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Assessment of the physicochemical conditions sediments in a polluted tidal flat colonized by microbial mats in Bahía Blanca Estuary (Argentina)

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ABSTRACT

The aim of this work is to assess the physicochemical conditions of the supratidal sediments colonized by microbial mats at two sites from Rosales Harbor (Bahía Blanca Estuary, Argentina) close to sewage discharge. Both sites differed in the size grain. No differences in pH, Eh and temperature were observed. Moisture retention and chlorophyll *a* concentration were significantly different between sites and sediment layers. Heavy metals and organic matter content were significantly higher in SII. No statistical differences were found in porewater nutrients concentration, being higher in SI (except DSi). The presence of *Escherichia coli* in water and sediment (1000 CFU/100 mL – uncountable and 35–40 CFU g^{-1} dw, respectively) evidenced microbial contamination in the study area. The relationships between the physicochemical parameters evaluated and the influence of the sewage discharge allow defining two different areas in the Rosales Harbor despite the proximity and the presence of microbial mats.

1. Introduction

Estuaries have been recognized as dynamic, complex and unique systems, which are included among the most productive marine ecosystems in the world (Chapman and Wang, 2001). They frequently experience anthropogenic eutrophication, resulting in changes in the biogeochemical conditions (Buddemeier et al., 2001; Cloern, 2001; Rabalais and Nixon, 2002). Moreover, as they are sites of ports, industrial, urban and recreational developments, and also received the sewages discharges, they act as sink and/or transitional way of several chemical pollutants as well as nutrients between freshwater, land and the open sea.

Tidal flats are among the most productive components of shelf ecosystems because a variety of biogeochemical functions are performed in them, including sediment deposition, nitrogen and phosphorous removal and recycling of both terrestrially and marine-derived organic matter and nutrients (DeBusk, 1999). In addition, depending on the grain size, the sediments of tidal flats are usually rich in trace metals that easily bind to the large surface area of the clay particles. Physical, chemical, and biological interactions between tidal flats and saltwater estuarine system can have significant influences on the transport and distribution of nutrient, organic matter and trace metals.

Surface sediments of tidal flats may be colonized by different populations of phototrophic and chemotrophic microorganism. Microphytobenthos is the major component of intertidal sediment microbial communities in terms of biomass and production, and it is a primary source of fixed carbon for food webs and provides a food source for animals such as deposit feeders (Thornton et al., 2002 and reference therein). When the microphytobenthos is abundant, it can help to stabilize the surface of the sediments (Paterson et al., 1990) by decreasing its interstices and may produce macroscopically recognizable microbial mats, often dominated by the filamentous cyanobacteruim *Microcoleus chthonoplastes* or by visible biofilms of epipelic diatoms generally dominated by *Cylindrotheca closterium* (de Winder et al., 1999; Pan et al., 2013a; Noffke et al., 2002). Most components of the microphytobenthos live grow and are consumed in the upper millimeters of shallow ecosystems without vegetation. While this may seem restrictive, not be construed as the microphytobenthos is unimportant in the marshes (MacIntyre et al., 1996).

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Mats are ubiquitous in nature, they are found in a variety of different environments such as intertidal and supratidal sediments, marine salterm, hot springs, hypersaline ponds and deserts (Demergasso et al., 2003; Franks and Stolz, 2009; Lovelock et al., 2010; Guézennec et al., 2011). They commonly appear as floating masses in marine waters or over the sediments surfaces. Moreover, in shallow environments such as estuaries, they develop at the water sediment interface, where they stabilize the sediment (Bender and Phillips, 2004; García de Oteyza et al., 2006). Mats colonization is favored by clean, translucent and fine-grained quartz sand deposited at sites where hydrodynamic flow is sufficient to sweep clay minerals from mats surfaces but insufficient to erode bioestabilized laminae (Noffke et al., 2002). The vertical stratification and type of microorganism of these communities depend strongly on physiological requirements and physicochemical properties. Important physical properties include light, temperature and pressure. Key chemical parameters include oxygen, pH, redox potential, salinity, and available electron acceptors and donors, as well as the presence or absence of specific chemical species (Franks and Stolz, 2009; Guézennec et al., 2011). An important biological process of the mats is the secretion of extracellular polymeric substances (EPS) which are composed by carbohydrates (90%), proteins, lipids and lipopolysaccharide (Stal, 2010). This mucilaginous matrix in which the particles and organism are embedded is associated at motility of microorganism and stabilization of tidal flat (Stal and de Brouwer, 2003; Underwood et al., 2004).

Microbial mats play key geoactive roles in the biosphere, particularly in the areas of element biotransformations and biogeochemical cycling, metal and mineral transformations, decomposition, bioweathering, and soil and sediment formation (Gadd, 2010). Mats present in environments polluted by heavy metals have been the object of several research into metal biosorption (Incharoensakdi and Kitjaharn, 2002; De Philippis et al., 2003) and toxicity studies (Tripathi et al., 2003; Heng et al., 2004). Moreover, EPS generally contains high molecular weight compounds with charged functional groups and possess both adsorptive and adhesive properties. Due to the presence of charged moieties, EPS ideally serves as a natural ligand source, providing binding sites for other charged particles/molecules including metals (Decho, 1990).

