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Spatial and long-term analyses of reference and sewage-impacted sites in the SW Atlantic (38°S, 57°W) for the assessment of sensitive and tolerant polychaetes

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ABSTRACT

Discharges of effluent in urbanized littoral areas produce nonlinear changes in benthic organisms. Data on the composition of the benthic community are often used to obtain environmental quality classifications that serve to indicate the health of the environment. This study conducted a comparative analysis of the polychaetes associated with mussel beds and related these results to the values of environmental variables at both reference and sewage-impacted sites over a 10 year period in a rocky intertidal habitat on the coast of the SW Atlantic. The results of the study showed spatial and temporal differences in the abundance and dominance of the polychaetes. The study also furnished evidence of a decrease in the environmental quality of the area. This study allowed the classification of the polychaetes into ecological groups, facilitating the calculation of environmental quality indexes.

1. Introduction

Macrobenthic species are sensitive indicators of changes in the quality of the marine environment due to their relatively sessile habits and their inability to avoid unfavorable conditions. Because benthic species are relatively long lived, they also integrate the characteristics of water and sediment quality over time, indicating temporal as well as chronic disturbances (Reiss and Kröncke, 2005). Therefore, changes in marine benthic communities over time have been used as indicators of environmental changes resulting from both natural variations (Kröncke, 1995; Kröncke et al., 1998, 2001) and anthropogenic disturbances (Pearson and Rosenberg, 1978; Underwood, 1996; Carroll et al., 2003).

Several authors view the polychaetes as the taxonomic group with the greatest sensitivity to alterations of soft substrates (Grassle and Grassle, 1977; Bellan, 1984; Ros et al., 1990) due to their ability to adapt to a broad range of habitats and environmental variation (Fauchald and Jumars, 1979). The presence or absence of specific polychaetes in marine sediments provides an excellent indication of the condition or health of the benthic environment. For example, the genus *Lumbrineris* is present in unpolluted environments, whereas spionids or capitellids are frequent in polluted areas (Pearson and Rosenberg, 1978; Ryggs, 1985; Tsutsumi, 1990; Pocklington and Wells, 1992; Dean, 2008). Changes in polychaete species composition from sensitive to tolerant can be observed along a gradient of contamination.

Human activities in coastal areas produce interactions that may be problematic and require resolution. Stakeholders require a simple, reliable indicator of ecological quality. New legislation (the European *Water Framework Directive* and the USA *Clean Water Act*) has driven the development of new indexes to assess the level of quality of coastal sites. These assessments often use an index based on benthic organisms to translate community composition into a quality classification. Generally, however, the classification of organisms into groups identified by their sensitivity to contamination gradients has previously included only organisms found in the Northern Hemisphere. To date, there have been no attempts to categorize polychaetes in the Southern Hemisphere into groups according to sensitivity due to a lack of appropriate taxonomic information and of long-term studies that compare reference and impacted sites.

Mar del Plata city (ca. 600,000 inhabitants) is the most important seaside resort in Argentina, receiving 2–3 million tourists during the summer (Bouvet et al., 2005). However, the city discharges untreated sewage effluent directly to the intertidal zone, producing

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unsuitable conditions for bathing along 15 of its 42 km of beaches (Scagliola et al., 2006).

The intertidal areas around Mar del Plata are characterized by dense mussel beds composed of the small mytilid *Brachidontes rodriguezii* and established on natural or artificial hard substrates (see Scelzo et al., 1996 and references therein). This species is considered an ecosystem engineer because it develops a three-dimensional habitat that provides shelter for organisms that are not present in the surrounding environment (Vallarino, 2002; Borthagaray and Carranza, 2007). Some mussel beds occupy abrasion platforms (geological formations of consolidated loess or stony rocks) in natural sites and around intertidal sewage outfalls. The occurrence of this intertidal community in both reference areas and sewage-impacted sites allows the quantitative study of the composition and distribution of polychaetes.

The aims of this study were to assess (a) the response of intertidal polychaetes associated with mussel beds from a spatial perspective (comparing reference and sewage-impacted sites) and from a temporal perspective of more than 10 years and (b) the classification of polychaetes into ecological groups to allow their use in the calculation of environmental quality indexes.

2. Materials and methods

2.1. Sample collection

The samples examined in this study were collected from three locations: Site 1 (9000–9150 m north of the sewage effluent), Site 2 (between 50 and 200 m south of the sewage effluent) and Site 3 (between 800 and 1000 m south of the effluent) (Fig. 1). Sampling was conducted at each site at the upper or middle intertidal level in intertidal mussel beds developed on abrasion platforms. At each site, 8–16 random sampling units were independently defined on separate rocks. The samples were collected with a 78 cm^2 core, 20 cm in length. A total of 75 sampling units were used. The sampling units were averaged to obtain a single sampling unit for the time (year) and for each site. However, four sampling units involving macrofauna were excluded from the analysis. Samples were collected during January, April and October 1998, 2001, 2004 and 2008; July and October 2005; November and March 1999 and 2000; November 1997 and 2003; and March 2002.

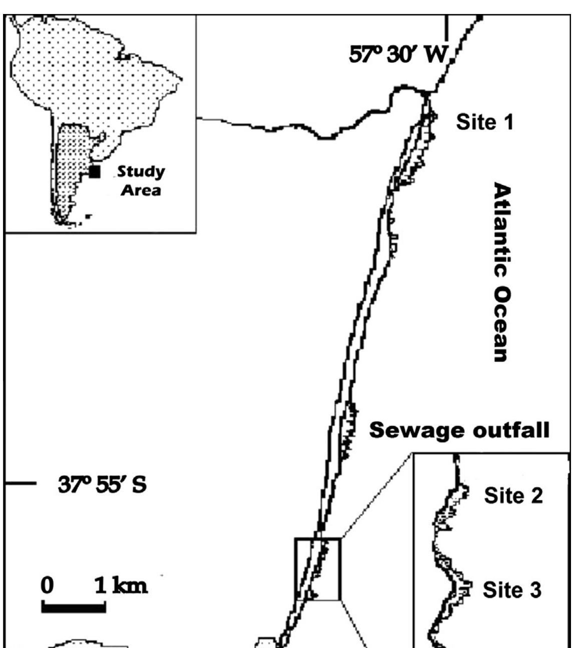

Fig. 1. Sampling sites around Mar del Plata city sewage discharge: control, impacted and control 2, 1997–2008.

