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Seasonal variation of peracarid assemblages in natural and artificial marine environments of the Southwestern Atlantic Ocean

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Abstract The diversity and seasonal variations of two assemblages of marine benthic peracarids were studied between a natural rocky shore and an artificial harbour area over a 12-month period. Samples were obtained monthly in La Estafeta, a rocky intertidal zone with low human impact, and Mar del Plata Harbour, a polluted environment, between March 2011 and March 2012. The two sites differed markedly in the composition and abundance of species across all seasons: the tanaid *Tanais dulongii* was most abundant in La Estafeta rocky shore, followed by the amphipods *Monocorophium acherusicum*, *Hyale grandicornis*, *Ampithoe valida*, the isopod *Idotea balthica*, the tanaid *Leptochelia* sp. and the isopod *Sphaeroma serratum*. In contrast, *M. acherusicum* was most abundant in the harbour area, followed by *T. dulongii*, *S. serratum*, *Ericthonius punctatus*, *I. balthica*, *Caprella equilibra* and *C. dilatata*. Total density of peracarids varied between months in La Estafeta rocky shore and Mar del Plata Harbour. In La Estafeta rocky shore mean density increased from March to May 2011 (autumn in the southern hemisphere; ca. 45,000 ind/m^2), decreased sharply until August and then increased in January 2012. In Mar del Plata Harbour the mean density was lower from March to October (ca. 500,000 ind/m^3), then increased and reached a maximum in January 2012 (more than 1,500,000 ind/m^3), and decreased until the following March. This study suggests that the differences in peracarid assemblages, diversity and seasonality could be related to an effect of temperature, but we should not rule out a synergistic effect of other factors, such as pollution, food availability and hydrodynamic factors.

Keywords Diversity · Harbour · Intertidal · Peracarida · Seasonal variation

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Introduction

The distribution, diversity and density of marine benthic species can vary between habitats due to different environmental conditions, such as temperature, salinity, pH, predation pressure, food or refuge availability and their seasonal changes (Bertness 1999; Wahl 2009; Thiel and Watling 2015). These variations are a consequence of the effects of such factors on the fitness or subsistence of species, which, in turn, alter their reproductive strategies, growth and behaviors (Stearns 1992, 2000).

Harbours are some of the most stressful environments for marine organisms worldwide, characterized by low pH, oxygen concentration and turbulence, and high levels of organic and inorganic pollutants (Darbra et al. 2009). These factors have a strong impact on biodiversity, affecting the life history traits of benthic species and therefore their distribution and abundance (Ward and Hutchings 1996; Wahl 2009). Studies of the associated biota have become very important to monitoring the health status of these environments (e.g. Pearson and Rosenberg 1978; Chintiroglou et al. 2004; Guerra-García and García–Gómez 2004; Martínez–Lladó et al. 2007; Lourido et al. 2008; Sánchez-Moyano and García-Asencio 2010; Esquete et al. 2011; Albano et al. 2013). The studies performed in these areas may be compared with areas with lower anthropogenic impacts that serve as controls in determining the effects of stressful conditions on organisms (Vallarino et al. 2002; Kalkan et al. 2007).

Peracarids are small benthic crustaceans that inhabit marine (e.g. deep sea, tidal flats and estuaries), freshwater and terrestrial environments (Schram 1986; Johnson et al. 2001; Martin and Davis 2006; Thiel and Hinojosa 2009). These organisms are one of the most diverse and dominant groups in marine environments, playing an important role as a food source for many organisms and structuring benthic assemblages (Duffy and Hay 2000; Esquete et al. 2011; Izquierdo and Guerra-García 2011). In addition, peracarids are good candidates for evaluating the effects of environmental conditions on biodiversity and life history of marine benthic macrofauna, due to their reproductive mode associated with life cycles without pelagic larvae, and thus low dispersal rates (Schram 1986; Johnson et al. 2001; Martin and Davis 2006; Thiel and Hinojosa 2009).

There are numerous reports of peracarid assemblages in Southwestern Atlantic harbours and pristine environments (e.g. Brankevich et al. 1988; Scelzo et al. 1996; Excoffon et al. 1999; Adami et al. 2004; López-Gappa et al. 2006; Albano et al. 2006, 2013; López-Gappa and Sueiro 2007; Sueiro et al. 2011; Chiesa and Alonso 2014; Schwindt et al. 2014; Carcedo et al. 2015; among others). However, these studies offer only snapshots of single sites and moments; analyses to compare populations encompassing longer periods of time are necessary in order to assess the effect of contrasting environmental conditions between habitats experiencing low and high human impacts. The main objective of this paper was to compare the assemblage of peracarid species between a natural rocky shore and an artificial harbour area. On the basis of the higher levels of pollutants, lower pH and oxygen concentration, and the less influence of hydrodynamic factors that characterize Mar del Plata harbor, we predict that peracarid assemblages in harbour environments will show lower diversity levels, but higher dominance of certain species less sensitive to environmental stressors compared to La Estafeta, as has been reported for several similar environments subjected to human impact (Pearson and Rosenberg 1978; Chintiroglou et al. 2004; Guerra-García and García–Gómez 2004; Martínez–Lladó et al. 2007; Lourido et al. 2008; Sánchez-Moyano and García-Asencio 2010).

