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Macrobenthic surf zone communities of temperate sandy beaches: spatial and temporal patterns

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Abstract

The spatial and temporal patterns within the surf zone epibenthic assemblages were studied in a coastal fringe of Argentina to determine whether assemblage compositions, abundance, species richness and diversity vary spatially and temporarily. Sampling was conducted seasonally in two sandy beaches over 2 years with a benthic sledge used to collect the fauna in the upper centimeters of soft bottom sediments and the epifauna on the sediment surface. Physical variables were measured in the same coastal sites where biological sampling was conducted. A total of 58 morphospecies were collected. Peracarid crustaceans were the most abundant group. The mysid *Pseudobranchiomysis arenae* (new genus–new species) (29.73 ± 17.79 ind. per sample) and the isopod *Leptoserolis bonaerensis* (51.54 ± 22.35 ind. per sample) were the most abundant and common species and were present regularly throughout the sampling period. Differences in the surf zone community composition were found between the beaches; these differences could be related to variation in physical parameters such as sand grain size and wave climate, indicating the possible influence of the morphodynamic state of the beaches on the epibenthic assemblages. A seasonal abundance trend was detected, reflecting the changes in abundance of the two dominant species; the richness pattern was not easily detectable due to the sporadic appearance of non-resident species in the surf zone, probably due to different causes, including dispersion by entry of water from surrounding areas, littoral currents and storms. The surf zone studied presents a complex and dynamic epibenthic community that appears to be influenced by the morphodynamic state of the beach and the dynamic of non-resident species.

Introduction

The surf zone of sandy beaches is the area between the breaking point of the wave and that covered by the subsequent uprush of water onto the beach (the swash). It is a transition zone between the dunes and the open sea, playing an important role in transporting materials and exchanging organic matter and nutrients with these adjacent environments (Brown & McLachlan 2002; McLachlan & Brown 2006).

This highly productive environment gives rise to a diverse marine fauna (McLachlan & Brown 2006) acting as refuge, feeding and nursery areas (Lasiak 1981, 1986; Senta & Kinoshita 1985; Araújo Silva *et al.* 2004; Marin Jarrin *et al.* 2009). The surf zone benthic assemblage is strongly influenced by physical parameters such as sediment particle size, wave climate and turbidity (Clark *et al.* 1996); and also by the periodic arrival of non-residents species from offshore ecosystems, brought by wind, wave and tidal advection (McLachlan & Brown 2006).

The main components of the surf zone invertebrate assemblages are peracarid crustaceans, with the additional presence of decapods, pycnogonids, euphausiids and copepods (Munilla *et al.* 1998), classified as epibenthos, hyperbenthos and endobenthos, based on their position relative to the water/sediment (*sensu* Mees & Jones 1997). Studies have been conducted around the world on all these assemblages (Hamerlynck & Mees 1991; Beyst *et al.* 2001a; Dominguez Granda *et al.* 2004; Janssen & Mulder 2005; Marin Jarrin & Shanks 2011), most of those in South America focusing on endobenthic assemblages (Demichelli 1984, 1985a,b; Borzone *et al.* 1996; Borzone & Souza 1997; Barros *et al.* 2001; Das Neves *et al.* 2007, 2008). Less attention has been paid to epibenthic and hyperbentic assemblages (Dominguez Granda *et al.* 2004), although they constitute an important link within the local food webs, being the key prey for fish in this zone (Takahashi *et al.* 1999; Beyst *et al.* 2001b, 2002).

In the particular case of the coastal fringe of Argentina, surf zone benthic assemblages have never been studied. The aims of this study are therefore to: (i) identify the epibenthic fauna occurring in the surf zone of a coastal fringe of Argentina; (ii) explore the physical factors influencing the community structure and (iii) analyze the seasonal patterns within the assemblages.

Materials and Methods

Study area

The southern coast of Buenos Aires Province presents an open and straight shoreline with an east-west orientation. Two oceanic exposed mesotidal sandy beaches were studied: Monte Hermoso (38°59′ S, 61°06′ W) and Pehuen-Có (39°00′ S, 61°37′ W) spaced 20 km apart (Fig. 1). These beaches are located 100 and 80 km, respectively, from to the mouth of the Bahía Blanca estuary. The area has a mesotidal regime with semidiurnal tides. The mean amplitude tide range varies between 2.32 and 3.35 m for neap and spring conditions, respectively, with a mean value of 3.10 m (Servicio de Hidrografía Naval, 2009). The Buenos Aires Province has a temperate climate, with average temperatures oscillating between 14 and 20 °C and a mean annual precipitation of 650 mm (Carbone 2003). The prevailing wind directions are from the N, NW and NE, but the strongest winds come from the S, SE and SW. There is an important regional coastal phenomenon called *sudestada* (southeasterns) characterized by strong SE winds of >35 km h^{-1}, persistent rains, and relatively low temperatures (Campo de Ferreras *et al.* 2004).