The samples from the mussel beds were fixed in a solution of 10% formaldehyde in sea water prior to laboratory analysis. The samples were sorted in the laboratory and sieved through 1 mm mesh. The polychaetes retained on the mesh were identified, quantified and preserved in 70% alcohol.

Selected environmental variables (the pH, turbidity, salinity and temperature of the seawater) were measured *in situ* with a U 10 Horiba in November and March 2000, 2001, 2003, 2004 and 2008. The total organic carbon content (%) was determined by titration from samples of the sediment occurring in the mussel beds (Walkley and Black, 1965).

2.2. Data analysis

The polychaetes were ranked according to their mean dominance. Dominance was defined as the ratio between the number of individuals of each species and the total abundance of polychaetes, expressed as a percentage.

Nonmetric multidimensional scaling (nMDS) was applied as an ordination method to calculate the distance between samples. The Bray-Curtis index and the fourth-root transformation were used. To assess the differences among the three previously defined groups (i.e., the sites), a one-way Analysis of Similarities (ANOSIM) was conducted. A Similarity Percentage analysis (SIMPER) was performed to assess the species that contributed most strongly to the differences among sites. Another SIMPER was conducted to assess the species that contributed most strongly to the differences among years. The dissimilarities among the years were analyzed with this method.

A quantitative analysis of the 10 most abundant polychaetes was performed. The averaged density was plotted year by year for the three sites and then graphically analyzed. A two-way ANOVA was not performed because no interactions were detected between sites and years.

The relationship between the environmental and biological variables was assessed with the BIO-ENV subroutine. All these analyses were performed with $PRIMER_5$.

3. Results

A total of 64,723 individuals belonging to 27 polychaete taxa (14 families) were recorded from 1997 to 2008 at the intertidal sites (Table 1). Most species were rare or in low abundance. The 10 most strongly dominant species represented more than 99.5% of the total abundance and were used in the quantitative analysis.

3.1. Spatial analysis

The nMDS (Fig. 2) shows the reference sites (1) at the lower left and a large number of sewage-impacted sites (2 and 3) in the central part of the graph. The sampling units from both the reference and the sewage-impacted sites (separated by a dotted line), grouped on the right, correspond to the sampling units for 2008. A one-way Analysis of Similarity (ANOSIM) showed significant differences (Global $R = 0.194$, $p = 0.1\%$), with the reference site differing from the impacted sites ($R_{3,2} = 0.005$, $p = 0.6\%$; $R_{2,1} = 0.289$, $p = 0.1\%$; $R_{3,1} = 0.2$, $p = 0.1\%$).

The SIMPER analysis identified the species that contributed most strongly to the differences among sites (Table 2). Site 2 (the closest site to the sewage outfall) was characterized by the capitellid

Table 1
List of polychaete taxa ranked according to their dominance. Species in bold were used in the quantitative long-term analysis.

Taxa	Dominance
Boccardia proboscidea	**36.42**
Boccardia spp.	**24.64**
Syllis prolixa	**13.48**
Leodamas uncinata	**8.3**
Rhynchospio glutea	**7.39**
Syllis gracilis	**4.19**
Capitella "capitata" sp.	**3.89**
Alitta succinea	**0.59**
Protocirrineris angelicolliatio	**0.37**
Caulleriella bremecae	**0.25**
Polychaete unid.2	0.12
Polychaete unid.1	0.1
Syllis unid.	0.08
Lumbrineris tetraura	0.04
Syllidae unid.	0.03
Phyllodoce sp.	0.03
Polydora sp.	0.02
Dodecaceria meridiana	0.02
Polychaete unid. 3	<0.01
Hesionidae unid.	<0.01
Spionidae unid.	<0.01
Glycera americana	<0.01
Heteromastus similis	<0.01
Terebellidae unid.	<0.01
Paleanotus intermedius	<0.01
Halosydnella sp.	<0.01
Lumbrineriopsis mucronata	<0.01
Oeonidae unid.	<0.01

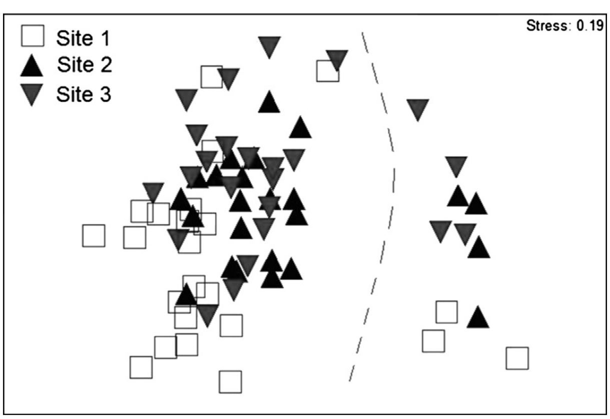

Fig. 2. nMDS showing the sampling units for Site 1 (open squares), Site 2 (triangle pointing upward) and Site 3 (triangle pointing downward). The sampling units for 2008 appear on the right-hand side of the figure, separated by a dotted line.

Capitella "capitata" sp. (most likely, a complex of species) and the spionids *Boccardia* spp. and *B. proboscidea*. Site 3 was characterized by the spionids *B. proboscidea*, *Syllis prolixa*, *Rhynchospio glutea* and *Leodamas* (formerly *Protoariciella*) *uncinata*. The mean abundance of *C. "capitata"* sp. was lower at Site 3 than at Site 2. Site 1 (the non-impacted site) showed the same composition of polychaetes as Sites 2 and 3, but the species at Site 1 were represented by fewer individuals.

