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article

Benthic marine algae from the insular areas of Paraná, Brazil: new database to support the conservation of marine ecosystems

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Abstract: This study describes the diversity of benthic marine algae from insular areas of the southern Brazilian coast. Algal samples were collected between 2006 and 2010 during the winter and the summer seasons at three sites in the coastal waters of Paraná, Brazil: Ilha do Mel, Currais Archipelago and Ilha do Farol. The samples were collected along parallel transects on the coast. In this survey, Paraná marine phycoflora comprised 139 taxa (90 Rhodophyta, 27 Chlorophyta and 22 Phaeophyceae). Fifty-two species represent new records for the state, and 14 taxa are present at all sampling sites and in both seasons. Higher diversities of rhodophytes and chlorophytes were observed at Ilha do Mel, while phaeophytes were more diverse at Currais Archipelago. Lower algal diversity was observed at Ilha do Farol, a sampling station which is near an urban area. Ceramiaceae, Rhodomelaceae and Corallinaceae were dominant among Rhodophyta, Cladophoraceae and Ulvaceae among Chlorophyta, and Dictyotaceae and Sargassaceae among Phaeophyceae. Seasonal and spatial differences in species composition could be explained by the availability of consolidated substrate, water transparency and proximity to an urban area. Seaweed biodiversity from the Paraná coast also presents low species richness compared to other Brazilian states as a result of the shorter coastline, lower availability of rocky shores, and the location between estuarine systems (Paranaguá and Guaratuba Bays). These bays input a large amount of continental water, resulting in decreased salinity, high concentrations of suspended particulate matter and low transparency in the water column. Knowledge of seaweed diversity is essential for conservation studies. In addition, environmental monitoring programs undertaken during medium- to long-term seasonal changes could be improved to reflect changes detected through new records, the introduction of alien species in the area of interest, or even dominance of opportunistic species over other taxa. Therefore, a database able to support the monitoring of biodiversity is a fundamental step in detecting environmental impacts that could change seaweed biogeography, mainly in urbanized and harbor areas.
Keywords: *Seaweeds, inventory, Paraná Coast, Southern Atlantic.*

PELLIZZARI, F., BERNARDI, J., SILVA, E.M., SILVA, M.C., YOKOYA, N.S. **Algas marinhas bentônicas de áreas insulares do Paraná, sul do Brasil: checklist, novas ocorrências para o Estado e implicações para a conservação.** Biota Neotropica. 14(2): e20130011. http://dx.doi.org/10.1590/1676-060320140615183049

Resumo: O presente estudo descreve a diversidade de algas marinhas bentônicas em áreas insulares da costa do Paraná, sul do Brasil. As amostras de algas foram coletadas entre 2006 e 2010 durante o inverno e o verão, em três locais: Ilha do Mel, Arquipélago de Currais e Ilha do Farol. A amostragem foi realizada ao longo de transectos paralelos à linha de costa e, na Ilha dos Currais, em diferentes profundidades. A ficoflora marinha paranaense é composta por 139 táxons (90 Rhodophyta, 27 Chlorophyta e 22 Phaeophyceae). Cinquenta e duas espécies são novas citações para o Estado do Paraná, e 14 táxons foram registrados em todos os locais estudados durante o verão e o inverno. Diferenças sazonais e espaciais na composição específica podem ser explicadas pela disponibilidade de substratos rochosos, transparência da água e proximidade com a área urbana. A maior diversidade de rodófitas e clorófitas foi observada na Ilha do Mel e a de feofíceas no Arquipélago de Currais. A menor diversidade de algas foi observada na Ilha do

Farol, ponto amostral mais próximo a uma área urbana. Ceramiaceae, Rhodomelaceae e Corallinaceae foram dominantes entre Rhodophyta, Cladophoraceae e Ulvaceae entre Chlorophyta, e Dictyotaceae e Sargassaceae entre Phaeophyceae. A diversidade de algas marinhas bentônicas na costa do Paraná é menor quando comparada a outros estados brasileiros e isto está associado à menor extensão de sua linha de costa, menor disponibilidade de substratos consolidados para recrutamento e localização entre dois sistemas estuarinos (baías de Paranaguá e de Guaratuba). Os estuários aumentam consideravelmente o aporte de água continental, diminuindo a salinidade, elevando as concentrações de material particulado em suspensão e reduzindo a transparência da água. O conhecimento da diversidade algácea é fundamental para estudos de conservação, sendo que câmbios sazonais em médio e longo prazo podem estar relacionados a alterações ambientais. O indicador destas mudanças pode ser a detecção de novas ocorrências, espécies novas ou ainda introdução de espécies exóticas na área em questão, ou mesmo pela dominância de táxons oportunistas. Portanto, uma base de dados que sustente um monitoramento da biodiversidade é relevante por detectar impactos que podem alterar padrões biogeográficos das comunidades de macroalgas, principalmente em regiões com influência de atividades antrópicas, como as zonas urbanas ou áreas portuárias.

