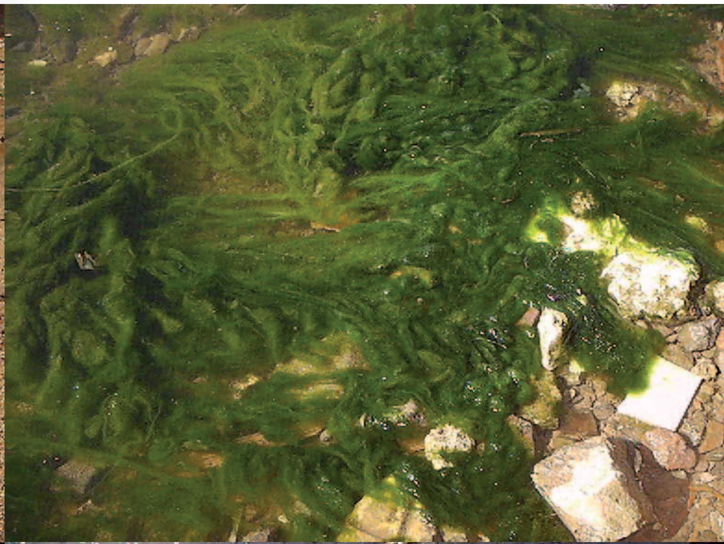
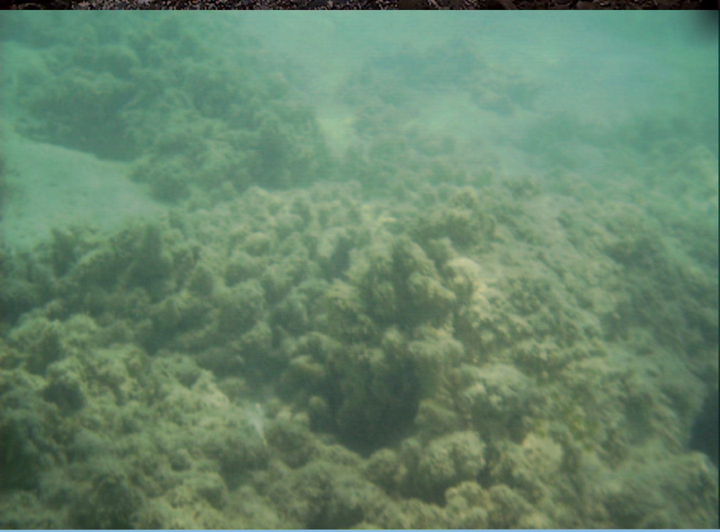
I.S.S.N.: 0212-5919

Thalassas

An International Journal of Marine Sciences

Number 28 (2) July 2012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I.S.S.N.: 0212-5919
Dep. Leg.: C379-83
Nº 28 (2) - 2012

Edita: Servizo de Publicacións
Universidade de Vigo.
Campus das Lagoas, Marcosende
36310 Vigo. España.

Impresa: en Vigo. España

Volume 28(2)

THALASSAS

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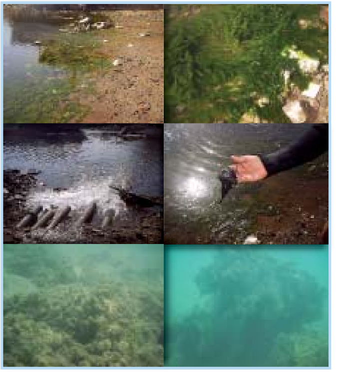

Cover Photograph:
Effect of desalination plants on the marine environment along the Red Sea, Egypt. (Case Study).

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THALASSAS

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An International Journal of Marine Sciences

NEARSHORE BENTHIC COMMUNITIES AND BIOENGINEERS FROM THE MACROTIDAL SAN JORGE GULF: PATAGONIA, ARGENTINA

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ABSTRACT

San Jorge Gulf, located in northern Patagonia, is characterized by extensive soft bottoms and large tidal ranges. A marine bottom section of 3 x 2 km, located off Caleta Olivia (Santa Cruz Province, Argentina) was sampled intensively during August 2008, covering a total of 35 oceanographic stations, with depths ranging from 25 to 48 m. Despite the small size of the surveyed area, and the short distance between stations, the study showed important bottom diversity, with patchiness distribution and associated with different biological assemblages. Through the geological and biological samples analysis, and subsequent statistical treatment, four main types of substratum were defined in the area, from those with very fine dominant sedimentary fraction to others with gravel dominance and also rocky platforms. The study area, of high hydrological energy, impacts on sediment dynamics, thus clogging phenomena are observed on rocky bottoms benthic communities. This clogging effect is mitigated in part by the bioengineering action of the polychaete *Eunice fraunfeldi*, whose long leathery tubes allow the settlement of various epibenthic species in areas dominated by soft bottoms, and thus reflecting the importance of bioengineering species creating special substrate for epibenthic communities.