3.2. Long-term trends

The species composition of the polychaetes changed over the years studied. Table 3 shows the rankings of the species for each year. *S. prolixa* was the most abundant in 1997 and 2004. The dominance of *Syllis gracilis* and *L. uncinata* was greater at Sites 1 and 3.

Boccardia spp. was generally the most abundant. It was dominant from 1998 to 2003 and sub-dominant in 2004–2005, reaching its highest abundance in 2003. During 2005, the dominant species was *Rhynchospio glutea*. The year 2008 was characterized by the dominant species *B. proboscidea*. All these species dominated at Site 2 (a sewage-impacted site).

The dissimilarities (SIMPER analysis) between all pairs of years showed a pattern of increasing disturbance from 1997 to 2008 (Table 4). In particular, 2003 showed significant differences due to the dominance of *Boccardia* spp., 2005 showed significant differences due to the dominance of *Rhynchospio glutea* and 2008 showed significant differences due to the dominance of *B. proboscidea* (Table 3).

3.3. Quantitative spatial and temporal trends

The polychaete species showed a variable pattern of densities over the study years and sites (Fig. 3). The syllid *S. prolixa* (Fig. 3a) was dominant in 1997, with mean densities of 8000 ind m^{-2} at Site 2 and 16000 ind m^{-2} at Site 3 followed by a subsequent decrease. *S. prolixa* reached a peak in 2001 (average 17000 ind m^{-2}), primarily at Site 3. At Site 1, this species showed a mean density of 12000 ind m^{-2} in 1999 and reached a peak of 9000 ind m^{-2} in 2002. The other syllid, *S. gracilis*, showed a mean density of 6000 ind m^{-2} at Site 3 in 1997 and reached a peak in 1998 at Site 1 (mean of 3000 ind m^{-2}). The mean density decreased over time (Fig. 3b).

Another dominant species at Site 1 was the orbiniid *L. uncinata*, which showed low mean densities except in 1997 and 2003 (2500–3000 ind m^{-2}). At Site 3, the density of this species ranged between 1000 and 2000 ind m^{-2} except for peaks in 2004 and 2005 (up to 6500 ind m^{-2}) (Fig. 3c).

The cirratulid *Protocirrineris angelicolliatio* showed very low mean densities. The highest densities were found at Sites 2 and 3 in 1997 (1250 ind m^{-2} and 500 ind m^{-2}, respectively). At the Site 1, this species was not recorded except in 1998, when it appeared at an extremely low density (Fig. 3d). *Caulleriella bremecae*, another cirratulid species, was abundant (mean densities between 700 and 1100 ind m^{-2}) during 1997 at Sites 2 and 3 and showed a peak of 1800 ind m^{-2} in 1998 at Site 2 (Fig. 3e). Subsequently, it was present at low densities.

Boccardia spp. always occurred at densities between 1000 and 9000 ind m^{-2} at Sites 2 and 3. However, it reached 38000 ind m^{-2} at Sites 2 and 3 during 2003 and was less abundant at Site 1 (Fig. 3f). Note that in 2008, *Boccardia proboscidea* was the only dominant species at Sites 2 and 3. The mean density of this species at the sewage-impacted sites reached values up to 80000 ind m^{-2} (Fig. 3h). Another spionid, *Rhynchospio glutea* (Fig. 3g), was always rare but showed a peak of 40000 ind m^{-2} in 2005 at Site 2.

Capitella "capitata" sp. characterized Site 2, the site closest to the sewage discharge (Fig. 3h). This species showed peaks of high density in Site 2 (between 2500 and 6500 ind m^{-2}) from 1997 to 2001. In 2003, this species showed very low densities. During 2004 and 2005, the species reached high densities (2500–3000 ind m^{-2}), but it was excluded from 2008. The species showed very low densities at Site 3 and was absent from Site 1.

The nereidid species *Alitta succinea* (formerly *Neanthes*) occurred at low densities (200–650 ind m^{-2}) at Site 2 (Fig. 3i) and reached a peak at Sites 1 and 3 in 2000 (300 ind m^{-2}). Beginning in 2001, the density of this species decreased at all sites.

3.4. Environmental variables

Organic matter (Fig. 4a) reached a peak at Site 2 during 2003 and reached a peak at all three sites in 2008. Turbidity (Fig. 4b) reached a peak in 2001 at Sites 2 and 3 (the sites closest to the

Table 2
SIMPER analysis showing the species that characterize the different Sites. Site 1 reference site, Site 2 at 50 m far from sewage discharge, and Site 3 at 1000 m far from the sewage discharge.

Taxa	Site 2 Av. Abund	Site 3 Av. Abund	Av. Diss	Diss (SD)	Contrib (%)	Cum (%)
Average dissimilarity = 73.31						
Boccardia spp.	40.48	38.81	18.74	0.96	25.57	25.57
Boccardia proboscidea	54.70	101.39	14.52	0.51	19.80	45.37
Syllis prolixa	13.69	37.55	13.30	1.00	18.15	63.52
Leodamas uncinata	9.66	19.79	7.38	0.76	10.07	73.58
Capitella"*capitata*" sp.	15.07	1.67	6.92	0.75	9.44	83.02
Rhynchospio glutea	2.60	29.33	6.15	0.39	8.39	91.41
Average dissimilarity = 76.68						
Taxa	Site 2 Av. Abund	Site 1 Av. Abund	Av. Diss	Diss (SD)	Contrib (%)	Cum (%)
Boccardia spp.	40.48	28.24	26.05	1.19	33.97	33.97
Capitella "capitata" sp.	15.07	0.25	11.92	0.83	15.55	49.52
Boccardia proboscidea	54.70	2.86	11.81	0.45	15.41	64.93
Syllis prolixa	13.69	7.60	10.27	0.81	13.39	78.32
Leodamas uncinata	9.66	6.78	7.80	0.68	10.17	88.48
Syllis gracilis	3.80	3.92	2.98	0.89	3.89	92.37
Average dissimilarity = 75.48						
Taxa	Site 3 Av. Abund	Site 1 Av. Abund	Av. Diss	Diss (SD)	Contrib (%)	Cum (%)
Boccardia spp.	38.81	28.24	23.90	1.08	31.66	31.66
Syllis prolixa	37.55	7.60	18.25	1.12	24.18	55.84
Boccardia proboscidea	101.39	2.86	10.76	0.44	14.25	70.09
Leodamas uncinata	19.79	6.78	8.18	0.98	10.84	80.93
Rhynchospio glutea	29.33	0.30	5.90	0.35	7.82	88.75
Syllis gracilis	10.55	3.92	5.55	0.91	7.36	96.10