Field sampling and laboratory procedures

The surf zone assemblages were sampled seasonally over 2 years (2009–2010) in Monte Hermoso and Pehuen-Có sandy beaches. At each beach, for each season, three samples were taken during the day at low tide with an epibenthic sledge (10 × 30 cm frame, 1-mm mesh) that collects the fauna in the upper centimeters of soft bottom sediments and the epifauna on the sediment surface (Sneli 1998). The sledge was hand-towed by two people parallel to the shoreline at 1 m depth for 5 min. Samples were preserved in 4% formaldehyde and were analyzed at the laboratory.

The physical variables were measured in the same coastal sites where biological sampling was conducted. Wave height (m) was determined by measuring breaking waves with graduated poles against the horizon (Emery 1961); wave period (s) was estimated as the time interval between consecutive breaking waves, measured with a stopwatch. Water salinity, temperature (°C), pH and turbidity (m) at the breaker were measured with a multiparameter sensor (Horiba U-10). Two sediment samples were taken with a plastic cylinder (10 cm diameter, 40 cm deep). Each sample was washed, dried, homogenized and weighed before mechanical sieving through the traditional sieve column.

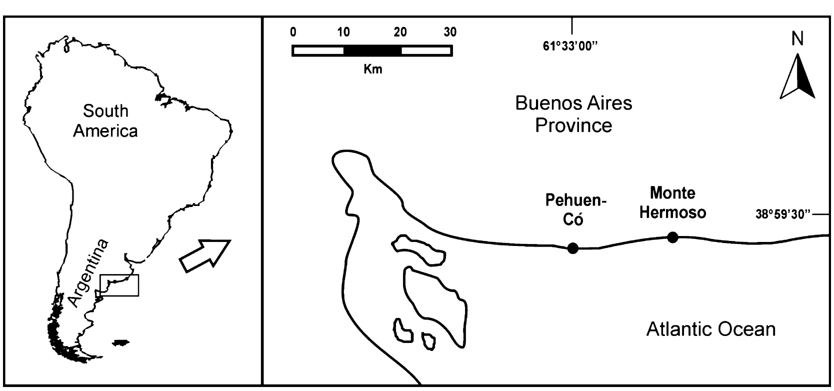

Fig. 1. Study area showing the location of sampling sites: Monte Hermoso and Pehuen-Có.

Organisms were identified using the available literature for the area (*e.g.* Boschi 1964; Bastida & Torti 1967, 1969, 1970, 1973; Orenzanz 1974; Boschi *et al.* 1992; Penchaszadeh 2004; Poore *et al.* 2009; Teso & Pastorino 2011). When a specimen could not be identified with certainty to species level but there was a clear morphological contrast between different individuals of the same genus, family or even a higher taxonomic level existed, it was defined as a specific morphospecies (sp. 1, sp. 2, etc.). All specimens examined were deposited in the Benthos Lab, IADO, Bahía Blanca city, Buenos Aires Province, Argentina (LB–CR). The type specimens of a new genus–new species of mysid (Carcedo *et al.* 2013) found in this study are deposited in the Natural Science Museum of La Plata city, Buenos Aires Province, Argentina (DZI-MLP).

Data analysis

A similarity matrix was obtained by applying the Bray–Curtis coefficient on transformed data [$\log_{10}$ (x + 1)] (Clarke & Warwick 1994). Multi-dimensional scaling (MDS) analysis was then performed and the groups determined by grouping of the samples. Species abundances were compared between beaches (Monte Hermoso and Pehuen-Có) and among seasons. The difference between groups was tested by two-way analysis of similarities (ANOSIM method, global test and pairwise tests) at a significance level of $P < 0.05$ and an R statistic > 0.5 (999 permutations). The SIMPER test (similarity percentages) was used to determine the contribution of the principal species to the formation of the groups.

The analysis of sand samples includes the calculation of average sand size (μ), standard deviation (σ), kurtosis (k) and asymmetry (s) according to Folk & Ward (1957). The environmental data matrix included 10 environmental variables (temperature, salinity, turbidity, pH, wave height, wave period, mean sand particle size, sorting index, skewness index and kurtosis index) and a similarity matrix between sampling sites was obtained by applying the Euclidean distance. Environmental variables were also analyzed by MDS with untransformed data. The set of environmental variables and the macrofauna data for each sampling site were then analyzed using the BIOENV routine. This routine selects the environmental variables that best explain the community pattern, through Spearman correlation analysis (ρs) by maximizing a rank correlation between their respective resemblance matrices. Values close to 1 represent the environmental variables that best explain the community pattern. Multivariate analyses were performed with PRIMER-E® 6 (Clarke & Gorley 2006).