Material and methods

Study area

The study was conducted in Mar del Plata Harbour (38° 02′ S, 57° 32′ W) and in the intertidal zone of La Estafeta rocky shore (38°10′ S, 57°38′ W; Fig. 1). Mar del Plata Harbour, built from 1913 to 1924, is a semiclosed area limited by two artificial breakwaters with an opening of approximately 300 m. Mean water depth is around 5 m, ranging between 3 and 10 m, and the bottom is composed of fine and very fine sands near the opening, and silt in the inner parts (Isla and Lasta 2006; Schwindt et al. 2010). The presence of several industries, sewage effluents and intense fishing activity, have favored the formation of a polluted area characterized by high levels of organic matter, hydrocarbons, copper and tributyltin (Penchaszadeh et al. 2001; Goldberg et al. 2004; Rivero et al. 2005; Albano et al. 2013; Laitano et al. 2015). Despite these conditions, artificial structures (e.g. wooden docks and marinas) allowed the development of an extremely diverse biota with ascidians, algae and polychaete tubes that provide refuge for fishes, molluscs, nematodes and crustaceans (Rivero 2005; Albano et al. 2006, 2013; Albano and Obenat 2009). In contrast, La Estafeta rocky shore is an abrasion platform located 15 km southward of Mar del Plata Harbour with a gentle slope (<1%) and numerous tidal pools (depth <0.3 m). This intertidal habitat is 70 m wide when tides recede and the substratum is composed of consolidated sediment (loess) and covered by algae (mainly *Ulva rigida* and *Corallina officinalis*), which serve as sites for feeding, breeding and shelter for a variety of benthic organisms, such as echinoderms, annelids, molluscs, nematodes and crustaceans (Baeza et al. 2010; Rumbold et al. 2012). There are no sewage pipes or drains and the site, since it is surrounded by cliffs (height = circa 40 m), is less accessible compared to Mar del Plata Harbour. Consequently, it has a lower degree of human impact (Rumbold et al. 2012, 2015). Both sites are subjected to a microtidal regime with mean amplitude of 0.8 m (Isla 2004).

According to Rumbold et al. (2015), Mar del Plata Harbour showed more anoxic and acidic conditions during the sampling period than La Estafeta rocky shore, indicating clearly that the harbour is a stressful environment. In Mar del Plata Harbour mean values of pH and dissolved oxygen were 8.23 and 8.71 mg/l, respectively, whereas in La Estafeta rocky shore they were 8.55 and 12.69 mg/l. Salinity measurements did not show differences between sites and months sampled (values close to 33 PSU). In the harbour area, though salinity can reach unusual values of 22 PSU, possibly related to heavy rainfall, the presence of a storm water duct and a creek that transports pluvial water from the urban area to the harbour (Schwindt et al. 2010). Moreover, the two environments did not show differences in seawater temperature and presented the same seasonal variation (Rumbold et al. 2015), characterized by lower values in winter and higher values in summer, varying between 9.3 - 23.8 °C. Mean values of the two sites are represented in Fig. 3.

Field sampling and laboratory procedures

Five samples were collected per site per month from March 2011 to March 2012, except in June 2011 in La Estafeta rocky shore and in February 2011 at both sites due

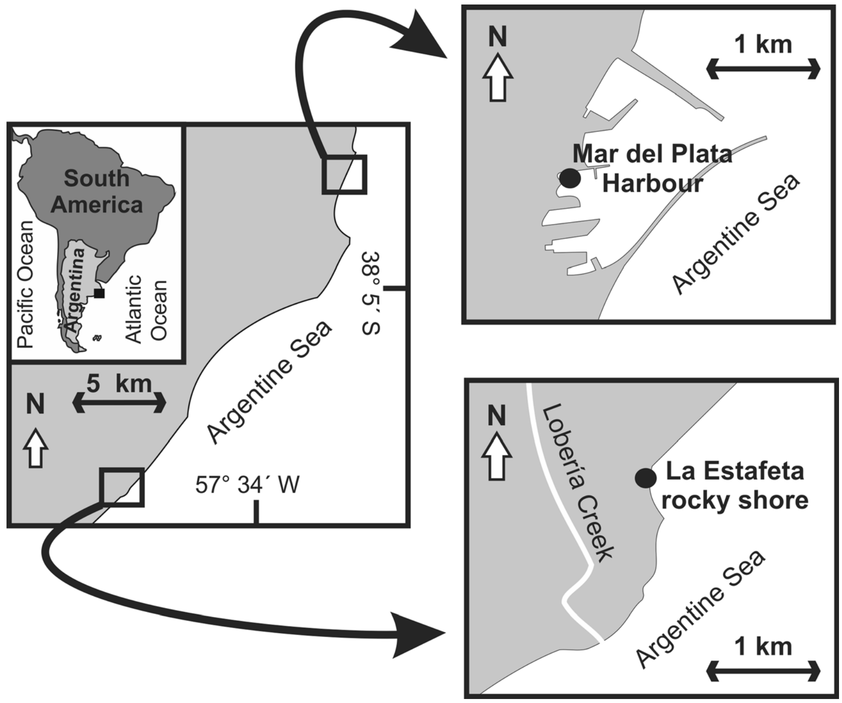

Fig. 1 Geographical localization of the study sites (●) located in La Estafeta rocky shore and Mar del Plata Harbour, Argentina (SW Atlantic)

