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RESEARCH ARTICLE

Molluscan assemblages associated with *Gigartina* beds in the Strait of Magellan and the South Shetland Islands (Antarctica): a comparison of composition and abundance

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ABSTRACT

In this paper we evaluated the composition and abundance of molluscs associated with beds of the red algae *Gigartina*, located in the South Shetland Islands (Antarctic Peninsula) and the Strait of Magellan (southern Chile). During the summer season of 2013, samples were obtained by scuba diving using a 0.25 m^2 quadrat, arranged randomly within the bed. We extracted a total of 15 quadrats per sampling site. For Antarctic Peninsula beds the most abundant species were the bivalve *Lissarca miliaris* (233 individuals) and the gastropod *Laevilacunaria antarctica* (94 individuals), while for Strait of Magellan beds the most abundant species was the polyplacophoran *Callochiton puniceus* (36 individuals). Comparative analysis between the two molluscan assemblages showed significant differences in the faunal composition between the Antarctic Peninsula and Strait of Magellan ($f = 64.474$; $p = 0.0001$). Therefore, molluscs reported in both areas are characteristic of their respective biogeographic area. Finally, *Gigartina* species play an important role in the formation of patterns of abundance and diversity of the communities associated with them.

KEYWORDS

Bivalvia; Gastropoda; Polyplacophora; algae beds; sub-Antarctic; diversity

ABBREVIATIONS

MBP: Magellanic biogeographical province; NMDS: non-metric multidimensional scaling ordination

Introduction

In the high-latitude MBP (Spalding et al. 2007), extensive macroalgae assemblages grow on hard substrates, between depths of approximately 0 and 20 m (Mansilla et al. 2013). These communities of macroalgae are characterized mainly by the presence of species of the order Laminariales, such as *Macrocystis pyrifera* and *Lessonia* spp. (Mansilla et al. 2014; Rosenfeld et al. 2014). In the Antarctic Peninsula, macroalgae communities are characterized by the presence of species of *Desmarestia* (Quartino et al. 2005). However, the Rhodophyta algae *Gigartina skottsbergii* is a characteristic species of the southern tip of South America (Ramírez & Santelices 1991) and West Antarctica; it is therefore a species from cold-temperate to cold waters. In the sub-Antarctic ecoregion this species is strictly sublittoral and grows on rocky substrate between 5 and 15 m deep (Ávila et al. 1999). Nevertheless Billard et al. (2015) show that *G. skottsbergii* has two divergent, monophyletic clades that may correspond to two cryptic species, making *Gigartina* sp. from Antarctica endemic to this area. In Antarctica it may live from the lower intertidal zone (pers. obs.) to shallow depths (Wiencke & Clayton 2002). *Gigartina skottsbergii* forms dense sublittoral beds reaching biomasses of about 1773 g m^{-2} and densities of 15 individuals m^{-2} (Ávila et al. 2004). Besides being primary producers and ecosystem engineers (Christie et al. 2009; Torres et al. 2015), macroalgae beds are important for sustenance of biodiversity because they can alter local environmental conditions (Stachowicz 2001), providing shelter, breeding places and/or food for many species of invertebrates and vertebrates (Ríos et al. 2007; Mansilla & Ávila 2011; Rosenfeld et al. 2015). Molluscs are one of the most representative and studied groups worldwide of this algae–mollusc interaction (see Vahl 1971; Salas & Hergueta 1986; Sánchez-Moyano et al. 2000; Rueda & Salas 2003; Amsler et al. 2015; Martin et al. 2016).

In the MBP, molluscs are one of the most representative and diverse groups of benthic marine environments, with more than 397 species reported (Linse 1999; Valdovinos 1999). Another important feature of Magellanic molluscs is that 35% of species are endemic to the MBP (Fortes & Absalao 2011). Among the molluscs, gastropods are the dominant group in terms of number of species, followed by bivalves (Linse et al. 2006; Clarke et al. 2007). Clarke et al. (2007) recorded a total of 549 species of gastropods and 158 bivalves

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Supplemental data for this article can be accessed here.

distributed in the Southern Ocean. Engl (2012) reported 336 species (plus 59 probably undescribed) of shelled gastropod and over 87 bivalves in Antarctic waters. Specifically, in the area of the Antarctic Peninsula, including the South Shetland Islands, the same authors recorded 130 species of molluscs, i.e., low species richness compared to that recorded in the MBP. In more detail, the sublittoral bottoms corresponding to the continental shelf were represented by 85 species of gastropod and 48 bivalves (Linse et al. 2006). In addition, molluscs exhibited several levels of species richness between different areas of the Southern Ocean and adjacent areas, such as the MBP (Linse et al. 2006). However, although in recent years efforts have increased to better understand MBP and Antarctic molluscan biodiversity (Linse 1999; Griffiths et al. 2003; Zelaya 2005; Linse et al. 2006; Clarke et al. 2007; Aldea et al. 2011; Pastorino 2016), few investigations have focused on the ecological interaction between macroalgae and Antarctic molluscs (Amsler et al. 2015).

