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Distribution and abundance patterns of echinoderms in the fjord and channel complex from a subantarctic north Patagonian Ice field, Magellan region

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Abstract: The existence of latitudinal marine biodiversity gradients from low to high-southern latitudes is a controversial issue regarding the marine biogeographic division in the Southeastern Pacific. In this region, the Northern Patagonian Icefield is considered a break point for faunistic elements derived from more northern or southern biogeographical realms. However, the division seems to be better defined by distribution patterns and endemism of specific marine taxa. There have been no exhaustive latitudinal benthic inventories compiled along the southern-eastern Pacific Chilean coastline. This study focuses on the spatial distribution variability and relative abundance of the sublittoral echinoderm assemblages and uses them to establish an evaluation of zoogeographic relationship in the Southeastern Pacific and Atlantic Oceans. This is the first time echinoderms have been used for this purpose. A total 3 665 echinoderm specimens were collected in two cruises. Within this organism pool, 29 species were distinguished, belonging to the asteroids (17 species), echinoids (6 species), ophiuroids (4 species) and holothurians (2 species); crinoids were not found. The dominant species were the asteroid *Ctenodiscus procurator,* the echinoid *Pseudechinus magellanicus,* the ophiuroid *Ophiuroglypha lymani*, and the irregular sea urchin *Tripylaster philippii*. The spatial distribution patterns for the echinoderm clusters along the study area showed only weak geographical trends. Stations belong in three groups: with influence of glacier processes, influence of waters of the open Pacific Ocean, and a third group of stations without any links to specific locations. Rev. Biol. Trop. 65(Suppl. 1): S60-S72. Epub 2017 November 01.

Key words: Patagonian icefield; zoogeography; Magellan region; invertebrates; asteroids.

Biogeographic division of the marine realm in the Southeastern Pacific is a controversial issue as also is the discussion about the existence of latitudinal marine biodiversity gradients from low to high-Antarctic latitudes (Crame, 1999; Gray, 2001, 2002; Arntz, 1999; Arntz*,* Lovrich, & Thatje, 2005). At the southern tip of South America there have been several attempts to produce a robust biogeographic zonation scheme based on distribution patterns of different macrofaunistic taxa (Viviani, 1979; Battström & Johanssen, 1983; Lancellotti & Vásquez, 1999; Camus, 2001). Camus (2001) resumed 27 biogeographic classifications published so far for the entire Chilean coastline.

Zoogeographically, the region from Chiloé to the southernmost Patagonian seems to be better defined by distribution patterns and endemism of specific marine benthic taxa, as has already been studied for ophiuroids (Dahm, 1999), holothurians (Pawson, 1969), echinoids (Pawson, 1966), asteroids (Codoceo & Andrade, 1978), molluscs (Valdovinos, Navarrete, & Marquet, 2003), bryozoan (Moyano, 1982, 1999), nudibranchia (Schrödl, 1999) and sea anemones (Häussermann, 2006).

The biogeographic patterns in this region are not unique to the region, rather they are the result of complex interactions between heterogeneous local abiotic phenomena and the biology of benthic organisms, their origin tolerance values to environmental parameters, physical characteristics along the Chilean coast (Pantoja, Iriarte, & Daneri, 2011) and dispersion processes whithin the different taxa of marine invertebrates (Camus, 2001). Geomorphologic glacier formation has influenced the biological history of the region. The presence/absence of massive glacier fronts create distinct local and regional abiotic and biotic differences (Kilian & Lamy, 2012; Kilian et al., 2013; Ríos, Kilian, & Mutschke, 2016; Darvill, Stokes, Bentley, Evans, & Lovell, 2016). Massive glacier advance and retreat has resulted in coastal fragmentation and created different habitat types. Their effects on biodiversity and the isolation of species in these heterogeneous area has not been explored in detail (Camus, 2001, Munilla & Soler, 2009). No exhaustive latitudinal benthic inventories carried out to date along the southern-eastern Pacific Chilean coastline have been performed so far to help address questions (Fernández et al., 2000; Escribano, Fernández, & Aranís, 2003).

The fjord and channel complex at the southern tip of South America has been extensively studied several times from 1995 onwards (Sievers, & Silva, 2006; Mutschke, 2008). It has been found from preliminary investigations that echinoderms are a dominant group, both in number and biomass, within the macrozoobenthos assemblages inhabiting this region (Ríos, Mutschke, Montiel, Gerdes, & Arntz, 2005; Mutschke, 2006; Ríos, Mutschke, & Montiel,, 2013). It is not clear yet whether this dominance continues into adjacent northern areas of this complex zone, although in southern parts (Straits of Magellan) concordance in terms of biomass has been found (Mutschke & Ríos, 2006).