Table 3
Average abundances of species in the different years. The sub-index represents the order within the year, not the comparison between years.

Taxa	1997	1998	1999	2000	2001	2002	2003	2004	2005	2008
Syllis prolixa	68.2_1	9.6_3	6.5_2	17.7_2	25.8_2	8.3_2	1.9_4	34.1_1	9.1_4	17.8_2
Syllis gracilis	24.4_2	8.2_4	2.9_4	4.1_5	6.2_5	3.06_3	2.9_3	7.4_5	3.5_6	0
Leodamas uncinata	11.9_3	16.6_2	2.4_5	5.2_4	6.3_4	0	13.9_2	23.1_3	18.2_3	7.2_3
Boccardia spp.	8.9_4	36.0_1	42.9_1	22.8_1	38.3_1	38.3_1	220.8_1	24.3_2	34.1_2	0
Capitella "capitata" sp.	6.4_5	6.7_5	3.8_3	11.4_3	7.4_3	3.2_4	0.8_6	6.7_6	6.3_5	0
Cauleriella bremecae	5.5_6	0.6_8	0.2_7	0	0.03_9	0	0	0.02_9	0	0
Rhynchospio glutea	1.4_7	0.0	0	3.1_6	0.07_8	0	1.3_5	17.8_4	83.3_1	0
Protocirrineris angelicolliatio	0.6_8	1.7_6	0.2_8	0.6_8	0.2_7	0	0	0.1_8	0	0
Alitta succinea	0.5_9	1.4_7	1.1_6	1.9_7	0.9_6	0.2_5	0.04_7	0.8_7	0.2_7	0
Boccardia proboscidea	0	0	0	0	0	0	0	0	0	406.2_1

Table 4
Dissimilarities between sampling years, summarized from the SIMPER analysis.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
1998	67.91								
1999	77.6	56.66							
2000	70.3	63.79	61.36						
2001	71.05	66.99	64.13	69.16					
2002	76.35	53.58	40.8	57.74	62.1				
2003	86.24	70.5	67.5	78.56	74.52	69.11			
2004	67.4	69.12	69.85	70.28	70.91	66.88	79.59		
2005	82.88	68.81	63.08	70.1	73.01	63.48	74.3	74.82	
2008	93.1	95.04	95.85	95.12	94.08	95.11	98.51	94.67	96.53

sewage discharge). During 2004 and 2008, turbidity was again observed at Sites 2 and 3, and the value of turbidity increased. The water temperature (Fig. 4c) reached a peak during 2000, 2001 and 2004 at the three sites (20–22 °C) due to seasonal changes. The pH (Fig. 4d) reached a peak at the three sites during 1999, 2003 and 2008 (8.2–8.4). Salinity showed relatively constant values (30–35) and was low at the impacted sites due to freshwater runoff. In 2008, salinity decreased abruptly at all sites (30–20) (Fig. 4e).

The BIO-ENV results showed that the maximum correlation ($r = 0.394$) of the environmental variables with the intertidal benthic community occurred if all five environmental variables (salinity, temperature, pH, turbidity and organic matter) were used.

4. Discussion

This study investigated the variations in the abundance and composition of the polychaetes at three sampling sites on the SW Atlantic shore. The study showed that the species composition of the polychaetes varied over time (years) and space (sites).

From a spatial perspective, note that Site 2 (the site nearest the sewage discharge) is permanently sewage-impacted, as previously shown by Elías et al. (2009). Only spionids and capitellids were dominant over time at this site. Spionids and capitellids are classical indicators of disturbance and are always present at organically enriched sites (e.g., Pearson and Rosenberg, 1978; Pocklington and Wells, 1992).