The main objective of this study was to characterize and compare molluscan assemblages associated with *Gigartina skottsbergii* beds in the Strait of Magellan and *Gigartina* sp. from the Antarctic Peninsula. The level of taxonomic affinity between the two provinces was also tested.

Material and methods

The study area was localized at four sampling sites with *G. skottsbergii* and *Gigartina* sp. beds: two in the Strait of Magellan – Punta Santa Maria, located in Tierra del Fuego (53° 21′ S; 70° 27′ W); Punta Santa Ana, located 60 km to the south of Punta Arenas (53° 37′ S; 70° 52′ W) – and in the Antarctic Peninsula: Punta Hanna (62° 39′ S; 60° 35′ W) and Fildes Bay (62° 12′ S; 58° 54′ W) (Fig. 1). The samples were obtained by scuba diving between 1 and 10 m depth in quadrats of 50 × 50 cm, which were selected randomly within each bed. In each quadrat, all molluscs were collected, and also the substrate, where *Gigartina* settled, was investigated. The rocks were subsequently scraped to ensure that all the species and specimens were collected. Each macroalgal sample was placed in a plastic bag. In the laboratory, each sample was gently stirred to detach the associated fauna. Once detached, the algae were removed from the bag and their fresh weight measured. Fifteen quadrats were sampled during one dive at each site, resulting in 60 quadrats per site (4 sites × 15 quadrats).

Molluscs density was standardized to individuals per gram of algal fresh weight. To determine the faunal composition – and their comparison – univariate and multivariate biodiversity analyses were performed using the Primer version 6.0 statistical package (Clarke & Gorley 2005). The univariate biodiversity measures calculated for each site were average species richness and average species abundance. Spearman rank correlation analysis was conducted to determine the correlation between mollusc abundance and macroalgal fresh biomass.

To show significant differences in abundance and species richness, including beds from both provinces, a nonparametric Mann–Whitney test was performed, using the Statistica 7.0 statistical package (StatSoft 2004; http://statistica.software.informer.com/7.0/).