Key words: benthic communities, bioengineers, macrotides, San Jorge gulf, Patagonia.

RESUMEN (Comunidades bentónicas costeras y bioingenieras macromareales del Golfo San Jorge: Patagonia, Argentina)

El Golfo San Jorge, ubicado en el norte de la Patagonia (Argentina), se caracteriza por extensos fondos blandos y amplios rangos mareales. Una porción del fondo marino de 3 x 2 km, ubicado costa afuera de Caleta Olivia (Provincia de Santa Cruz) fue muestreado según 35 estaciones oceanográficas en agosto de 2008, y a profundidades entre 25 y 48 m. A pesar del pequeño tamaño del área analizada, y la escasa distancia entre estaciones, se constató una significativa diversidad de fondos, con distribución según parches y asociados a diferentes conjuntos biológicos. A través de muestras geológicas y biológicas, y su tratamiento estadístico, cuatro tipos de sustratos fueron definidos para el área, desde los dominados por sedimentos muy finos a los compuestos por grava o plataformas rocosas. La alta energía de la zona impacta en la dinámica sedimentaria, y así se reconocieron fenómenos de sofocamiento de las comunidades bentónicas en fondos rocosos. Este efecto es mitigado en parte por la actividad del poliqueto *Eunice fraunfeldi*, cuyos largos tubos coriáceos permiten el asentamiento de varias especies epibentónicas en fondos blandos, y así reflejando la importancia de las especies bioingenieras en la creación de sustratos especiales para comunidades epibentónicas.

Palabras clave: comunidades bentónicas, bioingenieros, macromareas, Golfo San Jorge, Patagonia.

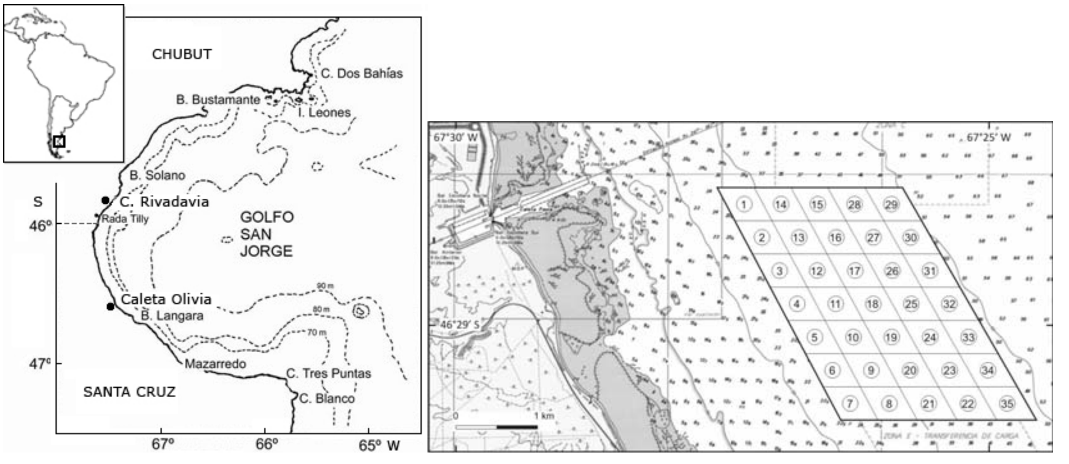

Figure 1:
Location map of San Jorge Gulf, with detail of sampling stations at Caleta Olivia (Santa Cruz).

INTRODUCTION

Macroinvertebrates from subtidal environments are conditioned by the bottom composition and the hydrological dynamics. Epifauna dominates in rocky bottoms, while infaunal benthic communities dominate where soft bottoms are stable (Elías 1995; López Gappa & Sueiro, 2007). Sediment transport can favour the food supply of bottom organisms but it can also induce clogging of benthic communities, especially in reduced extension areas where both types of bottoms coexist. Epifaunal subtidal assemblages are less studied than infaunal communities, although the former- in many areas- are continuously subject to instability related to sediment dynamics (Nichols *et al.* 2007).

In regard to hydrological dynamics, bays with low tidal range respond in relation to wave/wind effects. On the other hand, in macrotidal bays the benthic community is subject to intense currents twice a day. Therefore, nearshore fauna has significant changes in its composition in relation to the stress induced by the erosion of the substrate or the episodic sedimentation of mud over the benthos (Moreira *et al*. 2010).

Besides the effects of the bottom type as a limiting factor, epibiosis consortium process is another important factor in the structure of benthic communities. Some species offer a hard biological substrate for other organisms through their exoskeletons, in order to avoid assemblages clogging by soft sediments. Although epibiosis processes have been very well known since long time ago, in the last decades they were associated directly with other more complex ecological mechanisms (Jones *et al.* 1994).

