

Intertidal seaweeds from North Atlantic Patagonian coasts, Argentina

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Abstract: The coasts located between 39°S and 41°S in the Argentinean biogeographic province have been described by impoverished seaweed assemblages, however the floristic information about this region is sparse. The aim of this study was to survey the intertidal seaweeds inhabiting three sites in the oceanographic system “El Rincon” (Buenos Aires, Argentina). A total of 42 taxa were identified with a dominance of Rhodophyta species. The sandstone outcrops (SO) had 29 taxa, whereas both the tidal flat (TF) and oyster reefs (OR) had 11 taxa. The estuarial species *Ulva intestinalis* and *Ulva prolifera* were recorded in TF, whereas calcified macroalgae were only found in SO. The differences in richness and composition of seaweed assemblages were associated with substrate type, wave exposure, incident light and salinity. These differences were also evidenced by a dissimilar number of functional groups, which was higher in SO with a dominance of filamentous macroalgae.

Key words: biodiversity, El Rincon, functional groups, seaweeds, substrate

INTRODUCTION

Seaweeds are major components of intertidal and subtidal communities; they contribute significantly to marine primary production and constitute nursery habitats for a diverse benthic fauna (Lüning 1990). Because of their sessile condition, seaweeds are constrained to the effects of long-term exposure to environmental stress, resulting in changes in the structure of the assemblages as a consequence of community interactions (Eriksson et al. 2002; Karez et al. 2004; Kraufvelin et al. 2006; Pinedo et al. 2007). For this reason, seaweeds are considered useful descriptors

of environmental characteristics of coastal habitats, being used as ecological quality bioindicators under the Water Framework Directive (Directive 2000/60/EC).

Water temperature, salinity, light intensity, nutrient availability, wave exposure and substrate composition are among the most influencing abiotic factors that shape the communities of intertidal seaweeds (Dring 1992). Biotic factors such as competition and grazing pressure also influence the distribution and abundance of seaweeds in their habitat (Dayton 1971; Korpinen et al. 2007). The combination and interaction of these dynamic factors determines the composition and structure of seaweed assemblages (Dawes 1998; Dethier and Williams 2009).

Recent biogeographic studies along the Argentine coast have demonstrated that most of the seaweed studies were conducted at high latitudes (Liuzzi et al. 2011; Wieters et al. 2012), mainly in the provinces of Chubut, Santa Cruz and Tierra del Fuego (Mendoza 1999; Asensi and Küpper 2012; Boraso 2013). According to these studies the floristic information about the coasts located in latitudes lower than 42° S is sparse. The lower sampling effort on inferior latitudes may be in part related to the decreasing trend of seaweed biodiversity with decreasing latitude (Liuzzi et al. 2011). According to this study, the main points of reduction of seaweed biodiversity coincide with the boundary between two biogeographic provinces, the Argentinean province, which extends from the mouth of La Plata River (35° S) to a transition zone between 41–44° S, and the Magellanic province, that extends from Valdés Peninsula to the southern extreme of the continent (Balech and Ehrlich 2008). The coast of Buenos Aires Province has therefore been denoted as a region of impoverished algal assemblages (Liuzzi et al. 2011). However, between 39° and 41°S there is an important

oceanographic system known as “El Rincon”, which has become relevant during the last decades because it comprises valuable ecological and economical resources (Perrotta et al. 1999).

The lack of detailed historical records in this part of the country, coupled with the absence of a comprehensive and current picture of seaweed communities, provides little context to detect the floristic changes, hence the importance of building up a record of the intertidal seaweeds from this region.

The objectives of the present study were: 1) to record the intertidal macroalgal species present in different coasts of “El Rincon” coastal area; and 2) to evaluate the differences in species richness and functional groups in relation to oceanographic factors.

