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Assessing environmental health using ecological indices for soft bottom in sewage-affected rocky shores: The case of the largest seaside resort of SW Atlantic

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Efficient ecological indices can reflect the differences between impacted and nonimpacted sites, leading to significant variations at the contamination spatial scale. Here, we evaluated the spatial-temporal variability of 3 ecological indices (AMBI, M-AMBI, and BENTIX) in response to the distinct levels of sewage contamination. The indices were evaluated in two different ways: including *Brachidontes rodriguezii* (IBR) and excluding *B. rodriguezii* (EBR). The fact that mussel beds create a secondary infaunal habitat allows us to test these indices for soft bottoms in areas with rocky bottoms. The effectiveness and the level of agreement of these indices were increased when they were calculated with EBR. BENTIX and M-AMBI produced under- and overestimations of the ecological status of the studied sites. AMBI (EBR) seems to be better suited for environmental quality assessment in the study area. This index reduces the processing time of samples; thus, the AMBI (EBR) index could be used as a robust management tool for monitoring programs in areas with hard substrate.

1. Introduction

Contaminants are widespread in oceans worldwide. The human contribution to ocean contamination is incessant and global; this contribution includes urban and industrial waste, fishing, shipping, dredging, uncontrolled touristic activities, introduction of alien species, and climate change. In particular, coastal areas are the most dynamic but also the most populated areas of the world (Halpern et al., 2007). The need for reliable and accurate indicators of environmental health must therefore be in the agenda of every country with seacoasts. Ecological indices are very useful tools in decision-making processes because they describe the aggregate pressures affecting the ecosystem and can evaluate both the state of the ecosystem and the response of managers (Pintos et al., 2009).

Most of these indices are based on benthic organisms or on their assemblages (Warwick, 1993; Niemi and Mc Donalds, 2004; Simboura et al., 2005; Quintino et al., 2006; Salas et al., 2006; Devlin et al., 2007; Borja et al., 2008; Dauvin et al., 2010). Benthic communities integrate environmental conditions and changes occurred through time in a very effective manner, allowing therefore accounting for the types of disturbances that occur more often in coastal areas (i.e., organic enrichment, physical disturbance, or toxic pollution (Salas et al., 2006). The response of macrobenthic communities to several types of stress is well studied, based on multivariate analyses that consider variations in species diversity and their relative abundance between perturbed and control sites (Pearson and Rosenberg, 1978; Warwick and Clarke, 1993; Gray et al., 2002; Orfanidis et al., 2003; Ballesteros et al., 2007).

The efficiency of biotic indices or any inferences on their suitability requires some degree of congruence with criteria for degraded and undegraded sites based on non-biological measures such as chemical proxies of contamination (Benyi et al., 2009). There are a few works carried out in Latin-American environments; the studies of Muniz et al. (2005, 2011, 2012) were precursors, and similar studies were subsequently conducted for other environments (Omena et al., 2012; Albano et al., 2013; Quiroga et al., 2013; Brauko et al., 2015, 2016).

Mar del Plata city is situated at the Southwest Atlantic coast of Argentina (38° 00′S; 57° 32′W) (Fig. 1). The shoreline is characterized by many sandy open beaches alternating with abrasion platforms of consolidated loess, forming cemented sandstones (Amor et al., 1991). The coastline is influenced by a littoral current, predominantly flowing from South, and undergoes severe windstorms (from the SSE sector) mainly during autumn and winter. Tides have a semidiurnal regime, with a tidal amplitude range around 0.8 m and 1.6 m during exceptional tides. Sea surface temperature ranges between 9.3 °C in winter and 20 °C in summer (Guerrero and Piola, 1997), while seawater pH remains between 7 and 8.5 (Isla et al., 1998).