Palavras-chave: *macroalgas marinhas, inventário, litoral do Paraná, Atlântico Sul.*

Introduction

The human population growth associated with intense socioeconomic activities are causing increasing impact on the coastal environments. Climate changes have also resulted in increased precipitation in different South American regions, leading to higher freshwater inputs into marine ecosystems and causing a decrease in salinity in coastal waters which, in turn, affects photosynthesis in primary producers (Santos et al. 2011; Scherner et al. 2012, 2013). Nonetheless, approaches designed to conserve marine ecosystems are still poorly supported by biological data, thus requiring actions focused on the biological characterization of marine communities.

Seaweeds are highly sensitive to environmental changes, and exposure to the long-term effects of pollutants, and eutrophication tend to modify the community structure, favoring opportunistic species, while excluding late successional and fragile species (Santos et al. 2011; Scherner et al. 2013). The ecological relevance of these bioindicators can extend beyond their fundamental role in the trophic chains as primary producers, and include sheltering for marine fauna, bioremediation due to fast uptake of water-born contaminants, and also economic importance.

Algal diversity is a key indicator, or proxy, for monitoring. Since 2006, cooperative conservation programs have been developed along the Paraná coast (Pellizzari & Kawaii, 2010) to establish a protocol for coastal long-term monitoring in this area, and seaweed diversity has been used as a monitoring tool. However, this sort of program has been limited by the lack of updated surveys focused on seaweed diversity. Although studies on benthic marine algae from the Paraná coast were published around two decades ago, they were concentrated on only a few coastal locations at intertidal zones that surround mangrove and estuarine areas.

Seaweed inventory on a spatiotemporal scale allows investigators to detect the disappearance of some taxa or identify new records. These data may predict potential changes in species composition and distribution patterns that could, in turn, suggest the nature of local impacts, allowing the opportunity to apply preventive or mitigative measures, as well as distinguish between native and alien species.

Several surveys have reported on seaweed diversity in the islands and other open water marine ecosystems of Brazil (Eston et al. 1986; Alves, 1989; Pedrini et al. 1989; Figueiredo, 2006; Horta et al. 2008; Burgos et al. 2009; Rocha-Jorge, 2010). Compared with the sampling areas of the present study, these works sampled more biogeographically isolated islands and/or rocky outcrops, such as "*Laje de Santos*". In addition, most of these study sites were concentrated along the southeastern and northeastern Brazilian coast.

Seaweed diversity from Paraná State, the second shortest coastline in Brazil, is poorly known. Some taxonomic studies were carried out in past decades, such as that of Ugadim (1973, 1974, 1976) who studied seaweeds from southern São Paulo to northern Paraná. Other studies reported a checklist of conspicuous seaweeds from Ilha do Farol, Caiobá (Shirata et al. 1991), as well as seaweeds from mangroves in Ilha do Mel and Guaraqueçaba Islands, both respectively located in the outer and inner sectors of Paranaguá Bay (Shirata 1993a, b).

More recent studies were performed with the aim of establishing a biological and technical database for cultivating the monostromatic green seaweeds *Gayralia oxysperm*a (Kützing) K.L.Vinogradova ex Scagel et al. and *G. brasiliensis* Pellizzari, M.C. Oliveira & N.S. Yokoya in Paranaguá Bay (Pellizzari et al. 2007, 2008, 2013). Pellizzari & Kawaii (2010) reported protocols for monitoring based on physical, chemical and biological indicators in the Paranaguá Bay Estuarine Complex, and, finally, Pellizzari & Reis (2011) published a compilation of seaweed resources with the potential for cultivation along the southern and southeastern Brazilian coast.

The Paraná coast embraces the largest cereal port in South America (Paranaguá Harbor). It is well known that harbor activities can affect the conservation state of coastal ecosystems by their physical and chemical impacts or geomorphological changes in coastal waters. Also, these activities can cause species introduction, as well disappearance of sensitive species and/or the predominance of opportunistic taxa. In general, natural system degradation occurs at a faster rate than the remediation of natural systems by the introduction of conservation initiatives (Amado-Filho et al. 2006). For these reasons, this study proposed a biological database focused on seaweed diversity in insular areas of Paraná, aiming to support future coastal monitoring and or conservation programs.