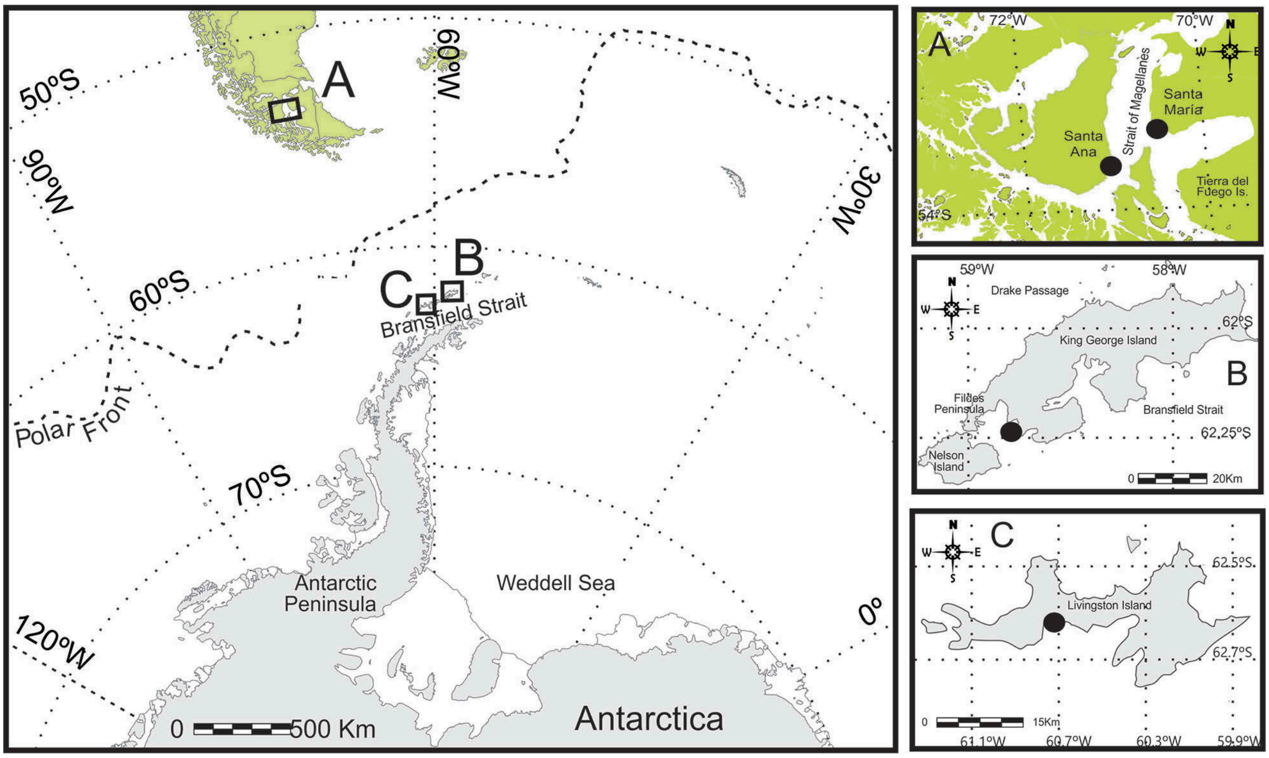

Figure 1. Sampling sites in the Strait of Magellan (A) and South Shetland Islands (B, C).

The specific importance of each species at each sampling site was determined by the similarity percentage, Simper (Clarke 1993). Once the most representative species of each group was known, complementary NMDS (Kruskal & Wish 1978) was performed to analyse graphically which species contributed to the similarity of each of the study areas. The data were transformed to presence and absence, to reduce the contribution of abundant species and to equate rare species.

To assess spatial differences in the structure of the assemblages, and as a measure of beta diversity, one-way Permdisp analysis was carried out. Dispersion was calculated as the average dissimilarity from individual observation units to their group centroid in multivariate space (Anderson 2006). Smaller dispersions among the assemblages depicted lower beta diversity.

In order to evaluate the affinity of different taxonomic levels (species, genus, family and order) among the study areas, spatial replacement taxonomic levels (beta diversity) was calculated, i.e., a measure of difference in the composition between two or more assemblages (Koleff 2005). To measure beta diversity, the presence and absence data of molluscan assemblages associated with *Gigartina* in the Magallanes area and Antarctic Peninsula were considered. In this way, the Whittaker (1972) index was calculated: $DB = (S_c/\alpha) - 1$, where S_c is species richness recorded in a sector set and α is the average number of species in both areas. This index ranges from 0 (when samples are absolutely identical in species composition) and 1 (the samples are absolutely different in their species composition) (Rau et al. 1998).

Finally, we used a linear dependence model to detect whether our sampling effort was able to estimate the total number of species of molluscs. This was designed to estimate species richness, depending on the number of samples (Soberón & Llorente 1993). All samples were randomized so as not to affect the shape of the curve (Colwell & Coddington 1994; Moreno & Halffter 2000). The Simplex and Quasi-Newton estimation methods of the statistical package Statistica 7 were used to estimate the coefficients of the nonlinear regression model.

Results

We collected a total of 600 specimens and identified 599 individuals to species level. Thirty-five species of molluscs in the classes Polyplacophora, Gastropoda and Bivalvia were represented (Table 1). Of the total, 270 specimens were bivalves, corresponding to 11 species, 254 were gastropods, corresponding to 17 species, and 75 were polyplacophorans, corresponding to seven species. The remaining specimen (the bivalve *Hiatella* sp.) was not assigned to a known species because we could not identify sufficient diagnostic characters. In terms of the number of species represented, Gastropoda (17 species belonging to nine families) came out on top, followed by Bivalvia (11 species belonging to six families) and Polyplacophora (seven species belonging to four families). The best-represented families were Littorinidae (four species) and Phylobryidae (four species).

For Antarctic Peninsula beds, the most abundant species were the bivalve *Lissarca miliaris* (233 individuals) and the gastropod *Laevilacunaria antarctica* (94 individuals), while for MBP beds the most abundant species were the polyplacophoran *Callochiton puniceus* (36 individuals) and the gastropod *Fissurella oriens* (22 individuals).

