Thalassas (2018) 34:131–138
DOI 10.1007/s41208-017-0045-y

Changes of Benthic Macrofaunal Composition on a Tidal Flat of Río Gallegos Estuary, Argentina

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Received: 16 May 2017 / Published online: 31 August 2017

Abstract This work analyzed the variation in composition and abundance of benthic assemblages in an intertidal environment of the Río Gallegos estuary, Argentina (51°35′ S - 69° 01′ W). The macrofauna was sampled in a tidal flat adjacent to the city in late summer of 2006 and 2013 (March). In total 27 macrofauna taxa were identified; the most abundant species were *Darina solenoides* (44%) in 2006 and *Fabricinuda* sp. (89%) in 2013. Biogenic structures composed of aggregates of polychaete (*Fabricinuda* sp.) tubes and sediment were observed for the first time in December 2006; they are spherical or of irregular shape, 1 to 3 m^2 in area, and up to 50 cm in height. In 2013 benthic composition was compared between biogenic aggregates ("patch") and the area outside them ("non-patch"). Species richness and total abundance of individuals were higher in the patch. The associated benthos was different; *Fabricinuda* sp. was dominant in the patch (107,780.7 indiv.m-^{2}, SD = 44,772.6), and *Kinbergonuphis dorsalis* (2139 indiv.m-^{2}, SD = 840) and *Notocirrus lorum* (1830 indiv.m-^{2}, SD = 516.4) in the non-patch. In 2013, four taxa that were not found in 2006 were recorded only in the patch samples, two bivalves (*Sphenia hatcheri* and *Malletia cumingii*) and two polychaetes (*Fabricinuda* sp. and *Ophioglycera eximia*). Polychaete aggregations have produced changes in number and abundance of benthic species at the lowest level of the tidal flat.

Keywords Temporal changes · Benthos · Southern Patagonia

Introduction

Macrobenthic species are sensitive indicators of changes in the quality of marine and estuarine coastal environments due to their relatively sessile habits and their inability to avoid unfavorable conditions. The effects of anthropogenic disturbances on the benthos include changes in diversity and abundance of species, and in the functional structure of the benthic community (López-Gappa et al. 1993; Warwik and Clark 1994; Elias et al. 2006; Ferrando et al. 2010; Sanchez et al. 2013). The presence or absence of some species in marine sediments provides an excellent indication of the condition of the benthic environment.

In the Rio Gallegos estuary (Patagonia, Argentina), different benthic species assemblages were identified and their distribution was associated with tidal level and type of sediment (Lizarralde and Pittaluga 2011). The polychaete *Scolecolepides uncinatus* was dominant in an assemblage restricted to the high intertidal levels, characterized by silty clay sediments; at the intermediate level, the clam *Darina solenoides* dominated in sandy sediments, and at low levels with fine sediments, the polychaete C*lymenella minor* and the bivalve *Mysella* sp. were the most abundant benthic species. Temporal variations detected in species abundance were mainly due to the incorporation of recruits to the populations, especially of the most abundant species.

Rio Gallegos city, located on the southern shore of the same name river, has undergone a rapid population increase in recent decades (INDEC 2010). The development of the city may have generated changes in the environment, as observed in other regions of Argentina (Lopez-Gappa et al. 1993; Vallarino et al. 2002; Ferrando et al. 2010; Elias et al. 2015).

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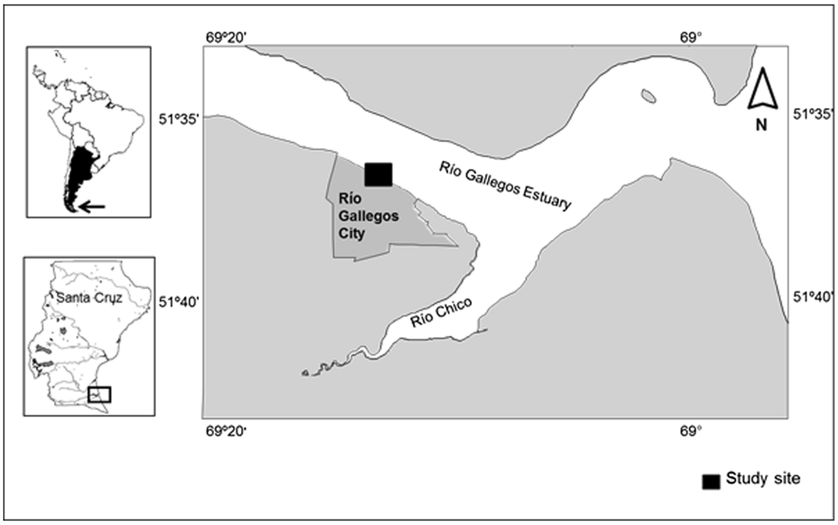


