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Change in the meiofauna community structure of sandy beaches of the Nuevo Gulf (Chubut, Argentina)

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ABSTRACT

The composition and distribution of the benthic meiofauna assemblages of the Nuevo Gulf (Chubut, Argentina) are described in relation to abiotic variables. The meiofauna and sediment samples were collected in the intertidal zone of four sandy beaches with different anthropic disturbances in June 2005. The samples were obtained at 20 sampling sites using a 2.5 cm diameter core tube at a depth of 10 cm. A total of 13 meiofauna taxa were identified, with the meiofauna being primarily represented by nematodes, gastrotrichs, ciliates and polychaetes and the meiofauna abundances ranging from 1.5 × 10^3 to 6.5 × 10^3 ind. 10 cm^{-2}. Univariate (one-way ANOVA test) and multivariate (ANOSIM/MDS test) analyses showed clear dissimilarities in community structures between sites with anthropic effects and those in pristine condition, revealed by the significant differences were found between beaches near to and far way from a city with port activity. The meiofaunal assemblage varied in abundance and diversity, and these changes in the community structure may have been related to environmental gradients on the shore. The BIO-ENV analysis showed that the redox potential discontinuity depth might be the main factor in the spatial distribution of organisms.

Key-Words: Meiofauna; Intertidal; Sandy sediment; Argentina.

INTRODUCTION

The interest of the benthic biologist in meiofauna increases started in the early 1980s. Probably the main obstacles of benthic meiofauna are its small size, together with difficulties in isolating the meiofauna from the sediments and the identification of species belonging to different taxa (Austen *et al.,* 1994).

Meiofaunal organisms play an important ecological role in the aquatic ecosystem and are well suited for environmental impact assessment studies. They have short generation times, continuous reproduction, and in situ direct development and, therefore, their potential for rapid response to environmental change is high (Giere, 1993; Fraschetti *et al.,* 2006; Gyedu-Ababio & Baird, 2006). The marine meiofauna is

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often a very useful tool for biological monitoring since the community structure may be sensitive to both natural and anthropogenic environmental disturbance (Mirto & Danovaro, 2004; Gyedu-Ababio & Baird, 2006; Moreno *et al.,* 2008). In addition, the beaches may function as natural filters responsible for the remineralization of substances, which then return to the sea as nutrients (Coull & Chandler, 2001). The interstitial system of the beaches and marshes, in particular the system protected by muddy sediments, is formed by long and intricate food chains of bacteria, unicellular algae and meiofauna at the first levels. Therefore, biological systems are the dependent on the productivity of coastal areas (Higgins & Thiel, 1988; Leguerrier *et al.,* 2003).

The growth and diversity of the meiofauna may be stimulated by feeding on bacteria, which could increase the recycling of nutrients into the ecosystem and thereby be expected to have a greater productivity (de Wit *et al.,* 2001; De Troch *et al.,* 2006). Moreover, the meiofauna can provide food for higher trophic levels, such as fish and marine invertebrates (Leduc & Probert, 2009). The spatial patterns of the structure of the meiofaunal community in sandy beaches of marine ecosystems may be associated with different environmental variables. Related to this, the sediment granulometry (Gómez Noguera & Hendrickx, 1997; Barnes *et al.,* 2008), the organic matter source in coastal sediments (Danovaro *et al.,* 2002; Flach *et al.,* 2002; Moreno *et al.,* 2008; Ingels *et al.,* 2009; Pusceddu *et al.,* 2009), and oxic and anoxic conditions in the interstitial pore space (Mirto *et al.,* 2000; Sutherland *et al.,* 2007) have a fundamental role in the richness and abundance of the benthic meiofauna.

The criteria in the study of benthic meiofauna were established by Giere (1993) and these concepts have been recently applied in Latin America. Various studies were carried out on the South American coasts, in the Magallanes' strait (Chen *et al.,* 1999), on the Brazilian coast (Netto *et al.,* 2005; Netto *et al.,* 2009) and on the Chilean coast (Neira *et al.,* 2001; Lee *et al.,* 2006; Veit-Köhler *et al.,* 2009). However, none of the studies took place on the Argentinean coasts.

In this paper, we analyze the structure of the meiofauna assemblages in the intertidal sandy sediment of the Nuevo Gulf (Chubut, Argentina), over increasing distances from the beach of Puerto Madryn to the mouth of the gulf. The objective of this work was to evaluate the meiofaunal community structure and their relation with measuring the abiotic variables, in order to determine if the number of taxa and abundances of meiofauna change along of different beaches with anthropic effects.

MATERIAL AND METHODS

Study area

The study area is located on the southern coasts of Nuevo Gulf (42°43'S, 65°02'W to 42°50'S, 64°52'W), and in the southern part of Península Valdés on the Atlantic coast of South America (Chubut province, Argentina) (Fig. 1). The physical characteristics are similar to dissipative beaches with fine sediment. The coastal area is characterized by rock outcrops of easily eroded materials, such as marine sediments, sandstones, tuffs and silt-stones (Haller, 1981).

The tidal current is the most important water movement and the regime is semi-diurnal, ranging in altitude from 4 to 7 m. The Nuevo Gulf area is situated in the arid Patagonian region, characterized by low and irregular rainfall regimes (173 mm per year) and strong, frequent winds. The average surface water temperature is 13.5°C, ranging from 9.8°C (August-September) to 16.5°C (February). The spring phytoplankton bloom starts in early October with a second smaller bloom occurring in late February. The mean chlorophyll *a* concentration is 0.5 mg m^{-3}, the primary production being limited by nitrate availability (Charpy & Charpy, 1977; Charpy-Roubaud *et al.,* 1982).

The city of Puerto Madryn, on the west coast of the Nuevo gulf, experiences notable changes in the characteristics of its surrounding waters due to sewage, storm-water and industrial discharges on its beaches. However, according to Esteves & De Vido de Mattio (1980), the variation in salinity in Nueva Gulf may be slower when compared to surrounding areas (the South). Therefore, in the vicinity of this bay, the movement of the water body may not participate in the general movement of the gulf, which depends mainly on the instantaneous direction and intensity of winds and tides (Krepper & Rivas, 1979).