These biological substrates, in many cases, create mesocosmos environments above the benthic layer subject to more stress due to clogging. Some of the organisms may also take advantage of these conditions living above the original bottom, avoiding predator actions or having a better access to water column preys, and also increasing community biodiversity (Margalef 1962, 1974; Rützler 1970; Jones *et al.* 1994; Nybakken & Bertness 2004; Levington 2009).

This process is fundamental in the development of epibenthic communities, and it can be easily observed in all the marine regions of the world. In our days this phenomena is included in the bioengineering concepts (Margalef 1962, 1974; Bastida *et al.* 1977; Bastida & Lichtschein 1978; Jones *et al.* 1994; Sosa 2006).

In the present paper, a reduced bottom area (3 x 2 km), between 25 and 48 m depth, was analyzed in order to study the composition and distribution of benthic macroinvertebrates and their relationships with different substrates and also in terms of determining bioengineering processes (Fig. 1).

SETTING

Argentine continental shelf is dominated by sandy bottoms (Fray & Ewing 1963; Vozza *et al.* 1974; Bastida *et al.* 1981, 1992) that vary in response to tidal energy, distance to coast, bioclastic abundance and bioturbation activity. The initial surveys conducted on the continental shelf of Buenos Aires Province (Olivier *et al.* 1968, Cortelezzi *et al.* 1971) and throughout the continental shelf (Bastida *et al.* 1981, 1992; Fernández *et al.* 2003, 2007a, 2007b, 2008) confirm the clear dominance of

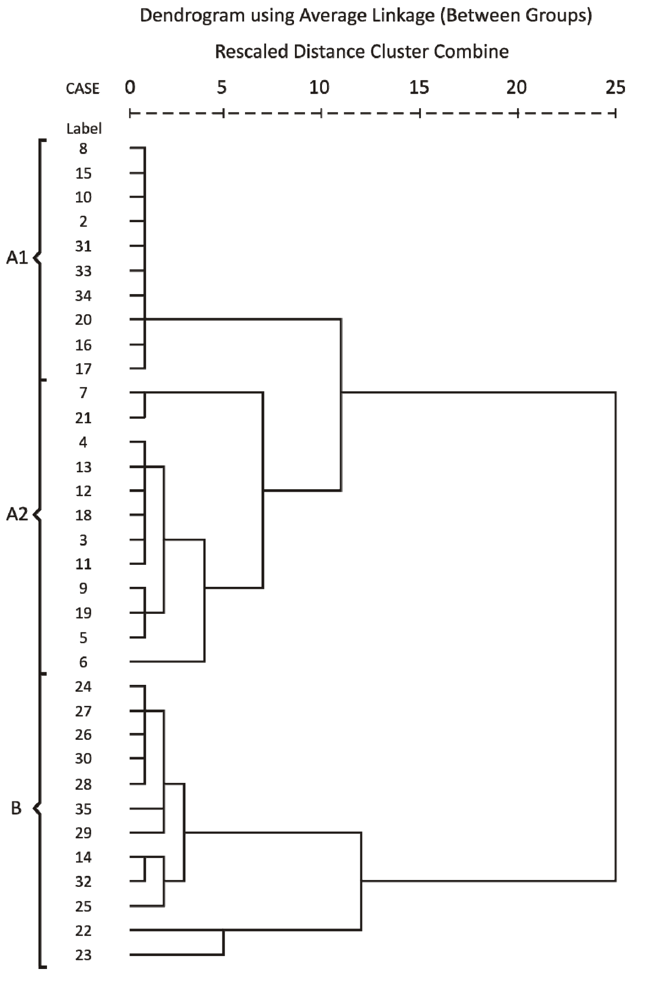

Figure 2:
Dendrogram based on the Euclidean distance of the sediments grain size and bottom characteristics of studied stations.

soft bottoms. However, in many of these surveys rocky bottoms were also detected, although of reduced surface and low altitude, thus clogging processes in areas of high energy may be frequent (Brankevich, 1990). Also the interaction between hard and soft bottoms has been recorded photographically in different parts of the continental shelf (Bastida, unpublished) (Fig. 6).

The San Jorge Gulf (Fig.1) is characterized by a significant amount of wave energy dispersed (Pousa *et al.* 1995).Tidal range increases towards the interior of the gulf to a macrotidal semidiurnal regime (Isla *et al.* 2002). Temperature fluctuates within the gulf between 7 and 13ºC; salinity is rather stable between 33.2 and 33.6 psu (Roux *et al.* 1995; Fernández *et al.* 2007a, 2008). The gulf is silted by mud, although fine, medium and coarse sand can be sampled from the shallow areas (Fernández *et al.* 2003). Gravel and rocky bottoms dominate towards the northern and southern capes (Cabo Tres Puntas, Cabo Dos Bahías and Cabo Blanco) and surrounded by areas composed of fine sand (Roux *et al.* 1995). Fine silt dominates towards the southwest area of the gulf.