Materials and Methods

1. Study area

Seaweeds from the Paraná coast were collected at three sampling stations: Ilha do Mel, Currais Archipelago and Ilha do Farol (Figure 1) during the summer and winter between 2006 and 2010. These islands are not considered to have a high degree of biogeographical isolation.

Ponta das Encantadas at Ilha do Mel (25°32'07''S and 48°19'52''W) is located 1.3 miles from the shore (Pontal do Paraná) at the mouth of Paranaguá Bay, showing an intermediate level of hydrodynamics. In general, this location shows a high concentration of suspended particulated matter and chlorophyll (Lana et al. 2001) among the sampled islands, resulting in a low water column. This continental island has a coastline that stretches 35 kilometers, and it is located on the northern boundary of our sampling area. The rocky boulders are composed of basalt, showing fractions of migmatite.

The Marine State Park of Currais Archipelago is a rocky basaltic outcropping formed by three oceanic islands and located about 10 miles from the coast (25°44'00''S and 48°22'00''W). The islands are orientated NW-SE, with the main island located on the eastern side of the archipelago (Borzone 1994). Ilha Grande was the sampling area, and it represents 81% of the immersed portion of the archipelago, showing real rocky shores with variable declivities, a short pebble beach, and mean depths lower than 15m. This island is preserved and shows the highest transparency and hydrodynamics among the sampled islands as a result of its exposure to open clear continental waters.

Ilha do Farol (25°51'9.01''S and 48°32'7.01''W) is the southern limit among our sampling stations, and it has a continental isthmus that allows transit only at ebbtide, being the nearest island from the coast and showing a sheltered side oriented to the mouth of Guaratuba Bay. The water transparency is variable following rainfall, and boulders along the shores show basaltic, gnaise and biolithic (*Phragmatopoma*) formations. Based on the evaluation of six water quality parameters (chlorophyll, Secchi depth, CO_2 saturation, dissolved inorganic nitrogen and phosphorus, and dissolved oxygen), Mizerkowski et al. (2012) suggested that Guaratuba Bay shows a low to medium trophic status, i.e., from meso- to oligotrophic, in turn indicating that the surrounding areas follow the same pattern. However, this island is located between two summer recreation areas in Paraná, Guaratuba and Caiobá Beaches, thus suffering from a huge input of organic matter from untreated sewage during the tourist season.