The total number of individuals (N), Margalef's species richness index (d), Shannon–Wiener diversity (H′) and Pielou (J′) diversity index were calculated. Differences in richness and diversity indexes, total abundance and the abundances of dominant species, were tested using a three-way ANOVA (factors: years, sampling sites and seasons). Before running the analysis, normality and homoscedasticity assumptions were examined (Levene 1960; Shapiro & Wilk 1965; Conover *et al.* 1981) and whenever necessary, data were appropriately transformed and newly tested. Significant differences were further analyzed using *a posteriori* Fisher (DMS) tests ($P < 0.05$).

Results

Faunistic composition

We collected 4036 organisms belonging to 58 morphospecies. Crustaceans were the most abundant taxonomic group (31 species, 81.55%), represented mainly by Peracarida: Amphipoda (11 species), Isopoda (8 species), Mysidacea (2 species), Tanaidacea (1 species) and Cumacea (1 species). The most abundant and common species was the isopod *Leptoserolis bonaerensis* (37.9% P – 89.58% D) and the mysid *Pseudobranchiomysis arenae* (23.19% P – 81.25% D), which represents a new genus–new species (Carcedo *et al.* 2013). Decapod crustaceans included eight species. Mollusca included eight species (9.92%), mostly Gastropoda (7 species) and Bivalvia (1 species). Polychaeta (8 species, 5.20%) and other less represented groups (Porifera, Ascidiacea, Sipuncula, Cnidaria and Bryozoa, 10 taxa in total) were also collected. Some invertebrates were abundant but infrequent: the mysid *Arthromysis magellanica,* the sea slug *Pleurobranchaea inconspicua* and the polychaete *Polycirrus* sp. (Table 1).

Physical characterization

The water temperature of the surf zone showed the same trend in both beaches and years, with a minimum recorded in winter (11.75 °C ± 0.55) and a maximum in summer (23.5 °C ± 0.35). Salinity show the same trend as temperature, with a minimum recorded in winter (26.4 ± 0.92) and maximum in summer (35.02 ± 1.80). Mean grain size differed between the two beaches: the predominant sediment type was classified as fine sand: 2.44 ϕ ± 0.13 at Monte Hermoso (100% of samples were fine sand) and 2.31 ϕ ± 0.16 at Pehuen-Có (76.92% of samples were fine grain, 19.23% medium grain). In general, sands were moderately sorted and curves of cumulative frequencies are negative asymmetric and platikurtic. The mean wave height was 1.25 ± 0.30 m at Monte Hermoso and 0.75 ± 0.10 m at Pehuen-Có. Average breaker period was 5.61 ± 1.01 s at Monte Hermoso and 6.86 ± 2.07 s at Pehuen-Có (Fig. 2).

Table 1. Dominance and presence of the organisms collected seasonally during 2009–2010 in Monte Hermoso and Pehuen-Có sandy beaches.

