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Maintenance dredging impacts on a highly stressed estuary (Guadalquivir estuary): A BACI approach through oligohaline and polyhaline habitats

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ABSTRACT

Understanding the effects of dredging in estuaries is a hard task due to the difficulty of implementing an adequate environmental diagnosis, as a consequence of the salinity gradient and anthropogenic disturbances. To assess the effects of maintenance dredging work on the Guadalquivir estuary (southwestern Spain), we used a Before-After-Control-Impact (BACI) approach to determine both direct and indirect effects in two salinity ranges. No effects were found on water and sediment physicochemical characteristics. The small impacts on dredged areas were followed by a rapid recovery of opportunistic species. The poor status of the benthos does not permit the detection of significant effects on macrofaunal community structure. The use of stable isotopes analysis to determine impacts on food web structure showed that changes over time seem to be explained by natural temporal variation rather than the dredging works. This paper emphasises the need to define proper management and conservation plans to improve the status of the benthic communities of the Guadalquivir estuary.

1. Introduction

Although estuaries are one of the most productive marine coastal environments in terms of biomass (Wolf, 1983; Wetzel et al., 2013), they often face perturbations (Dauvin et al., 2006; Sánchez-Moyano and García-Asencio, 2010). With more than 60% of Earth's population living in the coastal realm, estuarine ecosystems have been extensively altered by human activities (Ray, 2006). Furthermore, estuaries are dynamic and complex systems where high variability of the physical-chemical gradients makes them one of the most stressful aquatic environments (González-Ortegón et al., 2006; Dauvin, 2008). In this changeable scenario, characteristics of estuarine communities are strongly and directly related to parameters, such as turbidity, temperature and, particularly, salinity (Baldó and Cuesta, 2005; Dauvin, 2008). As a consequence, benthic community diversity is limited, but it is often associated with a high tolerance to variable environmental conditions (Dauvin, 2007). Interpreting disturbance effects in estuaries often is complex, because the dynamic geological, physical and chemical characteristics that rule those systems might be confused with anthropogenic impacts (Morrisey et al., 2003; Dauvin et al., 2006; Dauvin, 2008). An accurate evaluation of the anthropogenic impacts in estuaries is vital for the proper management of resources and maintaining good environmental health as well as reaching a “good environmental status” in the context of the requirements of the European Water Framework Directive (Taupp and Wetzel, 2013; Rehitha et al., 2017).

The Guadalquivir estuary (southwestern Spain) is a good example of this kind of stressed scenario. In this system, mixed natural perturbations, such as a horizontal salinity gradient, govern the composition and spatial distribution of the aquatic communities, while human activities have deeply modified the ecosystem (González-Ortegón et al., 2006; Castañeda and Drake, 2008; Llope, 2017). They vary from desiccation of tidal marshes and isolation of the estuary course from the original tidal marshes, reduction of freshwater inputs and eutrophication from urban and agricultural waters to maintenance dredging work (Taglialatela et al., 2014; Llope, 2017). The Guadalquivir estuary is the only navigable river in Spain and gives access to Seville harbour. To maintain navigability, the Autoridad Portuaria de Sevilla (APS) has performed maintenance dredging work every one or two years since 1985 (Gallego and García Novo, 2006). Dredging operations represent a potential risk to the estuarine environment; effects basically depend on the method used, duration and extension, amount of dredge material and sediment characteristics. These activities may cause changes in the seabed and natural fluctuations in water conditions, population dynamics and sedimentary composition of the system and the surrounding

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areas (Sánchez-Moyano et al., 2004; Barrio Froján et al., 2011; Ceia et al., 2013; Rehitha et al., 2017). Dredging often has more repercussions on benthic communities due to the relative immobility of organisms (Simonini et al., 2005). Macrofaunal communities play a crucial role in the structure and functioning of ecosystems, such as sediment stability, nutrient processing and contaminant sequestering (Thrush and Dayton, 2002; Ceia et al., 2013). In estuaries, macrofauna are also an important link between organic matter and predators (Kon et al., 2015) acting as a food source for the next trophic level, generally secondary consumers such as fish and shellfish (Bolam et al., 2011).

Studies assessing dredging effects on macrofaunal assemblages are widely available (Klapan et al., 1975; Newell et al., 1998; Sánchez-Moyano et al., 2004; Bemvenuti et al., 2005; Ponti et al., 2009; Rehitha et al., 2017). However, more focused studies on dredging effects in different salinity ranges in estuaries are rare, despite the fact that salinity is the major environmental factor influencing the distribution of organisms in estuaries (Attrill, 2002). Most monitoring programs in estuaries have been developed in higher salinity ranges, while low salinity areas have been scarcely studied (Vinagre et al., 2015). Moreover, studies analysing dredging impacts on food web structure are few. Stable isotopes analysis is a useful tool to determine anthropogenic impacts on food web structure in aquatic ecosystems (Ke et al., 2016). Nitrogen and carbon isotopic ratios can be used for tracing the natural or anthropogenic sources of nutrients in estuaries (Castro et al., 2007; Kon et al., 2012; Van De Merwe et al., 2016). Also, the different rates of nutrient assimilation by different organisms can reflect estuarine status over temporal scales (Van De Merwe et al., 2016). For this reason, isotope analysis could be a useful tool to assess dredging impacts and the potential following recovery.

