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Challenges for the WFD second management cycle after the implementation of a regional multi-municipality sanitation system in a coastal lagoon (Ria de Aveiro, Portugal)

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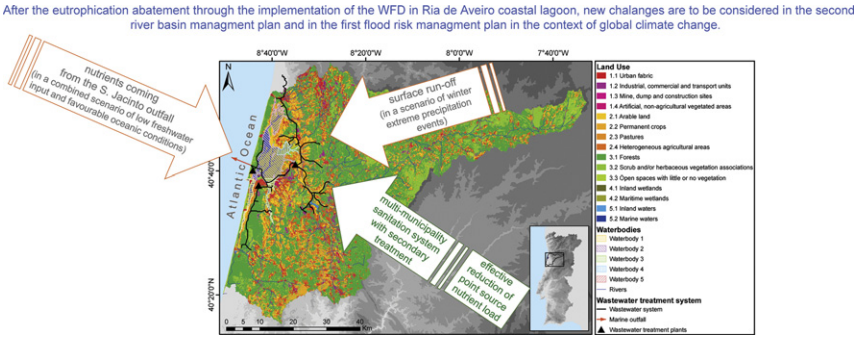
HIGHLIGHTS

- Impact of the new multi-municipality sanitation system (MMSS) in Ria de Aveiro
- Eutrophication abatement and new challenges for the WFD second management cycle
- Data of DIN, phosphate and chlorophyll *a* of 2001 and 2012 were compared.
- The new regional MMSS implemented in 2005 reduced the point source nutrient loads.
- Non-point sources still representing a challenge in the context of climate change.

GRAPHICAL ABSTRACT



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ABSTRACT

In the scope of the first WDF management cycle, a multi-municipality sanitation system with secondary treatment was implemented in 2005 in Ria de Aveiro coastal lagoon, with the treated effluent discharging into the Atlantic Ocean through a submarine outfall. The lagoon water chemical status was evaluated regarding dissolved inorganic nutrients and chlorophyll *a* before and after 2005. The S. Jacinto outfall has effectively reduced the point source nutrient loads (ammonium and phosphate) into Ria de Aveiro, representing a step forward for the implementation of the WFD, through eutrophication abatement. However, the lagoon remains exposed to non-point nitrogen sources, as a consequence of the current land use and water management, which in a scenario of winter extreme precipitation events, nutrients increase through surface run-off. Besides, in a combined scenario of low freshwater input into the lagoon and favourable oceanic condition, nutrients enter through Ria outer boundary coming from the S. Jacinto outfall. Thus, changes in the system hydrodynamics in the context of global change might pose new challenges regarding the WFD second management cycle involving the second river basin management plan and the first flood risk management plan, foreseeing the 'Good' ecological status in all Ria's Water Bodies.

1. Introduction

The trend of eutrophication in European aquatic systems, including transitional and coastal waters, has receive special attention since the

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second half of the 20th century, with a number of EU Directives, aiming at reducing the loads and impacts of nutrients, being adopted by the Member States (e.g. European Commission, 2009, 2014). Relevant examples are the Water Framework Directive (WFD, 2000/60/EC), and the Marine Strategy Framework Directive (MSFD, 2008/56/EC). The Water Framework Directive (WFD, 2000/60/EC) aims to maintain and improve the aquatic environment in the Community, and requires the achievement of Good Ecological Status or Good Ecological Potential of transitional and coastal waters across the EU by 2015. The Marine Strategy Framework Directive (MSFD, 2008/56/EC) aims to achieve Good Environmental Status of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The WFD is the main EU water policy instrument, making the EU water legislation more coherent and less contradictory (European Environmental Bureau, 2001). In this context, Nitrates Directive (91/676/EEC) forms an integral part of the WFD, being one of the key instruments in the protection of waters against agricultural pressures. The Urban Waste Water Treatment Directive (UWWT, 91/271/EEC) had an amendment (98/15/EC) to clarify the requirements of the Directive in relation to discharges from urban waste water treatment plants to sensitive areas which are subject to eutrophication.

In transitional waters, like Ria de Aveiro coastal lagoon, the most relevant EU policy targeting the loads and impacts of nutrients is WFD that was transposed into Portuguese law in 2005. Based on the timetable for the common implementation of the WFD, the first management cycle ended in 2015, and the second river basin management plan started in conjunction with the first flood risk management plan. This second cycle will end in 2021.

Two decades ago, the former Portuguese Water Institute (INAG), that is now Part of the Portuguese Environmental Agency (APA), promoted a study to identify the sensitive areas and vulnerable zones in transitional and coastal Portuguese systems. The resulting report concluded that the Ria de Aveiro has a moderate degree of eutrophication and low overall human influence in comparison to other estuarine systems (Ferreira et al., 2003). As the pressure from nutrient loads were not expected to increase, the Ria was not listed as a sensitive area (Directive 91/271/EEC) or vulnerable zone (Directive 91/676/EEC) (Ferreira et al., 2003). However, the same report classified the Ria de Aveiro as having a "high" level of expression for chlorophyll *a*, and the nutrient loads into the system were rated as "high".