This study focuses on the distribution of echinoderms, especially asteroids, along the Northern Patagonian Icefield. Several authors suggest this area as a break point for faunistic elements derived from more northern or southern biogeographical realms (Viviani, 1979; Battström & Johanssen, 1983; Lancellotti & Vásquez, 1999; Camus, 2001). The specific objectives of the study are (a) to describe for the first time the spatial variability and relative abundance of the sublitoral echinoderm assemblages in fjords and channels located along the Northern Patagonian Icefield; and (b) to establish an evaluation of the zoogeographic relationships of echinoderms in the Southeastern Pacific and Atlantic Oceans, focusing on data on asteroids distribution.

MATERIALS AND METHODS

Study area. The Pacific coast of the Southern tip of South America is structured by a complex system of fjords and channels with distinct local and regional abiotic –and presumably biotic– differences determined by the presence/absence of massive glacier fronts, which are part of the largest temperate ice masses in the southern hemisphere, the Northern and Southern Patagonian Icefields. (Hulton, Purves, McCulloch, Sugden, & Bentley, 2002; Kilian & Lamy, 2012; Kilian et al., 2013; Darvill, Stokes, Bentley, Evans, & Lovell, 2016). The thermal and saline structures of the interior waters in front of these icefields are affected by a peculiar topography (Pinochet & Salinas, 1996; Kilian *et al*., 2007). They receive inputs of different water masses from the adjacent Pacific Ocean (Palma & Silva, 2004) through numerous connecting channels. These waters mix in the interior zone with freshwater from precipitation, river flow, and meltwater from mountain glaciers, leading to a typically two-layered structure of the water column with higher temperature and lower salinity in the upper layer and a more stable, cooler deeper layer with higher salinity. In winter, the riverine freshwater input is cooler thus producing thermal inversion in the surface water layer. Towards the open Pacific shelf appears a distinct east/west gradient appears with an increase in salinity and temperature (Pinochet & Salinas, 1996). As a result, the waters along both icefields are a very complex system creating highly heterogeneous and particular abiotic and biotic habitat features for benthic organisms.

Samples analyzed in this article were collected at sites located in the warmer northern ice sheet domain where particularly rapid ice wastage occurs (Fig. 1).

Sampling procedures. Samples were collected during the CIMAR/FIORDO 7 (July 2001) and CIMAR/FIORDO 8 (July 2002) cruises of the Chilean Comité Oceanográfico Nacional (CONA) aboard the R/V Vidal Gormaz in the Austral winter season. 46 stations were sampled along fjords and channels located from 43º30´S; 072º30´W (Boca del Guafo) to 46º30´S; 75ºW (Golfo de Penas; Fig.1). The sampling locations, depths, and geographical coordinates are summarized in Table 1 for both cruises.

Trawl gear used was a modified Agassiz-type trawl (AGT; mouth width 1.5 m fitted with a 10 mm net) deployed once per location. From the moment of contact with the bottom, the AGT was towed at a speed of about 1.5 knots for 15 min. From each sample obtained per site and deployment, a 5 l sub-sample was separated for later analyses of sediments and benthos. Sub-samples were sieved on board through a 1 mm mesh and all echinoderms were separated out. Sorted specimens were preserved in a 4% hexamethylenetetramine buffered seawater formalin solution for later identification in the laboratory.

Identification of species was based mainly on the publications of Bernasconi (1953; 1962; 1963; 1964), Clark (1920), Clark & Downey