to bad weather conditions. The structure of the two habitats is extremely different, so it was not possible to use the same sampling protocol in both sites. In La Estafeta rocky shore samples were taken along a 60 m transect parallel to the coast line (15 m interval) at low intertidal level (ca. 70 m from cliffs). Samples were extracted from the seafloor at very low tide and consisted of algal patches of 0.0225 m^2 (using a quadrat of 0.15 × 0.15 m). In Mar del Plata Harbour subtidal samples were taken by hand (depth < 1 m) and consisted of 1000 cm^3 of extracted material from the fouling community adhered to the docks (ascidians, algae and polychaetes). Samples were placed in plastic containers and fixed *in situ* in 98% ethanol. In the laboratory, samples were sieved through a 0.35 mm mesh. All peracarid specimens were sorted, counted and identified to the lowest taxonomic level possible using a stereomicroscope and taxonomic guides (Alonso 1984, 2004; Bastida 2004; Chapman 2007; LeCroy 2007; Perez–Schultheiss 2009). Additionally, organisms were grouped according to functional group: opportunistic, predator/scavenger, suspension-feeder and grazer (Chintiroglou et al. 2004; Valdivia and Thiel 2006; Guerra-García and Tierno de Figueroa 2009; Prato et al. 2012; Rechimont et al. 2013). Density values obtained in La Estafeta rocky shore (individuals/0.0225 m^2) and Mar del Plata Harbour (individuals/1000 cm^3) were extrapolated as individuals/m^2 and individuals/m^3, respectively. As densities were expressed in different units, the results obtained were used only to determine seasonal variations and differences in composition of peracarids assemblages between environments.

Data analysis

ANOVAs and *post-hoc* tests were performed using R statistical software (R Development Core Team 2011), while nMDS, SIMPER analysis and diversity indexes were calculated using the PRIMER 6.1 package (Clarke and Warwick 1994; Clarke and Gorley 2006). Parametric tests were preferably used, but when the assumptions of parametric statistics were seriously violated, an appropriate nonparametric test was applied. Significance was assessed at $\alpha = 0.05$ (Underwood 1997). To determine if the total density of peracarids varied between months, a one-way ANOVA was used (Underwood 1997). To compare seasonal variations of total peracarids between environments relative abundances (monthly number of individuals of a percentage of total number of individuals) were calculated per month. Nonmetric Multidimensional scaling (nMDS) ordinations were used to show the monthly differences of peracarid assemblages among habitats on square-root transformed total abundance data, to reduce the influence of very abundant species, with a Bray-Curtis similarity matrix (Clarke and Warwick 1994). The similarity percentage analysis (SIMPER) was used to determine the species responsible for the differences in peracarid assemblages between study sites (Clarke and Warwick 1994). Populations that contributed more than 95% of cumulative dissimilarity between habitats were statistically analyzed using one-way ANOVA. To determine differences in diversity indices between study sites: species richness (*S*), Shannon-Wiener diversity index (H' $\log_2$; Shannon and

Wiener 1963) and Pielou's evenness (*J'*; Pielou 1966) were calculated monthly from area samples and tested between study sites through a two-way ANOVA (factors: month and study sites; Underwood 1997). Student-Newman-Keuls (SNK) was used for multiple comparisons of means among all months sampled and study sites.

Results

Composition of peracarid assemblages

A total of 53,912 peracarid individuals were counted and identified as ten species belonging to three taxa (six Amphipoda, two Isopoda, two Tanaidacea; Table 1). From these species seven were collected in La Estafeta rocky shore and seven in Mar del Plata Harbour, but only four of them were registered at both sites. In La Estafeta rocky shore 27,747 individuals were collected during the study period, with the tanaid *Tanais dulongii* representing the most abundant species (66.19% of total abundance), followed by the amphipods *Monocorophium acherusicum* (27.20%), *Hyale grandicornis* (4.21%), *Ampithoe valida* (0.98%), the isopod *Idotea balthica* (0.69%), the tanaid *Leptochelia* sp. (0.64%), and the isopod *Sphaeroma serratum* (0.09%). In Mar del Plata Harbour a total of 26,165 individuals were sorted from the samples, and the most abundant species was *M. acherusicum* (78.74%), followed by *T. dulongii* (12.59%). The remaining species had lower abundances: *S. serratum* (5.23%), *Ericthonius punctatus* (3.22%), *I. balthica* (0.18%), *Caprella equilibra* (0.03%) and *Caprella dilatata* (0.01%). The SIMPER analysis determined that *M. acherusicum*, *T. dulongii*, *S. serratum*, *H. grandicornis*, *E. punctatus*, *A. valida* and *Leptochelia* sp. were the species contributing most to dissimilarities between the two environments (total cumulative dissimilarity: 95.74%; Tables 2 and 3).

Abundance of peracarid assemblages

Total density of peracarids varied significantly between months in La Estafeta rocky shore and Mar del Plata Harbour (in both cases one-way ANOVA, $P < 0.001$; Fig. 2; Tables 4 and 5). In La Estafeta rocky shore mean density increased from January to May (mid-autumn), reaching a maximum of ca. 45,000 ind/m^2 (SNK-test, $P < 0.05$), decreased sharply until August and then steadily decreased until January (ca. 1,500-20,000 ind/m^2; SNK-test, $P > 0.05$). In Mar del Plata Harbour the mean density was lower than 500,000 ind/m^3 from March to October (SNK-test, $P > 0.05$), then increased and reached a maximum in January (mid–summer) of more than 1,500,000 ind/m^3 and decreased until the following March (SNK-test, $P < 0.05$).

The comparison of relative abundances of total peracarids between environments showed a marked difference in the seasonal variation, characterized by highest percentages in autumn and early winter in La Estafeta rocky shore and only in summer in Mar del Plata Harbour (Fig. 3). In addition, nMDS ordination plot of total abundances of peracarid assemblages established that samples of La Estafeta rocky shore and Mar del Plata Harbour showed a clear difference between sites (Fig. 4) and between months in each site. In La Estafeta rocky shore, *Ampithoe valida* was absent in November, *Sphaeroma serratum* from April to December and *Idotea balthica* during August and November. In Mar del Plata Harbour, *Caprella equilibra* and *C. dilatata* were absent from March to January, *I. balthica* from March to May and from September to October, and *E. punctatus* from August to November.