Molluscan assemblages from Antarctic Peninsula beds had a higher average abundance (21.9 ± 5.6 individuals) than MBP ones (7.05 ± 1.19), showing a significant difference between them ($Z = -3.0837$; $p = 0.002$). No significant differences in average species richness were evident ($Z = -1.5959$; $p = 0.110$) between Antarctic assemblages (4.3 ± 0.3) and MBP ones (3.70 ± 0.4). We observed a good correlation between *Gigartina* fresh biomass and the number of associated molluscs measured as total abundance (*Gigartina skottsbergii*: $r = 0.678$, $p < 0.05$; *Gigartina* sp.: $r = 0.616$, $p < 0.05$) (Fig. 2).

Simper analysis showed that the cluster of Antarctic Peninsula beds showed an average similarity of 76.31%. Meanwhile, the cluster of MBP beds presented an average similarity of 51.07%. The gastropods *Laevilacunaria antarctica* and *Nacella concinna* and the bivalve *Lissarca miliaris* were the species that most contributed to the similarity of the Antarctic Peninsula assemblages (Fig. 3), while for the MBP assemblages the polyplacophoran *Callochiton puniceus* and gastropod *Fissurella oriens* were species that most contributed to their similarity.

NMDS analysis (Fig. 3) revealed that species of both clusters (Antarctic and MBP) were located at a great distance (very low similarity between them). Comparative analysis between the two molluscan assemblages (Permdisp) showed significant differences in the faunal composition between the Antarctic Peninsula and Strait of Magellan ($f = 64.474$; $p = 0.0001$).

Turnover of the various taxonomic levels between the assemblages of the Antarctic Peninsula and Strait of Magellan presented a uniform pattern. The species and genus levels had the highest levels of turnover ($\beta_w = 1$ and 0.8, respectively). In general, almost all taxonomic levels had high turnover values ($\beta_w > 0.5$), except at the order level, which had a β_w value of 0.1 (Fig. 4).

The species richness associated with the sampling effort was determined by a linear dependence model. For the Antarctic Peninsula, prediction constants were $a = 5.3664$ and $b = 0.5370$; therefore, the expected maximum richness (a/b) was 10 species with $R^2 = 0.98$ and slope > 0.0000 (Fig. 5(a)). This value is the same as that observed in the field ($S = 10$). Finally, for the Strait of Magellan, prediction constants were $a = 3.1585$ and $b = 0.1272$;

Table 1. Systematic list of all mollusc species recorded, indicating their presence (+) in the beds of Strait of Magellan (MA) and the South Shetland Islands (SI).

Class to Family	Species	MA	SI
POLYPLACOPHORA			
Order Chitonia			
Ischnochitonidae	*Ischnochiton stramineus* (Sowerby in Broderip & Sowerby 1832)	+	
	Tonicina zschaui (Pfeffer 1886)		+
Callochitonidae	*Callochiton puniceus* (Couthouy MS Gould 1846)	+	
Chitonidae	*Tonicia lebruni* de Rochebrune 1884	+	
	Tonicia chilensis (Frembly 1827)	+	
	Tonicia atrata (Sowerby 1840)	+	
Mopaliidae	*Nuttallochiton martiali* (de Rochebrune in de Rochebrune & Mabille 1889)	+	
GASTROPODA			
Order Patellogastropoda			
Nacellidae	*Nacella deaurata* (Gmelin 1791)	+	
	Nacella flammea (Gmelin 1791)	+	
	Nacella concinna (Strebel 1908)		+
Lepetidae	*Iothia emarginuloides* (Philippi 1868)	+	
OrderVetigastropoda			
Fissurellidae	*Fissurella oriens* Sowerby 1835	+	
Calliostomatidae	*Margarella violacea* (King & Broderip 1832)	+	
Order Littorinimorpha			
Calyptraeidae	*Trochita pileus* (Lamarck 1822)	+	
Littorinidae	*Pellilitorina pellita* (Martens 1885)		+
	Laevilacunaria antarctica (Martens 1885)		+
	Laevilitorina antarctica (E. A. Smith 1902)		+
	Laevilitorina caliginosa (Gould 1849)		+
Ranellidae	*Fusitriton magellanicus* (Röding 1798)	+	
Order Neogastropoda			
Buccinidae	*Pareuthria cerealis* Rochebrune & Mabille 1885	+	
	Pareuthria fuscata (Bruguire 1789)	+	
Muricidae	*Trophon pallidus* (Broderip 1833)	+	
	Trophon nucelliformis Oliver & Picken 1984		+
	Xymenopsis muriciformis (King & Broderip 1832)	+	
BIVALVIA			
Order Pteriomorphia			
Mytilidae	*Aulacomya atra* (Molina 1782)	+	
	Mytilus E platensis d'Orbigny 1842	+	
Pectinidae	*Zygochlamys patagonica* (King & Broderip 1832)	+	
	Austrochlamys natans (Philippi 1845)	+	
Phylobryidae	*Philobrya sublaevis* Pelseneer 1903	+	
	Philobrya olstadi (Soot-Ryen 1951)		+
	Mysella subquadrata (Pesenner 1903)		+
	Lissarca miliaris (Philippi 1845)		+
Order Heterodonta			
Hiatellidae	*Hiatella* sp	+	
Carditidae	*Carditella naviformis* (Reeve 1843)	+	
Veneridae	*Tawera elliptica* (Hupé in Gay 1854)	+	
Gaimardiidae	*Gaimardia trapesina* (Lamark 1819)	+	