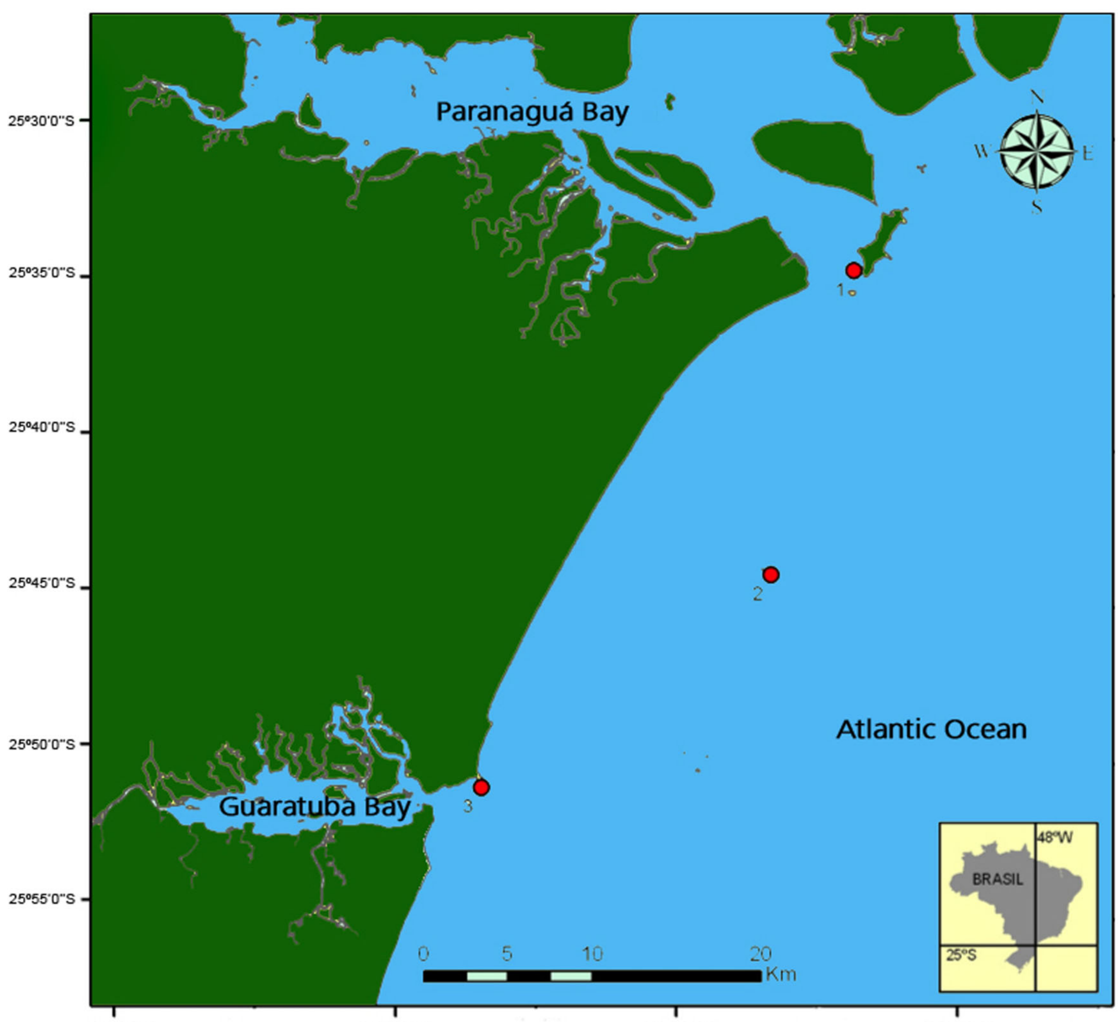

Figure 1. Sampling sites from the Paraná coast, southern Brazil. 1- Ponta das Encantadas, Ilha do Mel. 2- Ilha Grande, Currais Archipelago; 3- Ilha do Farol.

2. Sampling method and data analysis

Fertile specimens of each species (n=3) were collected by hand, using a spatula, inside replicated quadrats (1 m^2) randomly distributed in transects parallel to the coast (n=5 for each sampling zone: upper tidal, intertidal and subtidal). In the laboratory, the collected material was fixed in triplicate, using formalin 4% diluted with seawater. The taxonomic study was based on morphological and anatomical features observed in histological sections of vegetative and reproductive structures under stereomicroscopy and light microscopy (Olympus CX31 with image capturing). Species identification was based on specialized literature, and nomenclature updates were made following Wynne (2011) and Guiry & Guiry (2013). Some species were analyzed using molecular markers (SSU and ITS), after preserving algal material in SI GEL. Voucher specimens were deposited in the herbarium of the *Museu Botânico de Curitiba* (MBM). The seaweeds were grouped into morpho-functional categories, as proposed by Littler & Littler (1980) and Steneck & Dethier (1994).

In order to detect similarities among species and thus establish patterns of biodiversity, a cluster analysis was applied to compare sampling sites and seasons, using a presence-absence matrix of species and Bray-Curtis similarity index. The frequency of taxa was calculated using the constancy index (CI - Dajoz, 1973). According to this index, constant taxa were considered to be those that occurred in more than 50% of the samples. Accessory taxa were those occurring between 25% to 50% of the samples, and accidental (rare) taxa were those occurring in up to 25% of the samples. The proposed dendrograms were produced with the Primer-E statistics package (Plymouth Routines in Multivariate Ecological Research). Accidental (rare) species were deleted in the data matrix used to perform the CI in order to avoid generating noise in the results.

Results

A total of 139 taxa were identified, including 90 taxa of Rhodophyta, 27 species of Chlorophyta and 22 taxa of Phaeophyceae (Table 1), and 52 are new records for the Paraná coast (40 species of Rhodophyta, 7 of Phaeophyceae and 5 of Chlorophyta). Fourteen species were present for all sampling sites, including the green alga *Gayralia brasiliensis* Pellizzari, M.C.Oliveira & N. S. Yokoya, a recently described new species. Among red seaweeds, Rhodomelaceae (19 spp.), Ceramiaceae (12 spp.), and Corallinaceae (10 spp.) were the most representative families. Cladophoraceae (12 spp.) and Ulvaceae (5 spp.), as well as Dictyotaceae (8 taxa) and Sargassaceae (4 taxa), were the most representative families of green and brown algae, respectively. The most representative genus was *Ceramium* Roth (Rhodophyta), comprising seven species.