Table 1 Functional group and total mean density ± standard deviation of peracarid species of La Estafeta rocky shore (ind/m^2) and Mar del Plata Harbour (ind/m^3). (O: opportunistic; P/S: predator/scavenger; S: suspension-feeder; G: grazer)

Taxa	Functional group	La Estafeta rocky shore	Mar del Plata Harbour
Order Amphipoda			
Caprella dilatata Krøyer 1843	O	–	54.58 ± 131.49
Caprella equilibra Say 1818	P/S	–	117.57 ± 407.26
Ericthonius punctatus (Bate 1857)	S	–	21879.87 ± 65186.14
Hyale grandicornis (Krøyer 1845)	G	1017.98 ± 1131.11	–
Ampithoe valida Smith 1873	G	226.26 ± 323.91	–
Monocorophium acherusicum (Costa 1853)	S	6637.78 ± 5588.56	384387.56 ± 569135.46
Order Isopoda			
Idotea balthica (Pallas 1772)	O	163.43 ± 229.34	810.37 ± 2352.37
Sphaeroma serratum (Fabricius 1787)	O	22.83 ± 52.06	29565.04 ± 46758.19
Order Tanaidacea			
Leptochelia sp.	S	147.07 ± 192.68	–
Tanais dulongii (Audouin 1826)	S	14957.58 ± 11238.09	59200.07 ± 112402.89

Table 2 SIMPER analysis showing species contributing to dissimilarity between environments. (T: Tanaidacea; A: Amphipoda; I: Isopoda). Contribution (Contrib.) and Cumulative (Cum.) describe the contribution of each species to the Bray Curtis similarity

Taxa	Average density		Contrib. %	Cum. %
	La Estafeta rocky shore	Mar del Plata Harbour		
T. dulongii (T)	37.67	12.23	36.29	36.29
M. acherusicum (A)	24.18	32.81	24.17	60.46
H. grandicornis (A)	9.23	0.00	12.49	72.95
S. serratum (I)	0.65	7.83	8.80	81.75
A valida (A)	4.02	0.00	5.08	86.83
E. punctatus (A)	0.00	4.15	4.64	91.47
Leptochelia sp. (T)	3.43	0.00	4.26	95.74
I. balthica (I)	3.11	1.02	3.87	99.61
C. equilibra (A)	0.00	0.22	0.20	99.81
C. dilatata (A)	0.00	0.20	0.19	100.00

Average dissimilarity: 57.72%

The analysis of functional groups showed that suspension-feeders were dominant in both environments, with a relative abundance of ca. 95% (Fig. 5), followed by grazers in La Estafeta rocky shore and opportunistic species in Mar del Plata Harbour (5-6%). The other functional groups showed a lower percentage (<1%) (Fig. 6).

Variation in densities of most abundant species

The annual variation of densities of the seven species that contributed to 95.74% of total cumulative dissimilarity in peracarid assemblages is shown in Fig. 7. Except for *Ampithoe valida* in La Estafeta rocky shore, all the species showed significant differences between months sampled (one-way ANOVA, $P < 0.05$; Tables 4 and 5). Overall individual numbers of *Tanais dulongii* remained below 15,000 ind/m^2 (SNK-test, $P > 0.05$; Fig. 7a), but from May to July 2011 this population reached its maximum density in La Estafeta rocky shore (ca. 20,000-40,000 ind/m^2; SNK-test, $P < 0.05$). In contrast, the population of Mar del Plata Harbour remained homogeneous during the study period (ca. 1,000-100,000 ind/m^3; SNK-test, $P > 0.05$), except for March 2012 where it exceeded 400,000 ind/m^3.

Monocorophium acherusicum showed their highest densities only in March 2012 in La Estafeta rocky shore (ca. 20,000 ind/m^2; SNK-test, $P < 0.05$; Fig. 7b) and remained below 12,000 ind/m^2 during the rest of the months sampled (SNK-test, $P > 0.05$). In Mar del Plata Harbour the mean density was lower than 500,000 ind/m^3 (SNK-test, $P > 0.05$), but in December 2011 and January 2012 this population reached its maximum values (ca. 1,600,000 ind/m^3; SNK-test, $P < 0.05$).

In La Estafeta rocky shore, *Sphaeroma serratum* varied between 100-150 ind/m^2 during March 2011 and January 2012 (SNK-test, $P < 0.05$; Fig. 7d), and was absent the rest of study period. In Mar del Plata Harbour, this species reached its maximum values in March and April 2011 (ca. 120,000 ind/m^3; SNK-test, $P < 0.05$), while during the remaining months values were between 400-30,000 ind/m^3 (SNK-test, $P > 0.05$).

Table 3 Results of two-way ANOVA (factors: months and study site) for comparison of densities of: species richness (*S*), Shannon-Wiener diversity index (*H'*) and Pielou's evenness (*J'*) between sites and months. (*df*: degrees of freedom; MS: mean squares)

Comparison	Source of variation	*df*	MS	*F*	*P*
Species richness (*S*)	Month	10	6.26	8.29	<0.001
	Study site	1	51.09	67.73	<0.001
	Study site x Month	10	18.73	2.48	0.012
	Error	82	0.75		
Diversity (*H'*)	Month	10	0.66	7.59	<0.001
	Study site	1	3.75	43.24	<0.001
	Study site x Month	10	1.20	13.85	<0.001
	Error	82	0.09		
Evenness (*J'*)	Month	10	0.09	3.35	0.001
	Study site	1	0.39	13.69	<0.001
	Study site x Month	10	0.32	11.12	<0.001
	Error	82	0.03		