San Jorge Gulf is important for its biological and commercial activities. It is part of the nursery area of the hake (*Merluccius hubbsi*)*,* the main fish resource from Argentina, and a the fishing ground of the shrimp (*Pleoticus muelleri*) the more valuable fishing species of the country (Roux *et al.* 1995; Boschi 1997; Fernández *et al.* 2003; Fernández *et al.* 2007b,. San Jorge Gulf is also a major reproductive area of the lobster krill (*Munida gregaria*), one of the most important prey for top predators as big fish, birds and marine mammals of Patagonia (Vinuesa & Varisco 2007; Fainburg, 2010) The *Macrocystis pyrifera* kelp forests are also frequent in the gulf and other coastal localities of the Patagonian region.

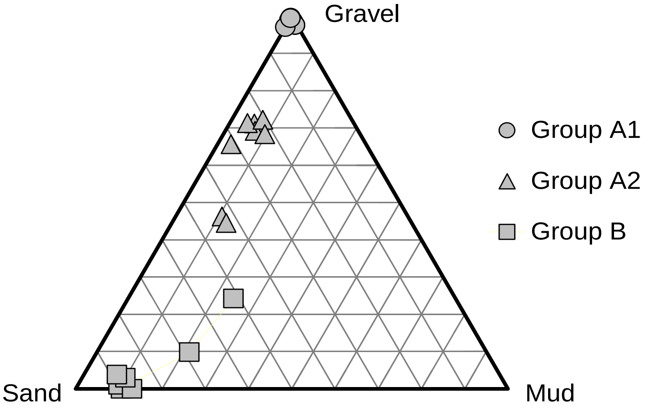

Figure 3:
Bottom substrate compositional triangle.

METHODS

Bottom sampling spanned between 46º 28´ 02" S and 46º 29´54" S, and depths between 25 and 48 m in front of Caleta Olivia harbour (Fig. 1). A total of 35 stations were sampled at distances of 500 m between each other. Quantitative Picard dredges of 60 x 20 cm were used to collect benthic macroinvertebrates and sediment samples.

Sediment samples were sieved in lab between 1 and 0.1 cm mesh. Data obtained from sediment were included in tables indicating percentages of gravel, coarse-very coarse sand, medium sand, fine sand, very fine sand, silt and clay (Table 1). Cluster analyses based on Euclidean distances were performed by the mean of the SPSS 11.5 package.

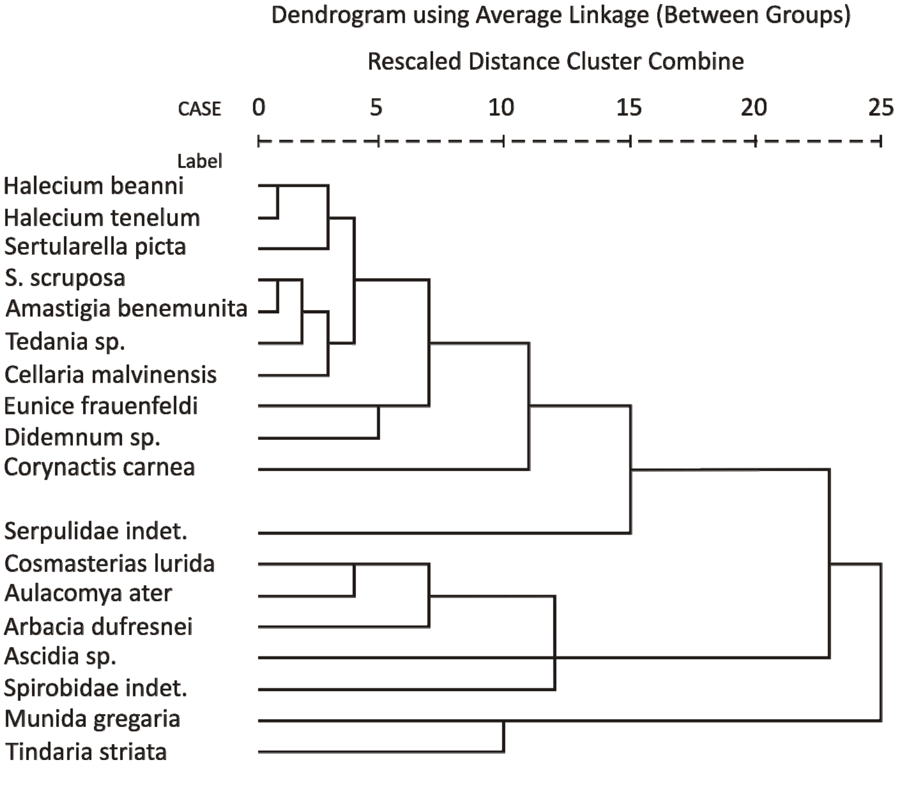

Figure 4: *Dendrogram based on the Pearson correlation coefficient showing the main association between benthic species.*

Biological samples were obtained from sieved sediment or fragmented rocks. Benthic organisms were classified to species or genus level and fixed in formalin and kept in alcohol 70%.