MATERIALS AND METHODS

Study area

The study was conducted at three coasts from “El Rincon” coastal area, an oceanographic system located between 39° and 41°S (Figure 1a). This area is characterized by a strong vertical homogeneity in the

low water column, as a consequence of the wind and tides effect (Guerrero 1998). The tidal regime in the area is semi-diurnal (SHN 2014).

The sampling was carried out in three characteristic sites, sandstone outcrops (SO), tidal flats (TF) and oyster reefs (OR).

The site SO (38°58' S, 061°40' W) is located in Pehuen Co-Monte Hermoso Geological, Paleontological and Archaeological Reserve. The coast is characterized by a sandy marine beach, with superficial gravel and an abrasion platform temporally exposed at different sections of the beach. The collection of seaweeds was carried out at the outcrops composed of a mixture of sand and mud (Figure 1b) (Caló et al. 1998).

Site TF (38°51' S, 062°08' W) is located in Bahía Blanca, Bahía Falsa and Bahía Verde Natural Reserve. The collection was carried out in a region of offshore bars formed by silt-clay and sandy-silt stone (Figure 1c). These tidal flats are characterized by the absence of tidal creeks and channels (Pratolongo et al. 2010).

Site OR (40°25' S, 062°25' W) is located in San Blas Natural Reserve (Figure 1d). The reserve comprises a

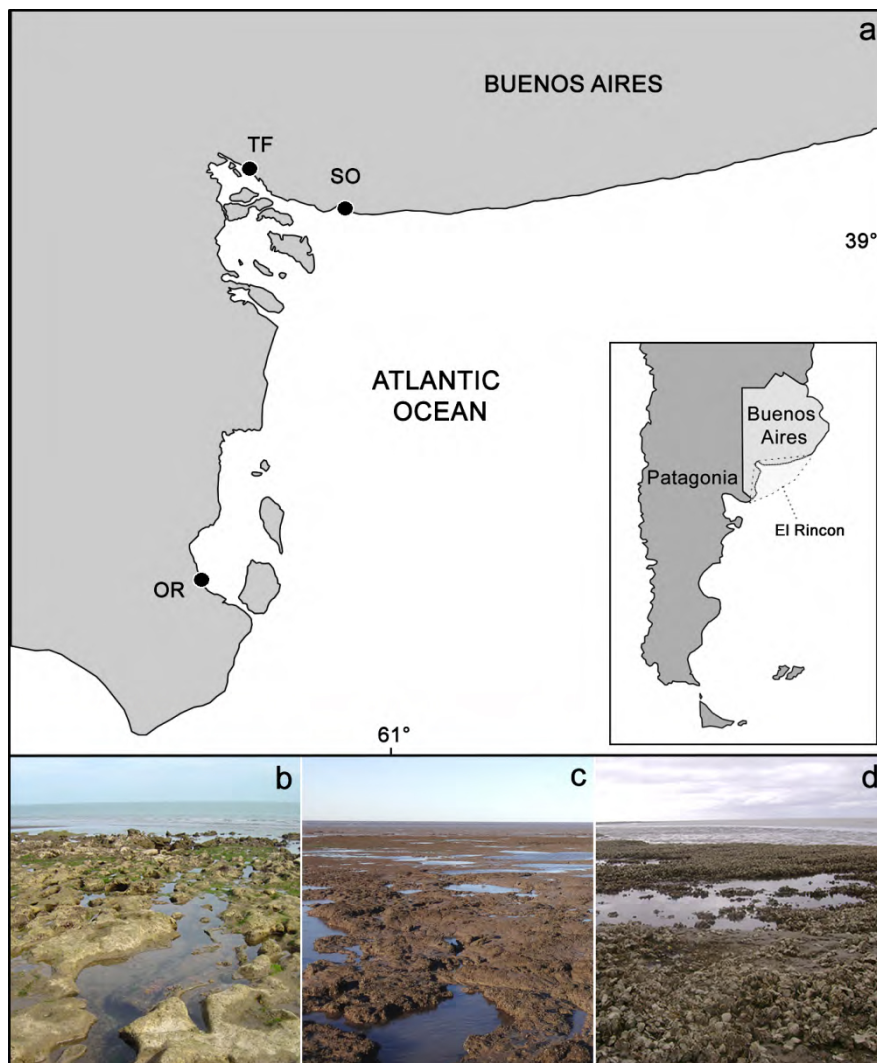


Figure 1. Location of the sampling sites in “El Rincon” coastal area (a) and general aspect of the intertidal zones in SO = sandstone outcrops (b), TF = tidal flats (c) and OR = oyster reef (d).