Sampling and sample processing

During June 2005, a systematic sampling was conduced on mesolitoral, and 20 samples were taken in areas with the presence of tubeworm polychaeta communities (Maldanidae family). The sampling sites were located at four sandy beaches separated by a rocky area called "restinga": At Nueva beach 11 sites were selected, and at Kaiser beach, Paraná beach and Cerro Avanzado beach three sites were selected for each beach (Fig. 1). Three replicates at each site were taken manually using a 2.5 cm diameter core tube at a depth of 10 cm to analyze the meiofauna.

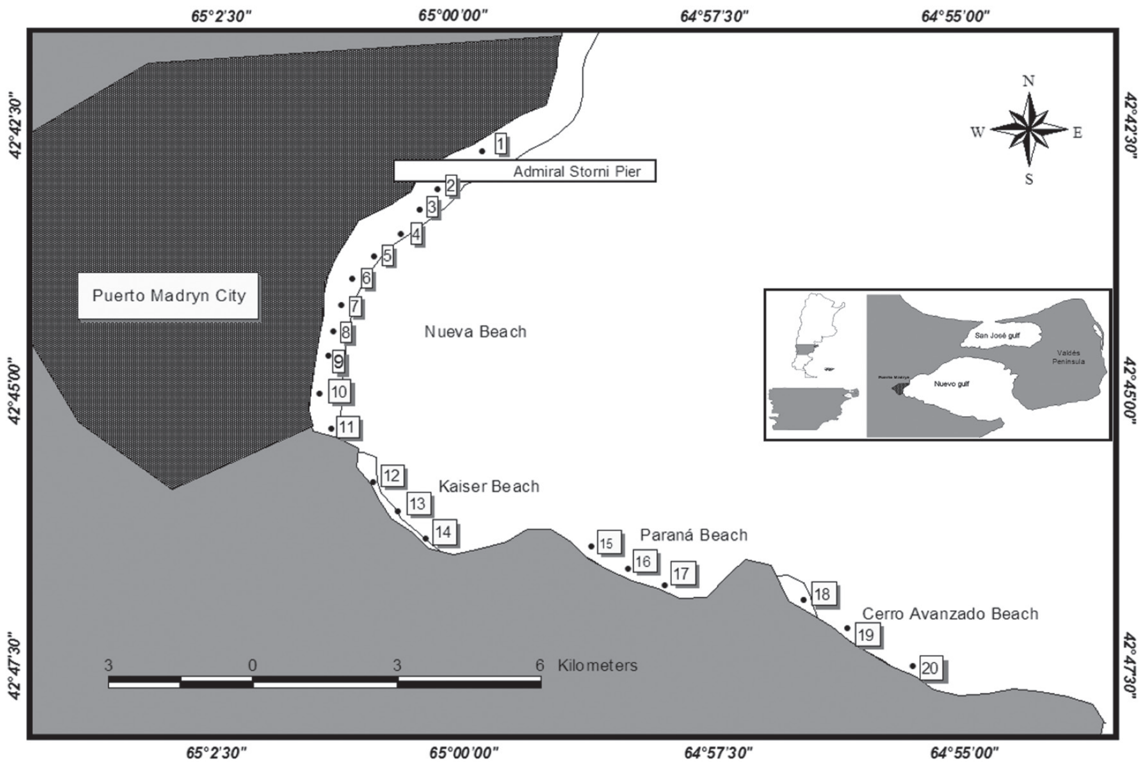

FIGURE 1: Location of study area in sandy beaches of Nuevo Gulf, showing the sampling sites (●).

All sampling units were preserved in 4% buffered formalin and stained with Rose Bengal. Later, these sampling units were elutriated of larger sand particles using a shake and decant procedure (Cross & Curran, 2000) and sieved through 0.50 and 0.05 mm mesh sizes. The content of the 0.05 mm sieve was recovered and preserved in the fixative Ditlevsen (1911). Then, the fauna were identified to higher taxa and counted under a stereomicroscope (Higgins & Thiel, 1988). The meiofaunal density was standardized to individuals per 10 cm^2.

Three replicates at each site were taken manually to analyze the sediment grain size, using a 2.5 cm diameter core tube at a depth of 5 cm. The mean grain size (MGS) was calculated, by sieving dried samples according to the International Test Sieve Standard R565, and the asymmetry and sorting coefficient were determined (Giere *et al.,* 1988). The percentage of silt/clay in the sediment was obtained by wet sieving using a 63 µm sieve to separate the fine and sand fractions, which were then dried at 80°C and weighed. The redox potential discontinuity depth (RPD in cm) was estimated visually as the depth at which the sediment color turned from brown to black. Sediment permeability was determined according to Jaramillo *et al.* (1993) and sediment temperatures (using a hand-held mercury thermometer) were also recorded at each site.

Data analyses

Univariate measures of the meiofauna taxa for each site were calculated, including number of taxa (S), total abundance (N), the Shannon-Wiener diversity indices (H') (calculated using Loge), Margalef's species richness (d) and evenness (Pielou's J) (Gobin & Warwick, 2006). The significance of differences in univariate measures between sites was tested using a one-way ANOVA. When necessary, data were fourth-root transformed to approximate normality. Tukey's HSD multiple comparison tests were used when significant differences were detected ($p < 0.05$). The similarity of meiofauna among sites was determined by cluster and non-metric multidimensional scaling ordinations (MDS) on fourth-root transformed data, using the Bray-Curtis similarity index. Formal significance tests for differences in the meiofauna community structure between sites were performed using the one-way ANOSIM test. Species contributing to dissimilarities between habitats were investigated using the similarities percentages procedure (SIMPER). For further details of the methods used, see Warwick & Clarke (1993) and Netto *et al.* (1999a).

Abiotic data were converted to approximate normality using a fourth-root transformation and ordinated using a correlation-based principal component analysis (PCA). Differences in abiotic variables between sites were then tested using a one-way ANOVA on fourth-root transformed data. In order to examine the relationships between benthic community patterns and the environmental structure of the sites, a Spearman rank correlation (*p*) was computed between the Bray-Curtis similarity faunal matrices and the Euclidean distance matrix derived from abiotic data in order to analyze the relationships between abiotic data and the benthic community structure. The relationships between the multivariate community structure and combinations of abiotic variables were then analysed using the BIO-ENV procedure (Warwick & Clarke, 1993; Netto *et al.,* 1999a) to define suites of variables which best explained the faunistic structure. All analyses were carried out with PRIMER v6 (Plymouth Routine In Multivariate Ecological Research) (Clarke *et al.,* 2005).