TAXON	% D	% P	TAXON	% D	% P
Phylum Arthropoda			**Phylum Annelida**		
Class Malacostraca			**Class Polychaeta**		
Superorder Peracarida			*Polycirrus* sp.	4.48	6.25
Order Mysidacea			*Australonuphis casamiquelorum*	0.71	12.50
Pseudobranchiomysis arenae	37.90	81.25	*Sabellaria nanella*	0.19	2.08
Arthromysis magellanica	6.98	10.42	*Lepidasthenia* sp.	0.14	10.42
Order Isopoda			Syllidae sp.	0.08	4.17
Leptoserolis bonaerensis	23.19	89.58	Phyllodocidae sp.	0.03	2.08
Idotea sp.	1.38	29.17	*Diopatra viridis*	0.03	2.08
Chiriscus giambiagiae	0.73	27.08	Polychaeta sp.	0.05	4.17
Macrochiridothea robusta	0.19	10.42	**Phylum Mollusca**		
Isopoda sp.	0.08	6.25	**Class Gastropoda**		
Chaetilia argentina	0.08	6.25	*Pleurobranchaea inconspicua*	8.47	12.50
Idotea balthica	0.11	6.25	*Buccinanops duartei*	0.11	4.17
Sphaeroma serratum	0.05	4.17	*Buccinanops globulosus*	0.65	29.17
Order Amphipoda			*Adelomelon brasiliana*	0.35	2.08
Monocorophium insidiosum	1.85	10.42	*Olivancillaria orbignyi*	0.03	2.08
Phoxocephalidae sp.	1.22	29.17	*Buccinanops moniliferum*	0.03	2.08
Amphipoda sp.1	1.30	18.75	*Notocochlis isabelleana*	0.03	2.08
Aoridae sp.	1.03	6.25	**Class Bivalvia**		
Ampeliscidae sp.	0.33	12.50	*Corbula patagonica*	1.09	16.67
Lysianassidae sp.	0.05	4.17	**Phylum Porifera**		
Liljeborgiidae sp.	0.03	2.08	Porifera sp. 1	0.03	2.08
Amphipoda sp. 2	0.11	6.25	Porifera sp. 2	0.03	2.08
Amphipoda sp. 3	0.03	2.08	**Phylum Chordata**		
Amphipoda sp. 4	0.03	2.08	**Clase Ascidiacea**		
Caprellida sp.	0.03	2.08	Ascidia sp. 1	0.02	3.84
Order Cumacea			Ascidia sp. 2	0.08	6.25
Cumacea sp.	0.05	4.17	**Phylum Sipuncula**		
Order Tanaidacea			**Class Sipunculidea**		
Tanaidaceo sp.	0.05	4.17	*Themiste petricola*	0.05	4.17
Superorder Eucarida			**Phylum Cnidaria**		
Order Decapoda			**Class Anthozoa**		
Artemesia longinaris	2.09	35.42	**Order Actiniaria**		
Pagurus criniticornis	0.43	25.00	Actiniaria sp.	0.05	4.17
Pachycheles laevidactylus	0.33	12.50	**Order Octocorallia**		
Cyrtograpsus angulatus	0.22	10.42	*Stylatula polyzoidea*	1.66	4.17
Blepharipoda doelloi	0.11	8.33	**Phylum Bryozoa**		
Austinixa patagoniensis	0.14	8.33	Bryozoa sp. 1	0.57	43.75
Libinia spinosa	0.03	2.08	Bryozoa sp. 2	0.52	39.58
Caridea sp.	0.08	4.17	Bryozoa sp. 3	0.30	22.92

Biological characterization

There were significant differences between beaches (Fig. 3) and among seasons (Fig. 4); two-way ANOSIM showed significant differences among beaches (across all seasons) and among seasons (across the two beaches). The pairwise test showed significant differences in five of six comparisons (Table 2). The SIMPER routine identified 15 species which contributed the most to the differences between the two beaches (Table 3), mainly due to the abundance of the isopod *Leptoserolis boneaerensis* at Monte Hermoso and the abundance of the mysid *Pseudobranchiomysis arenae* at Pehuen-Có. Eighteen species made the greatest contribution to dissimilarity between seasons (Table 4); *Leptoserolis bonaerensis* was more abundant during spring–summer, whereas *P. arenae* was more abundant during spring. During winter, the arrival of non-resident species such as *Pleurobranchaea inconspicua*, *Polycirrus* sp., *S. polyzoidea* and bryozoans was registered, whereas a great majority of the pecarid crustaceans present during the rest of the year were absent: *Monocorophium insidiosum*, *Idotea* sp. and organisms belonging to Ampeliscinae and Aoridae families. The BIOENV procedure showed that among all possible