Fig. 1 Study area in the Río Gallegos estuary, southern Patagonia, Argentina

In 2005, we started a program to monitor intertidal macrobenthic assemblages in an intertidal near the city in order to detect possible changes. In December 2006, a massive development of tube-building polychaetes was observed at the lower level of the tidal flat, which continued until dense aggregations were formed. Epibenthic biogenic structures are conspicuous features of many marine soft-bottom habitats; the most widespread ones include mussels, oyster beds and tube-dwelling polychaetes (Jones et al. 1994; Gutierrez et al. 2003). Some studies have analyzed the importance of high densities of tube-building polychaetes and how those densities influence the abundance, recruitment, survival and spatial distribution of other benthic species (Zühlke 2001; Bolam and Fernandes 2003; Jaubet et al. 2013; Colombo et al. 2013; Sanchez et al. 2013). Sediments in biogenic structures have been found to differ physically and to support meio- and macrofaunal communities that differ from those of adjacent areas that lack such structures (Callaway et al. 2010).

The aim of this work was to evaluate the changes in composition and abundance of benthic species assemblages in an intertidal environment of the Río Gallegos estuary, adjacent to the city.

Materials and Methods

The Río Gallegos estuary is located in southeastern continental Patagonia, Argentina (51°35′ S - 69° 01′ W) and discharges into the Atlantic Ocean. It is a 45-km-long macrotidal estuary, with a semidiurnal regime and a spring tidal range of up to 12 m. The southern shore is dominated by vast muddy intertidal flats, salt marshes, and complex channels, whereas the northern shore is high, with cliffs and gravel beach plains (Perillo et al. 1996). The climate is cool, with a mean annual temperature of 7.2 °C and almost constant westerly winds of a mean speed of 35 km/h.

The benthic macrofauna was sampled in an extensive tidal flat adjacent to the city (Fig. 1), in late summer of 2006 and 2013 (March). Samples were collected with a core of 10 cm internal diameter to a depth of 15 cm, at three tidal levels along a transect perpendicular to the waterline. Six biological samples were collected from each level; level 1 (upper level) was located on the uppermost intertidal flat region and level 3 (lower level) on the lowest one, with level 2 being at an intermediate level. Samples were sieved with a 0.25-mm mesh and frozen. The invertebrates were identified to the smallest possible taxonomic level and counted.

In March 2013 an additional sampling was conducted at level 3 (lower intertidal) to analyze the area with the presence of biogenic structures (hereafter referred to as "patch plots"), and the area outside the patches (hereafter referred to as "non-patch plots"). Six independent patch and non-patch plots were randomly chosen and six faunal samples were taken using a core (5 cm internal diameter to a depth of 15 cm). The samples were washed through a 0.25-mm mesh sieve. Three sediment samples were taken from each plot to analyze grain size through wet sieving and determine total organic matter content (loss on ignition at 450 °C for 5 h). Grain size and total organic matter data were compared using a *t* test.

Abundance was expressed as individuals.m^{-2} and dominance was calculated as the ratio between number of individuals of each species and total abundance (Mazé et al. 1990). The abundance data was analyzed using both univariate and multivariate tests. We calculated the species richness (S) per sample, the total abundance of individuals, Shannon diversity index (H′) and Pielou's evenness (J'), the last 2 indices using $\log_e$ in their formulation. In addition, the Taxonomic diversity (Δ) and Taxonomic distinction (Δ^*) were calculated using six hierarchical levels (Phylum, Class, Order, Family, Genus and Species) for macroinvertebrate data recorded in 2006 and 2013 (Warwick and Clarke 1995, 2001). The results were

Table 1 List of macrobenthic species recorded in 2006 and 2013. The species present (P) at the lower level of intertidal (2013, level 3) in both, patch and non-patch plots, are indicated