The highest seaweed diversity was observed at Ilha do Mel and Currais Archipelago (Figure 2). Currais showed the highest diversity during the summer, if compared with other islands, and most new records were reported for this island (Table 1).

The occurrence of 101 taxa was observed at Ilha do Mel, comprising 59 Rhodophyta, 27 Chlorophyta and 15 Phaeophyceae, and no seasonal differences in diversity were observed (Figure 2). The recently described species *Gayralia brasiliensis* occurred at all three sampling sites, and it was found on sheltered rocks or mangrove roots in areas with salinity around 30.

In Currais Archipelago, 101 taxa were found (64 taxa of Rhodophyta, 18 of Chlorophyta and 19 of Phaeophyceae), and the highest diversity occurred during the winter (Figure 2). The most representative families were Ceramiaceae, Corallinaceae and Rhodomelaceae (Table 1). Brown and green seaweeds mainly occurred down to depths of 3 m, and the predominant species were Dictyotales/Ectocarpales and Cladophoraceae, respectively. Until 6 m depth, the algal community was predominated by turf algae of articulated and non-articulated Corallinales, presenting Ceramiales as epiphytes. At greater depths, seaweed diversity was limited by the scarcity of consolidated substrate, fouling, and the presence of a high concentration of particulated organic material. The most representative taxa from this island were *Asparagopsis taxiformis* (Delile) Trevis, *Amphiroa* spp. and *Gelidium* spp. (Table 1).

At Ilha do Farol, 66 taxa were identified, including 37 Rhodophyta, 19 Chlorophyta and 10 Phaeophyceae, and the highest diversity was observed during the summer with biomass dominance of Ulvales opportunistic species (Figure 2, Table 1).

The most common species among the sampling sites were *Bryothamnion seaforthii* (Turner) Kutz., *Caulerpa fastigiata* Montagne, *Centroceras clavulatum* (C. Agardh in Kunth) Mont. in Durieu de Maisonneuve, *Chaetomorpha antennina* (Bory de Saint-Vincent) Kützing, *Cladophoropsis membranacea* (Hofman Bang ex C. Agardh) Børgesen, *Cladophora vagabunda* (Linnaeus) Hoek, *Codium decorticatum* (Woodward) M.A. Howe, *Gelidium pusillum* (Stackh.) Le Jolis, *Padina gymnospora* (Kützing) Sonder, *Pterocladiella capillacea* (S. G. Gmel.) Santel. & Hommers, *Rhizoclonium riparium* (Roth) Harvey, *Ulva lactuca* Linnaeus, *Sargassum cymosum* C. Agardh and *Pterosiphonia pennata* (C. Agardh) Falkenb.

Fourteen species (nine Chlorophyta, one Phaeophyceae and four Rhodophyta) occurred at all sampling sites and in both seasonal periods and could therefore be used as bioindicators for monitoring: *Caulerpa fastigiata, Codium decorticatum, Chaetomorpha anteninna, Cladophora vagabunda, Rhizoclonium riparium, Gayralia brasiliensis, Ulva fasciata* Delile, *U. flexuosa* Wulfen, *U. lactuca, Padina gymnospora, Centroceras clavulatum, Pterosiphonia pennata, Pterocladiella capillaceae* and *Hypnea musciformis* (Wulfen in Jacquin) J. V. Lamour (Table 1).

By constancy index (CI), it was shown that the seaweed taxa from insular areas of the Paraná coast are distributed as 44% accessory species and 33% accidental (rare) species, while only 23% of species are considered constant. Using full diversity, a dendrogram was produced and showed 62% similarity among samples collected during the summer at Ilha do Mel (IMV) and Ilha do Farol (IFV) and 61% between samples from the Currais Archipelago during summer and winter (CV and CI). CS and CI showed a cluster of only 45% with the other sites/seasons. When accidental (rare) species were disregarded, the dendrogram showed the same cluster pattern (Figure 3); however, the sampling sites showed higher similarity between IF and IM. IMV and IFV showed 71% of similarity, while CV and CI showed 69.4% similarity. Ilha do Mel during the winter (IMI) showed similarity of 63% between IMV and IFV. Ilha do Farol during the winter (IFI) clustered 56% with CV, and CI showed a cluster of only 52% with the other sites/seasons. To summarize, Currais Arquipelago showed a high similarity

Table 1. Composition of benthic marine algae species collected from islands of the Paraná coast sampled during summer (S) and winter (W) seasons.