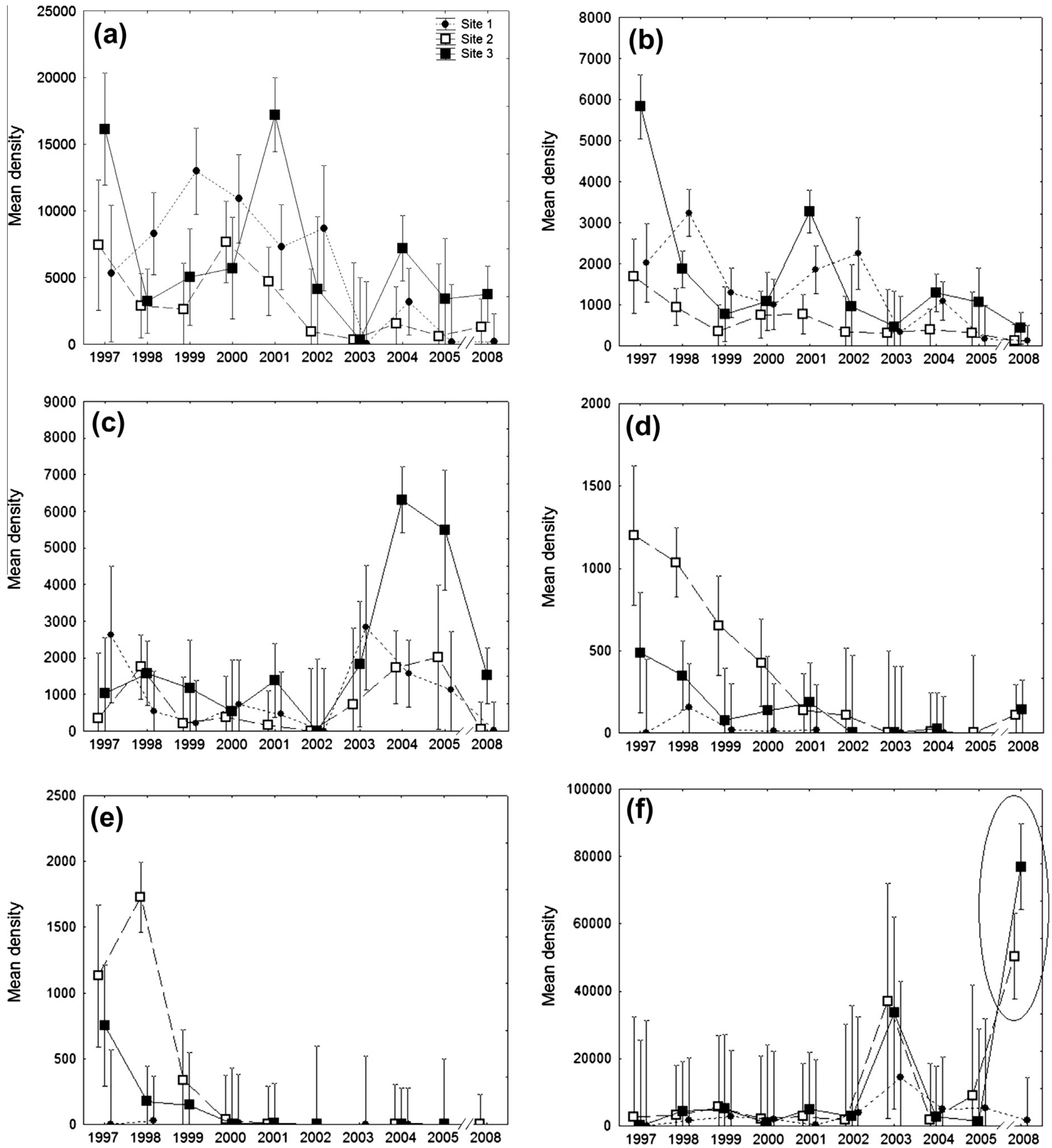

Fig. 3. Mean density of primary polychaete species at the Control, Impacted and Control 2 sites, 1999–2008: (a) *Syllis prolixa*, (b) *Syllis gracilis*, (c) *Leodamas uncinata*, (d) *Protocirrineris angelicolliatio*, (e) *Cauleriella bremecae*, (f) *Boccardia* spp., (g) *Rhynchospio glutea*, (h) *Capitella "capitata"* sp., (i) *Alitta succinea.* Note that different scales are used to represent the abundance over time.

Several studies conducted by the Mar del Plata Public Sanitation Works (the municipal enterprise in charge of the management of waste disposal) have shown that the sewage contains high levels of organic matter and low levels of heavy metals (below the values specified by national and international standards). The effluent pre-treatment plant retains 20–25 tons (wet weight) of solids daily. The raw sludge contains 86% organic matter and exhibits the following average annual concentrations: total nitrogen, 63.13 mg L^{-1}; total phosphorus, 6.88 mg L^{-1}; oil and grease, 67.11 mg L^{-1} (Scagliola et al., 2006; Scagliola et al., 2011).

Site 3 also showed signs of impact due to its proximity to the sewage discharge (800–1000 m south of the effluent). However, this site had served as a reference site (non-sewage-impacted site) in the initial studies (Vallarino, 2002; Vallarino et al., 2002; Vallarino and Elías, 2006; Elías et al., 2003, 2006). During most of the year, the longshore current (south to north) and the dominant winds (from the east or the south) push the sewage flume northward, far from the sampling sites and the city. However, the dominant winds are from the north during the summer and change the direction of the discharge plume to the south, i.e., toward the sampling area and the city. During the summer, heavy tourism also produces a significant increase in sewage volume, from 2.8 to 3.5 $m^3 s^{-1}$ (approximately 60% greater, Scagliola et al., 2006). These two factors produced a significant increase in pollution, which affected the intertidal benthic organisms (Vallarino and Elías, 2006; Elías et al., 2006). The present study shows that since 2005, Site 3 has been permanently sewage-impacted. This change was confirmed by the presence of a community structure and tolerant species characteristic of a sewage-impacted site. The increasing dissimilarity among the sampling years from 1997 to 2008 is