TABLE 1: Mean abundance (ind. 10 cm^{-2} ± SD) and total percentage of meiofauna taxa in sampling sites of Nuevo Gulf.

Taxa	1	2	3	4	5	6	7
Nematoda	5937.33 ± 2521.65	6101.67 ± 304.51	6147.33 ± 1476.59	6027.33 ± 2681.67	4553.33 ± 1669.70	5360.67 ± 869.23	2808.67 ± 303.01
Gastrotricha	330.67 ± 174.91	90.67 ± 8.08	27.33 ± 24.17	45.33 ± 8.62	26.33 ± 24.50	56.67 ± 19.86	137.33 ± 95.26
Ciliophora	105.67 ± 94.88	24.67 ± 8.02	10.33 ± 9.24	20.67 ± 22.85	24.00 ± 20.42	18.67 ± 13.58	115.33 ± 36.30
Polychaeta	14.33 ± 11.37	1.00 ± 1.73	0.67 ± 1.15	0.67 ± 1.15	4.33 ± 2.08	0.67 ± 1.15	5.33 ± 2.52
Turbellaria	62.67 ± 41.19	25.33 ± 8.39	28.33 ± 24.21	105.67 ± 26.08	12.33 ± 2.89	14.67 ± 20.21	40.00 ± 17.06
Copepoda	5.33 ± 2.52	6.33 ± 2.89	5.33 ± 4.93	1.67 ± 2.89	1.00 ± 1.73	2.67 ± 2.52	1.00 ± 1.73
Nemertina	34.67 ± 12.34	—	—	—	—	—	—
Cumacea	0.67 ± 1.15	—	—	—	1.00 ± 1.73	—	0.67 ± 1.15
Anphipoda	—	—	1.00 ± 1.73	0.67 ± 1.15	—	—	—
Foraminifera	—	—	—	—	—	—	—
Halacaroidea	—	—	1.00 ± 1.73	—	—	—	—
Ostracoda	—	0.67 ± 1.15	—	—	—	—	—
Oligochaeta	0.67 ± 1.15	—	—	0.67 ± 1.15	—	—	—

Taxa	8	9	10	11	12	13	14
Nematoda	2264.00 ± 201.48	1719.67 ± 411.62	2914.67 ± 642.32	3676.33 ± 897.14	3136.67 ± 457.73	2814.00 ± 1343.25	2945.00 ± 1544.21
Gastrotricha	628.33 ± 522.99	246.67 ± 49.86	104.00 ± 77.49	92.00 ± 81.50	23.33 ± 10.41	144.33 ± 199.51	236.00 ± 322.39
Ciliophora	229.33 ± 52.27	611.33 ± 353.63	57.67 ± 78.36	20.00 ± 15.1	4.33 ± 3.21	4.00 ± 3.46	4.00 ± 1.73
Polychaeta	196 ± 112.01	5.00 ± 3.46	1.00 ± 1.73	9.67 ± 11.93	0.67 ± 1.15	575.33 ± 642.09	—
Turbellaria	8.67 ± 6.51	11.33 ± 12.74	45.33 ± 12.5	1.67 ± 1.53	1.67 ± 1.53	2.67 ± 4.62	9.67 ± 7.02
Copepoda	5.00 ± 6.24	3.67 ± 4.04	2.00 ± 0.00	—	1.00 ± 1.73	0.67 ± 1.15	2.67 ± 4.62
Nemertina	—	—	—	—	—	—	0.67 ± 1.15
Cumacea	—	0.67 ± 1.15	1.33 ± 1.15	—	2.33 ± 0.58	1.33 ± 1.15	0.67 ± 1.15
Anphipoda	—	—	—	0.67 ± 1.15	1.67 ± 1.53	—	—
Foraminifera	—	—	—	—	—	—	0.67 ± 1.15
Halacaroidea	—	—	—	—	—	0.67 ± 1.15	—
Ostracoda	—	0.67 ± 1.15	—	—	—	0.67 ± 1.15	—
Oligochaeta	—	—	—	—	—	—	—

Taxa	15	16	17	18	19	20	Total %
Nematoda	1674.33 ± 709.89	3535.33 ± 1551.74	2874.67 ± 1704.39	3388.67 ± 2228.08	1558.67 ± 471.93	2345.00 ± 883.73	93.19
Gastrotricha	47.67 ± 45.63	209.00 ± 323.99	66.33 ± 53.29	5.33 ± 2.52	9.33 ± 2.89	49.33 ± 25.66	3.34
Ciliophora	16.33 ± 19.09	8.00 ± 10.39	21.00 ± 14.80	4.33 ± 1.15	2.67 ± 0.58	10.00 ± 10.54	1.70
Polychaeta	0.67 ± 1.15	0.67 ± 1.15	0.67 ± 1.15	1.00 ± 1.73	12.67 ± 21.94	2.00 ± 3.46	1.08
Turbellaria	3.67 ± 4.04	2.67 ± 0.58	13.67 ± 16.5	—	—	11.33 ± 12.74	0.52
Copepoda	5.00 ± 3.46	3.00 ± 1.73	9.33 ± 5.13	3.33 ± 1.53	2.33 ± 0.58	2.33 ± 2.52	0.08
Nemertina	—	0.67 ± 1.15	—	0.67 ± 1.15	—	—	0.05
Cumacea	—	0.67 ± 1.15	1.33 ± 1.15	—	1.67 ± 1.53	1.67 ± 2.89	0.02
Anphipoda	0.67 ± 1.15	—	—	—	—	—	0.01
Foraminifera	—	—	—	—	—	—	< 0.01
Halacaroidea	—	—	—	—	—	—	< 0.01
Ostracoda	—	—	—	—	—	—	< 0.01
Oligochaeta	—	—	1.67 ± 2.89	—	—	—	< 0.01

RESULTS

The meiofauna

The number of taxa, abundances and the total percentage of meiofauna in sampling sites of Nuevo Gulf are shown in Table 1. The number of taxa ranged from 6 to 9 per site, with abundance per site ranging from 1.5×10^3 to 6.5×10^3 ind. 10 cm^{-2}, and the mean abundance being 3.8×10^3 ind. 10 cm^{-2}. Nematodes were numerically dominant at all sites, accounting for more than 90% of the total meiofauna. Gastrotrichs (3%) were also present, but at lower abundances. Interstitial ciliates, polychaetes, turbellarians, nemertines, copepodes, cumaceans, amphipods, halacarids, ostracods and oligochaetes were also poorly represented. At sites 8 and 9, located at the central region of Nueva beach, the nematodes did not exceed 68% of all analyzed taxa, with the gastrotrichs (19%), polychaetes (7%) and ciliates (23%) gaining in importance.