Bahía Blanca Estuary (BBE) is integrated by a complex morphology composed by island, extensive muddy flats and channels subjected to a semidiurnal ebb and flood tidal action. At this site, there are good chances to introduce pollutants into the environment through man-activities. In the northern coast at the estuary is located the most important deep harbor system of Argentina, as well as several industries and populated cities as Bahía Blanca and Punta Alta. The middle zone of Bahía Blanca Estuary is characterized by extensive tidal flats (1000 m wide) covered by microbial mats in the upper intertidal and lower supratidal zones. The evolution of the microbial mat in the temperate estuary has been studied (Cuadrado et al., 2011) and also the relationship with seasonal changes, hidrodynamical and physical variables and the resulting sedimentary structures (Cuadrado et al., 2013a,b; Pan et al., 2013a,b). The domestic sewage dumping in estuarine channels has been classified as a potential source of pollution in Bahía Blanca estuarine system (Pierini et al., 2012); however, in the middle zone of the estuary this fact has not been studied yet. It is generally known that sewage contains in itself a diverse array of polluting agents including pathogens, organic substances, heavy metals and trace elements and so on, which pose direct and indirect effects on ecosystems and organisms (Islam and Tanaka, 2004).Thus, the main purpose of this study is to perform a physicochemical characterization of the sediments of a siliciclastic tidal flat colonized by microbial mats that received the input sewage discharge from Punta Alta City. Considering the hypothesis that the sewage discharge is affecting the characteristics and the quality of the supratidal sediments of the middle zone of the BBE, we analyze different sediment layers of two nearby sites and link physical and chemical variables to the spatial distribution of the sediments and to the development of microbial mats. In turn the influence of the domestic sewage discharge on the study area was evaluated by microbial analysis.

2. Materials and methods

2.1. Study site

The Bahía Blanca Estuary is located in the SW area of Buenos Aires province, Argentina (38°45′–39°25′S and 61°45′–62°30′W) (Fig. 1). A dry temperate climate is characteristic for this area, with a mean annual air temperature of 15.6 °C (mean temperatures range from 22.7 °C in January to 8.1 °C in July) and mean annual precipitation of 460.55 mm. The predominant wind direction is from the NNO, NO and N (mean velocity: 22.6 km/h) (Píccolo and Diez, 2004).

This estuary extends over about 2300 km^2 and comprises several tidal channels, extensive tidal flats (1150 km^2) with patches of low salt marshes, and islands (410 km^2) (Píccolo et al., 2008). It is categorized as mesotidal (Hayes, 1979); semi-diurnal tides predominate and the mean tidal amplitude is 2.5–3.4 m during neap and spring tides, respectively. At the northern boundaries of the estuary various ports (two are commercial ports), cities (Bahía Blanca, Punta Alta) and industries (oil, chemical, and plastic factories) are located. The soil is used mainly for agriculture and livestock development. Two freshwater tributaries enter the estuary from the northern shore: the Sauce Chico River (drainage area of 1600 km^2) and Napostá Grande Creek (drainage area of 1240 km^2) (Píccolo et al., 2008). Both tributaries behave similarly in spring and summer during maximum mean rainfall (Piccolo and Perillo, 1990). However, the largest input of freshwater, nutrients, and contaminants is provided by the sewage discharges from Bahía Blanca, Punta Alta, and Ingeniero White cities (Piccolo et al., 2008). Several articles have been published about physical and chemical parameters, dissolved nutrients in surface estuarine waters and porewater (Spetter, 2006; Negrin et al., 2013; Spetter et al., 2013 and references therein); and heavy metals in sediments (Marcovecchio and Ferrer, 2005; Botté et al., 2010) but mostly of them are from the inner part of the estuary. There are some recent works from the middle area of Bahía Blanca Estuary, but they were developed in the salt marshes (Negrin et al., 2011).

The present study was conducted in the Rosales Harbor (38°55′S; 62°03′W) tidal flat, in the middle zone of the estuary. It is a siliciclastic depositional system with large tidal flat, 1000 m wide and with a very gentle slope, composed of fine sediments that range in size from fine sand to mud. The substrate of the tidal flats often experiences large fluctuations in water content, salinity and temperature, resulting in extreme conditions that limit the range of organisms able to inhabit this environment. The upper intertidal and supratidal zones are colonized by benthic microbial communities that form biofilms and microbial mats (Cuadrado et al., 2011; Pan et al., 2013a,b); and the intertidal area is vegetated by the cordgrass *Spartina alterniflora*, while patches of *Sarcocornia ambigua* are distributed on the supratidal zone. These tidal flats and salt marshes are also dominated by the burrowing crab *Neohelice (=Chasmagnatus) granulata* (Spivak, 1997; Iribarne et al., 2003).

Two sampling sites (SI and SII, Fig. 1) located ≈420 m apart from each other at the low supratidal area, were established on the basis of sedimentologic characteristics and preliminary field