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Hydrological connectivity drives dissolved organic matter processing in an intermittent stream

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ABSTRACT

Hydrological conditions are key drivers of dissolved organic matter (DOM) processing in intermittent streams. However, there still exist major gaps in knowledge regarding the temporal dynamics of DOM processing during drought periods, as well as the role of the hyporheic zone (HZ). We conducted weekly sampling of surface water and hyporheic pore water during a drying/rewetting cycle and characterized DOM by fluorescence and absorbance properties. Overall, the contribution of allochthonous and humic-like DOM increased during base flow in early summer (pre-drought) and continued increasing throughout the drought period, which covered three phases: contraction, fragmentation and dry. The contribution of autochthonous DOM during this period was restricted to very specific points in time (the transition from contraction to fragmentation phase) and space (the HZ). Hydrological connectivity between the HZ and the surface water was a driver of DOM composition by supplying terrestrial, aromatic DOM to the HZ. The disconnection of the stream from the riparian groundwater enabled us to quantify the DOM retention/release in the HZ. DOM mass balance at the stream-hyporheic interface revealed the occurrence of two time periods with disproportionately high rates for DOM processing (hot moments) during the study period: (1) a short pulse of protein-like, autochthonous DOM net release at the beginning of the disconnection; and (2) a longer time period of increasing net dissolved organic carbon (DOC) retention up to 30% along 25 m of HZ length during fragmentation and dry phase. Remarkably, the net carbon retention was coupled to a decrease of aromatic and high molecular weight compounds, while protein-like, autochthonous DOM was released. This result evidenced that under drought conditions, the HZ becomes a sink for DOM compounds previously assumed to be recalcitrant in aquatic ecosystems and therefore highlights the importance of hydrological drivers on DOM processing.

1. Introduction

Intermittent streams are suspected to account for more than half of the global fluvial network, and flow intermittency is predicted to increase with climate change and increasing water use (Datry et al., 2014; Palmer et al., 2008). At the same time, fluvial networks are recognized as an important part of the global carbon cycle (Battin et al., 2008; Von Schiller et al., 2014). Consequently, the biogeochemistry of intermittent streams has received increasing attention from the scientific community in recent years (Datry et al., 2014; Larned et al., 2010; Leigh et al., 2015). In lotic ecosystems, drought periods strongly influence the quantity and characteristics of dissolved organic matter (DOM) (Butturini et al., 2016; Fellman et al., 2011; Vázquez et al., 2015; Von Schiller et al., 2015). Previous studies report an increase in fresh, non-humic DOM in the remaining surface water as drought proceeds (Vázquez et al., 2011; Von Schiller et al., 2015). Fragmentation of the fluvial continuum generates a set of distinct hydrological hot spots and drought greatly amplifies the qualitative heterogeneity of DOM (Vázquez et al., 2011). However, research has focused mainly on surface water (Butturini et al., 2016; Casas-Ruiz et al., 2016; Guarch-Ribot and Butturini, 2016; Fellman et al., 2011; Von Schiller et al., 2011, 2015; Vázquez et al., 2011) or riparian groundwater (Fellman et al., 2011; Romaní et al., 2006; Vázquez et al., 2007).

In contrast, few studies have tackled the role of the HZ within DOM transport and transformation during drought periods, even though the HZ is recognized as a biogeochemical hot spot (Boano et al., 2014; McClain et al., 2003). Moreover, the efficiency of the HZ

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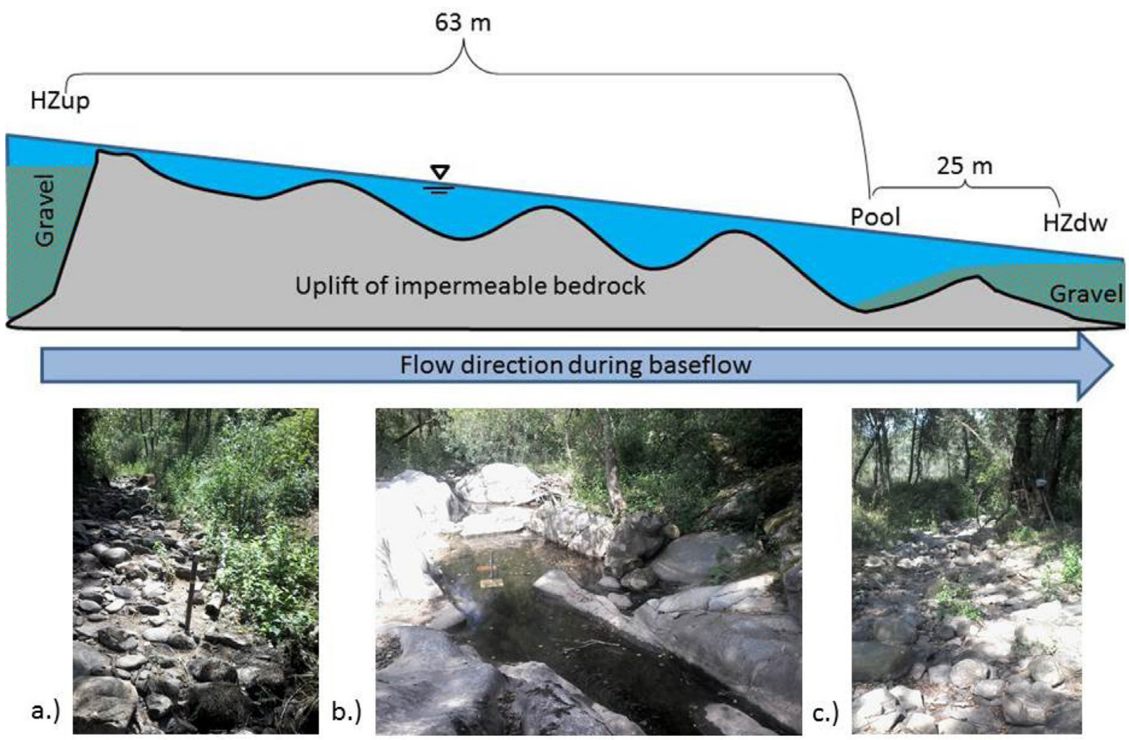

