Lyon (Olivier et al., 2009a; Santiago et al., 1994) and (ii) the persistence of numerous floodplain sectors with an array of water bodies differing in lateral connectivity (Amoros et al., 1987; Riquier et al., 2015). We selected sites from the two extremes of the lateral connectivity gradient (permanent connection upstream and downstream vs. disconnected at base flow) in floodplain sectors upstream and downstream of Lyon. In an integrative approach, we measured trace element concentrations in the three main abiotic compartments (dissolved in water, adsorbed to SPM and adsorbed to surface sediments) of the floodplain waterbodies as well as in different aquatic macroinvertebrates. Invertebrates are an useful model for metal risk assessment in floodplains because they are relatively sessile, exhibit a variety of feeding habits and play a role in the transfer of metals to upper trophic levels (i.e., fish and riparian predators). At the same time, they contribute to the floodplain ecosystem services (Wallace, 1996). Along the longitudinal gradient, we expected an increase in trace metals, in dissolved solids, conductivity, DOC and SPM. As SPM and sediments act often as buffers, a stronger increase of trace metal concentrations for these compartments could be anticipated. Along the lateral gradient, we expected higher SPM, sulphate and nitrate concentrations in connected sites, higher sodium and pH in disconnected sites (Carrel and Juget, 1987; Pongruktham and Ochs, 2015). For trace metals, we expected higher variations between disconnected sites because of the higher contribution of the catchment compared to river inputs into these sites.

2. Methods

2.1. Characterization of study site types

Twelve sites of the French Rhône floodplains were sampled in 2012. These sites can be separated into connected and disconnected sites, and are located in floodplain reaches upstream and downstream of Lyon (Fig. 1). The six disconnected sites (three upstream of Lyon and three downstream of Lyon) have no permanent connection with the main channel. They may be influenced by fluctuations of the groundwater table and some of the sites are occasionally reconnected during floods. The six connected sites all have an upstream and a downstream connection with the river and permanent water flow. As free flowing secondary channels were rare on the Lower Rhône at the time of sampling, two of the three connected Lower Rhône sites are in the main channel. Although these sites have all a permanent connection, the influence of the main river can still vary. These variations in connection with the main channel have been quantified by a synthetic index of lateral connectivity that includes several site characteristics (Paillex et al., 2007). In the rest of the paper, we refer to this index as lateral connectivity. Table 1 lists the connectivity ranges of sites in the four type-sector combinations.

Land-use around the sites was analyzed quantitatively in the CORINE Landcover GIS dataset. Prevalence of artificial, agricultural, forested and water surfaces was retrieved in a buffer zone of 1 km around all sites. Land-cover data were obtained from the European Environmental Agency (European Environment Agency (EEA), 2016). A circular buffer of 1 km radius was extracted around each site. Given the complex hydrology, circular buffers were preferred over semi-circular buffers which are sometimes used in water quality studies (Cai et al., 2015).

2.2. Field sampling

For the integrated analysis of trace metal distribution, we recorded general site parameters and sampled water, sediment, SPM and invertebrates. We measured pH and conductivity on site (Hach-Lange Multimeter, Rheineck, Switzerland).

We filtered water for DOC analysis on a pyrolyzed filter (0.72 μm glass fiber, Whatmann) and stored the samples in pyrolized glass