The number of taxa and abundance of meiofauna in beaches near to and far away from a city of Nuevo Gulf are shown in Table 2. Foraminifera was absent in beaches near the city. The abundance of nematodes, gastrotrichs, ciliates, turbellarians, nemertines and ostracods were higher in beaches near the city, except for polychaetes, copepods, cumaceans, amphipods and oligochaetes, which were higher in beaches far away.

The univariate measures derived from the meiofauna data in sampling sites are shown in Fig. 2. Significant differences were found using Tukey's HSD multiple comparison tests ($p < 0.05$). The total abundance (N) differed significantly ($p = 0.0004$) between the sites, with the lower values occurring at the Kaiser, Paraná, and Cerro Avanzado beaches. The diversity (H') differed significantly ($p < 0.0001$) between the sites, and the highest values were found at sites 8 and 9 of the Nueva beach, but neither the number of taxa (S) nor the evenness (J) differed significantly between the sites ($p = 0.4971$ and $p = 0.5834$, respectively).

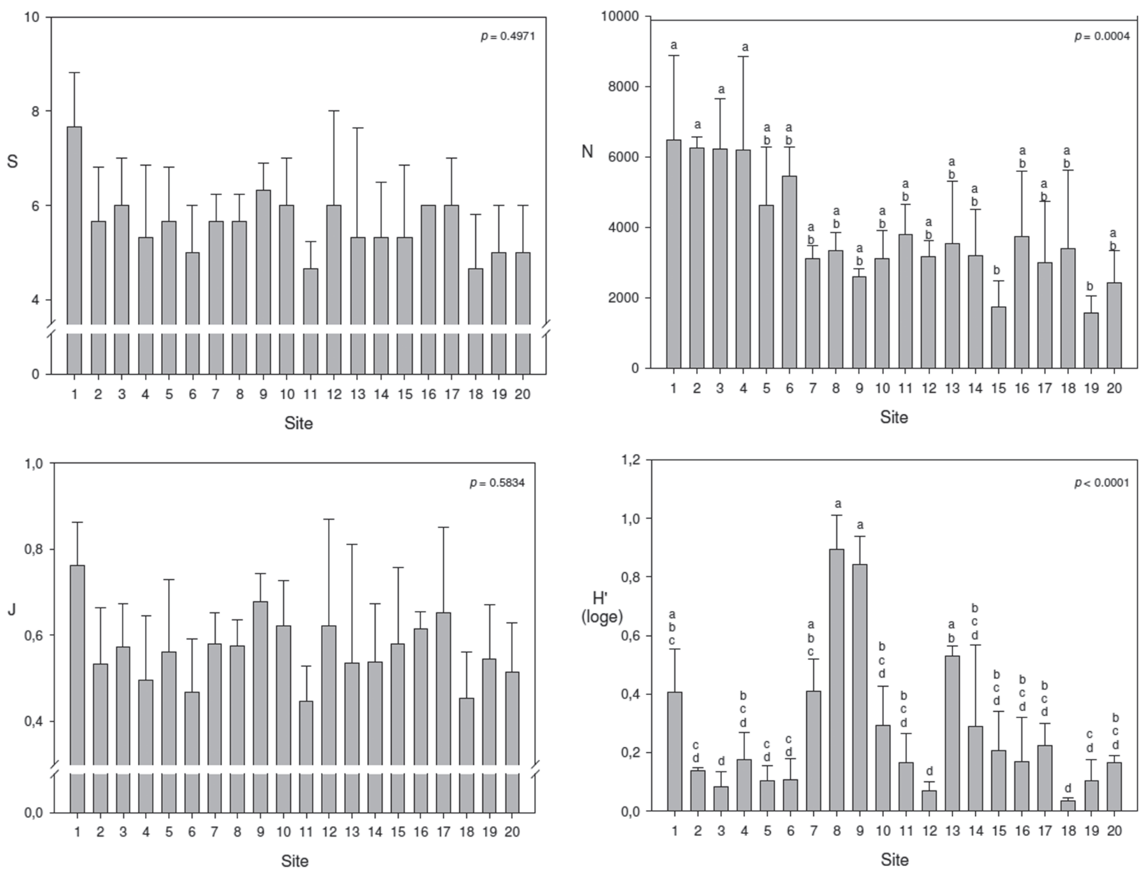

FIGURE 2: Means and standard deviation for univariate measures of the meiofauna community structure at different sites of Nuevo Gulf for number of taxa (S), abundance (N), Shannon-Wiener diversity (H') and evenness (Pielou's J). Analysis of variance (ANOVA). Note: Bars with the same letters are not significantly different (Tukey test, $p < 0.05$).

TABLE 2: Mean abundance (ind. 10 cm^{-2} ± SD) of meiofauna taxa in beaches near to and far away from a city of Nuevo gulf.