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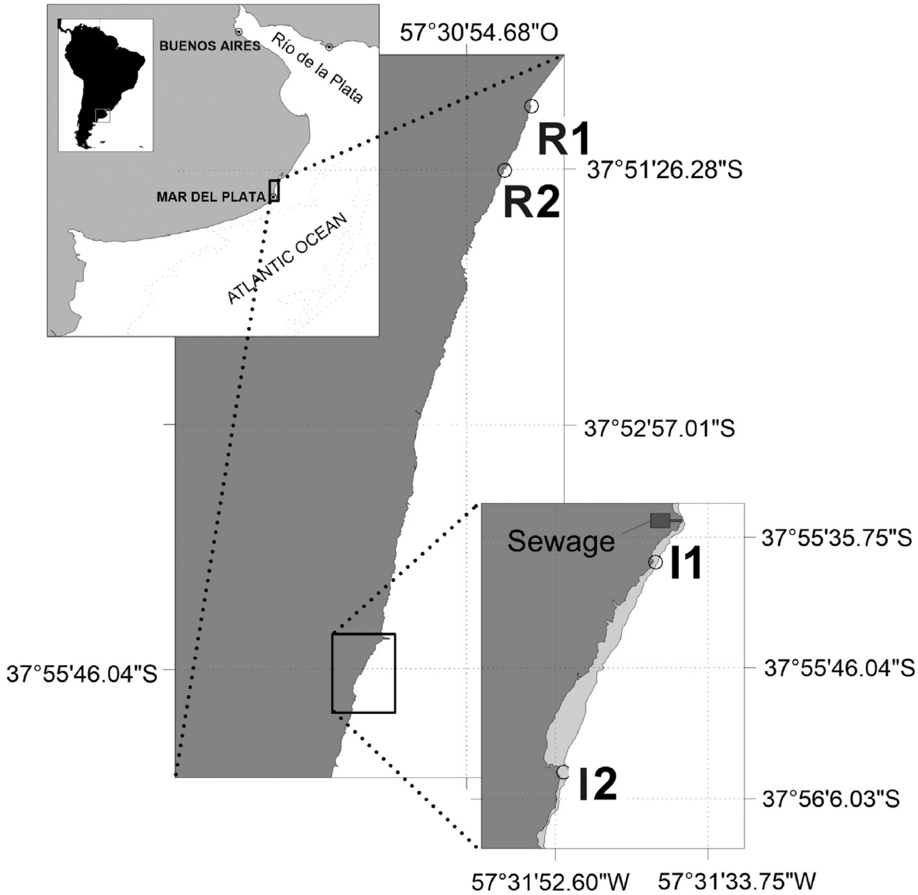

Fig. 1. Distribution of the sampling sites (I1, I2, R1, and R2) and intertidal sewage outfall location in the study area. Site I1 was located at 200 m to the south of the outfall, site I2 at 1000 m south, R1 at 9000 m north, and R2 8000 m to the north of the outfall.

Mar del Plata (ca. 600.000 inhabitants) is the largest seaside resort for sun and beach tourism in Argentina, receiving visits by >3 million people during summer (Bouvet et al., 2005). The city had the worst scenario for both their environmental status and health of people, because raw sewage was directly discharged to intertidal, with a mean volume of 2.8 $m^3 \cdot s^{-1}$ (up to 3.5 $m^3 \cdot s^{-1}$ in summer) (Scagliola et al., 2006). This situation produced 15 km of beaches unfit for bathing people because there was a risk for human health (Comino et al., 2010).

The epilithic intertidal community in natural habitats is dominated by mussel beds of the ecosystem engineer *Brachidontes rodriguezii*, forming a secondary infaunal habitat for several invertebrate fauna. The response of rocky intertidal benthic community to sewage discharges has been evaluated since 1997 (Elias et al., 2015), but no attempt to assess the ecological quality has yet been made. While the assessment of ecological status plays an important role in the management of coastal zones; only a small number of ecological indices are applicable to rocky bottoms (Mangialajo et al., 2007; Juanes et al., 2008; Borja et al., 2012; Díez et al., 2012; Guinda et al., 2014). These indices are very specific for areas where they were developed. An ecologically parsimonious approach dictates that investigators should place greater emphasis on evaluating the suitability of indices that already exist prior to developing new ones (Diaz et al., 2004). Therefore, in this contribution, we apply the most common and widespread indices developed for soft-bottom environments to assess environmental health in response to distinct levels of sewage contamination. The fact that mussel beds create a secondary infaunal habitat allows us to test these indices for soft bottoms in areas with rocky bottoms.

The aim of this study was to evaluate the spatial and temporal variability of the indices in response to the distinct levels of sewage contamination at different sites on intertidal abrasion platforms of Mar del Plata, Argentina. We tested 3 ecological indices, namely AMBI, M-AMBI, and BENTIX. The indices were evaluated in two different ways: (a) including *B. rodriguezii* (IBR) and (b) excluding *B. rodriguezii* (EBR). We hypothesized that the indices should preferably: (a) be highly correlated with the indicators of contamination; (b) vary significantly among impacted and nonimpacted sites; (c) provide values for poorer environmental conditions during the second year of the study due to higher levels of organic contamination; (d) present a high percentage of similarity among responses; and (e) show increased effectiveness when they are calculated without the ecosystem engineer, *B. rodriguezii*, because the abundance of this species at all sites (impacted and reference) reduced the differences between the indices values.

2. Materials and methods

2.1. Study area

The coast of Buenos Aires Province is dominated by sandy beaches; however, around Mar del Plata city, there are quartzite outcrops and almost horizontal intertidal abrasion platforms (geological formation of consolidated loess, limestone, stony rocks, or caliche). The sewage outfall of Mar del Plata city is located 9 km towards the north of the city center (N°11 route, km 507). This intertidal urban effluent discharged 241,920 m^3 of untreated sewage daily during the winter (flow average rate of 2.8 $m^3\ s^{-1}$) and 302,400 m^3 daily during the summer (average of 3.5 $m^3\ s^{-1}$) into the coastal waters (Scagliola et al., 2006), when between 2 and 3 million people visit the city (Bouvet et al., 2005).

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