	2006	2013		
	Dominance (%)	Dominance (%)	Patch	Non-patch
POLYCHAETA				
Fabricinuda sp.	0.0	89.5	P	
Notocirrus lorum (Ehlers, 1897)	6.0	4.0	P	P
Kinbergonuphis dorsalis (Ehlers, 1897)	5.6	0.4		P
Eteone sculpata Ehlers, 1897	1.5	0.1	P	
Glycinde armata (Kinberg, 1866)	2.5	0.7	P	P
*Ophioglycera eximia (*Ehlers, 1901)	0.0	0.1	P	
Lumbrineris cingulata Ehlers, 1897	3.0	1.8	P	P
Scoloplos (Leodamas) cirratus (Ehlers, 1897)	0.0	0.1	P	P
Aglaophamus praetiosus (Kinberg, 1866)	2.4	0.2		
Scolecolepides uncinatus Blake, J.A. (1983)	12.3	0.8		
Travisia sp.	0.1	0.1		P
Hemipodus sp	2.4	0.0		
Clymenella minor Arwidsson, 1911	4.7	0.0		
BIVALVIA				
Sphenia hatcheri Pilsbry, 1899	0.0	0.7	P	
Malletia cumingii (Hanley, 1860)	0.0	0.2	P	
Mytilus edulis platensis d'Orbigny, 1846	4.6	0.1	P	P
Darina solenoides (King, 1832)	44.0	0.4	P	
Mysella sp.	5.4	0.0		
Perumytilus purpuratus (Lamarck,1819)	1.2	0.1	P	
GASTROPODA				
Natica falklandica Preston, 1913	0.4	0.2	P	
Trophon geversianus (Pallas, 1774)	0.8	0.1		P
CRUSTACEA				
Jassa sp.	0.0	0.3	P	P
Monoculopsis vallentini Stebbing, 1914	1.9	0.0		
Edotia tuberculata Guérin-Méneville, 1843	0.3	0.0		
Peltarion spinosulum (White, 1843)	0.2	0.0		
Halicarcinus planatus (Fabricius, 1775)	0.1	0.0		
PRIAPULIDA				
Priapulus sp.	0.8	0.1	P	P
Number of Species	21	20	15	10

analyzed using a nonparametric test (Mann-Whitney), because the data did not meet the assumptions of homogeneity of variance (Zar 1999). The variation between years was compared without including samples of the "patch plots", and for "patch" and "non-patch" comparison, *Fabricinuda* sp. the species that forms the biogenic structure, was omitted, to avoid its inclusion as both a response variable and a factor.

The nonmetric multidimensional scaling ordination technique (MDS) was applied using the Bray-Curtis similarity index (calculated on square-root transformed species abundance). A similarity analysis (ANOSIM; $\alpha = 0.05$) was performed to evaluate differences between assemblages. Similarity percentage analysis (SIMPER) was used to explore the species contribution to similarity between the groups formed (Clarke 1993). All univariate and multivariate analyses were performed using the PRIMER v5 (Clarke and Gorley 2001).

Results

Benthic Macrofauna

We identified a total of 27 macrofaunal taxa. Polychaetes were highly diverse and included 13 taxa, followed by molluscs with 8. In 2013, we recorded six species that had not been