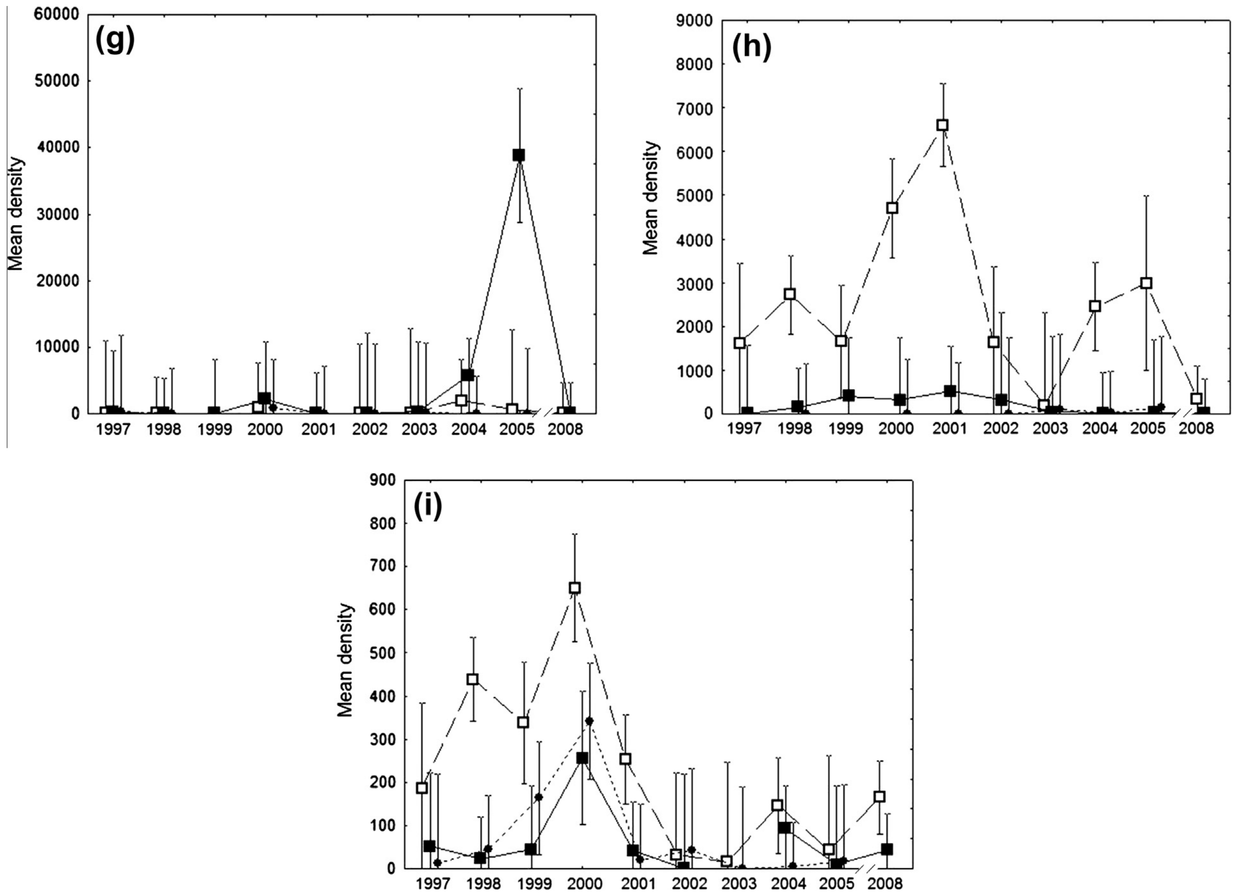

Fig. 3 (*continued*)

consistent with a pattern of increasing environmental deterioration. The organic matter in the sediments also shows increasing values at the sewage-impacted sites. This observation is consistent with the peaks in the abundance of spionids, indicator species for organic enrichment. The development of reefs of an exotic polychaete, *Boccardia proboscidea*, is an indicator of organic pollution (Jaubet et al., 2011; Garaffo et al., 2012) and represents an unequivocal sign of increasing pollution.

Other ecological studies at these sites affected by sewage discharges (Elías et al., 2006, 2003) have shown that the spionid species that indicated the occurrence of organic enrichment was *Boccardia polybranchia.* However, the spionids that indicate organic pollution belong to a suite of species. At least two primary species belonging to this suite have been identified in the area of the SW Atlantic coast corresponding to the study area: *Boccardia claparedei* (first identified and reported as *B. polybranchia*) and the exotic *Boccardia proboscidea* (both identified by V. Radashevsky). The first-named species belongs to the *Boccardia* spp. complex. It is suspected that other species could also be present in this complex. A taxonomic revision is required for this region, although such a revision is beyond the objectives of this work. *Boccardia* spp. are also frequently mentioned as species associated with sewage outfalls in the Southern Hemisphere, e.g., *B. polybranchia* or *B. proboscidea* in Australia (Dorsey, 1982). The same association has been reported from California (Dorsey et al., 1983).

B. proboscidea occurs naturally in Japan and on the western coast of North America (Hartman, 1940; Sato-Okoshi, 2000). It has been introduced to other parts of the Pacific (Bailey-Brock, 2000; Blake and Kudenov, 1978; Hewitt et al., 2004; Read, 2004; Sato-Okoshi et al., 2008) and to South Africa (Simon et al., 2010). Recently, the species has been found in Argentina in both the northern temperate region (Jaubet et al., 2011) and Patagonia (Radashevsky pers. com.). It has long been suspected that the species was present at Site 2 as a companion species of the intertidal community. In spring 2008, however, a demographic explosion of this species occurred in response to the increase in organic matter in the sediments due to sewage input, as shown in Fig. 4. In intertidal areas of the Pacific (California), the species has reached peaks of 164000 ind m^{-2} in association with a sewage discharge (Dorsey et al., 1983). However, in the SW Atlantic area of the current study, the species has reached extraordinary densities, with certain sampling units showing densities ranging from 848750 to 1465000 ind m^{-2} (Garaffo et al., 2012). These high densities, covering nearly 100% of the rocks, the result in massive reefs composed of sand tubes. These reefs are highly stable and compact; they can support the weight of a person walking over them (Jaubet et al., 2011). The reef covers the entire impacted site nearly completely, from the outfall to more than 2000 m south of the sewage effluent (including Site 3 and beyond).