shallow coastal ecosystem with islands, marshes, pebble beaches and sandy beaches (Álvarez and Rios 1988). The collection was carried out in an intertidal interrupted by a large oyster reef of the Pacific Oyster, *Crassostrea gigas* (Thunberg, 1793) (Borges 2005).

Field and laboratory methods

Sampling was carried out between 2007 and 2014, during low tide in the intertidal zone of each site. Seaweeds were sampled along transects located perpendicular to the coastline, collected manually into plastic bags and transported to the laboratory in cold boxes. Prior to examination, seaweeds were rinsed with filtered seawater and drained on blotting paper.

Observations of external appearance and vegetative and reproductive morphology were made on fresh specimens under a stereoscopic microscope (Wild Heerbrugg) and an inverted microscope (Nikon Eclipse TE).

Specimens were pressed in herbarium sheets and incorporated to the section Cryptogams of the BBB Herbarium of Universidad Nacional del Sur (UNS), Bahía Blanca, Argentina. Sections of the thalli were also preserved in 4% formaldehyde.

Taxonomic identification was carried out using traditional literature: Burrows (1987), Wormersley (1987), Schneider and Searles (1991), Freshwater and Rueness (1994), Littler and Littler (2000), Perrone et al. (2006), Stuercke and Freshwater (2008). Nomenclatural update was obtained from AlgaeBase (Guiry and Guiry 2014).

Seaweed taxa were classified according to descriptors and morphological groups proposed by Steneck and Dethier (1994) and modified by Balata et al. (2011), and the number of taxa belonging to each functional group was compared between the three study sites.

RESULTS

A total of 42 taxa were identified, 17 Rhodophyta, 13 Chlorophyta and 12 Phaeophyceae, distributed in 13 orders, 19 families, and 24 genera (Table 1). The percentage of taxa representing each group was 40%, 31% and 29%, respectively.

Of all sites, SO had the highest richness of seaweed, with a total of 29 taxa. An equal number of taxa was recorded at TF and OR, with 11 taxa in each site.

The three groups, Rhodophyta, Chlorophyta and Phaeophyceae, had the highest number of taxa in SO (Figure 2). Rhodophyta was the dominant group in TF (55% of the taxa) as well as in SO (41% of the taxa), while Chlorophyta was the dominant group in OR, with 45% of the taxa belonging to this group.

Five genera, *Polysiphonia*, *Ceramium*, *Gelidium*, *Punctaria* and *Ulva*, were present in the three sites, but only one species, *Bryopsis plumosa* (Hudson) C. Agardh, was common in the three sites. The genera *Leathesia*, *Dictyota*, *Saccharina*, *Petalonia*, *Sphacelaria*, *Codium*, *Jania*,

Table 1. List of seaweeds identified at each sampling site. SO = sandstone outcrops, TF = tidal flats and OR = oyster reef.