therefore, expected maximum richness (a/b) was 25 species with $R^2 = 0.97$ and slope = 0.069 (Fig. 5(b)). This value is the same as that observed in the field ($S = 25$).

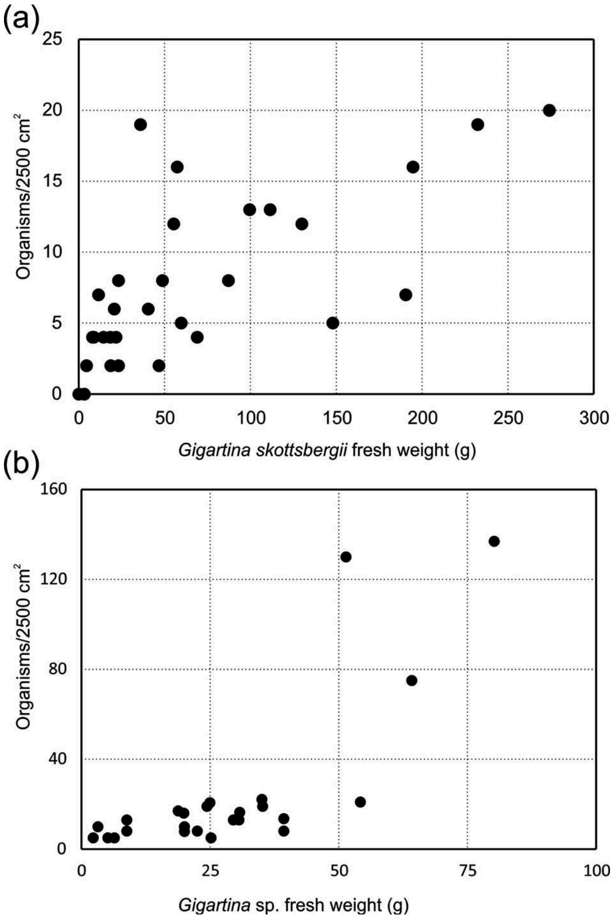

Figure 2. Total abundance of mollusc per macroalgae biomass of *Gigartina* in the four sampling localities: (a) populations the Strait of Magellan; (b) populations in the South Shetland Islands.

Discussion

This is the first comparative report of molluscan assemblages associated with the two *Gigartina* species between the Antarctic Peninsula and Strait of Magellan. For the Strait of Magellan there had already been a previous report by Rosenfeld et al. (2015) and for the Antarctic Peninsula one by Amsler et al. (2015).

The amount of mollusc species recorded in this work represents an average value similar to those reported in other studies carried out over the past 20 years in shallow subtidal rocky environments of the Antarctic Peninsula (Table 2). In this regard, the work with the highest number of species (Amsler et al. 2015) reported a total of 20 species of gastropod associated with *Gigartina* sp., but that work mainly focused on species of the class Gastropoda. However, in general all the works present a very similar mollusc species richness, being reports of assemblages with low species richness compared with molluscs from shallow subtidal habitats of the MBP, which have an average richness of 35 ± 13 species (Rosenfeld et al. 2015). However, although molluscan assemblages from shallow bottoms of the Antarctic Peninsula have lower species richness compared to MBP ones, the level of endemism is higher in assemblages from Antarctica. For example, of the 10 species recorded in