Based on the identified benthic species, a faunal inventory of the studied area was achieved (Table 2) and a basic data matrix was used for statistical handling.

In order to analyze the association among the most frequent benthic species, a dendrogram based in Pearson correlation R-mode was performed (Fig. 4) and a Q-mode dendrogram (Fig. 4) was designed to determine the biological affinity between stations.

RESULTS

Marine bottom characteristics.

Despite the small size of the studied area, there was a great diversity in its bottom substrates. Some sectors were dominated by rocky bottoms, others by gravel and sand, others exclusively by sand and finally bottom sectors with less sediment selection, composed by gravel, sands, silt and clay (Table1 and Fig. 8).

Dendrogram related with sea bottom characteristics, based on the Euclidean distance (Fig. 2), indicates two major groupings of stations (A and B). The subgroup A 1 consists of stations with a clear dominance of gravel representing 99% of the sample and directly linked to the platform rocky outcrops. In the subgroup A2 gravel is still the sediment dominant fraction, represented mostly as fragments of the rocky platform, but with values ranging between 45 and 70%; the sediment matrix is also integrated by other smaller grain size fractions.

Group B is characterized by stations with greater grain size variability, including different percentages of sand and mud; while few stations are composed by small size gravels.

The clustering shown in the last dendrogram is also expressed in the triangular graph (Fig. 3). In its upper angle we can observe the gravel dominance stations (A1), below them the medium sedimentary fractions (A2) and in the lower sector of the graph, the sand and pelites dominance in the sedimentary fraction (B).

Benthic community distribution

Benthic assemblages of the studied area are represented by 8 phyla, 35 genus and at least 37 species (Table 2). Stations biodiversity values (S) varies between 20 and 22. The Shannon index of ecological diversity is of 2.49, with H max= log S 3.178 and an evenness of 0.783.

The Pearson correlation dendrogram (Fig. 4) defines a total of three main groups. Group A concentrates all the fauna that colonize *Eunice frauenfeldi* polychaete tubes, a bioengineer species of this assemblage, which enables epizoites settlement of other species of small or medium size (Porifera 11.11%, Anthozoans and Hydrozoans 44.44%, Bryozoans 33.33% and Tunicates 11.11%) (Fig. 5).

Group B is an indicator of hard-bottom assemblage; its diversity is lower than in group A. It is dominated by sessile species such as Spirorbidae and Serpulidae polychaetes and the bivalve *Aulacomya ater;* between mobile species we can also mention the Echinoderms *Arbacia dufresnei* and *Cosmasterias lurida.*

Group C is poorly diversified and dominated by the filtering Pelecypod *Tindaria striata*, a soft bottom indicator species. The crustacean *Munida gregaria* is the subdominant species of the group, and because of its great mobility and food habits, it can be linked with both rocky and soft bottoms benthic assemblages (Group A and Group B, respectively) (Fig. 4).

Annelida and Mollusca are the dominant phyla (Table 2) in the studied area. Most of these species are subject to stress induced by high-energy waves or clogging when mud becomes dominant on the bottom. Some polychaetes species, as *Eunice frauenfeldi*, are able to construct large and resistant tubes as refuge. These tubes constitute a three dimensional protruding substrate where other benthic species find stability and shelter (Fig. 6 and 7).

In order to define the affinity between the various benthic stations, a Q-mode dendrogram was performed, using the Pearson correlation test (Fig. 8). Based on this dendrogram, and despite the small size of the study area, three main clusters were differentiated.

Group A is formed by stations inhabited by soft bottoms organisms. It is mainly characterized by the presence of *Tindaria striata* - *Munida gregaria* and some species of polychaetes poorly represented.

Group B is composed by stations with bioengineering processes promoted by the presence of *Eunice frauenfeldi* and its leathery tubes.

Group C clusters rocky bottom stations, mainly colonized by calcareous polychaete tubes of the Spirorbidae and Serpulidae family, and the Mytilidae mollusk *Aulacomya ater.*

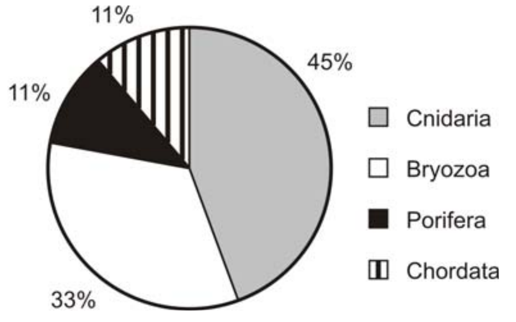

Figure 5:
Percentage of faunistic groups that act as epizoites of Eunice frauenfeldi polychaete tubes.

Figure 6:
Underwater photograph of benthic assemblages colonizing polychaete tubes.