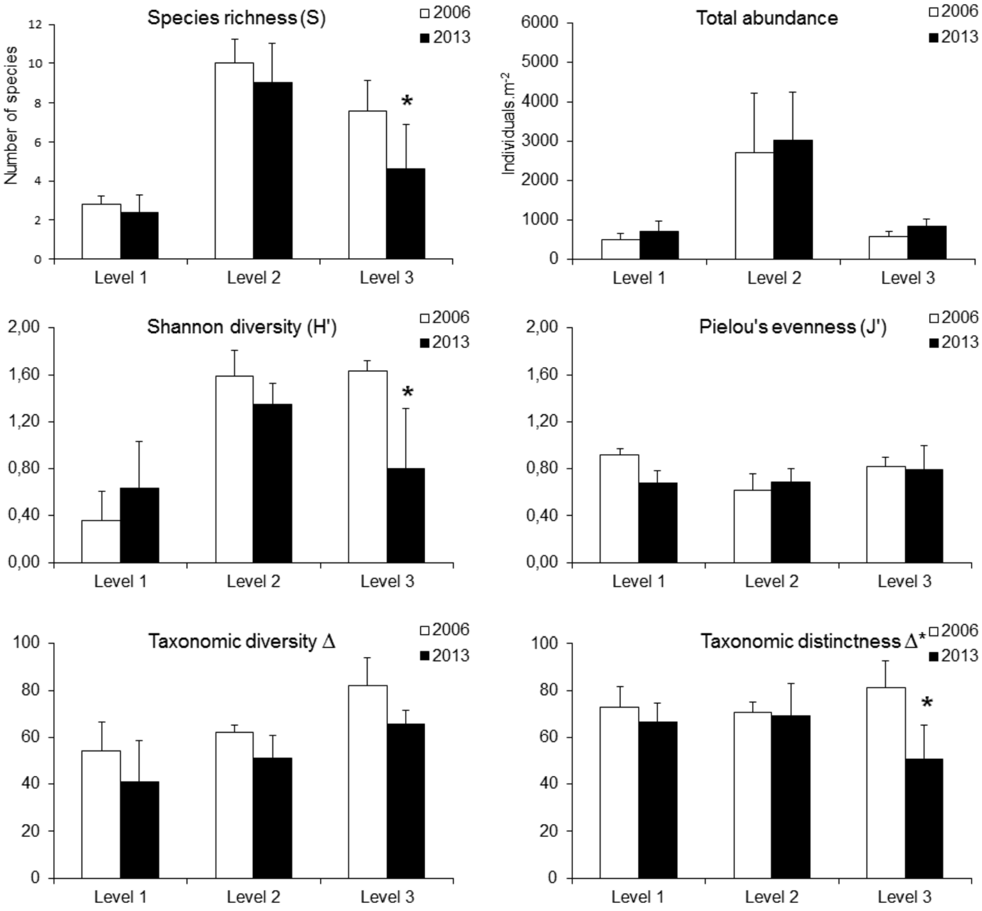


Fig. 2 Average (+SD) of species richness, total abundance, Shannon diversity index, Pielou's evenness, Taxonomic diversity and Taxonomic distinctness, by year and intertidal level. Significant differences are indicated with an asterisk (Mann-Whitney test, *n* = 36)

collected in 2006, two bivalves, three polychaetes and one crustacean. *Scolecolepides uncinatus* dominated the upper level of the tidal flat in both years (460 ind.m-^{2}, Standard deviation SD = 157 in 2006; 545 ind.m-^{2}, SD = 296 in 2013); *Darina solenoides* dominated the intermediate (1609 ind.m-^{2}, SD = 1100). *Mysella* sp. (485 ind.m-^{2}, SD = 389) and *Clymenella minor* (86 ind.m-^{2}, SD = 78) dominated the lower level of the intertidal in 2006. In 2013, *Notocirrus lorum* (727 ind.m-^{2}, SD = 1160) was dominant at the intermediate level and *Fabricinuda* sp. (61,298.7 ind.m-^{2}, SD = 58,780) was dominant at the lower level. The most abundant species were *Darina solenoides* (44%) in 2006 and *Fabricinuda* sp. (89.5%) in 2013 (Table 1).

Table 2 SIMPER analysis (excluding samples of the "patch area") showing the species that contributed to dissimilarities between years (%) and their average abundance (Av. abund. Square-root transformation)

Taxa	2006 Av. abund.	2013 Av. abund.	Contrib (%)
Notocirrus lorun	6.17	22.38	20.92
Darina solenoides	15.08	3.29	18.31
Lumbrineris cingulata	2.72	10.84	14.82
Mysella sp.	6.55	0.00	9.98
Glycinde armata	3.13	5.20	7.42
Kinbergonuphis dorsalis	6.13	6.45	5.74
Clymenella minor	5.33	0.00	5.72
Scolecolepides uncinatus	7.72	7.58	3.98
Eteone sculpta	2.99	2.28	3.61
Mytilus edulis platensis	3.71	1.84	3.13
Sphenia hatcheri	0.00	4.92	2.89
Monoculopsis vallentini	3.87	0.00	2.67

Univariate indices indicated differences ($p<0.05$) in total number of species between 2006 and 2013 at level 3 (excluding samples of the patch plots); Shannon diversity (H′) and Taxonomic distinctness was higher ($p<0.05$) in 2006 than in 2013, at level 3 (Fig. 2).