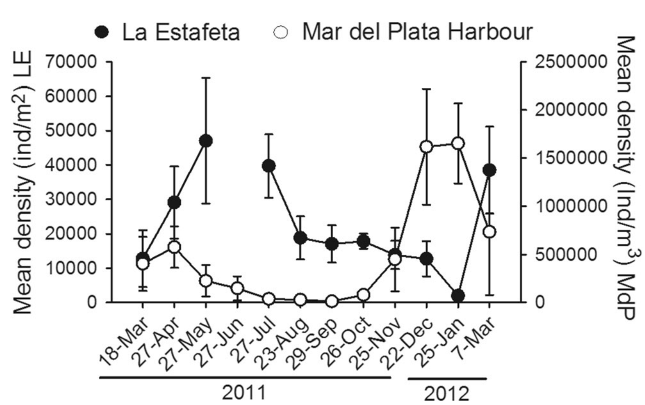

Fig. 2 Monthly variation of total mean density (mean ± standard deviation) of peracarids of La Estafeta rocky shore and Mar del Plata Harbour

Table 4 Results of one-way ANOVA for comparison of densities of La Estafeta rocky shore: total peracarids, *Monocorophium acherusicum*, *Tanais dulongii*, *Sphaeroma serratum*, *Hyale grandicornis* and *Idotea balthica* between months (T: Tanaidacea; A: Amphipoda; I: Isopoda; *df*: degrees of freedom; MS: mean squares)

La Estafeta rocky shore	Source of Variation	*df*	MS	*F*	*P*
Total peracarids	Month	10	963299970.37	12.04	<0.001
	Error	43	80013294.29		
T. dulongii (T)	Month	10	624168553.8	13.62	<0.001
	Error	43	45819185.76		
M. acherusicum (A)	Month	10	146905645.5	4.73	<0.001
	Error	40	31080155.56		
H. grandicornis (A)	Month	10	5415522.63	3.8	0.001
	Error	43	1424921.05		
S. serratum (I)	Month	10	12944.49	2.52	0.018
	Error	43	5142.69		
A. valida (A)	Month	10	523858.44	0.932	0.514
	Error	43	561851.29		
Leptochelia sp.	Month	10	83.18	6.781	<0.001
	Error	43	12.27		

Hyale grandicornis, *Leptochelia* sp. and *A. valida* were collected from La Estafeta rocky shore. *H. grandicornis* reached its maximum value in March 2011 (ca. 4,000 ind/m^2; SNK-test, $P < 0.05$; Fig. 7c) and during the remaining months numbers were below 1,500 ind/m^2 (SNK-test, $P > 0.05$), while *Leptochelia* sp. showed its highest values in May 2011 (ca. 15 ind/m^2; SNK-test, $P < 0.05$; Fig. 7g) and remained below 5 ind/m^2 the rest of the study period (SNK-test, $P > 0.05$). In contrast, the mean density of *A. valida* was less variable (ca. 500 ind/m^2; one-way ANOVA, $P = 0.514$; Fig. 7e), reaching its maximum in May 2011 (ca. 1000 ind/m^2).

Ericthonius puncatus showed a mean density lower than 3,500 ind/m^3 in Mar del Plata Harbour (SNK-test, $P > 0.05$; Fig. 7f), reaching its highest values in April 2011 (ca. 220,000 ind/m^3; SNK-test, $P < 0.05$).

Diversity

S, *H′* and *J′* indices showed significant differences between study sites (two-way ANOVA, $P < 0.001$; Table 3). On one hand, the pattern of annual variation of *S* was always higher in La Estafeta rocky shore than in Mar del Plata Harbour. It reached its lowest values in spring (except for November in La Estafeta rocky shore) and the highest in summer (SNK-test, $P < 0.05$; Fig. 6a). On the other hand, the pattern of annual variation of *H′* and *J′* differed markedly between sites. It was higher in La Estafeta rocky shore than in Mar del Plata Harbour in autumn and the beginning of winter, while the trend was reversed in the rest of sampling months, with a marked decrease of both indices during spring (SNK-test, $P < 0.05$; Fig. 6b and c).

Discussion

In our study, the superorder Peracarida was represented by the orders Amphipoda, Isopoda and Tanaidacea in both environments, as reported from other intertidal and subtidal hard-bottom communities studied in Argentina (Scelzo et al. 1996; Adami et al. 2004; Cuevas et al. 2006; Sueiro et al. 2011; Genzano et al. 2011; Albano 2012; Mendez et al.

Table 5 Results of one-way ANOVA for comparison of densities of Mar del Plata Harbour: total peracarids, *Monocorophium acherusicum*, *Tanais dulongii*, *Sphaeroma serratum*, *Ericthonius punctatus* and *Idotea balthica* between months (T: Tanaidacea; A: Amphipoda; I: Isopoda; *df*: degrees of freedom; MS: mean squares)

Mar del Plata Harbour	Source of Variation	*df*	MS	*F*	*P*
Total peracarids	Month	11	1559000000000.00	15.09	<0.001
	Error	43	103315793265.33		
T. dulongii (T)	Month	11	62670461887.40	2.87	0.007
	Error	43	21822407772.20		
M. acherusicum (A)	Month	11	1468000000000.00	23.22	<0.001
	Error	43	63235803342.38		
S. serratum (I)	Month	11	8501306216.75	2.69	0.010
	Error	43	3165597455.00		
E. punctatus (A)	Month	11	13231890996.33	8.03	<0.001
	Error	43	1647233446.90		

