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Sediment size distribution and composition in a reservoir affected by severe water level fluctuations

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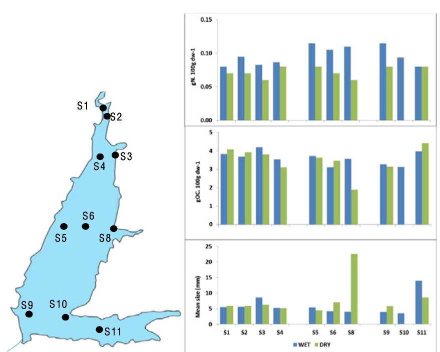
HIGHLIGHTS

- Barasona Reservoir stores a great amount of organic carbon in surface sediments.
- Sedimentary organic carbon is mainly from allochthonous origin.
- Water level fluctuation favoured homogeneity of surface sediment characteristics.
- Potential respiration rates in sediments are high and inversely related to C/N ratio.

GRAPHICAL ABSTRACT



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ABSTRACT

The reservoir sediments are important sinks for organic carbon (OC), the OC burial being dependent on two opposite processes, deposition and mineralization. Hence factors such as severe water level fluctuations are expected to influence the rate of OC accumulation as they may affect both deposition and mineralization. The Barasona Reservoir has been historically threatened by siltation, whilst the use of water for irrigation involves a drastic decrease of the water level. In this context, we have studied the physical and chemical characteristics (grain size, major and minor elemental compositions, organic and inorganic carbon, and nitrogen) of the recent sediments of the Barasona Reservoir and the relationships among them in order to: a) elucidate the main processes governing OC accumulation, b) evaluate the rate of OC mineralization and c) approach the effect of drought on the sediment characteristics in this system. Our results indicated that Barasona sediments were dominated by fine silts (>60%) and clays (>20%), the mean particle size decreasing from tail to dam. Desiccation increased particle sorting and size distribution became bimodal, but no effect on average size was observed. Attending to the composition, Barasona sediments were very homogeneous with low concentrations of nitrogen (TN) and phosphorus (<1.2 g kg^{-1} dw and <0.6 g kg^{-1}dw, respectively) and high concentration of OC (≈36 g kg^{-1} dw). TN was negatively related to dry weight. Sediment mixing due to drastic changes in water level may have favoured the observed homogeneity of Barasona sediments affecting carbon, major ions and grain size. The high amount of

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OC deposited in Barasona sediment suggested that the adsorption of OC onto fine particles was more important than in boreal lakes. The rate of oxygen consumption by wet sediment ranged from 2.26 to 3.15 mg O_2 m^{-2} day^{-1}, values close to those compiled for Mediterranean running waters.

1. Introduction

Management of water resources has involved the building of numerous differently-sized dams along rivers, especially in arid areas as the Mediterranean region. In the case of the Spanish Pyrenees, damming in the foothills of rivers that run through highly erodible soils has been relatively frequent. One of the worst consequences of damming in such particular catchments is the enhancement of reservoir siltation due to the inflow of high sediment loads and thus reduction of water storage capacity e.g. (Navas et al., 2004; López-Tarazón et al., 2009) together with the modification of the river geomorphology after the reservoir closing (Lobera et al., 2015), as well as the creation of lenthic environments with negative consequences for riverine ecosystems (Santos et al., 2015). Additionally, since fine sediments adsorb different compounds, such as organic matter, phosphorus or metals, sediment deposition can also alter the biogeochemical cycles of these elements (Friedl and Wüest, 2002; Meybeck et al., 2007; Lopez et al., 2009).

Carbon biogeochemistry in reservoirs has received a particular attention in recent years as they play a key role in the continental carbon cycle. The importance of reservoir sediments as sinks for organic carbon (OC) is currently widely recognized (Cole et al., 2007; Downing et al., 2008; Tranvik et al., 2009). The OC burial in reservoirs appears to be much higher than in natural lakes, and some studies indicate that burial rates are significantly greater in the smaller ones (Downing et al., 2008). However, other authors noted that, such high OC burial rates in reservoirs do not necessarily imply a long-term OC storage (Kastowski et al., 2011). From a biogeochemical point of view, a major descriptor of the role of sediments as carbon sinks is the OC burial efficiency (i.e. the proportion of deposited OC that is not mineralized to CO_2 and consequently is permanently buried (Sobek et al., 2011)). OC burial is thus the result of a balance between two opposite processes, the OC deposition and the OC mineralization.