Taxa	Near to	Far away
Nematoda	4319.18 ± 2002.37	2696.93 ± 1303.94
Gastrotricha	162.30 ± 226.73	87.85 ± 162.95
Ciliophora	112.52 ± 197.13	8.30 ± 10.09
Polychaeta	21.70 ± 62.88	65.96 ± 255.83
Turbellaria	32.36 ± 33.51	5.04 ± 8.04
Copepoda	3.09 ± 3.39	3.30 ± 3.47
Nemertina	3.15 ± 10.58	0.22 ± 0.64
Cumacea	0.39 ± 0.86	1.07 ± 1.36
Anphipoda	0.21 ± 0.70	0.26 ± 0.76
Foraminifera	—	0.07 ± 0.38
Halacaroidea	0.09 ± 0.52	0.07 ± 0.38
Ostracoda	0.12 ± 0.48	0.07 ± 0.38
Oligochaeta	0.12 ± 0.48	0.19 ± 0.96

The simulated distribution of the test statistic R in the ANOSIM analysis of the meiofauna community structure between beaches near to and far away from a city of Nuevo Gulf was realized *a priori.* Results of the global ANOSIM tests (R = 0.412; $p < 0.1$) confirmed that the structure of the meiofauna community was different between beaches near to and far away from the city

The MDS ordination of the meiofauna data from Nuevo Gulf sites (Fig. 3) indicated that the beaches near to the city of Nuevo Gulf showed differences from those far away from the Kaiser, Paraná and Cerro Avanzado beaches. The low stress factor of 0.15 indicates a good MDS ordination with no real prospect of a misleading interpretation. The analyses revealed clear differences in the community structures between the sites of the gulf, particularly between the Nueva beach and the other beaches.

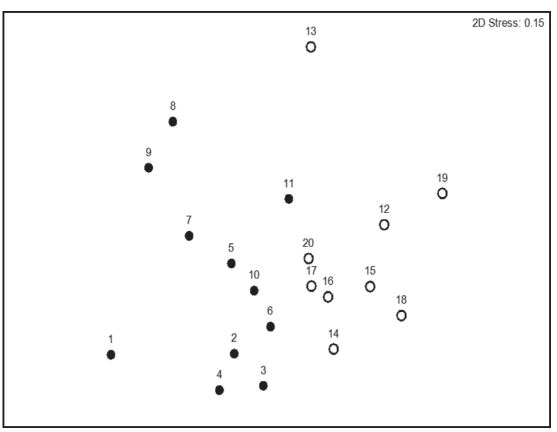

FIGURE 3: MDS ordinations from fourth root transformed abundances of meiofauna data in the beaches near to (●) and far away from (○) a city of Nuevo Gulf.

TABLE 3: The mean univariate measures of abundance of the meiofauna data collected in the beaches near to and far away from a city of Nuevo Gulf. Values are the means ± SD. Analysis of variance (ANOVA) and Tukey test ($p < 0.05$).

Univariate measures / Near to-Far away	S	N	J	H'(loge)
Near to	5.8 ± 1.1	4654.7 ± 1845.6	0.57 ± 0.13	0.33 ± 0.29
Far away	5.4 ± 1.2	2868.2 ± 1397.9	0.56 ± 0.16	0.20 ± 0.17
F-value	ns	19,4	ns	4,04
p	0.2170	< 0.0001	0.7116	0.0491

Note: ns = not-significant; $p < 0.05$ = is significant; S = number of taxa; N = total abundance; H' = Shannon-Wiener diversity indices calculated using Loge; J' = Pielou's evenness.

The SIMPER results demonstrated average similarities of 71.9% between beaches near to and far away from the city of Nuevo gulf. The taxa contributing most to the similarity term were Turbellaria (19.7%), Ciliophora (19.0%), Nematoda (17.5%) and Polycheata (15.7%).

Abiotic variables

All abiotic variables, except for asymmetry and sorting coefficients, varied significantly between the sites (Table 4i) and showed a gradual change from port to pristine areas. Sediments ranged from fine to silt-clay sand and from moderately well to very well sorted. The values of permeability in the sediment, around 3.0 ± 0.0 cm, were relatively low near to the Admiral Storni pier and showed a significant increase in the Kaiser and Paraná beaches (sites 11, 15, 16, 17), although a decrease was observed in the sediment permeability in the Cerro Avanzado beach. The temperature, around 9.0 ± 1.0°C (site 8), were significantly lower in the central area of Nuevo Gulf, and the redox potential discontinuity depth was significantly higher in both the Paraná and Cerro Avanzado beaches (site 15: 12.00 ± 0.00 cm and site 19: 12.33 ± 1.53 cm, respectively). In fact, the redox potential discontinuity showed an increasing trend along the entire sampled intertidal area, where the thinnest layer was observed next to the Admiral Storni pier and the central area of Nueva beach (site 4). The oxygenated layer values revealed a significant increase from the Kaiser beach to the Cerro Avanzado beach, and the mean grain size was significantly higher near to Admiral Storni pier (site 1: 191.00 ± 19.28 μm) and in the central area of the Nueva beach next to a rocky area (site 9: 180.93 ± 0.85 μm, site 10: 181.73 ± 1.50 μm and site 11: 189.60 ± 9.53 μm) as well as at Cerro

TABLE 4: Mean abiotic variables in sediment collected at the different sampling sites (i) and in the beaches near to and far away from a city of Nuevo gulf (ii). Values are the means ± SD. Analysis of variance (ANOVA) and Tukey test (α = 0.05) (n = 3 samples per site).