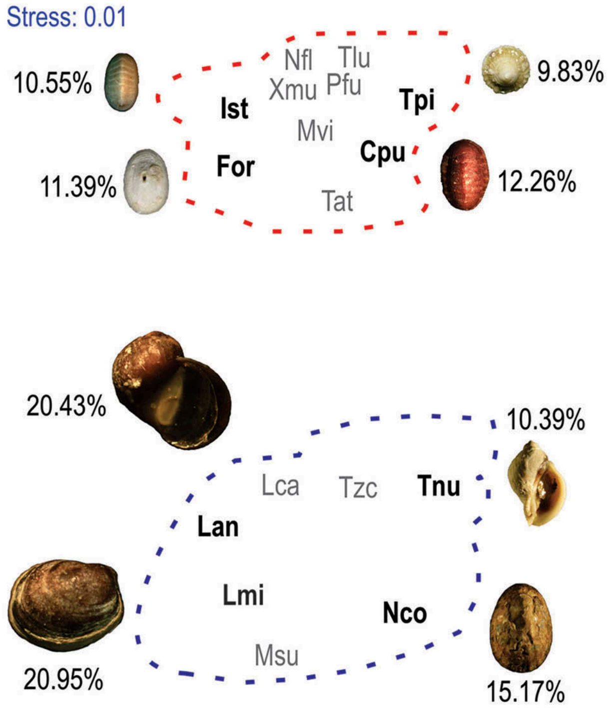

Figure 3. NMDS ordination of molluscan assemblages, showing arrangement of the species that most contributed to the similarity of each of their groups. Cpu (*Callochiton puniceus*), For (*Fissurella oriens*), Ist (*Ischnochiton stramineus*), Lan (*Laevilacunaria antarctica*), Lca (*Laevilitorina caliginosa*), Lmi (*Lissarca miliaris*), Mvi (*Margarella violacea*), Msu (*Mysella subquadrata*), Nco (*Nacella concinna*), Nfl (*Nacella flammea*), Pfu (*Pareuthria fuscata*), Tat (*Tonicia atrata*), Tlu (*Tonicia lebruni*), Tzc (*Tonicina zschaui*), Tpi (*Trochita pileus*), Tnu (*Trophon nucelliformis*), Xmu (*Xymenopsis muriciformis*).

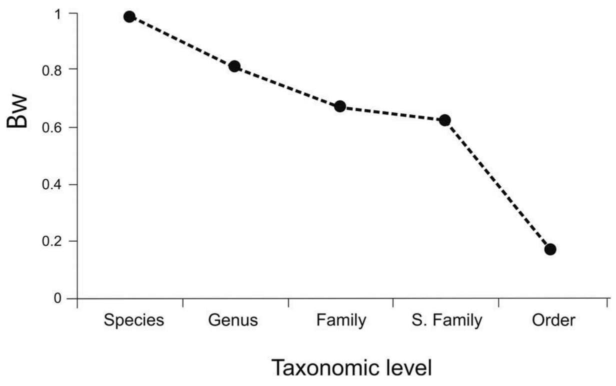

Figure 4. Relationship between taxonomic levels and turnover thereof.

this study, 70% are endemic to Antarctica, while of the 25 species recorded in the MBP only 28% are endemic to this biogeographic province (Rosenfeld et al. 2015). These endemism values are related to biogeographic patterns established by Griffiths et al. (2009), who posited that gastropods generally show a high level of endemism in all Antarctic regions. In our study of six species of gastropod registered in Antarctica, only the species *Laevilitorina caliginosa* reached the MBP, having the Chiloé Islands as a northern distribution boundary (Castellanos 1989).

From our investigation of all previous work, through a full listing of mollusc species, there has been a total of 55 species of mollusc (one Polyplacophora, 42 Gastropoda and 12 Bivalvia) inhabiting shallow rocky Antarctic environments (0–30 m) (Supplementary Table S1).

As in the work carried out by Jazdzewski et al. (2001) and Martin et al. (2016), the family with the most species in rocky shallow Antarctic environments was Littorinidae. Of the total number of recorded species, nine belong to the Littorinidae family, which could reflect that species of this family are more specialized to these extreme Antarctic environments, where during the winter the sea freezes (Wiencke & Clayton 2002; Waller et al. 2006). Although, Engl (2012) recorded eight species of *Prosipho* (family: Buccinidae): *P. astrolabiensis* (Strebel 1908), *P. crassicostatus* (Melvill & Standen 1907), *P. glacialis* Thiele 1912, *P. enricoi* Engl 2004, *P. harrietae* Engl & Schwabe 2003, *P. iodes* Oliver & Picken 1984, *P. mundus* E. A. Smith 1915, and *P. turritus* Oliver & Picken 1984, from rocky shallow waters, none of these species were recorded in the descriptive benthic studies of the last 22 years (Supplementary Table S1). In contrast, in the MBP the most representative family in shallow bottom assemblages was Buccinidae, with more than 10 species (Ríos et al. 2003; Aldea et al. 2011), which may reflect the high diversity presented by this group in the MBP. In the Linse's species checklist of Linse (1999), 27 species of Buccinidae (as Buccinulidae) for the MBP were reported. Another gastropod family