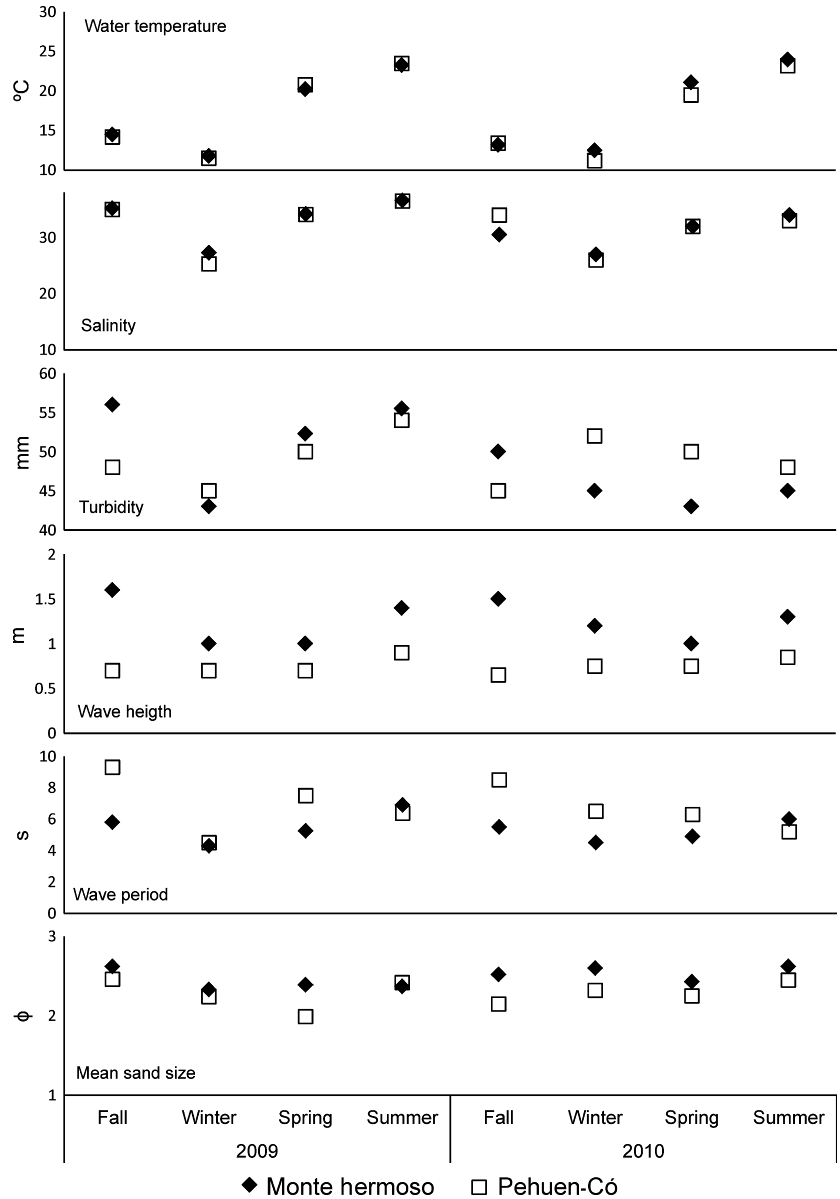

Fig. 2. Physical features of the studied beaches.

combinations of the nine environmental variables, wave height, wave period and sand particle size were the major variables influencing the faunal pattern showed in the MDS ordination (ρ = 0.51).

The Margalef index (d) showed a significant year × beach interaction, showing variability among years, with higher values in Monte Hermoso during 2009 but no significant differences during 2010. Also, no significant differences were observed between seasons. No significant differences were observed in the Shannon diversity index (H′) and Pielou index (J′) among years, beaches and seasons. Total abundance (N) showed a significant year × beach × season interaction, showing variability among years and seasons: significant differences were observed between the beaches. Monte Hermoso showed a higher abundance during 2009, but no significant differences were observed among seasons. During 2010, Pehuen-Có show higher total abundance during fall and winter. Analysis of variance performed on the most abundant species gave results similar to those observed in the SIMPER analysis. Abundance of dominant species exhibited significant year × beach × season interaction, showing variability among years and seasons: the mysid *P. arenae* show higher values of abundance in Pehuen-Có; during 2009 no significant differences were registered between seasons, whereas during 2010 higher values of

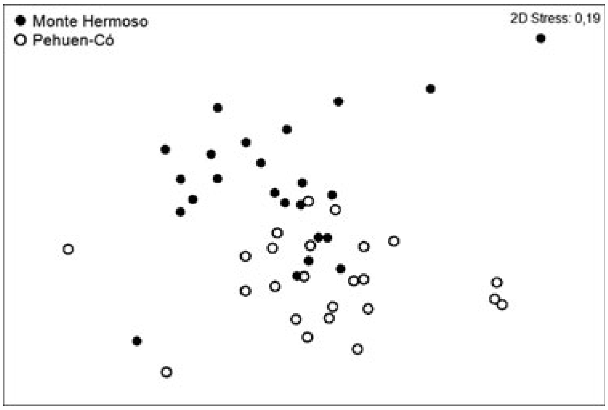

Fig. 3. MDS plot of macrobenthic community data obtained in the two sampling sites (Bray–Curtis similarity).

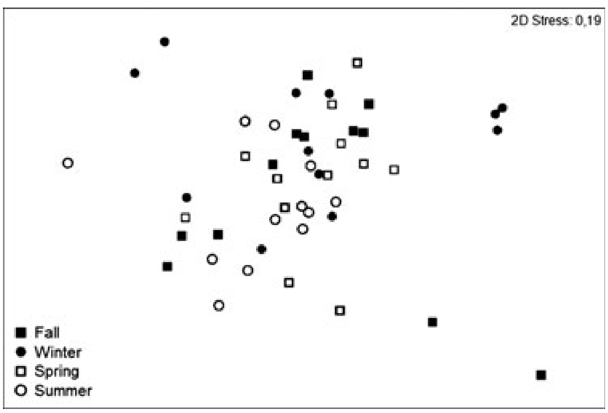

Fig. 4. MDS plot of macrobenthic community data throughout the study period (Bray–Curtis similarity).

Table 2. Results of global and pairwise test (global R and P) from two-way ANOSIM for differences among beaches and seasons.