Figure 7:
Detail of the bioengineer polychaete Eunice frauenfeldi*; specimen and tube.*

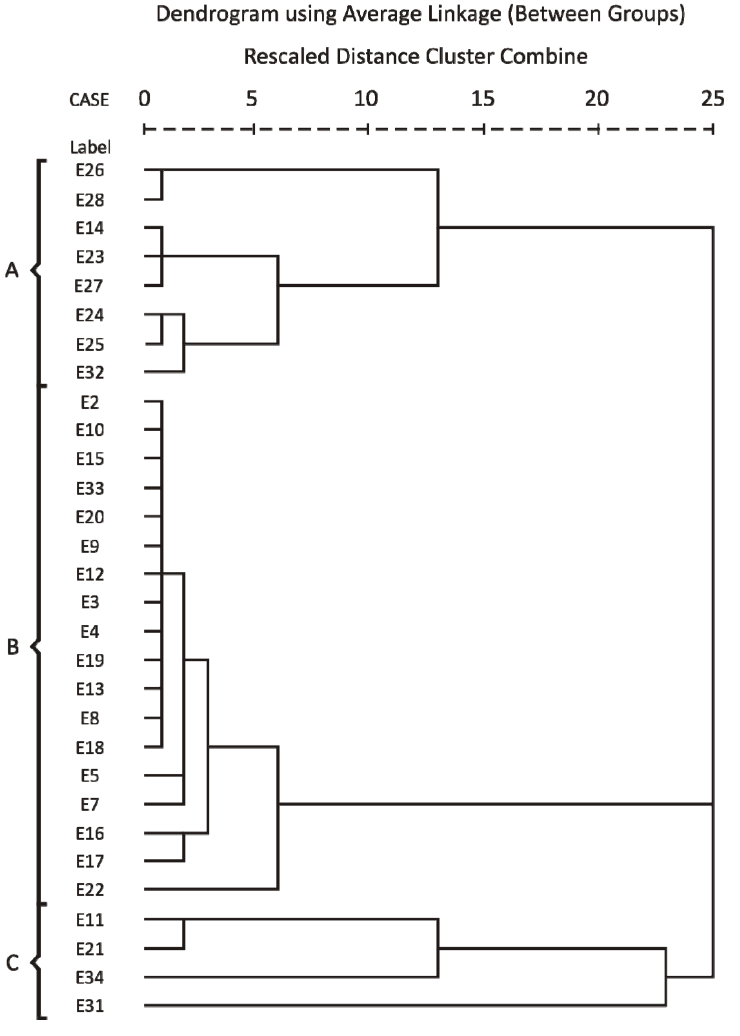

Figure 8:
Dendrogram based on the Pearson correlation coefficient showing stations clustering, according to the presence of benthic species.

DISCUSSION AND CONCLUSIONS

The scarcity of hard bottoms and the abundance of larvae of epifaunal species make these small rocky bottoms a competitive substrate for the development of epibenthic communities. Same processes take place over hard biological substrates as mollusk shells or polychaete tubes, resulting these mechanisms, in some cases, a good palliative against the clogging effects (Jumars & Nowell 1984; Miller *et al.* 1984). Particularly for the San Jorge Gulf, wind resuspension by strong wind is a factor that can induce clogging most of the year (Ward 1985; Demers *et al.* 1987).

Another aspect to consider is that most of oceanographic surveys of coastal and shelf bottoms of Argentina were planned to cover relatively large areas with low density of stations. This aspect made them impossible to determine the real level of variability of the marine bottom substrates in small areas.

The present study based on a small area, but with a high number of stations, allowed us to observe a high variability of substrates not recorded in previous studies. The bottoms in the area of Caleta Olivia are distributed as irregular patches that occupy small areas, suggesting high energy dynamics (mostly conditioned by large tidal ranges) and seasonal variations in the bottom structure related to storm events. The shallow depth of the study area 25 - 48m is another factor that affects water dynamics (Fig. 9).

Considering the geological aspects, rocky platforms dominate at the bottom of the gulf, with gentle slopes

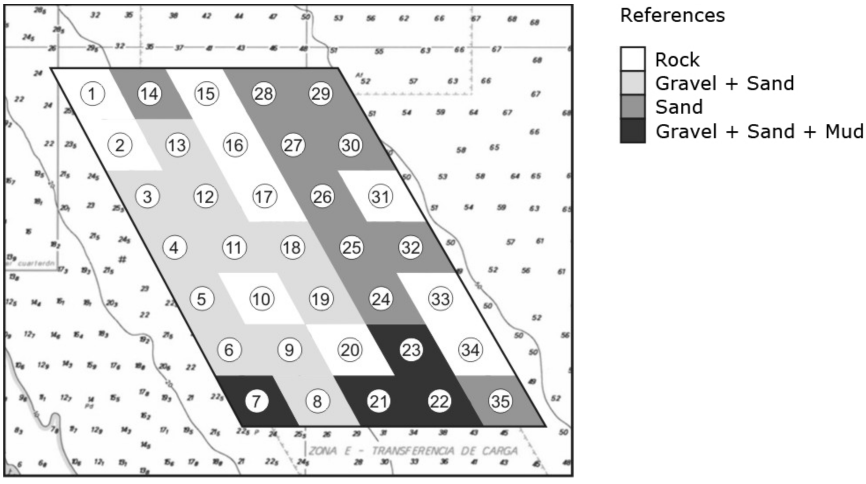

Figure 9: *Classification of marine bottom substrates along the studied stations.*

without significant irregularities, and with a thin cover of sediment, responsible of the clogging processes. At the area of this study, significant variations of the composition of the marine bottom were distributed into 4 types of substrates (Fig. 9).