PHYLUM/ Order/Family	Taxon	Site		
		SO	TF	OR
RHODOPHYTA (Classes Florideophyceae and Bangiophyceae)				
Rhodymeniales				
Rhodymeniaceae	<i>Rhodymenia pseudopalmata</i> (J. V. Lamouroux) P. C. Silva	x		
Ceramiales				
Wrangeliaceae	<i>Neoptilota asplenioides</i> (Esper) Kylin ex Sacgel, Garbary, Gorden & Hawkes	x		
Rhodomelaceae	<i>Pterosiphonia dendroidea</i> (Montagne) Falkenberg	x		
	<i>Polysiphonia absissa</i> J. D. hooker & Harvey	x	x	
	<i>Polysiphonia brodiei</i> (Dillwyn) Sprengel	x		
	<i>Polysiphonia morrowii</i> Harvey		x	x
	<i>Polysiphonia denudata</i> (Dillwyn) Greville ex Harvey	x		
	<i>Neosiphonia harveyi</i> (Bailey) M. S. Kim, H. G. Choi, Guiry & G. W. Saunders		x	
Ceramiceae	<i>Ceramium rubrum</i> C. Agardh	x		
	<i>Ceramium strictum</i> Greville & Harvey			x
	<i>Ceramium diaphanum</i> (Lightfoot) Roth		x	
Corallinales				
Corallinaceae	<i>Corallina elongata</i> J. Ellis & Solander	x		
	<i>Jania rubens</i> (Linnaeus) J.V. Lamouroux	x		
Gigartinales				
Mychodeaceae	<i>Mychodea carnosa</i> J.D. Hooker & Harvey	x		
Gelidiales				
Gelidiaceae	<i>Gelidium pusillum</i> (Stackhouse) Le Jolis	x	x	
	<i>Gelidium crinale</i> (Hare ex Turner) Gaillon		x	x
Bangiiales				
Bangiaceae	<i>Pyropia thuretii</i> (Setchell & E.Y. Dawson) J.E. Sutherland, L.E. Aguilar Rosas & R. Aguilar Rosas	x		
HETEROKONTOPHYTA (Class Phaeophyceae)				
Ectocarpales				
Ectocarpaceae	<i>Ectocarpus</i> sp.	x		
	<i>Ectocarpus siliculosus</i> (Dillwyn) Lyngbye			x
Scytosiphonaceae	<i>Petalonia fascia</i> (O.F. Müller) Kuntze	x		
	<i>Scytosiphon dotyi</i> M.J. Wynne	x		
	<i>Scytosiphon lomentaria</i> (Lyngbye) Link			x
Chordariaceae	<i>Punctaria latifolia</i> Greville		x	x
	<i>Punctaria plantaginea</i> (Roth) Greville	x		
	<i>Leathesia difformis</i> Areschoug	x		
Dictyotales				
Dictyotaceae	<i>Dictyota dichotoma</i> (Hudson) J.V. Lamouroux	x		
	<i>Dictyota dichotoma</i> var. <i>intricata</i> (C. Agardh) Greville	x		
Sphacelariales				
Sphacelariaceae	<i>Sphacelaria cirrosa</i> (Roth) C. Agardh	x		
Laminariales				
Laminariaceae	<i>Saccharina sessilis</i> (C. Agardh) Kuntze	x		
CHLOROPHYTA (Class Ulvophyceae)				
Ulvales				
Kornmanniaceae	<i>Blidingia marginata</i> (J. Agardh) P.J.L. Dangeard			x
	<i>Blidingia minima</i> (Nägeli ex Kützing) Kylin	x		
Ulvaceae	<i>Ulva lactuca</i> Linnaeus	x	x	
	<i>Ulva linza</i> Linnaeus	x		x
	<i>Ulva gigantea</i> (Kützing) Bliding			x
	<i>Ulva prolifera</i> O. F. Müller		x	
	<i>Ulva intestinalis</i> Linnaeus		x	
Bryopsidales				
Bryopsidaceae	<i>Bryopsis plumosa</i> (Hudson) C. Agardh	x	x	x
Codiaceae	<i>Codium fragile</i> (Suringar) Hariot	x		
	<i>Codium vermilara</i> (Olivi) Delle Chiaje	x		
	<i>Codium tomentosum</i> Stackhouse	x		
Cladophorales				
Cladophoraceae	<i>Cladophora albida</i> (Nees) Kützing			x
	<i>Cladophora lehmanniana</i> (Lindenberg) Kützing	x		