TAXA	Ilha do Mel		Currais Archipelago		Ilha do Farol	
	S	W	S	W	S	W
CHLOROPHYTA						
Bryopsidales						
Bryopsidaceae						
Bryopsis pennata J.V. Lamouroux	+	-	+	-	+	-
Caulerpaceae						
Caulerpa fastigiata Montagne	+	+	+	+	+	+
Caulerpa sp.	+	-	-	-	+	-
Codiaceae						
Codium decorticatum (Woodward) M.A. Howe	+	+	+	+	+	+
Codium sp.	-	+	-	+	-	-
Codium taylorii P.C. Silva	+	-	-	-	+	+
Udoteaceae						
Boodleopsis pusilla (F.S. Collins) W.R. Taylor, A.B. Joly & Bernatowicz	+	+	+	-	+	+
Cladophorales						
Boodleaceae						
Cladophoropsis membranacea (Hofman Bang ex C. Agardh) Børgesen	-	+	+	-	-	+
Cladophoraceae						
Chaetomorpha aerea (Dillwyn) Kützing	+	-	-	-	-	-
Chaetomorpha antennina (Bory de Saint-Vincent) Kützing	+	+	+	+	+	+
Chaetomorpha brachygona Harvey	+	-	-	+	-	-
Cladophora albida (Nees) Kutzing	+	-	-	-	-	-
Cladophora montagneana Kützing	-	+	-	+	-	+
Cladophora prolifera (Roth) Kützing	-	+	+	-	-	+
Cladophora sp.	-	+	-	-	-	-
Cladophora vagabunda (Linnaeus) Hoek	+	+	+	+	+	+
Rhizoclonium africanum Kützing	-	+	+	-	-	+
Rhizoclonium riparium (Roth) Harvey	+	+	+	+	+	+
Rhizoclonium sp.	+	-	-	-	-	-
Rhizoclonium tortuosum (Dillwyn) Kützing	+	+	-	-	-	-
Ulotrichales						
Gayraliaceae						
Gayralia brasiliensis Pellizzari, M.C. Oliveira et N.S. Yokoya	+	+	+	+	+	+
Gayralia oxysperma (Kützing) K.L. Vinogradova ex Scagel et al.	+	+	-	-	-	-
Ulvales						
Ulvaceae						
Ulva clathrata (Roth) C. Agardh	+	+	+	+	+	-
Ulva fasciata Delile	+	+	+	+	+	+
Ulva flexuosa Wulfen	+	+	+	+	+	+
Ulva lactuca Linnaeus	+	+	+	+	+	+
Ulva linza Linnaeus	-	+	-	-	-	+
Total 27	20	20	15	13	14	16
OCHROPHYTA						
Dictyotales						
Dictyotaceae						
Canistrocarpus cervicornis (Kutzing) de Paula & de Clerck	+	+	-	+	-	-
Canistrocarpus cervicornis f. pseudohamatus (Cribb) M.J. Wynne	-	+	-	+	-	-
Dictyopteris delicatula J.V. Lamouroux	-	+	-	+	-	-
Dictyota menstrualis (Hoyt) Schnetter, Hörning & Weber-Peukert	+	+	-	+	-	-
Lobophora variegata (Lamouroux) Womersley ex Oliveira	-	-	+	-	+	-
Padina antillarum (Kutzing) Piccone	-	-	-	-	+	-
Padina gymnospora (Kützing) Sonder	+	+	+	+	+	+
Spatoglossum schroederi (C. Agardh) Kützing	-	+	-	+	-	-
Ectocarpales						
Acinetosporaceae						

Continued on next page

Table 1. Continued.