	Global test		Pairwise test		
	R	P	Group	R	P
Between beaches	0.31	0.001	–	–	–
Between seasons	0.17	0.001	F-W	0.18	0.03
			F-Sp	0.17	0.03
			F-Su	0.16	0.03
			W-Sp	0.23	0.003
			Wi-Su	0.21	0.01
			Sp-Su	0.09	0.1

F = fall, W = winter, Sp = spring, Su = summer.

abundance were registered during spring. The isopod *L. bonaerensis* showed higher abundance in Monte Hermoso; during 2009 higher abundance was registered during spring, summer and fall (Table 5, Fig. 5).

Table 3. Differences in average abundances of species which contribute to dissimilarity between beaches (SIMPER).

	Group Monte Hermoso	Group Pehuen-Có
P. arenae	12.75	46.71
L. bonaerensis	28.54	7.04
P. inconspicua	–	13
A. magellanica	6.79	3.92
Polycirrus sp.	–	6.88
A. longinaris	1.33	1.88
M. insidiosum	2.75	0.08
Idotea sp.	1.75	0.38
Phoxocephalidae sp.	1.58	0.29
Aoridae sp.	0.25	1.33
Amphipoda sp. 1	0.63	1.38
C. patagonica	1.46	0.21
B. globulosus	0.75	0.25
C. giambiagiae	0.58	0.54
S. polyzoidea	–	2.54

Table 4. Differences in average abundances of species which contribute to dissimilarity between seasons (SIMPER).

	Group fall	Group winter	Group spring	Group summer
P. arenae	18.5	22.5	60.58	17.33
L. bonaerensis	14.33	10.42	19.33	27.08
P. inconspicua	0.67	25.33	–	–
Polycirrus sp.	–	13.75	–	–
Idotea sp.	2.67	–	0.83	0.75
Amphipoda sp. 1	0.58	2.42	0.92	0.08
A. longinaris	2.17	0.67	2.25	1.33
S. polyzoidea	–	5.08	–	–
Phoxocephalidae sp.	0.42	0.5	1.75	1.08
B. globulosus	0.42	0.25		1.08
C. giambiagiae	0.58	0.17	0.58	0.92
A. magellanica	0.75	–	20.67	–
Bryozoa sp. 2	0.5	0.58	0.25	0.17
C. patagonica	–	0.42	2.42	0.5
Onuphidae sp.	–	1.92	0.25	–
M. insidiosum	0.17	–	0.17	5.33
Ampeliscidae sp.	0.08	–	–	0.67
Aoridae sp.	–	–	0.42	2.75

Discussion

The Argentinian temperate surf zone located in the SW Atlantic (approximately 40 °S) is inhabited by a diverse community composed mainly of peracarid crustaceans (mysids, amphipods, isopods). This is consistent with reports on other surf zone sandy beaches where peracarid crustaceans, mainly mysids, are resident species, exhibiting high densities and usually patchy distribution (San Vicente & Sorbe 1999; Beyst *et al.* 2001a; McLachlan &

Table 5. Summary of results of analysis of variance (three-way ANOVA) and DMS test.

Variables	Year	Beach	Season	Y × Be	Y × Se	Si × Se	Y × Si × Se	DMS
d	1.96 ns	0.51 ns	0.51 ns	5.03 *	1.19 ns	2.63 ns	1.13 ns	
2009	..	4.57 *	0.25 ns	..	..	1.14 ns	..	Mh > Pc
2010	..	1.12 ns	1.4 ns	..	..	2.56 ns	..	Mh = Pc
H'	0.49 ns	0.27 ns	0.45 ns	2.19 ns	1.04 ns	0.51 ns	2.21 ns	Mh = Pc
J'	0.05 ns	0.06 ns	0.94 ns	0.76 ns	0.99 ns	0.28 ns	2.54 ns	Mh = Pc
N	2.37 ns	0.93 ns	3.17 *	17.21 ***	1.79 ns	1.12 ns	3.34 *	
2009	..	5.84 *	2.23 ns	..	..	0.41 ns	..	Mh > Pc
2010	..	11.55 **	2.67 ns	..	..	3.63 *	..	
F	..	18.09 *	..	..	..	..	..	Mh < Pc
W	..	9.21 *	..	..	..	..	..	Mh < Pc
Sp	..	0.70 ns	..	..	..	..	..	Mh = Pc
Su	..	1.00 ns	..	..	..	..	..	Mh = Pc
N *P. arenae*	0.01 ns	24.81 ***	2.38 ns	4.02 ns	4.57 **	0.78 ns	2.41 ns	
2009	..	6.03 *	2.70 ns	..	..	2.69 ns	..	Mh < Pc
2010	..	19.27 ***	3.92 *	..	..	0.96 ns	..	Mh < Pc; Sp > F = W = Su
N *L. bonaerensis*	13.67 ***	32.21 ***	7.69 ***	0.97 ns	1.91 ns	1.66 ns	3.90 *	
2009	..	31.60 ***	5.12 *	..	..	0.55 ns	..	Mh > Pc; W < F = Sp = Su
2010	..	8.47 *	4.63 *	..	..	3.98 *	..	
F	..	1.05 ns	..	..	..	..	..	Mh = Pc
W	..	9.63*	..	..	..	..	..	Mh > Pc
Sp	..	11.34*	..	..	..	..	..	Mh > Pc
Su	..	2.58 ns	..	..	..	..	..	Mh = Pc