i) Abiotic variables	*Sk*	*So*	Permeability (cm)	Temperature (°C)	RPD (cm)	MGS (µm)	Fine fract. %
Site							
1	0.77 ± 0.35	1.51 ± 0.49	1.7 ± 0.6 a	9.3 ± 1.2 ab	5.33 ± 1.04 ab	191.00 ± 19.28 b	2.50 ± 0.07 bc
2	1.00 ± 0.02	1.15 ± 0.02	2.0 ± 0.5 ab	11.0 ± 1.0 c	8.17 ± 1.04 bcde	166.23 ± 5.02 ab	3.02 ± 0.50 c
3	0.99 ± 0.01	1.14 ± 0.01	1.8 ± 0.3 ab	11.0 ± 1.0 c	7.33 ± 1.04 abcd	171.67 ± 7.01 ab	2.18 ± 0.44 abc
4	1.01 ± 0.01	1.17 ± 0.02	2.3 ± 0.3 ab	11.0 ± 1.0 c	4.07 ± 1.4 a	154.17 ± 14.43 ab	2.57 ± 0.52 bc
5	1.00 ± 0.03	1.18 ± 0.01	2.2 ± 0.3 ab	11.0 ± 1.0 c	6.00 ± 1.00 abc	143.77 ± 18.75 ab	2.13 ± 0.24 abc
6	1.05 ± 0.06	1.19 ± 0.04	2.3 ± 0.3 ab	11.0 ± 1.0 c	7.67 ± 1.26 bcde	158.33 ± 7.22 ab	2.51 ± 0.51 bc
7	1.06 ± 0.10	1.19 ± 0.06	2.3 ± 0.3 ab	11.2 ± 0.3 c	8.50 ± 0.50 bcde	161.80 ± 5.05 ab	1.99 ± 0.27 abc
8	0.98 ± 0.01	1.13 ± 0.00	2.8 ± 0.3 ab	9.0 ± 1.0 a	8.17 ± 1.44 bcde	175.73 ± 1.59 ab	1.43 ± 0.30 abc
9	0.99 ± 0.00	1.12 ± 0.01	2.2 ± 0.3 ab	9.7 ± 0.6 abc	6.17 ± 0.76 abc	180.93 ± 0.85 b	1.79 ± 0.17 abc
10	0.99 ± 0.00	1.12 ± 0.00	2.3 ± 0.6 ab	10.3 ± 0.6 abc	9.67 ± 2.25 cde	181.73 ± 1.50 b	1.65 ± 0.18 abc
11	0.98 ± 0.00	1.14 ± 0.01	3.0 ± 0.0 b	9.7 ± 0.6 abc	6.67 ± 0.76 abcd	189.60 ± 9.53 b	2.23 ± 1.24 abc
12	1.00 ± 0.01	1.18 ± 0.03	2.0 ± 0.0 ab	10.7 ± 0.6 bc	10.83 ± 2.57 de	162.60 ± 6.50 ab	1.10 ± 0.72 a
13	0.98 ± 0.02	1.19 ± 0.00	3.0 ± 1.0 ab	11.0 ± 1.0 c	7.67 ± 0.58 bcde	164.87 ± 57.53 ab	2.25 ± 0.28 abc
14	1.02 ± 0.01	1.19 ± 0.01	2.3 ± 0.6 ab	11.0 ± 1.0 c	8.50 ± 2.50 bcde	144.27 ± 5.51 ab	2.04 ± 0.27 abc
15	1.00 ± 0.02	1.19 ± 0.00	3.0 ± 0.0 b	11.0 ± 1.0 abc	12.00 ± 0.00 e	128.00 ± 2.60 a	1.58 ± 0.06 abc
16	1.01 ± 0.02	1.18 ± 0.02	3.0 ± 0.0 b	10.0 ± 0.0 abc	10.83 ± 0.29 de	149.13 ± 12.40 ab	1.35 ± 0.05 ab
17	0.99 ± 0.03	1.19 ± 0.01	3.0 ± 1.0 ab	10.0 ± 0.0 abc	9.00 ± 0.00 bcde	143.60 ± 31.50 ab	1.65 ± 0.29 abc
18	0.98 ± 0.00	1.15 ± 0.02	1.8 ± 0.3 ab	11.0 ± 1.0 c	6.83 ± 0.76 abcd	173.03 ± 7.16 ab	2.11 ± 0.99 abc
19	1.00 ± 0.02	1.16 ± 0.03	2.0 ± 0.0 ab	11.0 ± 1.0 c	12.33 ± 1.53 e	161.47 ± 9.05 ab	2.29 ± 0.40 abc
20	0.93 ± 0.11	1.21 ± 0.10	1.8 ± 0.3 ab	11.0 ± 1.0 c	7.00 ± 2.00 abcd	185.77 ± 19.30 b	1.88 ± 0.57 abc
F-value	ns	ns	3.19	5.58	7.6	2.99	2.7
p	0.2925	0.0844	0.001	< 0.0001	< 0.0001	0.0018	0.0041
ii) Abiotic variables	***Sk***	***So***	**Permeability (cm)**	**Temperature (°C)**	**RPD (cm)**	**MGS (µm)**	**Fine fract. %**
Near to-Far away							
Near to	0.98 ± 0.12	1.19 ± 0.16	2.3 ± 0.5	10.4 ± 0.9	7.07 ± 1.85	170.45 ± 16.93	2.18 ± 0.61
Far away	0.99 ± 0.04	1.18 ± 0.04	2.4 ± 0.7	10.6 ± 0.5	9.44 ± 2.38	156.97 ± 25.88	1.81 ± 0.57
F-value	ns	ns	1.08	1.68	18.02	6.45	6.11
p	0.7581	0.9482	0.3024	0.2003	0.0001	0.0138	0.0164

Note: ns = not-significant; p < 0.05 = is significant; different letters show differences between means; Sk = asymmetry coefficients; So = sorting coefficients; RPD = redox potential discontinuity depth; MGS = mean grain size; Fine fract. % = silt/clay percentage.

Avanzado beach (site 20: 185.77 ± 19.30 µm). The fine fraction percentage was significantly higher near to Admiral Storni pier (site 2: 3.02 ± 0.50%), with a marked decrease occurring towards the restinga area of Nueva beach. In addition, the fine fraction percentage showed an increase in both the Kaiser and Cerro Avanzado beaches. All the abiotic variables, except for the asymmetry and mixture coefficients, permeability and temperature, varied significantly between beaches near to and far away from the city of Nuevo Gulf (Table 4ii). The redox potential discontinuity depth was significantly higher in beaches far away from the city (9.44 ± 2.38 cm) whereas mean grain size was significantly higher in beaches near to the city (170.45 ± 16.93 µm), with the fine fraction percentage also being significantly higher at this location (2.18 ± 0.61%).

The ordination by PCA (Fig. 4) of abiotic data showed the clear site distinction of the gulf. The first two components explained 72.9% of the data variance (PC1 = 46.7%, PC2 = 26.2%). Sites 9, 10 and 11 in beaches near to the a city were associated with the mean grain size, and the sites 12, 15, 16 and 17 in beaches far away from the city were mainly associated to the redox potential discontinuity depth.