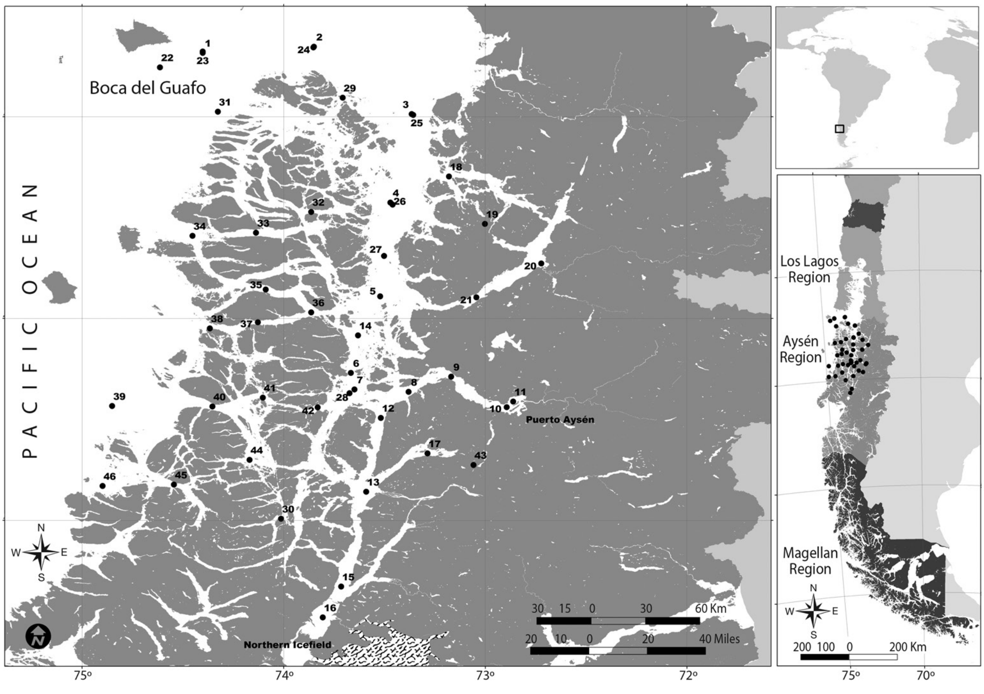

Fig. 1. Study area and location of 46 sampling sites in the southern fjord and channels complex, Chilean Patagonia sampled in the CIMAR Fiordos Cruise 7 and 8.

Fig. 1. Área de estudio y localización de los 46 sitios de muestreo, considerados en el Crucerp Fiordos CIMAR 7 y 8, los fiordos del sur y los complejos de canales.

TABLE 1
General characteristics of the 46 sampling sites considered in the CIMAR Fiordos Cruise 7 and 8,
to the southern fjord and channels complex, Magellanic región, Chile

CUADRO 1
Características generales de 46 sitios de muestreo considerados en los Cruceros Fiordos CIMAR 7 y 8,
de los fiordos del sur y el complejo de canales, región Magallánica, Chile

Station N°	Latitude (S)	Longitude (W)	Depth (m)	Site name	Sampling date
1	43°40.99	74°24.10	202	Boca del Guafo	08/07/2001
2	43°39.18	73°50.95	170	Boca del Guafo	08/07/2001
3	43°59.19	73°21.87	179	Canal Moraleda	09/07/2001
4	44°25.50	73°28.20	410	Canal Moraleda	09/07/2001
5	44°53.38	73°31.25	198	Canal Moraleda	09/07/2001
6	45°16.17	73°39.98	64	Canal Moraleda	09/07/2001
7	45°21.10	73°38.88	156	Canal Moraleda	09/07/2001
8	45°21.80	73°22.78	248	Seno Aysén	09/07/2001
9	45°17.28	73°10.13	339	Seno Aysén	10/07/2001
10	45°26.36	72°53.56	174	Seno Aysén	10/07/2001
11	45°24.69	72°51.64	156	Seno Aysén	11/07/2001
12	45°29.56	73°31.03	304	Canal Costa	10/07/2001
13	45°51.50	73°35.41	110	Seno Elefantes	13/07/2001
14	45°05.01	73°37.82	56	Seno Elefantes	14/07/2001
15	46°19.69	73°42.88	20	Seno Elefantes	14/07/2001
16	46°28.88	73°48.32	116	Seno Elefantes	15/07/2001
17	45°40.07	73°17.17	270	Seno Quitralco	17/07/2001
18	44°17.76	73°10.78	444	Canal Jacaf	19/07/2001
19	44°31.85	72°60.09	258	Seno Ventisquero	19/07/2001
20	44°43.59	72.43.30	196	Canal Puyuhuapi	18/07/2001
21	44°53.69	73.02.60	238	Canal Puyuhuapi	17/07/2001
22	43°45.29	74°36.78	240	Boca del Guafo	06/07/2002
23	43°40.57	74°24.07	200	Boca del Guafo	06/07/2002
24	43°39.36	73°51.11	189	Boca del Guafo	06/07/2002
25	43°59.43	73°21.43	170	Canal Moraleda	06/07/2002
26	44°26.11	73°27.54	380	Canal Moraleda	07/07/2002
27	44°41.37	73°30.10	322	Canal Moraleda	07/07/2002
28	45°22.21	73°40.40	87	Canal Moraleda	07/07/2002
29	43°54.33	73°42.41	58	Canal Leucayec	20/07/2002
30	45°59.50	74°00.77	203	Canal Taumapu	20/07/2002
31	43°58.50	74°19.58	190	Canal Taumapu	20/07/2002
32	44°28.29	73°51.79	132	Canal Baeza	17/07/2002
33	44°34.50	74°08.19	200	Canal King	17/07/2002
34	44°35.40	74°27.13	156	Canal King	16/07/2002
35	44°51.36	74°05.34	160	Canal Goñy	16/07/2002
36	44°58.17	73°51.79	180	Canal Ninaulac	11/07/2002
37	45°01.08	74°07.66	274	Canal Ninaulac	11/07/2002
38	45°02.90	74°21.94	154	Canal Ninaulac	12/07/2002
39	45°26.00	74°51.03	90	Canal Darwin	10/07/2002
40	45°26.16	74°21.18	224	Canal Darwin	10/07/2002
41	45°23.49	74°06.20	170	Canal Darwin	10/07/2002
42	45°26.38	73°49.85	242	Canal Darwin	10/07/2002
43	45°43.55	73°03.48	86	Canal Chacabuco	08/07/2002
44	45°42.00	74°10.13	61	Canal Chacabuco	08/07/2002
45	45°49.34	74°32.65	210	Canal Pulluche	08/07/2002
46	45°49.76	74°53.89	82	Bahía Anna Pink	09/07/2002

(1992), Castillo (1968), Larraín (1975), Madsen (1956) and Pawson (1969).