4.1. Classification of polychaetes in ecological groups

Syllids have proven highly useful as an indicator taxon, although they show reactions that are opposite to those usually observed in other polychaete families. They are known to be highly sensitive to pollution or other types of stress, decreasing in numbers of species and individuals or completely disappearing (Giangrande et al., 2004; Musco et al., 2004). In the present study, syllid species were found at both the reference sites and the sewage-impacted sites. The abundances of these species varied spatially. They were dominant at the non-impacted sites but

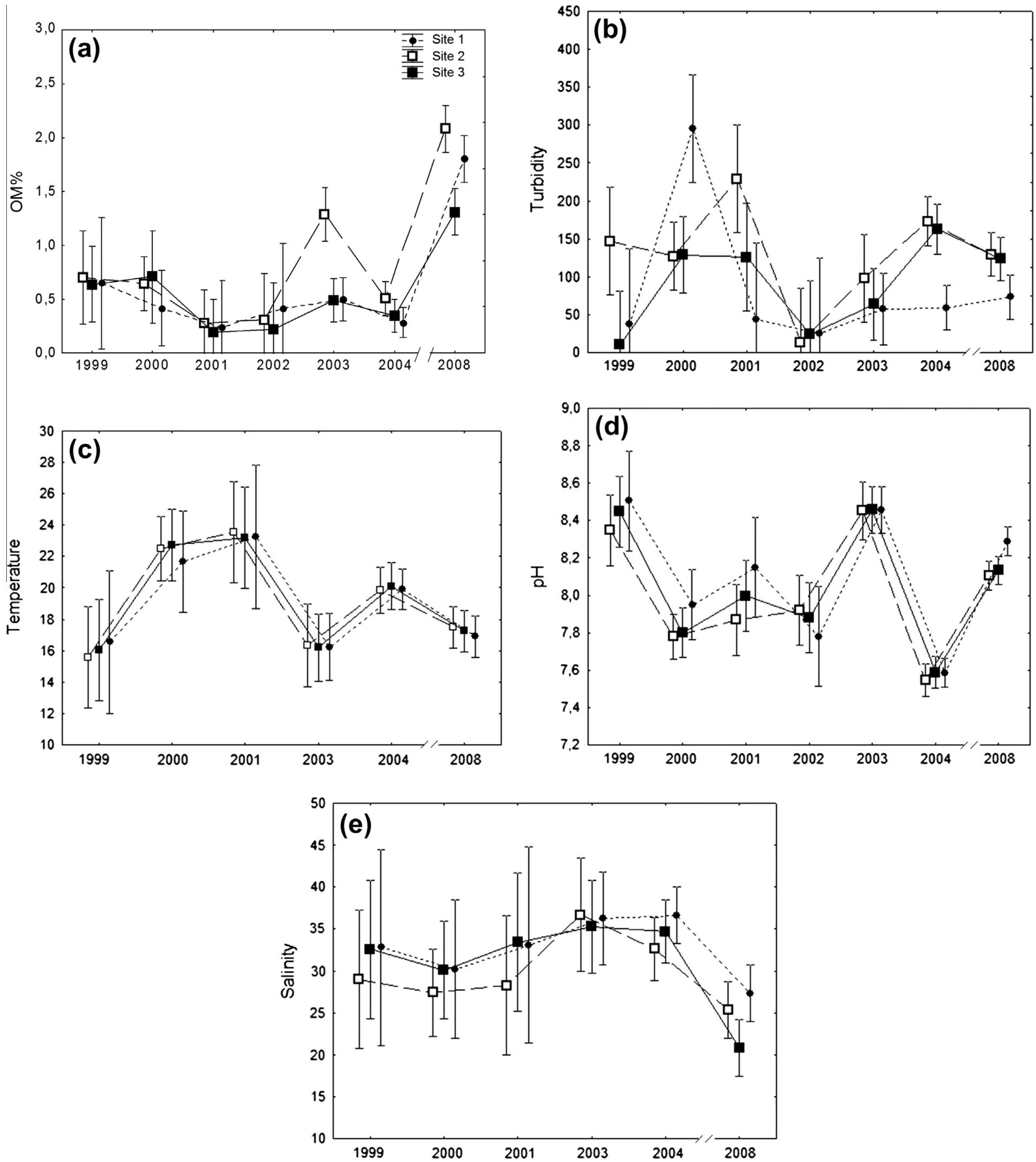

Fig. 4. Environmental variables at Sites 1, 2 and 3, 1999–2008: (a) organic matter (OM%), (b) turbidity, (c) temperature, (d) pH, (e) salinity.

abundant at the sewage-impacted sites. This pattern has been consistent over the years of the study.

Opportunistic forms appear to be very rare among Syllids. A taxon identified as *Syllis* cfr. *hyaline* was the only polychaete present at a site influenced by a high-temperature water discharge (Giangrande et al., 2005). Another taxon often collected in stressed environments is *S. gracilis*, which has been shown to be a complex of sibling species (Cognetti and Maltagliati, 2000). Lastly, *Syllis prolifera*, from the Mediterranean Sea, is a species that is considered to increase in abundance with increasing environmental stress (Bellan, 1980; Giangrande, 1988). On the South Adriatic coast, several substantial changes in the species composition and abundance of Syllidae were observed in relation to a putatively affected area (Musco et al., 2004). Syllid species appear to respond rapidly to disturbance, with changes occurring primarily at shallow depths. A population of *S. prolifera* declined at an impacted site due to the high sedimentation rate (Giangrande et al., 2005).

The species that characterized the non-impacted sites in the initial sampling years (1997–2000) were *Syllis prolixa*, *S. gracilis* and the orbiniid *Leodamas uncinata* (Elías et al., 2006, 2003). All these species dominated the reference sites and are the only polychaetes associated with mussel beds in natural areas (Olivier et al., 1966; Scelzo et al., 1996). The species were negatively correlated with organic enrichment (Elías et al., 2003). According to this response, the syllids and the orbiniid must be classified in groups I or II. However, this long-term study showed that these species were indifferent or tolerant to certain levels of organic matter. These species must be considered tolerant to low organic contamination and would therefore belong in group III. This observation suggests that both syllid species are deposit feeders of some sort (or at least facultative deposit feeders), whereas Fauchald and Jumars (1979) previously suggested that they were carnivores. However, *S. gracilis* and, most likely, also *S. prolixa* (Paola, pers. comm.) represent complexes of sibling species. A taxonomic study of these polychaetes is needed to assess the identity of the species and their specific response to organic enrichment.