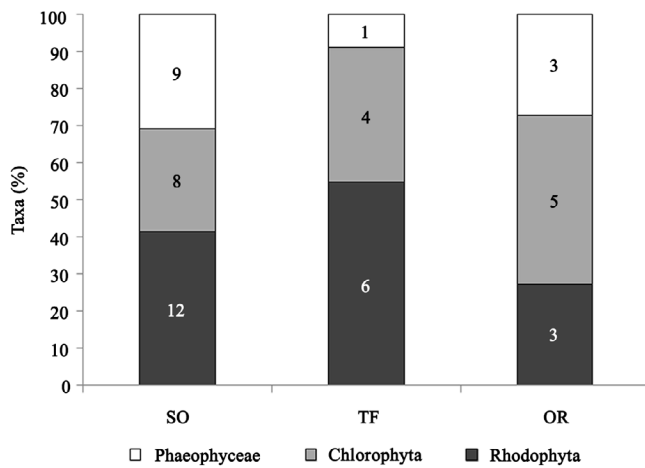


Figure 2. Percentage of taxa corresponding to Rhodophyta, Phaeophyceae and Chlorophyta recorded in each sampling site. SO = sandstone outcrops, TF = tidal flats and OR = oyster reef. Numbers inside the bars represent the number of taxa of each group.

Corallina, *Pyropia*, *Mychodea*, *Pterosiphonia*, *Neoptilota* and *Rhodymenia* were restricted to the intertidal of SO, and were not observed in the other sites. Two species typical of estuarial waters, *Ulva intestinalis* Linnaeus and *Ulva prolifera* O.F. Müller, were only recorded in TF. On the other hand, two species of calcified macroalgae, *Jania rubens* (Linnaeus) J.V. Lamouroux and *Corallina elongata* J. Ellis & Solander, were recorded in SO, whereas no calcified macroalgae was registered in TF and OR.

Regarding the morphological functional groups, a total of 17 groups were recorded at SO, while the number of groups present at TF and OR was considerably lower, with six and seven groups, respectively (Table 2). Considering the three sites, the best represented functional groups were filamentous uniseriate and pluriseriate with erect thallus (19%), blade-like (12%), filamentous uniseriate (10%) and tubular (10%).

The number of functional groups was highest at SO, where there were many different morphologies and forms of macroalgae. The taxa with 'filamentous uniseriate and pluriseriate erect thallus' were the most abundant at SO; at TF the majority of the taxa belonged to the functional groups 'blade-like' and 'filamentous uniseriate and pluriseriate with erect thallus', whereas at OR blade, filamentous and tubular macroalgae were similarly represented (Figure 3).

DISCUSSION

Rhodophyta was the best represented group in terms of number of taxa, while Chlorophyta and Phaeophyceae were similarly represented. The proportion of the three groups follows the trend observed by Liuzzi et al. (2011) and by Miloslavich et al. (2011) for the Argentinean coast. The total number of Rhodophyta, Chlorophyta and Phaeophyceae taxa found in the three sites represented an 11%, 22% and 20% of the total species of each group registered for the Patagonian shelf subregion of South America (Miloslavich et al. 2011).

Total seaweed richness was higher than expected considering the study of Liuzzi et al. (2011), who point out that coasts from Río Negro and Buenos Aires provinces should be regarded as impoverished in terms of seaweed diversity.

The richness of genera was lower than that recorded by Sar et al. (1984) for the coast of Mar del Plata in Buenos Aires Province (38°S), whereas the total number of species was similar. Both sites shared more than 60% of the genera and nine species.

The highest richness of seaweeds found at SO could be due to the different oceanographic characteristics of this coast. The main difference between the three coasts is related to the degree of wave exposure, since TF and OR are less exposed to waves than SO because

Table 2. Classification of seaweed taxa found in the study sites according to functional groups delimited by Balata et al. (2011).