Data analysis. Multivariate statistics were applied to perform community analyses using the software package PRIMER v.6 (Clarke & Gorley 2006). Statistical analyses were based on presence/absence data of echinoderm species at each station. Agassiz trawl not allow a quantitative estimation of density. We prefer the presence/ absence transformation for a proper comparison between sampling station. The similarity profile test (SIMPROF) routine was used to test the internal group structure in the full set of samples, i.e. to demonstrate the statistical significance of differences among the groups defined by the cluster analysis. Dominant species in each group were determined considering only species with more than 4% of contribution to the relative abundance in each group. Multidimensional scaling (MDS) and analyses of similarity in, and dissimilarity between groups were performed using the Bray–Curtis Index. The dominance of species was corroborated with the routine SIMPER from PRIMER, which calculates similarities within groups and dissimilarities between groups resulting from cluster and multidimensional scaling.

RESULTS

Species numbers and composition. A total 3 665 echinoderm specimens were collected from these two cruises. The numbers of species collected per station varied between 982. There was a weak trend of higher collection numbers at stations inside the complex channel system. Most specimens were collected at St. 9 (982) in Seno Aysén at St. 19 (662) in Seno Ventisquero and at St. 8 (423) in the western entrance of Seno Aysén. Almost three quarters (73%) of the entire echinoderm specimens were collected at just 7 stations, and less than 10 specimens were found at 19 stations in the subsample trawled material. The most diverse echinoderm inventory came from St. 36, 37, 40 and 41, where ≥ 10 species were collected; at 4 stations 6 to 9 species were found and ≤ 5 were collected at the other 37 stations. Within this organism pool 29 species of echinoderm were distinguished - asteroids (17 species, 59%), echinoids (6 species, 21%), ophiuroids (4 species, 13%) and holothurians (2 species, 7%); crinoids were not found (Fig. 2). The most dominant species collected were the asteroid *Ctenodiscus procurator* (1 332 individuals), the echinoids *Pseudechinus magellanicus* (1 041 specimens) and *T. philippii* (279 specimens), and the ophiuroid *Ophiuroglypha lymani (*314 specimens), between them accounting for almost 81 % of the entire echinoderms collected. Ten other species were collected in numbers between 10 and 114, 13 species were found with < 10 specimens, two of them, *Cheiraster (Luidiaster) planeta* and *D. singularis* were only found in a single specimen.

The most frequently found species *P. magellanicus, T. phillipii, Cosmasterias lurida,* and *Arbacia dufresni,* occurred at 22, 17, and 15 stations, respectively. These species were part of a group of 7 seastars and echinoids, which were collected at ≥ 10 stations. Twelve species were collected at 4 to 6 stations and 10 species were found at less than three stations.

Species groups, composition and distribution patterns within the study area. The SIMPROF procedure of the similarity matrix based on presence/absence data identified three main clusters (group a=14 stn; group b=8 stn; group c= 22stn) and these groups were also confirmed by multi-dimensional scaling (Fig. 2). Two single stations (St. 25 at Canal Moraleda and St. 46 at Bahía Anna Pink) were separated from the main groups. Both had only one echinoderm species and differed in more than 98% from the general conglomerates defined by cluster and nMDS analyses. The SIMPER analysis showed relatively low average ´within-group similarities´ for these clusters (Table 3). The highest value was for group b with 50.8 %; *Porania antarctica*, *A. dufresni* and *C. lurida* were the main contributors to this similarity. Next was group c followed with 46.2 % within group similarity, mainly due to