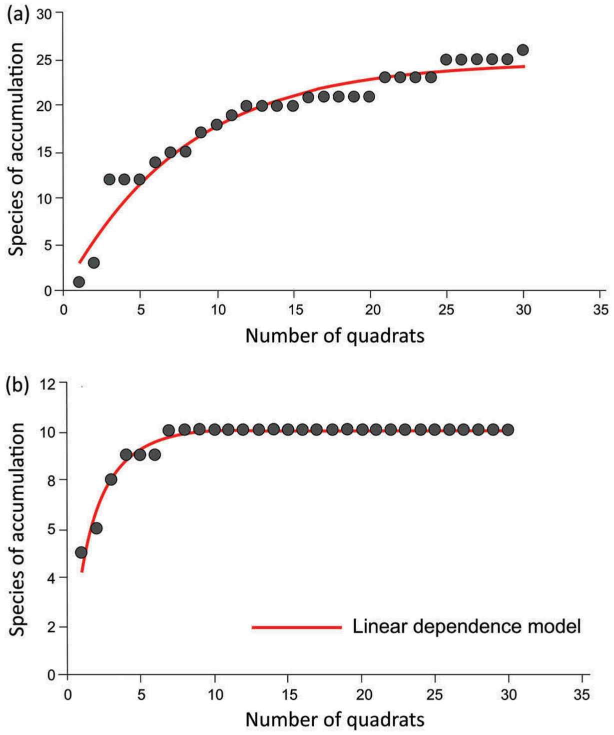

Figure 5. Linear dependence model to estimate the species richness associated with sampling efforts at sampling sites: (a) Strait of Magellan and (b) South Shetland Islands.

Table 2. Number of mollusc species in Antarctica recorded in works since 1994. We took into account studies where intertidal and sublittoral samples were collected (all studies with sampling depths less than 30 m were included and considered as 'shallow water').

Source	Depth	Gastropoda	Bivalvia	Polyplacophora	Total species
Martin et al. 2016	0 m	9	4	0	13
Bowden 2005	8 to ca. 20 m	9	1	0	10
Waller et al. 2006	0 to ca. 6 m	6	4	0	10
Bick & Arlt 2013	0 m	6	3	0	9
Gambi et al. 1994	0 to ca. 16 m	7	1	0	8
Jazdzewski et al. 2001	0 m	5	0	0	5
Valdivia et al. 2015	0–30 m	4	3	1	8
Amsler et al. 2015	6–16 m	20	0	0	20
Aghmich et al. 2016	0 m	7	3	0	10
		8 ± 1.7	2.1 ± 1.7	0.11 ± 0.4	10.3 ± 2.6
This record	0 to ca. 7 m	6	3	1	10

representative in the MBP is Calliostomatidae. Linse (1999) used the name Trochidae to group all species of Calliostomatidae, reporting 16 species for the MBP. This group of gastropods is characterized as representative in subtidal studies of the Strait of Magellan (see Ríos et al. 2003; Aldea et al. 2011; Rosenfeld et al. 2015). For example, Calliostomatidae species such as *Margarella violacea* have been reported as the most abundant (Aldea et al. 2011), as in this study, in which *M. violacea* was one of the representative MBP species (Fig. 6). Regarding polyplacophorans, it should be noted that for the Strait of Magellan assemblage, six species were recorded inhabiting beds of *Gigartina*, while for the Antarctic Peninsula we only recorded one species (*Tonicina zschaui*), and generally in work on shallow environments of Antarctica no polyplacophoran species are reported. Therefore, polyplacophorans showed a drastic reduction in species richness compared to the MBP.

The affinity of molluscs at species level between the Strait of Magellan and South Shetland Islands is quite low (Linse et al. 2006). However, these authors mentioned that at higher taxonomic levels (e.g., families) the affinity increases. Nevertheless, in this study we observed that even replacement at superfamily level between assemblages is high ($\beta_w = 0.6$); therefore, molluscs reported in both areas are characteristic of their respective biogeographic area.