The results of Spearman correlations analyses showed that the meiofauna was significantly correlated with abiotic variables ($p < 0.001$). For a Pearson correlation analysis of all the measured abiotic variables, the highest correlation was 0.65. Thus, all variables, except for asymmetry and sorting coefficients, were used in the BIO-ENV analyses to define sets of abiotic variables, which showed the highest correlation values with the meiofauna data. The results for

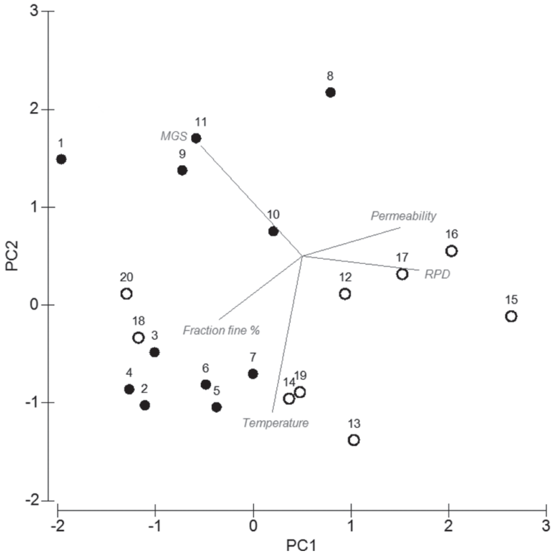

FIGURE 4: Principal component analysis ordinations from fourth root transformed data of abiotic variables in the beaches near to (●) and far away from (○) the city of Nuevo Gulf. RPD: redox potential discontinuity dept; MGS: mean grain size.

the meiofauna data revealed correlation values lower than 0.45, which therefore were not well explained by the measured abiotic variables. However, the results of MDS and PCA ordinations showed similar patterns, and the meiofauna may have presented a similar pattern mainly due to the redox potencial discontinuity depth.

DISCUSSION

Meiofaunal characteristics

The meiofaunal abundance recorded in the beaches of the Nuevo Gulf (1.5×10^3 and 6.5×10^3 ind. 10 cm^{-2}) was found within the range elsewhere for template beaches with fine sediment. This abundance is approximately 10^3 individuals per 10 cm^2, according to Gómez Noguera & Hendrickx (1997), Dittmann (2000) and Veit-Köhler *et al.* (2009). However, it is higher than for Mediterranean Sea beaches with fine sediment (Mirto *et al.,* 2000; Flach *et al.,* 2002; Moreno *et al.,* 2008). In this study area, the numbers of taxa of meiofauna (6 to 9 taxa) were lower than the values obtained by Rodríguez *et al.* (2003) of sandy beaches in northern Spain, *i.e.* between 8 and 14 taxa per beach. We observed that the most abundant taxa were nematodes, gastrotrichs and ciliates, in contrast with the findings of other studies on coastal environments, where Dittmann (2000), Rodríguez *et al.* (2003) and Sajan *et al.* (2010) demonstrated that copepod taxa was second in the order of dominance. The number of taxa and abundance of meiofauna were higher in beaches near to than far away from a city of Nuevo Gulf (Tabla 3). On the other hand, the polychaete abundance was higher in beaches far away from than near to this city. These results were in agreement with Fraschetti *et al.* (2006) who demonstrated that the meiofauna community structure change by anthropic effects and in particular the polychaetes abundance is negatively affected in zone with sewage discharges.

Relationships between meiofauna and sediment characteristics

Sediments from the beaches of Nuevo gulf were symmetric, homogeneously sorted and with fine sand, revealing a low energy environment. These sediments are characteristic of dissipative beaches, which have gentler slopes and often have fine sand (Yamanaka *et al.,* 2010). Both the abundance and diversity of the benthic meiofauna in this area reflected the degree of disturbance to which this community was subjected, with the meiofauna being characterized by its high density and relatively low diversity in the beaches of Nuevo Gulf. However, these values do not concur with those of Raffaelli & Hawkins (1996) or Yamanaka *et al.* (2010), who concluded that more dissipative beaches with gentler slopes and finer particle sizes often support a higher number of species and a greater abundance.

The meiofauna community structures clearly showed a pattern that was related to differences in the physical environments of the beaches of the sand flats of the Nuevo Gulf, with the highest abundance being observed near to the Admiral Storni pier and in the central areas of Nueva beach. This area was characterized by high percentages of fine fraction, low permeability of the sediment and a thin oxygenated layer. The Admiral Storni pier houses on cylindrical docks have very diverse communities of bivalve filter feeders, dominated by *Aulacomya atra atra* (Bala & Pastor de Ward, 2000). According to Mirto *et al.* (2000), the mussels, in general, induce changes in the sediment characteristcs, leading to the oxygen penetrability inside the sediment being reduced in sites related to very dense mussels communities. Also, the biodeposition by bivalves generally provides a strong input of organic matter of high quality and availability to benthic assemblages.

Bala & Pastor de Ward (2000) indicated that the biodeposition due to the presence of *A. atra atra* might have a local effect in the increased sedimentation next to the pier dock. They suggested that, in general, the availability of oxygen in the sediment surface layer might be due to the movement of the water column (Mirto *et al.,* 2000), with the intertidal zone next to the Admiral Storni pier being probably sheltered from the movement from the water column due to the presence of pier docks causing a higher sedimentation in this area. In addition, they argued that the biodeposition due to mussel activities could have led to a significant increase in phytopigment concentrations, and that this accumulation was apparently related to the phytoplankton blooms that were filtered and compacted by mussels and discharged to the sediments, suggesting that total phytopigments (such as chlorophyll-*a*) might be used as tracers of mussel biodeposition. In a study in Nuevo Gulf by Pastor & Bala (1996), it was shown that significant concentrations of chlorophyll-*a* near to the Admiral Storni pier were due to a biodeposition process by the presence of bivalve dominant populations of *A. atra atra.*

In contrast, the area next to Nueva beach "restinga" (sites 7-11) showed a decrease in abundance and an increase in diversity. This trend continued to Cerro Avanzado beach, where there was a decrease in the fine fraction percentage and an increase the depth of the anoxic layer. Despite the contribution of fine material together with the decomposition of this material at the disposal sites, anoxic conditions in sediment zones and changes could have been produced by the resulting strong reducing conditions that prevailed just below the sediment surface, with may inhibit settlement or survival of the most sensitive species (Boyd *et al.,* 2000).