Fig. 1. Scheme of longitudinal profile of the reach between HZup and HZdw. Photos of HZup (a), pool (b) and HZdw (c).

to retain labile carbon is positively related to the residence time of hyporheic flow paths (Baker et al., 1999). However, the HZ of perennial streams has also been identified as a source of recalcitrant DOM, but to a lower extent than its overall retention capacity (Battin et al., 2003). Sobczak and Findlay (2002) found dissolved organic carbon (DOC) concentration to decrease within a range of 19% to 28% along a HZ length of 4 m in mesocosm experiments. These results highlight the potential of the HZ as an important DOM sink in fluvial systems. Additionally, they have reported significant decreases of DOC concentrations in pore water along hyporheic flow paths for several streams, but the clear delineation between hydrological and biogeochemical controls on DOC in natural systems entail difficulties. DOM retention of the HZ can be overestimated due to dilution with DOM poor ground water. We expected to overcome this uncertainty and tested the potential of the HZ for DOM retention in a natural system, because the HZ is reported to be disconnected from riparian groundwater during drought (Bernal et al., 2013). Additionally, when surface run-off is zero and water flow is restricted to the HZ, the quantification of DOM retention and release under drought conditions is relatively simple.

We hypothesize that hydrological connectivity along hyporheic flow paths under drought conditions is a major driver of changes in DOM quality and quantity. According to previous studies we predicted an increase in autochthonous, non-humic DOM in the remaining surface water as drought proceeds and the fast retention of this autochthonous input in the HZ. We want to address the lack of knowledge of biogeochemical transformation processes in space (hot spots) and time (hot moments) by exploring the HZ and adjacent surface water during hydrological disconnection of the river continuum caused by a seasonal summer drought and stream bed geomorphology characteristics in a Mediterranean intermittent stream. Our goals were (1) to investigate the DOM quality changes along a hyporheic flow path during different hydrological conditions and (2) to use the simplification of the system to perform an in situ DOM mass balance in the HZ.

2. Methods

2.1. Study site

This study was performed in Fuirosos, a semi-pristine Mediterranean third order stream in the north-east of the Iberian Peninsula. The Fuirosos catchment is forested with less than 2% of agricultural land use (Bernal et al., 2006) at an altitude between 50 and 770 m a.s.l. (Vázquez et al., 2015). The climate is typically Mediterranean with mean annual temperatures ranging from 3 °C in January to 24 °C in August (Butturini et al., 2002), an average annual mean precipitation of 750 mm, mostly in spring and autumn (Vázquez et al., 2007), and an average annual potential evapotranspiration of approx. 975 mm (Medici et al., 2010). The study site, shown in Fig. 1 was a 150 m long reach, located at the valley bottom between 160 and 165 m a.s.l. (latitude 41 ° 42′23″–28″, longitude 2 ° 34′81″–86″). This reach is characterized by the uplift of the granitic bedrock, interrupting the permeable streambed composed of alluvial gravel (2–5 cm) with sandy and silty fractions. The exposed impermeable bedrock channel is 67 m long and then covered again by the alluvial sediments forming a HZ of approximately 1–2 m of depth with an approx. hydraulic conductivity of 10^{-3} m/s estimated by pumping of the wells installed in the HZ (Baxter et al., 2003), which is the expected range of gravel (Domenico and Schwartz, 1998). The hyporheic connectivity is restricted to surface flow by the uplift of the bedrock acting as a natural barrier. Due to the impermeability of the bedrock channel surface water is still captured in small pools (5–7 m^3), even when there is no surface flow present in the rest of the stream.

2.2. Sampling strategy

We performed weekly samplings from June until October 2014 to follow the dry-rewetting cycle. The choice for this time period was based on previous investigations of this stream (Bernal et al.,