From the biological point of view, the effect of clogging in the study area is clearly evidenced by the rocky bottom communities, which show low biodiversity or no colonization because they were covered by a sedimentary mantle until shortly before the time of this sampling. At some stations, through fragments of abiotic sedimentary rocks, it was possible to confirm historical clogging events by imprints and remains of calcareous organisms attached to the substrate (Polychaeta Serpulidae, Spirorbidae, Bryozoans Membraniporidae and Balanidae Cirripeds).

The statistical treatment of biological samples indicate the presence of different benthic assemblages or communities in the study area (Fig. 4) and each of these assemblages (Group A, B and C) is associated in turn with substrates of different features confirming the conditioning exerted by the substrate on the type and abundance of benthic communities (Fig 8).

The rocky bottom benthic assemblage (group B) shows low abundance of organisms and low diversity, as a result of the effect of clogging. In short, it is an impoverished community when compared with another assemblage of the Patagonian coast not affected by clogging phenomena (Olivier *et al*. 1966; Cuevas *et al*. 2006).

The group C has low diversity and is dominated by *Tindari striata*, a good indicator species of sandy sediments, however *Munida gregaria* (subdominant species) is not a good indicator of substrates, because due to their high mobility and plasticity (Perez Barros 2004; Vinuesa & Varisco 2007) can be integrated into other assemblages and hence its links with groups A and B of the corresponding dendrogram (Fig. 8).

The group A assemblage is characterized by the dominance of epizoites species colonizing the leathery tube of the polychaete *Eunice frauenfeldi*, so that assemblage is not directly linked with the sediment but with the biological substrate. *Eunice frauenfeldi* may be present in variable-grained soft bottoms, but the organism must have certain percentage of gravel to allow the initial anchoring of the tube. With the passage of time and the growth of the polychaete, the tube can remain supported directly over the fine sediments surrounding the gravel initially colonized by the bioengineer polychaete.

Today, due to the rise of the concept of bioengineering, the phenomenon of epibiosis consortium has increased in consideration by ecologists as an important mechanism in structuring benthic communities and ecosystems.

The community controlled by bioengineers was not recognized in other macrotidal bays dominated by mud in the Patagonian coast, although bioengineering processes has been detected in certain soft bottom areas of the Argentine Continental Shelf (Olivier *et al.* 1968; Bastida *et al.* 1992).

The study of consortia, as a biological and ecological phenomena, has attracted the attention of naturalists since ancient times. However, the wide range of diverse consortia has not been addressed with similar dedication. Most of the efforts have been devoted to the knowledge

Table 1:
Grain-size percentages of sampled stations.

		Sand fraction				
Station	Gravel	coarse and very coarse sand	Medium sand	Fine sand	Very fine sand	Mud
1	99,60%	0,40%	0,00%	0,00%	0,00%	0,00%
2	99,61%	0,39%	0,00%	0,00%	0,00%	0,00%
31	99,64%	0,36%	0,00%	0,00%	0,00%	0,00%
8	99,60%	0,40%	0,00%	0,00%	0,00%	0,00%
15	99,60%	0,40%	0,00%	0,00%	0,00%	0,00%
10	99,59%	0,41%	0,00%	0,00%	0,00%	0,00%
33	99,54%	0,46%	0,00%	0,00%	0,00%	0,00%
34	99,52%	0,48%	0,00%	0,00%	0,00%	0,00%
20	99,47%	0,53%	0,00%	0,00%	0,00%	0,00%
17	99,08%	0,92%	0,00%	0,00%	0,00%	0,00%
3	71,66%	0,63%	0,41%	2,14%	19,37%	5,79%
11	71,11%	0,92%	0,37%	2,09%	19,60%	5,92%
18	70,01%	1,05%	0,43%	2,40%	20,29%	5,82%
12	69,90%	1,05%	0,43%	2,40%	20,24%	5,97%
4	69,81%	0,72%	0,47%	2,44%	21,80%	5,49%
13	68,42%	1,16%	0,45%	2,68%	22,20%	5,09%
19	66,69%	2,71%	2,20%	4,33%	18,34%	5,72%
9	66,04%	5,91%	1,08%	4,61%	17,45%	4,90%
5	65,19%	3,12%	1,91%	7,37%	16,67%	5,73%
6	58,65%	3,20%	1,80%	9,33%	20,52%	6,49%
7	44,79%	8,59%	2,61%	8,08%	23,24%	12,69%
21	44,53%	8,60%	2,61%	7,95%	23,73%	12,57%
22	24,16%	4,71%	1,99%	9,30%	35,37%	24,47%
23	9,81%	8,33%	9,13%	7,49%	43,84%	21,40%
29	0,01%	0,03%	0,10%	5,12%	86,70%	8,04%
14	0,00%	1,88%	1,60%	10,12%	75,80%	10,59%
24	0,00%	0,13%	0,38%	6,66%	80,48%	12,35%
25	0,00%	3,44%	1,61%	5,00%	77,20%	12,75%
26	0,00%	0,06%	0,12%	6,77%	83,54%	9,52%
27	0,00%	0,03%	0,29%	5,17%	81,44%	13,06%
28	0,00%	0,14%	0,16%	8,67%	80,68%	10,36%
30	0,00%	0,06%	0,15%	6,88%	82,41%	10,49%
32	0,00%	0,05%	0,23%	11,75%	75,59%	12,39%
35	0,00%	0,03%	0,09%	3,72%	84,10%	12,05%