The results of the MDS ordination and the ANOSIM tests for meiofauna data of Nuevo Gulf showed similarities, in which the structure of the benthic communities clearly differed between beaches near to and far away from the city, probably related to changes in the abiotic variables. At the sites of beaches near to the city, a higher meiofanua abundance was found next to Admiral Storni pier and the central area of Nueva beach. Moreover, a higher fine fraction percentage, a lower permeability of sediment and a thin oxygenated layer were found next to the pier. Also, at beach sites far away from the city, Kaiser, Paraná and Cerro Avanzado, a lower meiofanua abundance was found together with a lower fine fraction percentage and a thick oxygenated layer.

In general, the main factor influencing the sediment characteristics of this bay may not be the movement of the water body, which depends mainly on the instantaneous direction and intensity of the winds and tides (Krepper & Rivas, 1979). Instead, particle size appears to be the main factor affecting the abundance and species composition of meiofauna organisms in the benthic environment (Coull, 1988). Netto *et al.* (1999a, b), at Rocas Atoll in the northeast of Brazil, showed that differences in community structure are related to meiofauna local transport processes and sedimentation caused by the intense movement of water through the atoll. According to Danovaro *et al.* (2002), in a study on the Italian coast, changes in grain size are presumably caused by alterations to the hydrodynamic conditions and the topography on a micro-scale. In this study, the sampling sites were taken at the lower intertidal level of the beach and on polychaetes communities (Maldanidae family). These community organisms construct tubes that protrude out of the sediment into the water column, and Murray *et al.* (2002) established that when these tubes were rare, local erosion is likely to occur. However, where there are abundant tubes, sediment accumulation is more probable.

The results of the data analysis showed that the average similarity was high at all sites for both groups – beaches near to or far away from the city of the Nuevo Gulf. The meiofauna data showed that turbellarians, ciliates, nematodes and polychaetes contributed most to the break-down of similarity between groups, with these taxa being responsible for the changes in community composition. Mean higher abundance of turbellarian was found at beaches near than far away from the city, which having a lower oxygenated layer and grain size. However, the benthic turbellarian systems are generally represented in oxygenated substrates and in wave-protected beaches, with little mixing of the sediments (Cannon & Faubel, 1988). In this study, mean higher abundance of ciliate was found in beaches near from the city, where have predominated the fine sediments. These results are in agreement with the reports of Corliss *et al.* (1988), where the ciliate abundances are commonly found in fine sediment (between 100 and 300 μm). Boyd *et al.* (2000) have established that nematode communities can provide a sensitive indicator of change in response to dredged material disposal. Moreover, Moreno *et al.* (2008) have shown that the nematode assemblages can increase significantly at both sites, with fine sediment and high pollution effects. In addition, the structure of the nematode assemblages in the sediment layers is also affected, probably by changes in the redox conditions caused by the bioirrigating effects (Tita *et al.,* 2000).

Nematodes are assumed to be quite resistant to sediment organic enrichment and the resulting reducing conditions (Mirto *et al.,* 2000). In this study, although nematode was the most abundant taxon (90%) at all the sites, the highest abundance was found at sites between the Admiral Storni pier and in the central area of Nueva beach (sites 1-6), with high levels of fine fraction and low levels of both permeability and oxygen layer.

Changes in the meiofaunal structure may be induced by biodeposition effects. Nematodes together with turbellarians, among others, might represent useful indicators of biodeposition disturbance (Mirto *et al.,* 2000). Furthermore, polychaete assemblages were the most abundant in beaches far away from the city, where the sediment showed a high oxygenation. These results concur with the reports of Sutherland *et al.* (2007), where the abundance of polychaetes decreased with increasing free sulphide concentrations in the sediment. It is also important to highlight that the gastrotrich distribution showed a high abundance in two areas – the Admiral Storni pier and site 8 in Nueva beach – and was associated to the increase of sediment granulometry.

Redox potential discontinuity depth (RPD) was the abiotic factor that most influenced the meiofaunal distribution, which showed that the oxygen availability between beaches near to and far away from the city was different. This result is in agreement with the reports of Mazzola *et al.* (2000) and Mirto *et al.* (2000), who found a strong association between the meiofaunal community and the interstitial oxygen content, with the nematodes in particular revealing themselves to be more tolerant than the other organisms to suboxic/anoxic conditions.

CONCLUSIONS

The patterns described in the present study show that differences in the meiofauna community structure in the intertidal sandy beaches of Nuevo Gulf were significant and were related to changes in the abiotic variables, with the main factor seeming to be the oxygen availability in the sediment. Similar studies are now needed to investigate if this trend still holds over the complete spectrum of exposure along the Patagonian coast or elsewhere. In this way, it should be possible to establish general patterns of sandy beach meiofaunal variability.

RESUMEN

La composición y distribución de la meiofauna bentónica del Golfo Nuevo (Chubut, Argentina) se describen en relación a las variables ambientales. La meiofauna y el sedimento de la zona intermareal de cuatro playas de arena con diferentes perturbaciones antrópicas fueron recolectadas en Junio de 2005. Las muestras se colectaron en 20 sitios de muestreo con tubos core de 2,5 cm de diámetro y 10 cm de profundidad. Fueron identificados 13 taxones de meiofauna, representados principalmente por nematodos, gastrotricos, ciliados y poliquetos y la abundancia de la meiofauna que fue desde 1,5 × 10^3 a 6,5 × 10^3 ind. 10 cm^{-2}. Los análisis univariado (ANOVA de una-vía) y multivariado (ANOSIM/MDS) indicaron diferencias significativas en las estructuras de la comunidad entre los sitios con efectos antrópicos y aquellos en condiciones prístinas, revelando que estas diferencias fueron entre las playas próximas y alejadas de una ciudad con la actividad portuaria. Los cambios en la estructura de la comunidad (abundancia y diversidad) pueden haber estado relacionados con gradientes ambientales próximos a la costa. El análisis BIO-ENV mostró que la profundidad de la discontinuidad del potencial redox puede ser el principal factor que influye en la distribución espacial de los organismos.

Palabras-Claves: Meiofauna; Intermareal; Sedimento arenoso; Argentina.

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