SIMPER analysis (excluding the patch samples); showed dissimilarities (88.3%) between years, which were attributed mainly to the densities of *Notocirrus lorum*, *Darina solenoides* y *Lumbrinereis cingulata* (Table 2). SIMPER analysis also indicated that *S. uncinatus* (30.5%), *D. solenoides* (21.2%), *Mysella* sp. (15.2%) and *Clymenella minor* (9.2%) were the species that most contributed to the similarities of 2006 samples (76.1%). *S. uncinatus* (29.6%), *N. lorum*

Fig. 3 Lower intertidal level covered by the biogenic structures of *Fabricinuda* sp. in year 2013

(26.2%) and *Kinbergonuphis dorsalis* (13.4%) most contributed to the similarities detected in 2013 (69.2%).

Biogenic Aggregations

We observed the biogenic structure for the first time in December 2006. By 2013, it was prominent, covering an extensive area parallel to the coast at the lower level of the tidal flat (level 3). The structure was spherical or of irregular shape, with a variable area ranging from 1 to 3 m^2 and height reaching up to 50 cm; it was composed of aggregates of polychaete tubes and sediment (Fig. 3). A total of 18 taxa were recorded at level 3, 15 in the patch samples and 10 in the non-patch ones (Table 1). Two bivalves (*Sphenia hatcheri* and *Malletia cumingii*) and two polychaetes (*Fabricinuda* sp. and *Ophioglycera eximia*), recorded for the first time to the sampling site, were exclusively associated with the biogenic structures. *Fabricinuda* sp. was dominant in the patch plot (107,780.7 ind.m-^{2}, SD = 44,772.6), being 80 times more abundant than the second most abundant species, *Jassa sp.* In the non-patch plots *Kinbergonuphis dorsalis* (2138.6 ind.m-^{2}, SD = 840) and *Notocirrus lorum* (1830 ind.m-^{2}, SD =516.4) were the most abundant (Fig. 4). Patch and non-patch plot samples differed (p<0.05) in total number of species, total abundance of individuals, Pielou's evenness and Shannon diversity index (Fig. 5).

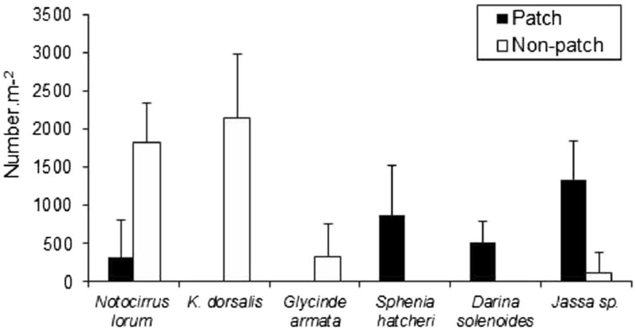


Fig. 4 Average (number.m^{-2} + SD) of the most abundant species (excluding *Fabricinuda* sp.) in the patch and non-patch samples in year 2013