of those consortia of practical consequences as parasitism and others of striking features, as is the case of symbiosis and foresia, among others (Margalef 1962, 1974; Bastida *et al.* 1977).

Perhaps epibiosis - the relationship between two different species, were one of the species act as a biological substratum and the other as a benthic colonizer (epizoites or epiphytes)- was of less interest for naturalists, or it was considered a phenomenon of difficult interpretation, and for that reasons have not been thoroughly treated. This relationship between two or more species can have a highly variable significance in the economy of ecosystems, ranging from a very close relationship to indifference between the associated species.

Biological consortia can provide, from the ecological point of view, valuable knowledge in relation to the evolutionary process of marine benthic communities. In the case of exclusive epibionts (organisms that are linked to a particular species or genus as a biological substrate for settlement) these have undoubtedly supported during the evolutionary process the effect of selection pressure, that has led to an adaptation of one or both parties involved, both in regard to morphological aspect, general behavior and, in some cases, chemicals production for promoting

Table 2:
List of the principal benthic species of the studied area.

Phylum Bryozoa		*Cellaria malvinensis*
		Scrupocellaria scruposa puelcha
		Amastigia benemunita
Phylum Annelida	Clase Polychaeta	Harmotoinae indet.
		Lepidonotidae indet.
		Terebillides stroemii
		Nephtys magellanica
		Syllidae indet
		Maldanidae indet.
		Eunice frauenfeldi
		Serpulidae indet.
		Spirobidae indet.
Phylum Mollusca	Clase Gasteropoda	*Photinula coerulescens*
		Calyptrea pileus
		Calyptrea pileolus
		Calliostoma coppingeri
		Polinices patagonicus
	Clase Bivalvia	*Aulacomya ater*
		Tindaria striata
	Clase Polplacophora	*Tonicia chilensis*
Phylum Arthropoda	Subphylum Crustacea	*Munida gregaria*
		Peltarion spinosulum
		Anfípodo gamárido indet.
Phylum Echinodermata	Clase Asteroidea	*Platisteria sp.*
		Cosmasterias lurida
	Clase Echinoidea	*Pseudechinus magellanicus*
		Arbacia dufresnei
		Tripylaster philippi
	Clase Ophiuroidea	*Ophiura sp* .
Phylum Chordata	Subphylum Urochordata	*Ascidia* sp.
		Molgulidae indet.
		Didemnum sp.

attachments. These aspects are well manifested in the epibionts with specialized adhesive organs, chemical receptors, or those that are set in certain parts of the body of the substrate organism in connection with some of the vital activities it develops (Wilson 1952; Crisp & Williams 1960; Margalef 1962; Williams 1964; Rützler 1970; Stebbing 1971, 1972; Bastida *et al*. 1977).

Experimental studies on epibenthic communities have shown in Argentine harbour areas the importance of the phenomenon of epibiosis during different stages of the ecological succession of these communities and provide also important knowledge for biofouling control systems (Rascio *et al*. 1969; Bastida 1971; Bastida & Torti, 1973; Piriz 1972; Bastida *et al*. 1977, 1978, 2011).

In the particular case of *Eunice frauenfeldi*, it plays a significant role in the ecology of the study area. Their leathery tubes can reach several meters in length and allow the development of epibenthic species typical of rocky bottoms on soft-bottom areas (Fainburg 2010).

ACKNOWLEDGEMENTS

This work could not have been possible without the help of YPF company and the crew of the research vessel “Mr. Bigg”. We also want to thank Dr. Juan Pablo Martin (UNPA) for his collaboration in the identification of polychaetes and Dr. Viviana Quse (IUCN- UNL) for the manuscript review.

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(Received: January, 22, 2012; Accepted: April, 30, 2012)