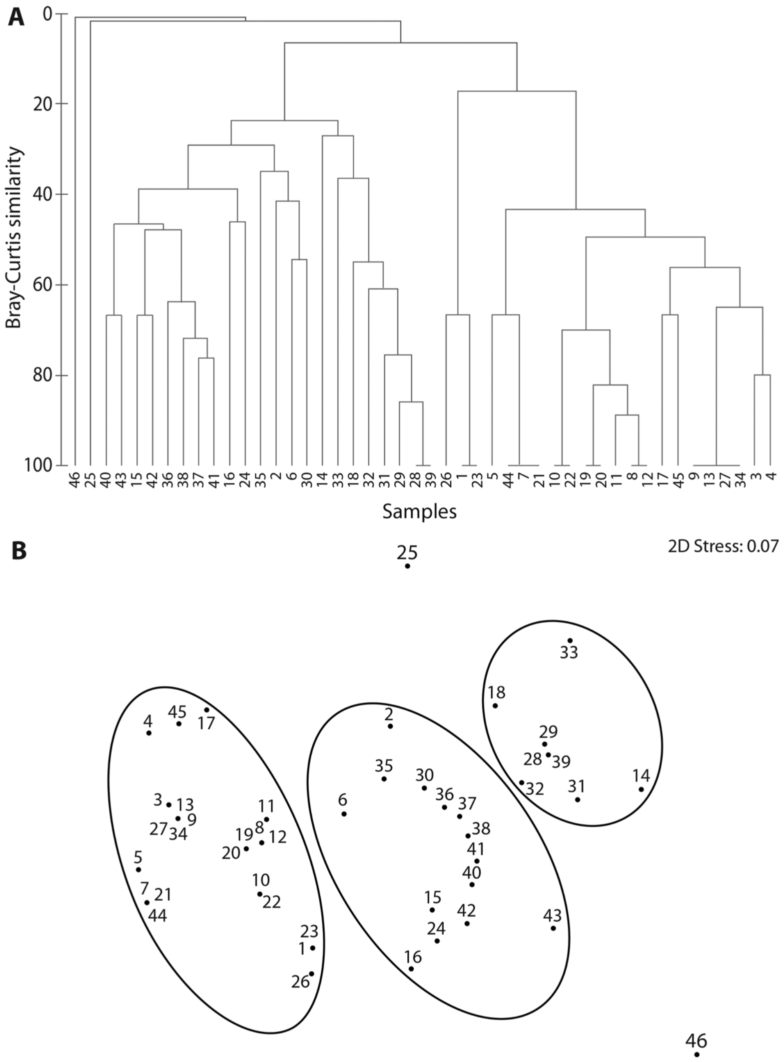

Fig. 2. A) Cluster analysis and B) multidimensional scaling ordination for presence/absence transformed echinoderm species data.

Fig. 2. A). Análisis cluster y B) Análisis de escalamiento multidimensional para los datos transformados de presencia / ausencia de las especies de equinodermos.

the contribution of *T. philippii, C. procurator* and *P. magellanicus*. Lowest ´within-group similarity´ resulted for group a (39.1 %) due to the presence of *P. magellanicus, Asterina fimbriata,* and *C. lurida*.

The average ´between-group dissimilarities´ varied between 76.3% (groups a and b), and 99.5 % (c and b) with an intermediate value of 89.9 % dissimilarity between groups c and a. The spatial distribution patterns for the echinoderm clusters showed only weak trends. Sampling stations forming the group "c" were distributed mainly -but not exclusively- in those areas more directly influenced by the glacier processes. Cluster "b" corresponds to sampling stations more related to the direct influence of open waters of the Pacific Ocean, whereas stations forming cluster "a" did not show any preference to specific locations.

TABLE 2

Relative abundance of echinoderms collected in the 46 sampling sites considered in the CIMAR Fiordos Cruise 7 and 8, to the southern fjord and channels complex, using an AGT trawl

CUADRO 2

Abundancia relativa de los equinodermos recolectados en 46 sitios de muestreo considerados en los Cruceros Fiordos CIMAR 7 y 8, de los fiordos del sur y el complejo de canales, usando una red de arrastre AGT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
ASTEROIDEA																																														
Ctenodiscus procurator	0	0	24	8	0	0	0	12	974	0	11	242	4	0	0	0	4	0	27	8	0	0	0	0	0	0	2	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	10	0
Porania antarctica	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	3	0	0	4	1	0	0	12	7	2	1	0	2	0	0	0	0	0
Cosmasterias lurida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	1	0	0	0	0	0	0	0	0	0	1	11	2	3	4	0	0	0	24	5	1	4	15	23	7	3	0	0	0
Cycethra verrucosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Solaster regularis	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	29	13	1	0	0	0	0	0	0	0	0
Poraniopsis echinaster	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	2	0	2	0	0	0
Calyptraster tenuissimus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Odontaster meridionalis	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0	0	2	0	0	0
Henricia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	5	1	0	0	0	0	0
Henricia obesa	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterina fimbriata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	3	1	0	24	1	21	1	0	0	0
Ceramaster patagonicus	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lophaster stellans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	7	2	0	2	1	0	0	0	0	0
Labidiaster radiosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Odontaster penicillatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
Cheiraster (Luidiaster) planeta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplodontias singularis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
OPHIUROIDEA																																														
Astrotoma agassizii	0	38	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophiuroglypha lymani	0	0	0	0	0	0	0	251	0	0	1	47	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Gorgonocephalus chilensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Ophiomyxa vivipara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	77	15	0	0	0	0	0
ECHINOIDEA																																														
Pseudechinus magellanicus	157	0	0	0	0	2	0	114	0	2	4	1	0	0	1	1	0	0	561	6	0	43	43	44	0	2	0	0	0	6	0	0	0	0	6	2	15	7	0	8	15	1	0	0	0	0
Arbacia dufresnii	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	1	1	1	0	0	1	12	24	10	3	3	31	0	0	0	0	0
Austrocidaris canaliculata	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Loxechinus albus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	7	1	0	0	0	0
Tripylaster philippii	0	0	5	0	1	1	1	46	8	17	17	66	1	0	0	0	0	0	74	1	2	10	0	0	0	0	23	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	0	0
Brisaster moseleyi	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HOLOTHUROIDEA																																														
Psolus sp.	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	16	0	0	0	0	0	0	43	0	0	0	0	0	0	0	0	0
Pseudocnus dubiosus leoninus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1