In this context, we analysed the effects of dredging work carried out in the Guadalquivir estuary in two different salinity gradient ranges with a Before-After Control-Impact (BACI) analysis (Underwood, 1991). We combined a classical approach assessing the dredging impact on the physicochemical and biological characteristics of the system, and we incorporated a new approach based on the analysis of stable isotope values of carbon and nitrogen. This study specifically aims to assess (i) effects of dredging on sediment and water characteristics and on macrofaunal communities and (ii) indirect effects on the surrounding shallower habitat and on the whole food web structure.

2. Materials and methods

2.1. Study area

The Guadalquivir estuary is located in southwestern Spain. It extends from the mouth in Sanlúcar de Barrameda (Atlantic Ocean) to the Alcalá del Río dam, 110 km upstream. This estuary plays a critical role in the ecological and economic sustainability of very sensitive and protected areas of southwestern Spain (e.g., National Park of Doñana) (Tornero et al., 2014)· The Guadalquivir estuary is a well-mixed and tidally dominated system (3.5 m tidal range at the mouth in spring tides) (Díez-Minguito, 2012), which presents a longitudinal salinity gradient with temporal displacement by tides, discharges and seasonal variations (González-Ortegón et al., 2014). In order to guarantee a minimum navigation depth of 6.5 m, the channel is dredged every one or two years (Ruiz et al., 2015). In summer 2015, a maintenance dredging operation was carried out in several estuarine sections. The dredging work was performed by trailer suction dredge. Our study was focused on two dredging sections, one in the polyhaline range (18–30 PSU) and the other in the oligohaline range (< 5 PSU), locally known as Salinas and La Gola, respectively (Fig. 1). Approximately 74,000 and 22,000 m^3 of dredged material were extracted in each range, respectively.

2.2. Sampling design

Our sampling was designed according to a BACI approach (Underwood, 1994). In total, four sampling surveys were carried out: two pre-dredging (June and July 2015) and two post-dredging (October 2015 and August 2016) surveys. In both salinity ranges, two areas were established: one within the dredged section and the other (as a control) far away from the influence of these operations but always at the same salinity range intervals. Establishing more control areas in the same salinity ranges were not possible due to the areas not affected by the dredging being spatially limited (ca. 2 km). In each area, three stations were randomly located inside of the navigation channel and the other three in the shallower left margin in order to assess the direct and indirect effects of dredging in those habitats, respectively. Three samples were taken for macrofaunal analysis with a Van Veen grab (0.15 m^2 total sampling area per station and date). For posterior analysis, all stations were pooled together and were considered replicates of each area. Macrofaunal samples were sieved through a 0.5-mm mesh sieve, and infauna was preserved in ethanol (70%) and stained with rose bengal for subsequent identification and quantification at the lowest possible taxonomic level.

To relate the effects of dredging on sediment characteristics, one additional sample was taken for grain size distribution, particulate organic matter (POM) content and redox potential. Grain size distribution was measured as percentages of 100 g of dry sediment passed through a series of sieves (5 mm, 2 mm, 1 mm, 0.5 mm, 0.250 mm, 0.125 mm and 0.063 mm). Also, the median grain size (Q_{50}) and sorting coefficient (S_0) (Trask, 1950) were calculated. Granulometric typology was established according to the Wentworth geometric scale (Buchanan, 1984). The POM content was determined by calculating the weight difference between the dried sediment samples of three replicates (at 60 °C until dried weight stabilisation) and after combustion (500 °C for 4 h). Apparent redox potential was measured with a pH meter (WTW pH 1970i with SenTix ORP electrode).

For the heavy metals and trace element concentrations analyses, sediments were taken from the uppermost 2 cm. In the laboratory, sediment samples were air-dried, crushed and sieved though a 2-mm sieve and then ground to < 60 μm. These samples were digested with aqua regia (1:3 conc HNO_3: HCl) in a microwave digester. Quantification of elements in the extracts was achieved using a VARIAN ICP 720-ES (simultaneous ICP-OES with axially viewed plasma). The accuracy of the analytical methods was assessed via a reference soil sample from the Wageningen Evaluating Programs for Analytical Laboratories (WEPAL) for soils, International Soil-Analytical Exchange (ISE). The index of geoaccumulation (I_{geo}) has been used as a relative measure of metal pollution in sediments for Cr, Cu and Zn according to the regional background established by Ruiz (2001) for unpolluted sandy and silty-clayey sediments and is given by: $I_{geo} = \log_2 (Cn/1.5\ Bn)$, where Cn is the value of the element n and Bn is the background data of that element. Following Ruiz (2001), the index values were divided into five groups: unpolluted ($I_{geo} < 1$); very lowly polluted ($1 < I_{geo} < 2$); lowly polluted ($2 < I_{geo} < 3$); moderately polluted ($3 < I_{geo} < 4$); highly polluted ($4 < I_{geo} < 5$) and very highly polluted ($I_{geo} > 5$). Comparisons between metal concentrations and sediment quality values (SQVs) proposed by Long et al. (1995) and Delvalls and Chapman (1998) have also been performed. Heavy metals in water and sediment were only measured in the channel area in July and October 2015 and August 2016.

Water parameters were analysed from the bottom layer with a multiparametric probe Eureka Manta 2 with pH, dissolved oxygen, salinity and turbidity sensors. A 5-l water sample from 1 m above the bottom was collected with a Niskin bottle and then filtered through a GF/C Whatman glass fibre filter with an air vacuum pump; then, suspended organic matter (SUOM) and total suspended solids (TSS) were calculated. SUOM was determined with the same procedure as POM.

We investigated the possible impact of the dredging work on the