The cirratulids *Caulleriella bremecae* and *Protocirrineris angelicolliatio* were common and abundant at intermediate distances from the sewage effluent. They are indicators of moderate organic contamination or first indicators of increasing organic contamination (see Elías et al., 2006). In this study, cirratulids appeared at Sites 2 and 3, associated with high levels of organic matter. *P. angelicolliatio* is a natural inhabitant of rocky shores, usually associated with low intertidal levels and found in mussel beds (Elías and Rivero, 2008; Orensanz pers. comm.). The other cirratulid, *C. bremecae*, has been described as an inhabitant of areas organically enriched by sewage effluent; *Caulleriella galeanoi* and *Dodecaceria meridiana* have also been considered to inhabit areas of this type (Elías and Rivero, 2008). However, all these species declined during the study period as the organic contamination increased. Although cirratulids are traditionally classified in group IV, these species must be considered to belong to group III.

At sites that are organically enriched by discharges of sewage, *Boccardia* spp. proliferates and increases because these worms ingest the film of organic matter deposited at the surface (Grall and Glemarec, 1997). According to their preference for organically enriched sites, these species must be considered in group III, i.e., species tolerant of excess organic matter enrichment. Although these species may appear in natural conditions, their populations are stimulated by organic enrichment. However, the exotic spionid *Boccardia proboscidea* must be considered as a member of group IV (second-order opportunist species) because of their tolerance to high levels of organic pollution in highly contaminated sites. By definition, this species belongs to group IV, i.e., small species with a short life cycle adapted to life in reducing sediments where they can proliferate (http://ambi.azti.es).

Rynchospio glutea is an infaunal polychaete and has been recorded from sandy beaches in Patagonia (Escofet, 1983; Orensanz et al., unpubl. data). The occurrence of this species was enhanced at Sites 2 and 3 during 2005. For this reason, it could be considered to belong to group III.

The complex *Capitella* ''*capitata*'' sp. is considered to belong to group V (first-order opportunist species, deposit feeders that proliferate in sediments under reducing conditions up to the surface). *Capitella ''capitata''* sp. (see Pearson and Rosenberg, 1978; Pocklington and Wells, 1992; Reish, 1957; Tsutsumi, 1990) dominated the sites closest to the sewage outfall. In this study, this species showed peaks of high density only at Site 3. However, during summer and as a result of the increased organic pollution and wind conditions, Site 3 had low mean densities of *C. ''capitata''* sp. (Elías et al., 2006). This species was replaced by *Boccardia* spp. at the site most heavily impacted by sewage (Site 2) during 2003 and 2008, when organic matter reached its maximum values. However, *C. ''capitata''* sp. is the polychaete that is best adapted to organically enriched habitats. A possible explanation of the exclusion of this polychaete complex from most sewage-impacted sites is its habitat/feeding type. *Capitella* is infaunal, and the excessive organic matter in the mussel matrix could generate unfavorable conditions (anoxia or toxic gases), whereas *Boccardia* is tubiculous and feeds at the water–sediment interface, avoiding anoxia and toxic gases. The initial stage of succession in heavily contaminated enriched sediments is characterized by tube-dwelling filter-feeding polychaetes (Pearson and Rosenberg, 1978). Under heavy organic pollution, *C. ''capitata''* sp. was found to be absent from the impacted site during the summer (Elías et al., 2006). It was also absent from the inner docks of the Mar del Plata harbor (Rivero et al., 2005).

Another species enhanced by the sewage discharge was *Alitta succinea*. This species was formerly described as *Neanthes succinea* from the mixohaline waters of a coastal lagoon (Orensanz and Estivariz, 1971). *Neanthes* spp. has been found in or around organically polluted zones (Pearson and Rosenberg, 1978) and has been considered tolerant (group III). A previous study (Elías et al., 2003) recorded *N. succinea* for the first time at an impacted site of the SW Atlantic. In the recent invasion of *Boccardia proboscidea*, the only associated polychaete that can live within the reef is *A. succinea* (Jaubet pers. obs.). Despite its ''large'' size, this species must be considered to belong to group IV because of its subsurface feeding type and tolerance to anoxic conditions within the reefs formed by *B. proboscidea*.

Other intertidal polychaetes not included in this analysis but potentially useful as environmental indicators were also classified: *Lumbrineris tetraura*, *Lumbrineriopsis mucronata*, *Phyllodoce* sp., *Glycera americana* and *Paleanotus intermedius* (group I, very sensitive species); *Polydora* spp. and *Heteromastus similis* (group III, tolerant species).

5. Conclusions

This study is the first investigation of polychaetes based on a long-time series of data collected from both organically contaminated and reference sites in Argentina. The composition and abundance of the polychaetes showed strong spatial and temporal trends. The opportunistic and tolerant polychaetes *Capitella ''capitata''* sp., *Boccardia* spp., *B. proboscidea* and *Alitta succinea* were abundant and dominant at the sewage-impacted sites, whereas *Syllis prolixa*, *S. gracilis* and *Leodamas uncinata* were dominant at the reference site. Increasing contamination has been observed since 2005. The final step in the process of environmental degradation has been the development of a sewage-induced reef constructed by the exotic polychaete *Boccardia proboscidea*. This study is the first characterization of polychaetes according to the classification of benthic organisms in ecological groups for use in the calculation of environmental quality indexes. The information could be useful for local authorities and stakeholders in Mar del Plata city (the most popular recreational seashore area in Argentina). The findings of this study can eventually be extrapolated to adjacent coastal localities and other portions of the warm temperate biogeographical region extending from northern Argentina and Uruguay to southern Brazil.

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