TABLE 3
Percentage contribution of echinoderms species to the Bray-Curtis similarity and dissimilarity values within and between groups of sites as defined by the cluster and nMDS analysis

CUADRO 3
Porcentaje de contribución de las species de equinodermos con los valores de similitud y disimilitud de Bray-Curtis según las agrupaciones de sitios definidas en los análisis de nMDS y cluster

	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Group a Average similarity: 39.12					
Pseudechinus magellanicus	0.86	10.23	1.44	26.15	26.15
Asterina fimbriata	0.71	6.61	0.92	16.89	43.04
Cosmasterias lurida	0.64	5.32	0.75	13.60	56.64
Group b Average similarity: 50.83					
Porania antarctica	0.75	17.53	0.96	34.50	34.50
Arbacia dufresnii	0.75	17.20	0.99	33.84	68.33
Cosmasterias lurida	0.75	16.10	1.00	31.67	100.00
Group c Average similarity: 46.24					
Tripylaster philippii	0.73	23.65	0.93	51.14	51.14
Ctenodiscus procurator	0.59	13.51	0.67	29.22	80.36
Pseudechinus magellanicus	0.45	8.09	0.45	17.50	97.87

Groups a & b Average dissimilarity = 76.32

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Group a	Group b				
Pseudechinus magellanicus	0.86	0.00	8.89	1.89	11.64	11.64
Asterina fimbriata	0.71	0.00	7.16	1.34	9.38	21.02
Porania antarctica	0.36	0.75	6.29	1.07	8.24	29.26
Arbacia dufresnii	0.64	0.75	4.84	0.82	6.34	35.60
Cosmasterias lurida	0.64	0.75	4.67	0.81	6.11	41.72
Odontaster meridionalis	0.43	0.00	4.00	0.81	5.24	46.96
Solaster regularis	0.36	0.13	3.49	0.76	4.57	51.53

Groups c & a Average dissimilarity = 89.94

	Group c	Group a				
Asterina fimbriata	0.00	0.71	7.78	1.34	8.65	8.65
Tripylaster philippii	0.73	0.07	7.65	1.31	8.50	17.16
Cosmasterias lurida	0.00	0.64	7.08	1.16	7.87	25.02
Arbacia dufresnii	0.00	0.64	6.40	1.20	7.12	32.14
Ctenodiscus procurator	0.59	0.00	6.31	1.09	7.01	39.16
Pseudechinus magellanicus	0.45	0.86	6.23	0.97	6.93	46.09
Odontaster meridionalis	0.00	0.43	4.32	0.81	4.80	50.89

Groups c & b Average dissimilarity = 99.53

	Group c	Group b				
Porania antarctica	0.00	0.75	15.49	1.33	15.57	15.57
Tripylaster philippii	0.73	0.00	15.04	1.33	15.11	30.68
Arbacia dufresnii	0.00	0.75	14.98	1.47	15.05	45.72
Cosmasterias lurida	0.00	0.75	14.32	1.50	14.38	60.11

DISCUSSION

Several studies along the Chilean Pacific coastline (Challenger Expedition in 1872-1876, Sladen, 1889; Lund University Expedition 1948-49, Madsen, 1956) concluded that the distribution of macrobenthic invertebrates along the Chilean coastline is discontinuous (Viviani, 1979; Brattström & Johanssen, 1983; Camus, 2001). Most studies so far have proposed two basic biogeographical provinces/regions along Chile: the northern warm-temperate Peruvian Province and the southern cold-water Magellanic Province. The border at about 42° S between these provinces coincides conveniently with abrupt changes in topography, climate and hydrography (Ahumada, Pinto, & Camus, 2000).

Since 1980, there has been intensive aquaculture along this coast (salmon) and extensive fishing of crustaceans, molluscs and echinoderms. Hence studies on the marine benthic fauna in the fjords and channel ecosystems have become more important. Recently, extensive efforts have been made to sample the macrobenthic communities in this part of South America, vast areas of which are among the poorest studied regions worldwide. The first main expedition was with the "Victor Hensen" Magellan Campaign in 1994 (Arntz, 1999) and followed by several Chilean expeditions under the umbrella of the *CIMAR* Program (Mutschke, 2008; Sivers & Silva, 2006). Through these knowledge about the Magellan benthos has greatly increased, especially with respect to benthic species inventories (bryozoans, echinoderms, polychaetes, decapods, molluscs), although still being far from complete.