TAXA	Ilha do Mel		Currais Archipelago		Ilha do Farol	
Feldmannia irregularis (Kützing) G.Hamel	+	-	-	-	-	-
Feldmannia mitchelliae (Harvey) H.S. Kim	-	-	+	+	-	-
Chordariaceae						
Levringia brasiliensis (Montagne) A.B. Joly	+	-	+	-	-	-
Protectocarpus speciosus (Børgesen) Kornmann	-	-	-	+	-	-
Scytosiphonaceae						
Chnoospora minima (K. Hering) Papenfuss	-	-	-	+	+	-
Colpomenia sinuosa (Mertens ex Roth) Derbès & Solie	+	-	+	+	-	-
Petalonia fascia (O.F. Müller) Kuntze	+	-	-	+	-	+
Fucales						
Sargassaceae						
Sargassum cymosum C. Agardh	+	-	-	+	+	+
Sargassum cymosum var. nanum E. de Paula & E. C. Oliveira	-	-	+	+	+	-
Sargassum stenophyllum Martius	+	-	-	+	+	+
Sargassum vulgare C. Agardh	-	-	-	-	+	-
Ralfsiales						
Neoralfsiaceae						
Neoralfsia expansa (J.Agardh) P.-E.Lim & H.Kawai ex Cormaci & G.Furnari	-	+	+	+	-	-
Scytothamnales						
Bachelotiaceae						
Bachelotia antillarum (Grunow) Gerloff	+	-	+	+	-	+
Sphacelariales						
Sphacelariaceae						
Sphacelaria brachygona Montagne	+	-	+	-	-	-
Total 22	**11**	**7**	**9**	**16**	**8**	**5**
RHODOPHYTA						
Acrochaetiales						
Acrochaetiaceae						
Acrochaetium flexuosum Vickers	-	-	+	+	-	-
Acrochaetium microscopicum (Nägeli ex Kützing) Nägeli	-	-	-	+	-	-
Bangiales						
Bangiaceae						
Pyropia acanthophora (E.C.Oliveira & Coll) M.C.Oliveira, D.Milstein & E.C.Oliveira	+	+	+	-	+	-
Pyropia acanthophora var. *brasiliensis* (E.C.Oliveira & Coll) M.C. Oliveira, D. Milstein & E.C. Oliveira	-	+	-	-	-	+
Pyropia spiralis (E.C.Oliveira & Coll) M.C.Oliveira, D.Milstein & E.C.Oliveira	-	+	-	-	-	+
Pyropia suborbiculata (Kjellman) J.E.Sutherland, H.G.Choi, M.S. Hwang & W.A.Nelson	+	+	+	-	+	+
Bonnemaisoniales						
Bonnemaisoniaceae						
Asparagopsis taxiformis (Delile) Trevis.	+	+	+	+	-	-
Ceramiales						
Ceramiaceae						
Aglaothamnion felliponei (M. Howe) N. Aponte, D. L. Ballant. & J. N.Norris	+	+	-	-	+	-
Aglaothamnion uruguayense (W. R. Taylor) N. Aponte, D. L. Ballant	+	-	-	-	+	+
Centroceras clavulatum (C. Agardh in Kunth) Mont. in Durieu de Maisonneuve	+	+	+	+	+	+
Centrocerocolax ubatubensis A. B. Joly	-	+	-	+	-	-
Ceramium brasiliense A. B. Joly	-	+	+	-	+	-
Ceramium brevizonatum H.E. Petersen	+	-	+	-	-	-
Ceramium dawsonii A. B. Joly	+	-	+	+	+	-
Ceramium deslongchampsii Chauv. ex Duby	-	-	+	-	-	-

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Table 1. Continued.