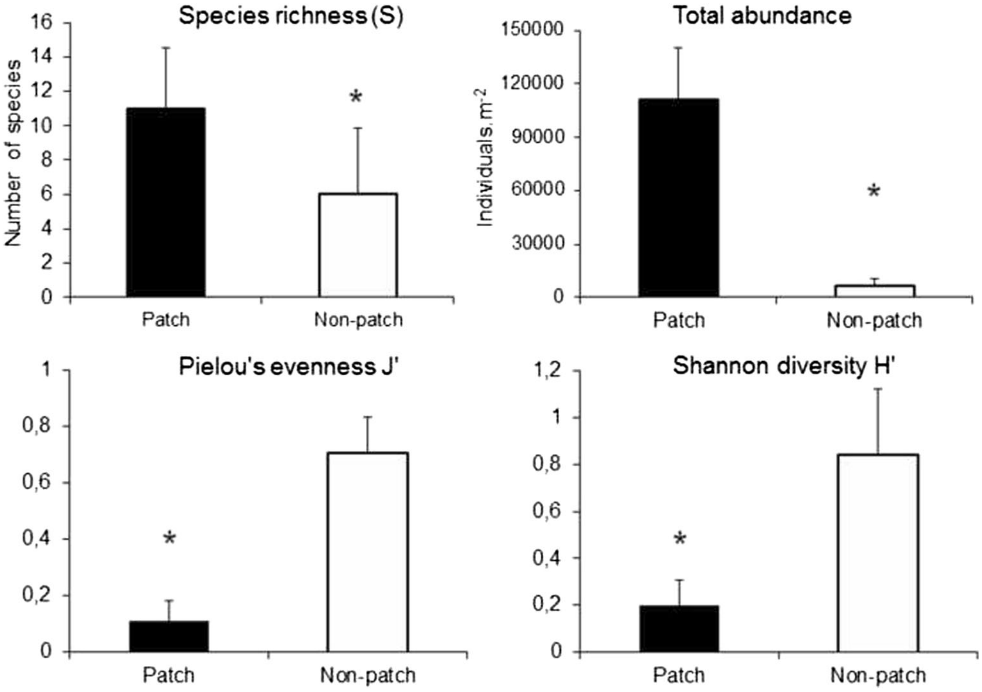
The NMDS ordinations (Fig. 6) reflected the differences, separating patch from non-patch samples (ANOSIM Global R = 0,847; p = 0.001). The patch plot group (excluding *Fabricinuda* sp.) was mainly characterized by *Sphenia hatcheri* and *Jassa* sp. (average similarity 66.9%), and the non-patch plot group (average similarity 70.8%) by *Kinbergonuphis dorsalis* and *Notocirrus lorum* (Table 3).

The sediments of the biogenic structures (patch plots) and of the area outside (non-patch plots) were composed mostly of fine fractions (fine sand, very fine sand and silt-clay). The t test performed between the means of the fractions showed significant differences ($p < 0.05$) in the very fine sand proportions (Fig. 7). No significant differences were observed ($p > 0.5$) in total organic matter of biogenic aggregates sediments (patch plot average = 2.10, SD = 0.27) and the area outside them (non-patch plot average = 1.95, SD = 0.12).

Discussion

In the tidal flat, adjacent to the Río Gallegos city, the species composition of benthos assemblages differed between sampling years, as well as between patch and non-patch plots. In 2013 we did not record *Mysella* sp. or *Clymenella minor,* two species characteristic of the lower intertidal, as described by Lizarralde and Pittaluga (2011) in a previous study conducted at the same sampling site. The clam *Darina solenoides* was the most abundant species (44%) in 2006, but in 2013 the

Fig. 5 Average (+SD) of species richness, total abundance, Pielou's evenness and Shannon diversity index from patch and non-patch samples (2013, level 3). Significant differences are indicated with an asterisk (Mann-Whitney test, *n* = 12)



polychaete *Fabricinuda* sp. represented more than 89% of all collected individuals. Diversity indices (S, H′, Δ, Δ*) differed between years. The highest taxonomic diversity and taxonomic distinction values were found in 2006, level 3 (Δ = 84.1 and Δ* = 100), indicating that in 2013 the species had a close taxonomic relationship. The most abundant species were *Scolecolepides uncinatus* at the upper intertidal level in both years; *Darina solenoides* at the intermediate, and *Mysella* sp. and *Clymenella minor* at the lower level in 2006. In 2013, *Notocirrus lorum* dominated the intermediate level and *Fabricinuda* sp. was dominant at the low intertidal; the latter forming solid biogenic structures.

The genus *Fabricinuda* (Fitzhugh 1990) comprises slender, small-sized worms occurring mostly in fine sediments at intertidal areas. Unlike most sabellids, they are not only filter-feeders, but also deposit feeders (Fauchald and Jumars 1979). No species of this genus has been cited for Argentina. At present, we do not know the origin of the taxa in the estuary and cannot ascertain that it is a non-native species; the material has been referred to an expert in Fabriciinae for specific identification or description of a new species, if applicable. *Fabricinuda* sp. may have coexisted with other benthic species in the intertidal and may have gone undetected until some changes in the environment produced population increases.