Number	Functionalgroup	Taxa
1	Blade-like	<i>Ulva lactuca</i> , <i>Ulva linza</i> , <i>Ulva prolifera</i> , <i>Ulva intestinalis</i> , <i>Ulva gigantea</i>
2	Blade-like with one or few layers of cells	<i>Pyropia thuretii</i>
3	Codium with erect thallus	<i>Codium fragile</i> , <i>Codium vermilara</i> , <i>Codium tomentosum</i>
4	Compressed with blade-like habit	<i>Petalonia fascia</i> , <i>Punctaria latifolia</i> , <i>Punctaria plantaginea</i>
5	Compressed with branched or divided thallus	<i>Dictyota dichotoma</i> , <i>Dictyota dichotoma</i> var. <i>intrincata</i>
6	Filamentous uniseriate	<i>Ectocarpus</i> sp., <i>Ectocarpus siliculosus</i> , <i>Cladophora albida</i> , <i>Cladophora lehmanniana</i>
7	Filamentous uniseriate and pluriseriate with erect thallus	<i>Neoptilota asplenioides</i> , <i>Pterosiphonia dendroidea</i> , <i>Polysiphonia abscissa</i> , <i>Polysiphonia morrowii</i> , <i>Polysiphonia denudata</i> , <i>Ceramium rubrum</i> , <i>Ceramium strictum</i> , <i>Ceramium diaphanum</i>
8	Flattened macrophytes with cortication	<i>Rhodymenia pseudopalmata</i>
9	Hollow with spherical or subspherical shape	<i>Leathesia difformis</i>
10	Kelp-like	<i>Saccharina sessilis</i>
11	Larger-sized articulate corallines	<i>Corallina elongata</i>
12	Larger-sized corticated	<i>Mychodea carnosa</i> , <i>Gelidium pusillum</i> , <i>Gelidium crinale</i>
13	Siphonous with thin separated filaments	<i>Bryopsis plumosa</i>
14	Smaller size corticated	<i>Polysiphonia brodiei</i> , <i>Neosiphonia harveyi</i>
15	Smaller-sized articulated corallines	<i>Jania rubens</i>
16	Smaller-sized filamentous pluriseriate	<i>Sphacelaria cirrosa</i>
17	Tubular	<i>Scytosiphon lomentaria</i> , <i>Scytosiphon dotyi</i> , <i>Blidingia marginata</i> , <i>Blidingia minima</i>