This study as part of the *CIMAR Fiordo* Programms 7 and 8 is based on a collection of samples from 46 stations in an area of about 6,000 km^2 along the Southern and Northern Patagonian Icefields, some hundred miles south of the border between the two biogeographical provinces. This region has to be regarded as an ecologically young and complex system, with highly heterogeneous and particular habitat features for the benthos. This complex heterogeneity might explain the distribution pattern related to the three groups found from the cluster analysis, although ´within-group average similarities´ where rather low.

A total 29 echinoderm species were identified with a clear predominance of the Class Asteroidea, followed by the Classes Echinoidea, Ophiuroidea and Holothuroidea. This class abundance order seems to be a common characteristic in macrobenthic communities living in Chilean southernmost fjords and channels. Perez-Ruzafa et al. (2013) described the echinoderms in the marine communities around the cone of South America as one of the most conspicuous phylum. According to these authors, 45 asteroid species are described from the Magellan waters, constituting by far the most diverse echinoderm group as also holds true for Argentine waters with 52 species and for Antarctica with 295 species. All species found in this study were also found by Pérez-Ruzafa et al. (2013) for the Magellan region. Nineteen of these are also described for the Argentine -Atlantic sector, 6 of these species (*P. antarctica, Cycethra verrucosa, Odontaster penicillatus, Astrotoma agassizii, O. lymani, Gorgonocephalus chilensis*) occur in Antarctic waters (Griffiths, Danis, & Clarke, 2011) and five of these species (*P. antarctica, C.verrucosa, L. stellans, O. penicillatus, G. chilensis*) were described in the Temperate Peruvian Province (Mutschke, Ríos, Aldea, Montiel, & Silva, 2016).

Palma et al. (2005) found several polychaete and echinoderm species, which also occurred in Antarctic and sub-Antarctic waters further south. The authors hypothesized that the Antarctic Intermediate Water (AAIW), which stretches along the Chilean continental margin in 400 to 1200 m deep, transports these species to the northern latitudes. The widespread distribution patterns of many echinoderms in waters at the southern tip of South America agrees with the results of other specific studies such as those of Lancellotti & Vásquez (1999), Larraín, Mutschke, Riveros, & Solar, (1999), Penchaszadeh, Bigatti, & Miloslavich (2004), Ríos, Mutschke, Montiel, Gerdes,

& Arntz, (2005), López-Gappa & Sueiro (2007), González-Wevar et al. (2016), probably mirroring abilities of these invertebrates to cope with the environmental heterogeneity in this hydrographic and ecological complex fjord and channel system. Examples of these echinoderms are *G. chilensis* and *A. agassizii*, species that inhabit the Atlantic and Pacific coastlines of South America as well as in Antarctic waters (Hunter & Halanych, 2008).

The results show a distribution pattern among the stations in reference to the species that characterize them, both qualitatively and quantitatively (Fig. 3). Higher abundances *T. philippii* of *C. procurator*, and *P. magellanicus* were found in fjords that form Aysén and Puyuhuapi Sounds- areas with the lowest species richness. This group of species was representative of the group c stations characterized by low temperatures and high presence of clay on the bottom and in the water column, caused by melting of glaciers in the main fjords. The group b stations, characterized by *P. antarctica*, *A. dufresnii* and *C. lurida*, was related to sites where there was a higher oceanic influence. On the other hand, *Cosmasterias lurida* and *P. magellanicus* (representative of group a stations) were mainly distributed in the channels area, with a higher dispersion of the asteroid and an increment of uniformity that is reflected in a higher number of species and a lower abundance of each one of them. Other studies have suggested that oligotrophic waters (nutrient - poor) and a high discharge of sediments limits richness and abundance in the fjords and channel's benthic ecosystems during the aestival period (Silva & Prego, 2002). However, there are seasonal fluctuations that have not been studied and which might better explain the trends observed in the marine ecosystems, especially those related to areas that are near the South Ice Fields (Ríos, Mutschke, Montiel, Gerdes, & Arntz, 2005). The sampling period of the present work was developed in winter season when sedimentation caused by the glaciers melting is lower than in the aestival season. This fact might mean that the communities present in these areas develop in a better way when the main restriction of the benthic communities in these environments decreases and this would explain the high abundance of the species found.

