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# Sewage contamination of sediments from two Portuguese Atlantic coastal systems, revealed by fecal sterols

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ABSTRACT

Fecal sterols in sediments were used to assess the degree of sewage contamination in Ria de Aveiro lagoon and Mondego River estuary for the first time. Coprostanol, the major fecal sterol, averaged $1.82 \pm 4.12$ μg $g^{-1}$, with maxima of 16.6 μg $g^{-1}$. The northwestern sector of the Ria and a marina at Mondego estuary showed the highest level of sewage contamination. This scenario was confirmed by several diagnostic ratios based on fecal sterols and other phytosterols. Our data revealed that in spite of the improvements achieved in the last decades, there is still a need for control the organic inputs into the aquatic environment in the studied regions.


The current state of fecal contamination in Portuguese estuaries is limited and therefore, in order to fill this gap, a study was conducted in the Ria de Aveiro, a coastal lagoon in northwestern Portugal and in Mondego estuary (60 km south of Ria de Aveiro) (Fig. 1). The two areas receive inputs from agriculture, urban and industrial activities, but these anthropogenic pressures may have different proportions in the two systems. Ria de Aveiro is a shallow coastal lagoon with a total catchment area of 3600 $km^2$ and it is permanently connected to the Atlantic Ocean through a single inlet (Fig. 1a). The major freshwater input to the lagoon is mostly from the Vouga river (catchment area of approximately 3363 $km^2$) whereas the other three small rivers (catchment areas of 104 $km^2$, 105 $km^2$ and 302 $km^2$) have a much lower contribution (LAGOONS, 2012). The population living around the lagoon and in the Vouga river drainage basin is around 1147,300 but the highest population density is concentrated around the lagoon (Centro, 2012). The Vouga drainage basin is mostly occupied by forest and farmlands, whereas most industry is concentrated around the lagoon, especially in the northern part (LAGOONS, 2012). During decades, several pollution problems have been reported due to the input of effluents from several anthropogenic activities to the lagoon (Ferreira et al., 2003; LAGOONS, 2012). However, in the last years the implementation of environmental protection measures resulted in a substantial reduction in the pollution inputs from point sources. In the particular case of organic inputs, the implementation of an integrated wastewater treatment system and the construction of a submarine outfall were of utmost importance. Indeed, Ria de Aveiro has been classified to be in a reasonable good state of environmental preservation, despite being quite urbanized and industrialized (LAGOONS, 2012).

The Mondego estuary is much smaller than the lagoon (16 $km^2$) and comprises a northern and southern arm separated by an island (Fig. 1b). The northern arm is the deeper, constituting the main navigation channel, whereas the southern arm is shallower, with large areas of intertidal flats exposed during low tide (Lillebø et al., 2007). The main freshwater input to the estuary comes from the northern channel through the Mondego river, which drains a 6670 $km^2$ watershed, whereas the water circulation in the south channel is mainly tidally driven, with freshwater inputs from the small tributary Pranto river (Ferreira et al., 2003; Lillebø et al., 2007). The population living in the Mondego drainage basin is around 1235,000 but it is not concentrated around the estuary as in the case of the lagoon (Centro, 2012). Although less industrialized than the Ria de Aveiro, Mondego estuary is impacted by agriculture receiving runoffs from upstream cultivated land and livestock activities.

Both studied areas were subjected to direct discharges of urban sewage during centuries, but in the last decades large investments