The inputs of allochthonous and autochthonous organic matter determine the rate of OC deposition. The highest sedimentation rates have been observed in artificial lakes e.g. (Dean and Gorham, 1998; Filstrup et al., 2009) and also OC deposition appears high in small lakes that have steep catchment areas with agricultural land use (Kastowski et al., 2011), because of enhanced erosion that may be aggravated in the course of land use conflicts (Pacheco et al., 2014; Valle Junior et al., 2014). On the other hand, mineralization of deposited OC diminishes the permanent burial. Hence, factors that favoured mineralization such as temperature or oxygen availability should reduce OC burial efficiency (Sobek et al., 2009; Gudasz et al., 2010). Organic matter mineralization comprises aerobic respiration, which consumes oxygen and produces dissolved inorganic carbon (DIC), and also anaerobic pathways when oxygen is not available, which consume other electron acceptors. Since aerobic respiration is the predominant pathway in inland aquatic systems, respiration rates have been widely measured from both DIC production, and from oxygen consumption (López, 2003; Gudasz et al., 2012; Cardoso et al., 2014). The results indicate a great variability depending on systems, rivers and streams presenting higher rates than reservoirs (Cardoso et al., 2014). Contrarily, mechanisms that prevent OC mineralization should favour OC accumulation. Organic matter adsorption onto the surface of mineral particles, especially those with the smallest size, has been reported as a key mechanism of OC preservation in soils and marine sediments (Rothman and Forney, 2007; Nadeu et al., 2011). In spite of that, the relevance of OC adsorption onto clays in freshwater sediments is not evident and some studies indicated that its role as regulator of burial efficiency of OC is only of a minor importance (Sobek et al., 2009, 2011).

Additionally, the role of drought has to be taken into account in arid regions in relation to the OC accumulation/mineralization in sediments. Some studies have pointed out that allochthonous inputs of dissolved organic carbon (DOC) are strongly coupled with hydrologic fluctuations, being modulated by the dry periods (Clark et al., 2005; Vazquez et al., 2011). Furthermore, some other authors have shown OC processing in dry sediments may be relevant in temporary watercourses (Timoner et al., 2012; Gallo et al., 2013; von Schiller et al., 2014). However, studies on the effect of water level changes over transport and accumulation of particulate organic carbon are scarce.

The Barasona Reservoir, built in 1932, is one of the oldest in the Ebro basin. It has suffered from intense siltation over the last 65 years, reducing its storage capacity in about one third (Valero-Garcés et al., 1997). Several studies on sediment deposition and sources (Palazón and Navas, 2014) and sediment transport in the catchment (López-Tarazón et al., 2010) have been carried out in this reservoir. However lesser is known about the carbon cycle in the reservoir and the processes that modulate recent organic matter accumulation. Within this background, the aims of this paper are to:

A. describe the physical and chemical characteristics (i.e., grain size, major and minor elemental composition, organic and inorganic carbon, and nitrogen) of the recent sediments of the Barasona Reservoir.
B. establish the relationships between the sediments' physical characteristics and the carbon and nitrogen contents in order to elucidate the main processes governing OC accumulation.
C. investigate the effect of drought on the aforementioned characteristics and relationships.
D. obtain a preliminary approach to the rate of mineralization of OC in these sediments.

This approach combined with the simultaneous study of the characteristics and dynamics of the suspended sediment (and associated carbon and nitrogen) which inflows and leaves the reservoir at the annual scale (López-Tarazón et al., 2009) will contribute to greatly improve our knowledge of the carbon cycle at the Barasona Reservoir in particular and, in a wider sense, of the Mediterranean reservoirs carbon cycle.

2. Study area

The Barasona Reservoir catchment (1509 km^2) is located in the central part of the Spanish Pyrenees and encompasses the Ésera and the Isábena basins (1064 km^2 and 445 km^2 respectively) (Fig. 1). The Barasona Reservoir had an original capacity of 71 hm^3, but this was enlarged in 1972 providing a new storage capacity of 92 hm^3, impounding 15% of the annual runoff of the reservoir draining catchment. The reservoir supplies water to the Aragón and Catalunya Channel, irrigating more than 100,000 ha of lowland agriculture. The reservoir has been historically threatened by siltation due to the fine sediments coming from a characteristic badland stripes located in the middle part of both the Ésera and Isábena basins (Fig. 1). Previous studies demonstrate that human activity, through land use change, exert a major influence on the delivery of suspended solids (Valero-Garcés et al., 1997). Despite their small area (<1% of the total catchment area in the case of the Isábena), badlands have been proved to be the largest suspended sediment producers (Valero-Garcés et al., 1999; López-Tarazón et al., 2009). Therefore, since its construction, the reservoir has been silting up at a rate of between 0.3 and 0.5 hm^3 of deposited sediment per

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