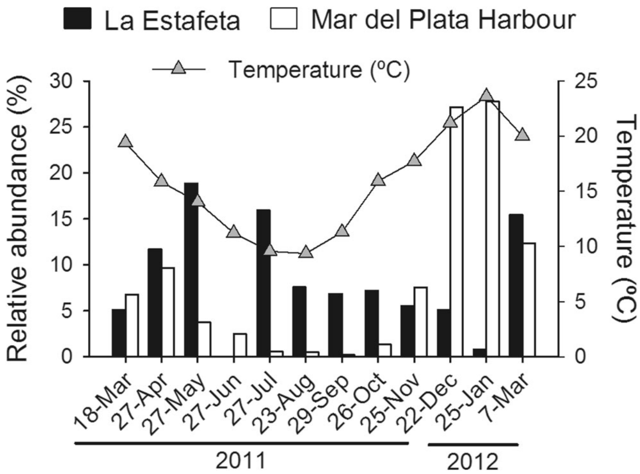

Fig. 3 Monthly variation of seawater temperature and relative abundance (%) of peracarids of La Estafeta rocky shore and Mar del Plata Harbour

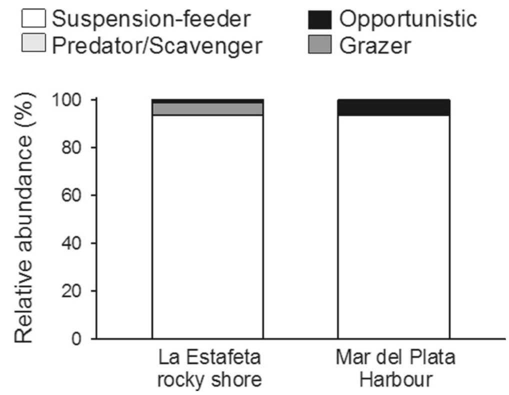

Fig. 5 Relative abundance (%) of functional groups of peracarids of La Estafeta rocky shore and Mar del Plata Harbour

2015). However, we found differences in numerical dominance between the two sites studied: amphipods were most abundant in the harbour, followed by tanaidaceans, while it was the opposite in La Estafeta rocky shore, suggesting a differential response of these orders to environmental conditions, which is concordant with patterns observed in other harbour areas around the world (Chintiroglou et al. 2004; Guerra-García and García–Gómez 2004; Martínez–Lladó et al. 2007; Lourido et al. 2008; Sánchez-Moyano et al. 2010).

Suspension-feeding was the dominant trophic habit in both environments. Several authors proposed that hydrodynamic factors are most relevant to the structure of intertidal and subtidal marine communities and the establishment of species with a particular trophic habit (Sepúlveda et al. 2003; Guerra-García et al. 2009; Izquierdo and Guerra-García 2011; Bueno et al. 2016). For example, in environments exposed to strong wave action (e.g. intertidal zones) organic matter is continuously suspended, favoring the presence of suspension-feeders, while in habitats subjected to weaker currents (e.g. harbours), more organic matter is deposited and the presence of grazers and opportunistic species increases (McQuaid and Branch 1984; Sepúlveda et al. 2003; Izquierdo and Guerra-García 2011; Bueno et al. 2016). However, in the present study this pattern was not observed and so the presence of suspension-feeders in Mar del Plata Harbour is likely related to the continuous supply of organic material from industrial and sewage effluents (Bastida et al. 1971; Rivero et al. 2005; Albano et al. 2013).

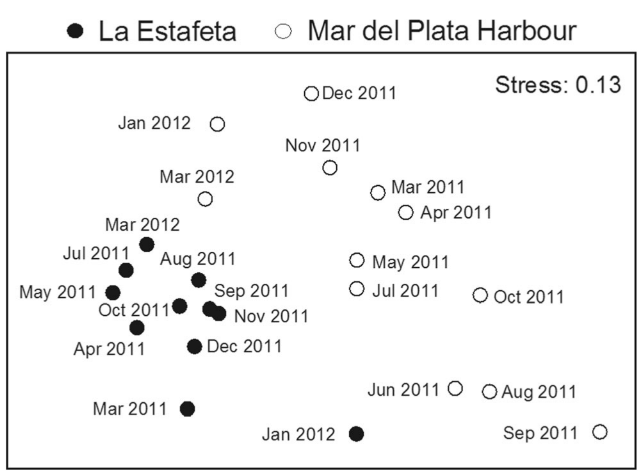

Fig. 4 Two-dimensional nMDS ordination plot of monthly peracarid densities of La Estafeta rocky shore and Mar del Plata Harbour

Species richness was lower in Mar del Plata Harbour than in La Estafeta rocky shore. According to Bueno et al. (2016) environments exposed to hydrodynamic factors are subjected to water renewal, which would improve the oxygen levels of the environment, favoring species settlement and increasing richness values. Environmental conditions of Mar del Plata Harbour would favor a decrease in species richness related to the presence of toxic chemicals, higher eutrophication levels, and the low salinity and oxygen values registered in this habitat (Penchaszadeh et al. 2001; Goldberg et al. 2004; Rivero et al. 2005; Albano et al. 2013; Laitano et al. 2015), as has been suggested by reports from several harbours around the world (Chintiroglou et al. 2004; Martínez–Lladó et al. 2007; Darbra et al. 2009; Chen et al. 2010).

Diversity and evenness indices showed a seasonal variation that differed slightly between sites: maximal values during winter and minimal ones in summer in Mar del Plata Harbour, while in La Estafeta rocky shore both indices decreased during autumn and winter. Higher temperatures play an important role in the annual pattern of peracarid species, increasing their reproductive activity (i.e. promoting juvenile growth and sexual maturity) and consequently increasing their density (Pöckl 1992; McKenney and Celestial 1995; Maranhão and Marques 2003; Fockedey et al. 2005; Tsoi et al. 2005; Henninger et al. 2010; Hosono 2011). In the current study, the high densities of *Monocorophium acherusicum* in Mar del Plata Harbour registered during spring and summer, coinciding with their highest reproductive and recruitment period, as has been previously reported by Rumbold et al. (2016), could explain the dominance and a marked decrease of diversity and evenness.