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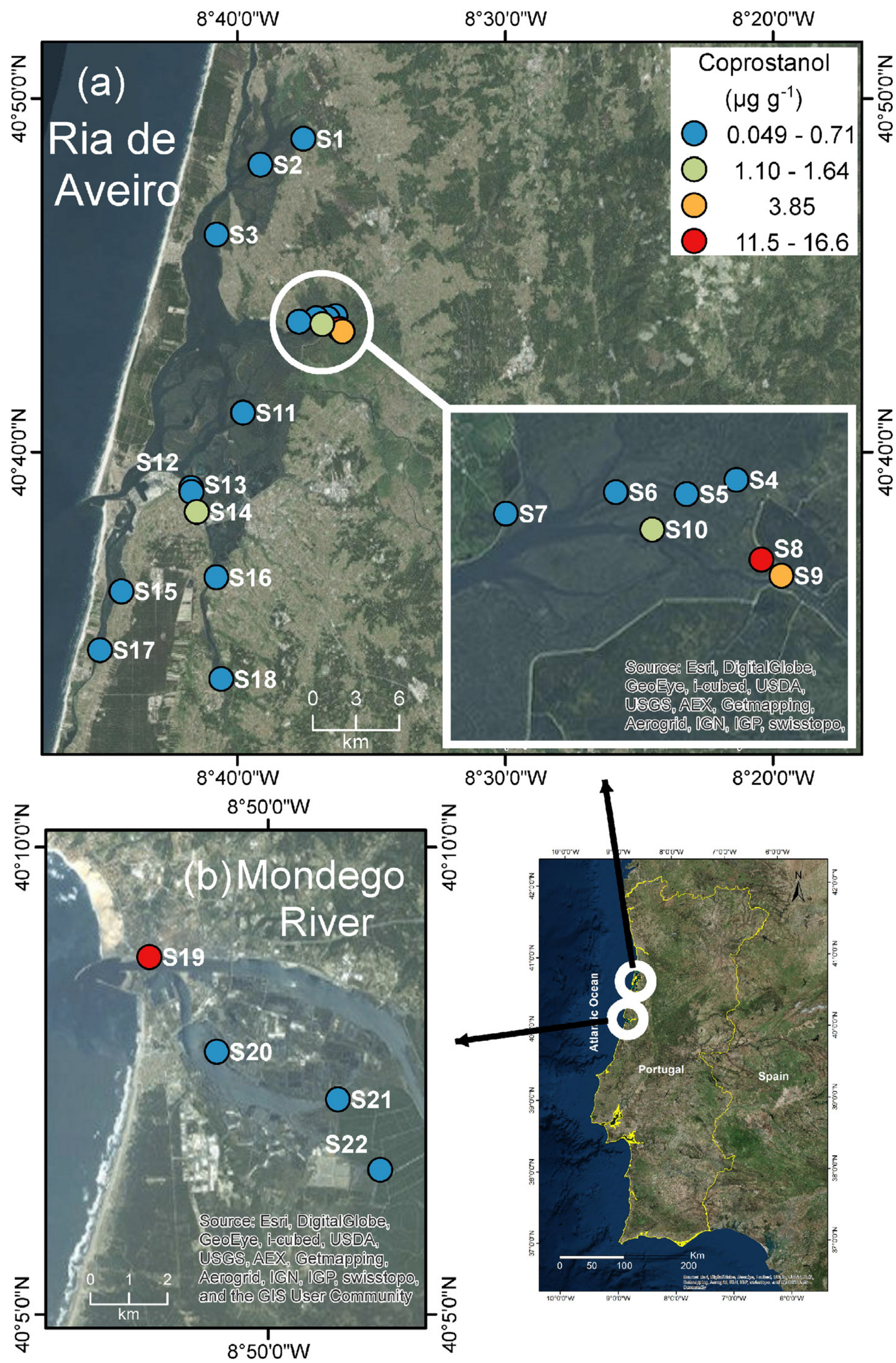


**Fig. 1.** Sampling stations in Ria de Aveiro and Mondego River estuary, including coprostanol concentrations.

have been made in order to improve the drainage and treatment systems of urban wastewaters. Nevertheless, in 2012, the wastewater treatment covered only 66% of the population in the studied areas, and 70% were connected to the drainage system (Centro, 2012). Therefore, despite the improvement, there are still some direct discharges into the aquatic systems of untreated wastewater, and in several treatment plants (almost 50%, mostly in Mondego drainage basin) only a primary treatment is performed. In addition, accidental discharges, malfunction of wastewater treatment plant (WWTP), and the non-compliance with legal obligations in some systems may be a source of contamination (Centro, 2012; Cerqueira et al., 2008). Moreover, domestic and industrial discharges not connected to treatment system, and other diffuse sources such as agriculture can contribute significantly to the organic inputs in the aquatic systems (Centro, 2012; Cerqueira et al., 2008; Lillebø et al., 2007).

Coprostanol (5β-cholestan-3β-ol) and other sterols associated, even though not exclusively, to fecal material such as cholesterol (cholest-5-en-3β-ol), epicoprostanol (5β-cholestan-3α-ol), ethylcoprostanol (24-ethyl-5β-cholestan-3β-ol) and sitosterol (24-ethylcholest-5-en-3β-ol), have been successfully used to evaluate the input and accumulation of sewage-derived organic matter (OM) in aquatic systems. These include systems from temperate (e.g., Biache and Philp, 2013; Bull et al., 2002; Choi et al., 2009; Grimalt et al., 1990; Leeming and Nichols, 1996; Mudge et al., 1999; Readman et al., 2005), tropical/sub-tropical (e.g., Carreira et al., 2004; de Abreu-Mota et al., 2014; Ekklesia et al.,