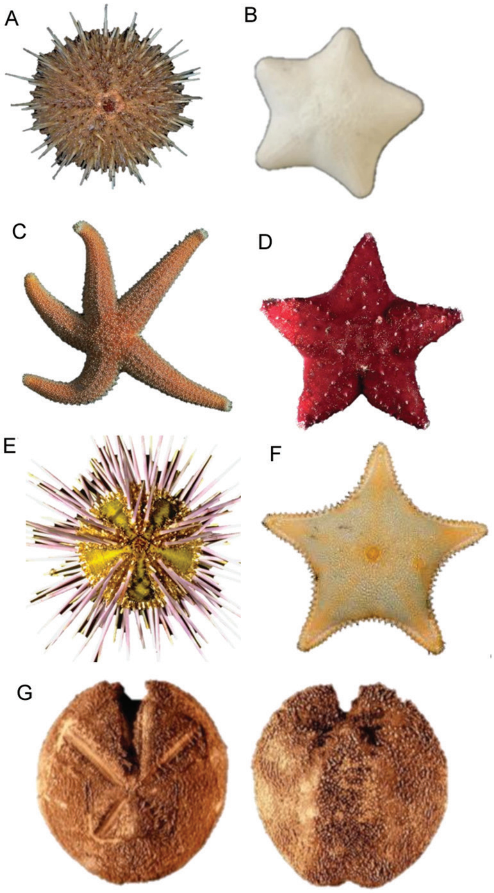

Fig. 3. The most common species composition collected at 46 stations in the Aysén region in July 2001 and 2002. A) *Pseudechinus magellanicus;* B) *Asterina fimbriata*; C) *Cosmasterias lurida;* D) *Porania antárctica;* E) *Arbacia dufresnii*, F) *Ctenodiscus procurator;* G) *Trypilaster philippii.*

Fig 3. Composición de especies más comunes recolectadas en las 46 estaciones en la región de Aysén en Julio 2001 y 2002. A) *Pseudechinus magellanicus;* B) *Asterina fimbriata*; C) *Cosmasterias lurida;* D) *Porania antárctica;* E) *Arbacia dufresnii*, F) *Ctenodiscus procurator;* G) *Trypilaster philippii.*

The most recent studies in this area (Ríos, Mutschke, Montiel, Gerdes, & Arntz, 2005, Ríos, Mutschke, & Montiel, 2013) do not cover eventual changes in the faunistic composition along longitudinal gradients from inland areas of channels and fjords towards the exposed coast, they have only evaluated latitudinal gradients. From other studies, three phytoplanktonic groups have been differentiated according to their species characteristics (Avaria, Cáceres, & Muñoz, 2004) that agree with the geographic and oceanographic differences related to the stations groups a and b in this study. According to Avaria, Cáceres, & Muñoz (2004), a zone of inland channels corresponding to the stations located in the interior area of fjords and sounds, a zone of exterior channels grouped (both corresponding to the group of stations b) and a zone of oceanic influence, (concordant with the group of stations a), are recognized.

Further studies, to describe the distributional patterns of other benthic marine invertebrates in this highly complex system are necessary to improve our understanding of the processes driving the ecology and zoogeography from this isolated, heterogeneous and pristine area.

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RESUMEN

La existencia de un gradiente latitudinal de biodiversidad marina de bajas a altas latitudes es un aspecto controversial de acuerdo a la división biogeográfica marina en el Pacífico suroriental. En esta región, los campos Patagónicos de hielo Norte han sido considerados un punto de quiebre para los elementos faunísticos derivados de reinos biogeográficos más al norte o más al sur. Sin embargo, las divisiones parecen estar mejor definidas por patrones de distribución y de endemismo de taxones marinos específicos. No ha habido un inventario exhaustivo del bentos a lo largo de la línea de costa del Pacífico sureste de Chile. Este estudio se enfoca en la variabilidad de la distribución espacial y en la abundancia relativa del ensamble de equinodermos sublitorales, aspectos que se utilizan para establecer una evaluación de las relaciones zoogeográficas en los océanos Pacífico sureste y Atlántico. Esta es la primera vez que los equinodermos han sido utilizados para este propósito. Un total de 3 665 especímenes de equinodermos fueron colectados en dos cruceros. Se identificaron 29 especies de asteroideos (17 especies), equinoideos (seis especies), ofiuroideos (cuatro especies) y holoturoideos (dos especies); no se encontraron crinoideos. Las especies dominantes fueron los asteroideos *Ctenodiscus procurator,*el equinoideo *Pseudechinus magellanicus,*el ofiuroideo *Ophiuroglypha lymani*, y el erizo de mar irregular *Tripylaster philippii*. Los patrones de distribución espacial para las agrupaciones a lo largo del área de estudio mostraron solo tendencias geográficas débiles. Las estaciones pertenecieron a tres agrupaciones: con influencia de procesos glaciares, influencia de aguas abiertas del Océano Pacífico, y un tercer grupo de estaciones sin ninguna conexión con localidades específicas.

Palabras clave: Campo de hielo patagónico; zoogeografía; región de Magallanes; invertebrados; asteroideos.

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