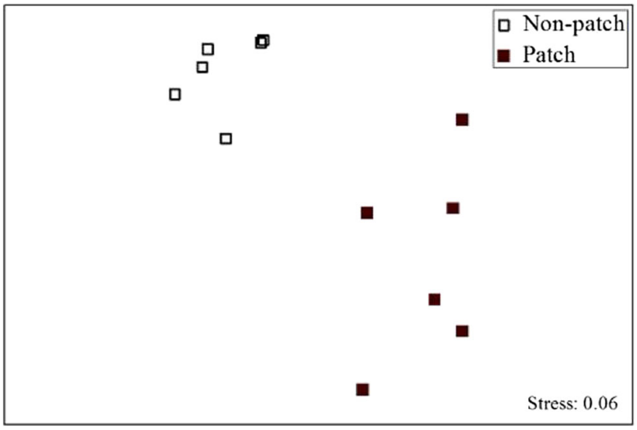


Fig. 6 MDS ordination of patch and non-patch samples (2013, level 3)

Some species of tube-building polychaete aggregations have been indicated to have a positive effect on benthic fauna by increasing habitat complexity and heterogeneity (Reise et al. 2009; Godet et al. 2011). In the *Fabricinuda* biogenic structures, the number of species was higher than in the no-patch plots, with four species being exclusively recorded on those structures. Diversity indices (H′ and J') were significantly lower in patch plots due to the dominance of *Fabricinuda* sp., with records of up to 140,000 individuals.m^{-2}. Total abundance and species richness were significantly lower in the non-patch plots, where *Kinbergonuphis dorsalis* and *Notocirrus lorum* were the most abundant species.

The biogenic aggregation is considered a reef when it creates a massive structure by accumulation of individuals that usually elevate from the seabed or form a substantial habitat (Holt et al. 1998). Some reef-builder worms are often bioengineers because they structure their physical and biological environment, which increases spatial complexity; thus, they create microhabitats that provide numerous spatial niches for a large number of associated species (Callaway et al. 2010;

Table 3 SIMPER analysis showing the species that contributed to the similarity between patch and non-patch groups in 2013 (excluding *Fabricinuda* sp.)

Taxa	Patch Contrib %	
Sphenia hatcheri	47.49	
Jassa sp.	29.13	
Notocirrus lorum	6.65	
Darina solenoides	3.76	
		Non-Patch Contrib %
Kinbergonuphis dorsalis		48.55
Notocirrus lorum		35.08
Glycinde armata		10.49

Godet et al. 2011). It has been indicated that the presence of high densities of polychaetes and the stability of these structures may also lead to changes in sediment type (Van der Zee et al. 2015); accordingly, we observed that in the biogenic structures, the proportion of very fine sands was higher than in the surrounding area. There are three records of polychaete reefs on the Argentina coast; *Ficopomatus enigmaticus* built calcareous tubes (Schwindt and Iribarne 1998), *Sabellaria nanella* (Bremec et al. 2013) and *Boccardia proboscidea* (Jaubet et al. 2011) form reefs of sand tubes. The biogenic structures of *Fabricinuda* sp. are also constructed of sandy tubes.

The presence of the reefs has produced changes in number and abundance of benthic species at the lowest level of the tidal flat. In addition, two benthic species previously identified as characteristic of the tidal flat (Lizarralde and Pittaluga 2011) were not recorded in 2013. To better understand the evolution of the biogenic structures of *Fabricinuda* sp. long-term studies that monitor their expansion in the estuary are needed, in order to elucidate its response to changes in the environment.

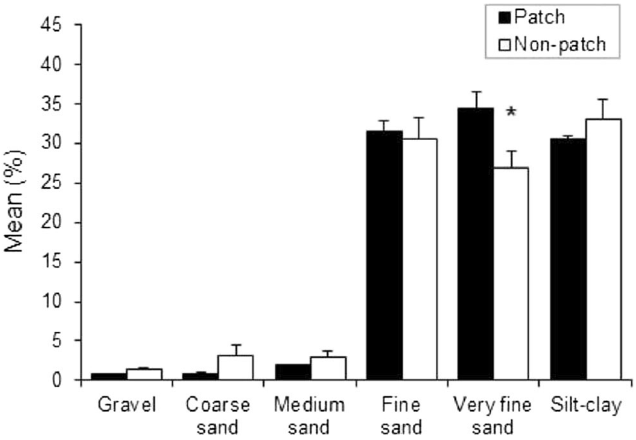


Fig. 7 Grain size of sediments in the patch and non-patch plots. Significant differences between means are indicated with an asterisk (*t* test, *n* = 12)

Acknowledgements This study was supported by the Universidad Nacional de la Patagonia Austral.

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