Variables: d, Margalef index; H', Shannon index; J', Pielou index; N, total abundance; N *P. areane*, *P. arenae* abundance; N *L. bonaerensis*, *L. bonaerensis* abundance.
Factors: Y, year; Be, beach; Se, season (F: fall, W: winter, Sp: spring, Su: summer)
ns = not significant.
*P < 0.05; **P < 0.01; ***P < 0.001.

Brown 2006). These crustaceans play an important role in exchanging organic matter and nutrients in the surf zone and are considered to be a major food resource for some fishes and birds (Lasiak 1986; Lasiak & McLachlan 1987; Beyst *et al.* 2001b).

The surf zone community composition varies among beaches, with distinct species dominating each beach, the isopod *Leptoserolis bonaerensis* in Monte Hermoso and the mysid *Pseudobranchiomysis arenae* in Pehuen-Có. The main differences in the surf zone community composition between beaches have been correlated with variations in physical parameters such as sand grain size and wave climate. It has been reported that an increase in sediment grain size caused a significant increase in the burial time of isopods (Griffith & Telford 1985); the coarser sediments of Pehuen-Có beach could increase the burrowing time of *L. bonaerensis*, which could entail longer exposure to predators on this beach, resulting in the different abundance patterns observed.

It is well known that the morphodynamic state is the key variable controlling the sandy beach macrofauna of intertidal zones, with an increase in species richness and abundance from reflective to dissipative beaches, due to both harsh swash climate and coarse sands (McLachlan *et al.* 1993, 1995; Defeo *et al.* 2001; Defeo & McLachlan 2005). However, only a few studies have compared benthic communities in different morphodynamic states in the surf zone (Borzone *et al.* 1996; Barros *et al.* 2001; Das Neves *et al.* 2007, 2008) and therefore the global patterns and processes that dominate the surf zone of sandy beaches are still unknown. In our study we report some differences in biological descriptors between beaches: species richness and abundance were higher at Monte Hermoso than at Pehuen-Có, except for the cold season of the second year, when abundance showed the opposite trends. These differences could be related to the morphodynamic gradient existing between the two beaches (C. Carcedo, unpublished): Monte Hermoso is a dissipative beach, whereas Pehuen-Có has an intermediate morphodynamic state, *i.e.* it exhibits physical characteristics of both dissipative and reflective beaches (*sensu* Wright & Short 1984).

A seasonal abundance trend was detected, reflecting the changes in abundance of the two dominant species, but the richness pattern was not easily detectable due to the appearance of non-resident species in the surf zone. The influence of littoral currents in transporting and dispersing species has been observed in many sandy beaches on neighboring estuarine zones (Godefroid *et al.* 1999; Gomes *et al.* 2003; Strydom 2003; Strydom & d'Hotman