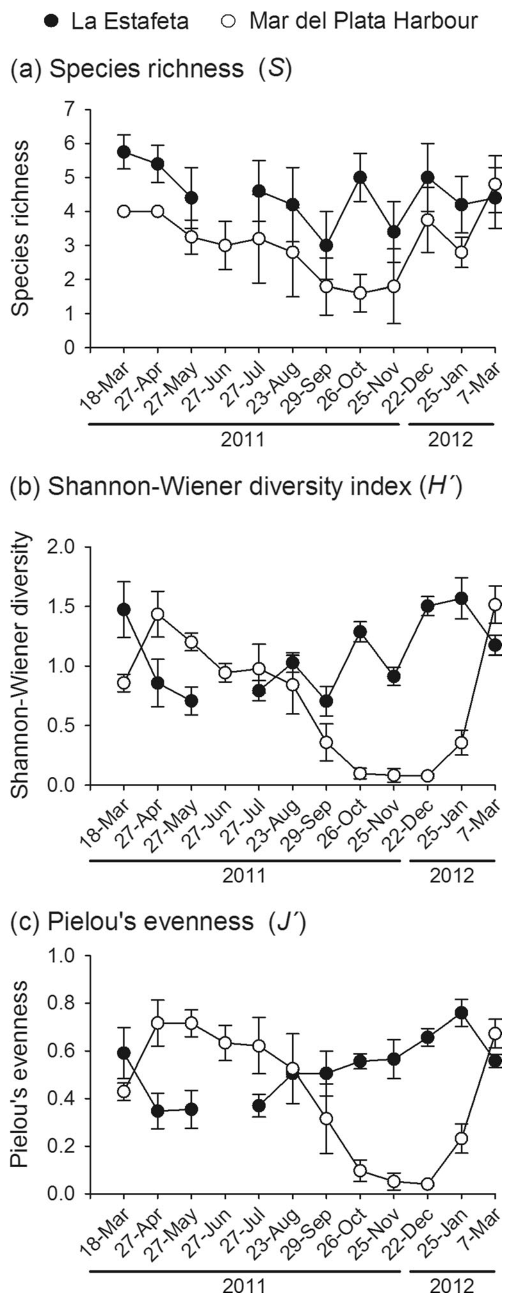

Fig. 6 Monthly variation (mean ± standard deviation) of species richness (**a**), Shannon-Wiener diversity index (**b**) and Pielou's evenness (**c**) of peracarid taxa in La Estafeta rocky shore and Mar del Plata Harbour

By way of contrast, in La Estafeta rocky shore, lower values of diversity and evenness indices during autumn-winter could be explained by the fact that in intertidal environments some species reach their highest densities during the colder seasons (e.g. *M. acherusicum*, *Tanais dulongii* and *Ampithoe valida*) which could be related to more favorable conditions for reproduction and recruitment. In other species, though, lower temperatures increase mortality rates, resulting in a reduction of density (Kneib 1984; Bertness 1999; Rumbold et al. 2012). Thus, temperature could affect peracarid species in different ways, producing changes in their reproductive traits and densities, which would explain the seasonal differences between density peaks, diversity and evenness indices between environments. On the other hand, several studies have shown that stressful conditions of environments subjected to high human impact can affect the development, reproduction, lifespan and mortality rates of peracarid species, altering their seasonal variation (Sánchez-Moyano et al. 2000; Chintiroglou et al. 2004; Guerra-García and García–Gómez 2004; Martínez–Lladó et al. 2007). The effects of specific pollutants and ecological factors, such as predation pressure, shelter sites or food availability would require more field and laboratory surveys (Stearns 2000).

Multivariate analysis of peracarid species revealed that species composition differed markedly between the two environments as well as between months (Fig. 4). The amphipods *Hyale grandicornis*, *A. valida* and the tanaid *Leptochelia* sp. were absent in Mar del Plata Harbour, while the amphipods *Caprella dilatata*, *Caprella equilibra* and *Ericthonius punctatus* were absent in La Estafeta rocky shore. All the species recorded in Mar del Plata Harbour had previously been reported from environments contaminated with organic or/and inorganic matter, and some of them are considered as bioindicators of contamination (Reizopouloua and Nicolaidou 2004; Lee and Lee 2005; Kalkan et al. 2007; Guerra-García et al. 2010; Sánchez-Moyano and García-Asencio 2010; El-Din et al. 2014). The lack of *Leptochelia* sp. (reported as *Leptognathia* sp. by Albano and Obenat 2009) and *H. grandicornis* in the harbour samples is not indicative that both species are sensitive to contaminants, because they had been detected in other areas of Mar del Plata Harbour before (Alonso 2004; Albano and Obenat 2009). On the contrary, laboratory bioassays with *A. valida* have determined that this species is sensitive to hydrocarbons, which could explain the absence of specimens in the harbour (Lee et al. 1981). The absence of caprellids in La Estafeta rocky shore should be viewed with care and may represent a particular spatial or temporal circumstance, since Albano (2012) have reported the presence of *C. equilibra* at this site and *C. dilatata* was detected at other marine intertidal sites located to the North and South of La Estafeta (López-Gappa et al. 2006). On the other hand, the lack of *E. punctatus* in La Estafeta rocky shore may be related to suboptimal conditions for its settlement, such as the presence of stronger competitors, greater numbers of predators, inadequate shelter and high exposure to wave action, among others (Galil et al. 2011). Although its population dynamics have already been studied by Rumbold et al. (2016) in Mar del Plata Harbour, more monitoring studies are needed in the coming years to determine its invasive potential. Finally, some species showed a discontinuity in their monthly density in La Estafeta rocky shore (*A. valida*, *S. serratum* and *I. balthica*) and Mar del Plata Harbour (*C. dilatata*, *C. equilibra*, *I balthica* and *E. punctatus*). This variation could possibly be related to higher mortality rates (e.g. lower temperatures, predation pressure and pollutant