Finally, we note that in shallow-bottom systems in Antarctica, disturbances caused by advance and retreat of the ice play a key role in structuring

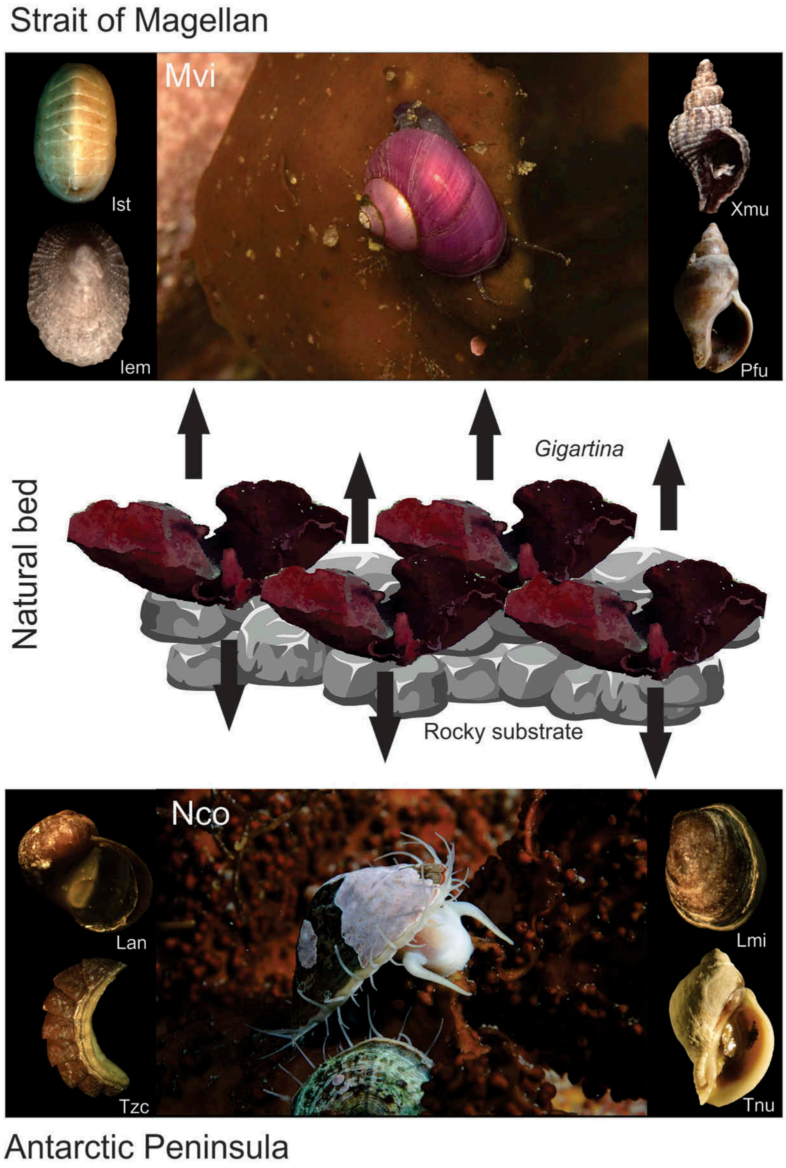

Figure 6. Representative species found in *Gigartina* beds in the Strait of Magellan and South Shetland Islands. Iem (*Iothia emarginuloides*); for other abbreviated species names see labels of Fig. 3.

communities (Waller et al. 2006; Valdivia et al. 2015). Previous studies have shown that the highest diversities have been recorded in locations that undergo the greatest degree of physical disturbances by advancing ice (Waller et al. 2006), since all taxa present in these localities inhabit more specific habitats under boulders rather than on them. The presence of populations of macroalgae on the rocky coast of the Antarctic Peninsula should also contribute considerably as habitats for a variety of sessile and mobile fauna, since the creation and complexity of habitats that form the different macroalgae species play an important role in the formation of patterns of abundance and diversity of the communities associated with them (Torres et al. 2015; Valdivia et al. 2015). These patterns were observed by Martin et al. (2016) in populations of *Adenocystis utricularis* and *Iridaea cordata* around King George Island, by Amsler et al. (2015) in populations of eight dominant species of macroalgae and observed in this study in populations of *Gigartina* species on both sides of the polar front.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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