Ria de Aveiro is located in a complex coastal region in terms of natural capital, associated socio-economic activities and management instruments and institutions (e.g. Lillebø et al., 2015; Sousa et al., 2016). The population in the watershed area of Ria de Aveiro increased in the last decades, with 353,688 inhabitants registered in 2011, more 103,668 than in 2001 (National Census reports for 2001 and 2011, data available at https://www.ine.pt/). Before the implementation of the WFD, most of the population within the Ria de Aveiro watershed used septic tanks or other small scale systems for sewage disposal with poor or no subsequent treatment. In order to relieve the anthropogenic pressure inside the system, namely the loading of nutrients, several interventions have been made in the lagoon with a significant investment in the treatment of sewage and industrial effluents in the last years. In 2005, SIMRIA (SIMRIA - Saneamento Integrado dos Municípios da Ria SA), the company responsible for the implementation and management of the sanitation system in Ria the Aveiro, implemented a new regional multi-municipality sanitation system with secondary level wastewater treatment. This multi-municipality sanitation system was connected to a submarine outfall (S. Jacinto outfall) reducing the sewage drained directly to the lagoon. According to Cunha and Almeida (2006), the treated effluent that is discharged through the S. Jacinto outfall contains only a minor fraction of domestic sewage (<20%), being mostly composed of industrial effluent from a paper mill located in Cacia, Aveiro. The Estarreja Chemical Complex (ECC) was also a source of industrial effluents for several years. Until 1975, industrial effluents from the ECC, including the ones rich in ammonium, nitrates and sulphates (Schramm and Nienhuis, 1996) were discharged into human shaped channels through agricultural fields and grazing lands into the Estarreja channel and then to an inner 2 km^2 basin, the Laranjo basin. After 1975, the effluents were discharged directly by pipes into the Estarreja Channel. In 2005 the effluents discharged into the Estarreja Channel were channeled to the new regional multi-municipality sanitation system and discharged to the Ocean through a submarine outfall (S. Jacinto outfall). Therefore, the main objective of this work was to determine the impact of the new multi-municipality sanitation system with secondary treatment in the water quality of Ria de Aveiro coastal lagoon, evaluating the dissolved inorganic nutrients, phosphate and chlorophyll *a* before and after its implementation. The results are discussed in terms of eutrophication abatement, implementation of the WFD and new challenges regarding the second WFD management cycle.

2. Material and methods

2.1. Study area

Ria de Aveiro is located on the northwestern coast of Portugal, between 40° 38′N and 40° 57′N (Fig. 1). This temperate system is a shallow and well mixed coastal lagoon forming four main Channels, Mira, Ílhavo, Espinheiro and S. Jacinto-Ovar, characterized by extensive intertidal mud and sand flats, salt marshes and islands. Ria de Aveiro lagoon is divided in five transitional water bodies (WB) (Fig. 2). These water bodies were classified as follow: WB1 – A natural (unmodified) water body that includes the Mira channel and Barra, the connection to the Atlantic Ocean, classified with a 'Good' Water Ecological Status; WB2 – A heavily modified water body corresponding to the central area of the lagoons with a 'Moderate' Water Potential Ecological Status; WB3 – A natural water body that corresponds to the Ílhavo channel with a 'Good' Water Ecological Status; WB4 – A natural water body that includes the Murtosa channel and the Laranjo basin with a 'Moderate' Water Ecological Status; and WB5 – A natural water body that corresponds to the Ovar channel with a 'Poor' Water Ecological Status (MAMAOT/ARHCentro, 2012). The lagoon is part of the Natura 2000 network (EU Habitats Directive). It is a designated Special Protected Area, including several areas classified as Sites of Community Importance, and is protected by the EU Birds Directive (79/409/CEE). The lagoon is also a Portuguese and International long-term ecological research site, housing one of the largest continuous salt marshes in Europe. The system's natural capital is an important factor for the development of the municipalities situated in the lagoon area. The only connection between Ria's and the Atlantic Ocean is made through an artificial inlet constructed in 1808 (1.3 km length, 350 m wide and 20 m depth) (Fig. 1). The lagoon watershed area supports activities intrinsically associated to coastal areas, namely urban settlements, port facilities, industries, aquacultures, salt-production, fishing, agriculture and livestock farms (Fig. 2). Regarding hydrodynamics, it is a mesotidal lagoon, characterized by semidiurnal tides, which are the main forcing agent driving water circulation in the lagoon (e.g. Dias et al., 2000; Lopes et al., 2015). The tidal time delay, relative to the mouth, is about 6 h in the upper reaches of the channels. The total catchment area of the Ria de Aveiro is c. 3500 km^2 of which c. 80% is drained by the River Vouga (Stefanova et al., 2015). The Vouga catchment mean annual precipitation is about 1100 mm · $year^{-1}$ (Hesse et al., 2015a) and 75% of the precipitation occurs between October and March (Rocha et al., 2015). The catchment is influenced by a humid and temperate climate, and largely covered by forest and semi-natural areas (60%), followed by agricultural areas (29% with single or combined production of corn, winter pastures, potatoes, vineyard's and oats), and by urbanized areas, wetlands and water bodies (11% altogether) (Fig. 2) (Hesse et al., 2015a; Rocha et al., 2015). The major fluvial inputs are from Rivers Vouga at the Espinheiro channel and Antuã at the Laranjo basin. The Boco river, at the southern end of Ílhavo channel, has negligible flow, as well as the Cáster and the