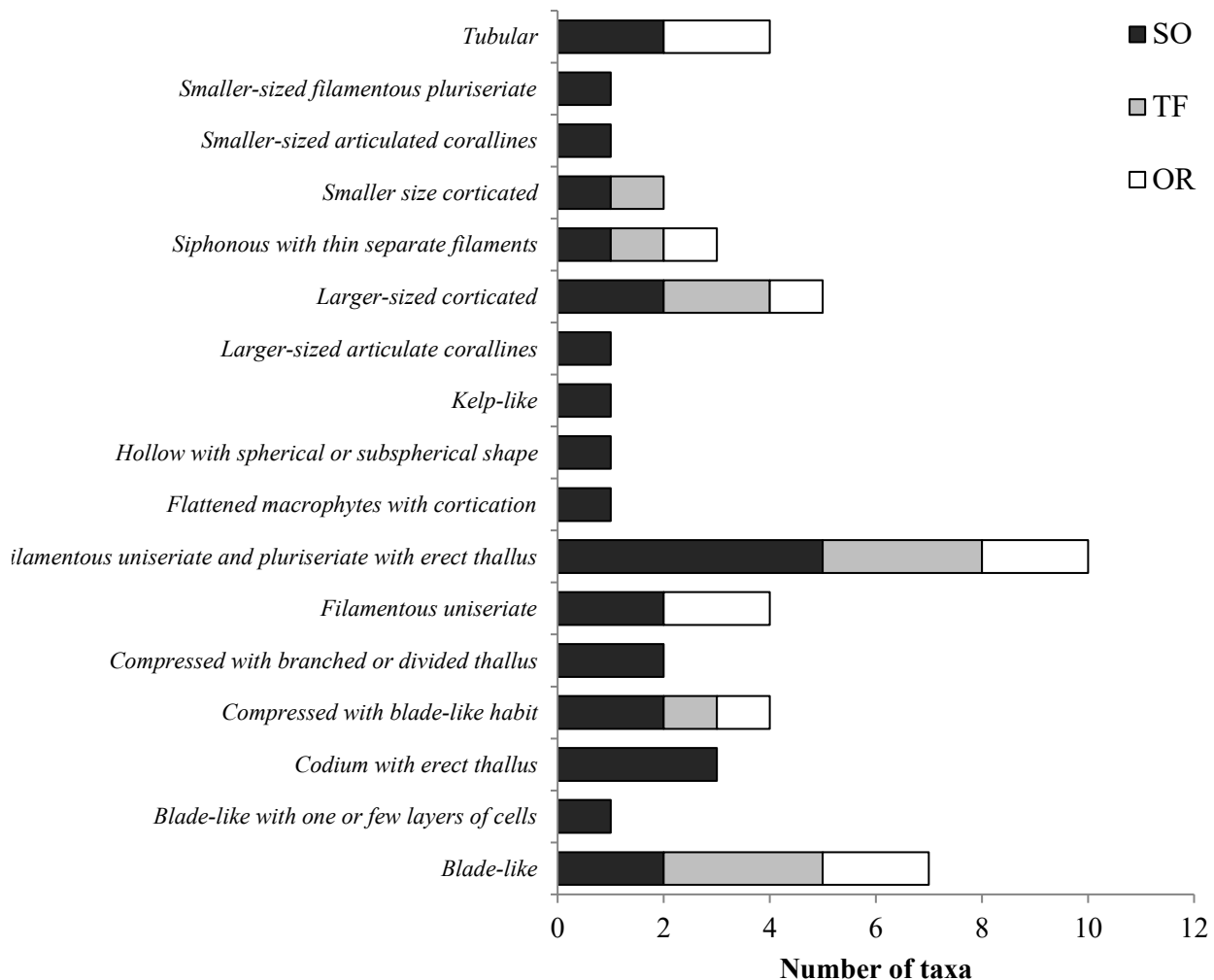


Figure 3. Number of taxa of each functional group found in each sampling site. SO = sandstone outcrops, TF = tidal flats and OR = oyster reef.

both coasts are ‘protected’ either in the inner part of an estuary (TF) or in a shallow bay (OR). As a consequence, the waters of TF and OR are more turbid than those of SO, limiting the growth of seaweeds. In these systems, the low penetration of light through the water column difficults the settlement of sensible species, while it favors the settlement of tolerant ones such as opportunistic seaweeds with rapid growth rates such as *Ulva*, and small turf-like Rhodophyta such as *Gelidium*, which are commonly dominant in shallow reefs (Hay 1981).

Another difference is the mixture of marine water with freshwater. The variability of salinity at TF is high (16 to 40) because of its location in the Bahía Blanca Estuary (Freije and Marcovecchio 2004). On the other hand, SO does not have the influence of freshwater, whereas OR receives a small discharge of freshwater from Riacho Azul, which is less important. The low species richness observed at TF may also be related to a higher gradient of physiological stress, as has been observed for marine organisms inhabiting estuarial coasts (Sanders 1968; Wolff 1972).

Another important factor determining the composition of seaweed communities is the availability of substrate. Increased substrate microtopography can have positive effects on the abundance of certain macroalgal species (Irving and Connel 2002). TF and OR have less diversity of microhabitats because the outcrops are flat, with shallow tide pools. Contrastingly, the outcrops at SO are higher and rugged, which gives rise to a more complex substrate structure, and consequently a higher diversity of microhabitats (Hurd et al. 2014).