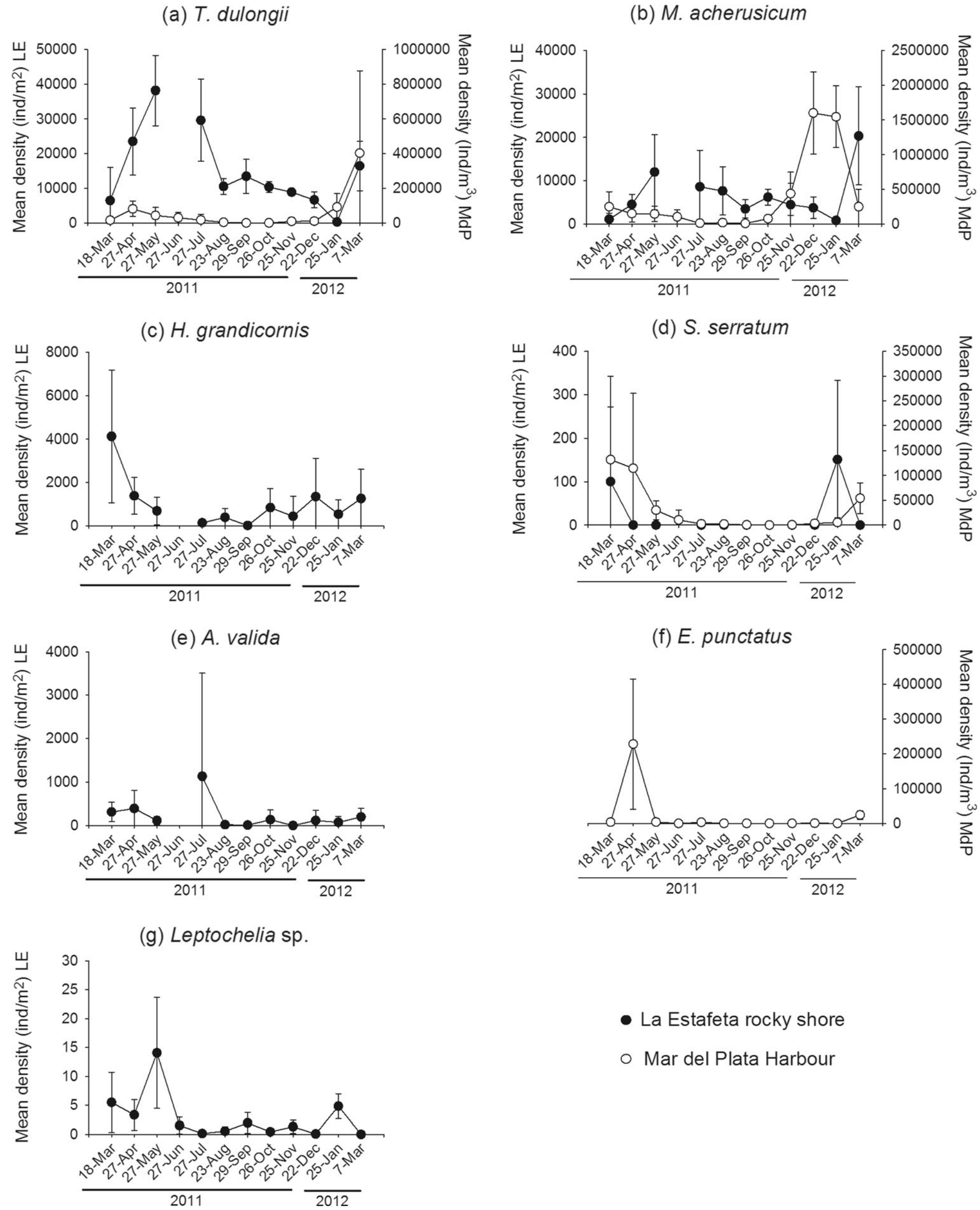

Fig. 7 Monthly variation of total mean density (mean ± standard error) of peracarid species that most contributed to dissimilarities (>95% of cumulative dissimilarity) between La Estafeta rocky shore (LE) and Mar del Plata Harbour (MdP): *Tanais dulongii* (**a**), *Monocorophium acherusicum* (**b**), *Hyale grandicornis* (**c**), *Sphaeroma serratum* (**d**), *Amphitoe valida* (**e**), *Ericthonius punctatus* (**f**) and *Leptochelia* sp. (**g**)

concentration) or migration to other areas (Rumbold et al. 2016), but the explanation of the proximal causes of the observed differences would require more studies and detailed laboratory and field experiments.

The present study suggests that the differences in peracarid assemblages and the seasonal variations between environments, characterized by highest densities in autumn and early winter in La Estafeta rocky shore and only in summer in Mar del Plata Harbour, could be related to a differential effect of temperature on reproductive traits of these organisms. However, we should not rule out a synergistic effect of pollutants, food availability and hydrodynamic factors. Further studies are necessary to identify the factors in detail, and to demonstrate experimentally their effect and their impact on the life history traits of these species.

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