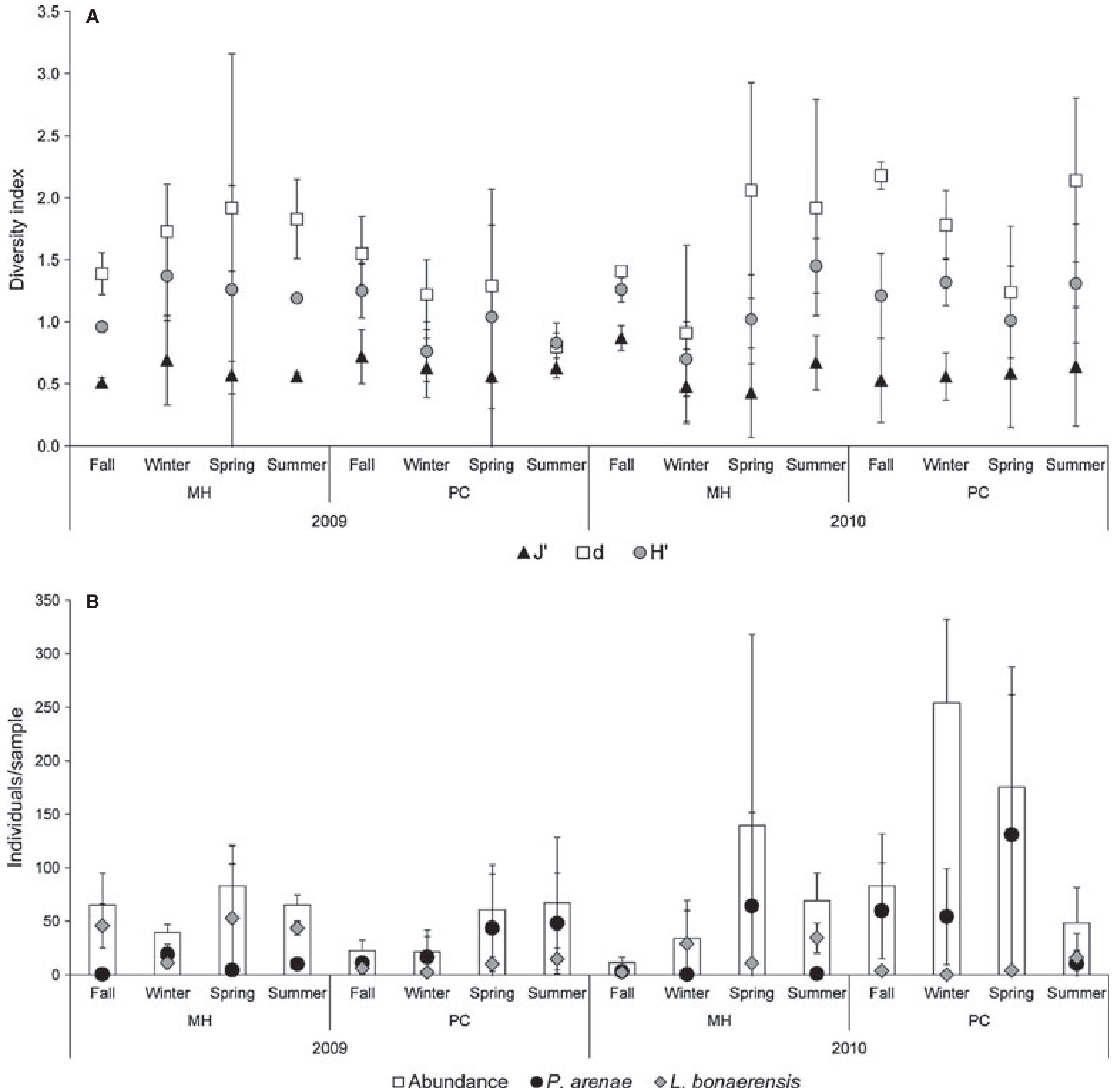

Fig. 5. (A) Mean value and standard deviation (SD) of Margalef index (d), Shannon index (H′) and Pielou index (J′) for each year, beach and season. (B) Mean value and standard deviation (SD) of total abundance and the abundances of the dominant species. MH, Monte Hermoso; PC, Pehuen-Co´.

2005; Sato *et al.* 2008). The surf zone of the sandy beaches studied is characterized by warm waters, contrary to what one would have expected by the oceanographic platform conditions in the region (Martos & Piccolo 1988); this phenomenon is due to the export of warm waters from the Bahía Blanca Estuary, a process that gives rise not only to higher temperatures but also to a high load of suspended sediment and some invertebrates (Perillo *et al.* 2000; Gibbins *et al.* 2007). The detection of non-resident, typically estuarine species such as the octocoral *Stylatula polyzoidea* and the mysid *Arthromysis magellanica* (Elías *et al.* 2007; Hoffmeyer & Mianzan 2007) is evidence of this process.

The massive and sporadic presence of other non-resident species in the surf zone may be due to storms coming from the southeast and southwest that generate large waves, strong winds (above 80 km h^{-1}) and a higher water level (Caló *et al.* 2005), and result in the arrival of organisms from adjacent areas that remain temporarily in the surf zone. This is the case of the sea slug *Pleurobranchaea inconspicua* and ovicapsules of the gastropod *Adelomelon brasiliana*, typical species of the subtidal zone (Marcus & Marcus 1969; Luzzatto 2006; Muniain *et al.* 2007) and the crab *Pachycheles laevidactylus*, the mytilid *Brachidontes rodriguezii*, the endolithic sipunculid *Themiste petricola*, the worm *Sabellaria nanella* and the bryozoan species that typically inhabit the rocky bottoms of small hard microsubstrates (Bremec *et al.* 2013).

To better understand the functioning of surf zone ecosystems, focused ecological studies are required to elucidate the trophic role of dominant species, the dynamics of the occurrence of non-resident species, and the influence of other physical parameters not considered in this study.

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