Consistent with the results of Liuzzi et al. (2011), filamentous macroalgae were the best represented (31%), followed by blade-like (foliose) (21%) and corticated macroalgae (12%). The absence of kelp-like macroalgae, except for the potential introduction of *Saccharina sessilis* (C. Agardh) Kuntze, may be related to high water temperature and low flow energy, since this group usually inhabits cold waters with high current energy (Lüning 1990; Liuzzi et al. 2011; McGlathery et al. 2013). In Argentina, they are common in southern regions (Asensi 1966) but disappear north of 42° S (Liuzzi et al. 2011).

The uniform representation of functional groups observed at TF and OR was a consequence of a low number of species. On the other hand, the higher richness observed in SO resulted in a higher diversity of functional groups, where a few forms were dominant.

Several taxa recorded at SO were representative of different levels of the theoretical intertidal zonation. *Pyropia* is characteristic of the upper intertidal, *Corallina* and *Jania* usually inhabit middle to low intertidal, whereas *Codium* and *Dictyota* are characteristic of low intertidal-subtidal. On the other hand, the absence of the spray phenomenon at TF and OR, as a result of low wave energy, might prevent seaweed species to colonize higher intertidal levels in those sites.

TF has been pointed as an eutrophic system, in part because of natural causes and in part due to the high input of nutrients from urban settlements (Lara et al. 1985). According to that, many of the taxa recorded are typically from eutrophic coasts, which are opportunistic and ephemeral like *Ulva* and *Polysiphonia* (Littler and Littler 1984).

The occurrence of *Punctaria latifolia* Greville was occasional at TF and a well-established population was not observed, with only some thalli unattached and sparsely distributed among the stems of *Spartina* sp. were found. On the other hand, red macroalgae such as *Ceramium* and *Polysiphonia* developed conspicuous populations in TF, they are frequently found in estuarial habitats (Orris 1980).

Several species of marine and freshwater macroalgae have been recorded in the Bahía Blanca Estuary, namely, *Enteromorpha flexuosa* (Wulfen) J. Agardh, *Cladophora surera* Parodi & Cáceres, *Ulva* sp., *Chaetomorpha aerea* (Dillwyn) Kützinger, *Gracilaria verrucosa* (Hudson) Papenfuss, *Polysiphonia* sp., *Ceramium* sp., *Ectocarpus siliculosus* (Dillwyn) Lyngbye, *Hinckia hinckisiae* (Harvey) P. C. Silva and *Punctaria* sp. (Perillo et al. 2001). However, in the present study only species of *Polysiphonia*, *Ceramium*, *Ulva* and *Punctaria* were found in TF.

The recorded species *Neoptilota asplenioides* (Esper) Kylin ex Scagel, Garbary, Golden & Hawkes, *Polysiphonia denudate* (Dillwyn) Greville ex Harvey, *Mychodea carnosa* J. D. Hooker & Harvey, *Gelidium pusillum* (Stackhouse) Le Jolis, *Pyropia thuretii* (Setchell & E. Y. Dawson) Sutherland, L. E. Aguilar-Rosas & R. Aguilar-Rosas, *Dictyota dichotoma* var. *intrincata* (C. Agardh) Greville, *Saccharina sessilis*, *Ulva gigantea* (Kützinger) Bliding and *Codium tomentosum* Stackhouse constitute new records for Argentina.

Of all taxa recorded, three species may be considered as introduced, *Polysiphonia morrowii* Harvey (Croce and Parodi 2014), *Neosiphonia harveyi* (Bailey) Kim, Choi, Guiry & Saunders (Boraso 2013) and *Saccharina sessilis* (unpublished data).

This study contributes to fill the gap of information about macroalgae species inhabiting the Argentinean coasts between 39° S and 41° S, providing fundamental data for biogeographical studies.

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