TAXA	Ilha do Mel		Currais Archipelago		Ilha do Farol	
Ceramium diaphanum (Lightfoot) Roth	+	-	-	+	-	-
Ceramium sp.	+	-	-	-	+	-
Ceramium tenerrimum (G. Martens) Okamura	-	-	+	+	-	-
Gayliella flaccida (Harvey ex Kützing) T.O.Cho & L.J.McIvor	+	-	+	-	-	-
Dasyaceae						
Dasya rigidula (Kutzing) Ardissone	-	-	-	+	-	-
Delesseriaceae						
Acrosorium ciliolatum (Harvey) Kylin	-	-	+	-	-	-
Caloglossa leprieurii (Mont.) G. Martens	+	+	-	-	+	-
Hypoglossum hypoglossoides (Stackhouse) F.S. Collins & Hervey	-	+	-	+	-	+
Rhodomelaceae						
Acanthophora spicifera (Vahl) Børgesen	+	+	+	-	+	-
Bostrychia calliptera Montagne	+	+	-	-	-	-
Bostrychia montagnei Harvey	+	+	-	-	+	+
Bostrychia moritziana (Sonder ex Kutzing) J. Agardh	+	+	-	-	-	-
Bostrychia radicans (Mont.) Mont. In Orbigny	+	+	-	-	+	+
Bostrychia tenella (J. V. Lamour.) J. Agardh	+	+	-	-	-	-
Bryocladia thyrsigera (J. Agardh) F. Shmitz	-	-	+	-	+	-
*Bryothamnion seaforthii (*Turner) Kutz.	+	-	+	+	+	-
Chondria atropurpurea Harvey	-	+	-	+	-	-
Dawsoniocolax bostrychiae A.B. Joly e Yamaguishi-Tomita	-	+	-	-	-	-
Herposiphonia secunda f. tenella (C. Agardh) Ambronn	+	-	+	+	+	-
Neosiphonia ferulacea (Suhr ex J. Agardh) S. M. Guim. & M. T. Fujii	-	-	+	+	-	-
Neosiphonia tepida (Hollenb.) S. M. Guim. & M. T. Fujii	-	-	-	+	-	-
Palisada flagellifera (J.Agardh) K.W.Nam	+	+	-	+	-	-
Palisada perforata (Bory) K.W. Nam	-	-	+	-	+	-
Polysiphonia howei Hollenberg	-	+	-	-	-	+
Polysiphonia sp.	-	-	+	-	+	-
Pterosiphonia parasitica (Hudson) Falkenberg	-	+	-	-	-	-
Pterosiphonia pennata (C. Agardh) Falkenb.	+	+	+	+	+	+
Spyridiaceae						
Spyridia hypnoides (Bory in Belanger) Papenf.	+	-	+	+	-	-
Wrangeliaceae						
Pleonosporium sp.	-	-	+	+	-	-
Ptilothamnion speluncarum (Collins & Herv.) D. L. Ballant. & M. J. Wynne	-	-	-	+	-	-
Wrangelia argus (Mont.) Mont.	+	+	+	+	-	-
Colaconematales						
Colaconemataceae						
Colaconema codicola (Børgesen) H.Stegenga, J.J.Bolton, & R.J.Anderson	-	+	-	+	-	-
Corallinales						
Corallinaceae						
Amphiroa anastomosan Weber-van Bosse	-	-	+	-	-	-
Amphiroa beauvoisii J. V. Lamour.	+	+	+	+	-	-
Amphiroa fragilissima (L.) J. V. Lamour.	-	-	+	+	-	-
Amphiroa sp.	-	-	-	+	-	-
Arthrocardia flabellata (Kütz.) Manza	-	+	-	+	-	+
Corallina officinalis Linnaeus	-	+	-	-	-	-
Jania adhaerens J. V. Lamour.	-	-	+	+	-	-
Jania prolifera A. B. Joly	-	-	+	+	-	-
Jania rubens (Linnaeus) J.V. Lamouroux	+	-	+	-	-	-
Lithophyllum stictaeforme (J.E. Areschough) Hauck	-	-	+	+	-	-
Erythopeltidales						

Continued on next page

Table 1. Continued.

TAXA	Ilha do Mel		Currais Archipelago		Ilha do Farol	
Erythrotrichiaceae						
Sahlingia subintegra (Rosenv.) Kornmann	-	-	+	-	-	-
Gelidiales						
Gelidiaceae						
Gelidium crinale (Hare ex Turner) Gaillon	+	-	-	-	-	-
Gelidium floridanum W.R. Taylor	+	+	+	-	-	-
Gelidium pusillum (Stackh.) Le Jolis	+	+	+	-	+	+
Gelidium sp.1	+	-	-	-	-	-
Gelidium sp.2	-	-	-	-	+	-
Pterocladiaceae						
Pterocladiella capillacea (S. G. Gmel.) Santel. & Hommers.	+	+	+	+	+	+
Gigartinales						
Caulacanthaceae						
Catenella caespitosa (Withering) L.M. Irvine	+	-	-	-	-	-
Cystocloniaceae						
Craspedocarpus jolyi (E.C.Oliviera) Schneider	+	-	-	-	-	-
Hypnea musciformis (Wulfen in Jacquin) J. V. Lamour.	+	+	+	+	+	+
Hypnea spinella (C. Agardh) Ku?tz.	+	-	+	+	+	-
Gigartinaceae						
Chondracanthus acicularis (Roth) Fredericq	-	-	+	-	+	-
Chondracanthus elegans (Grev. in J. St. Hil.) Guiry	-	-	-	-	+	-
Chondracantus teedei (Mertens ex Roth) Kützing	-	+	-	+	-	-
Chondracanthus sp.	-	+	-	-	-	-
Phyllophoraceae						
Gymnogongrus griffithsiae (Tuner) Mart.	+	+	+	-	+	-
Gracilariales						
Gracilariaceae						
Gracilaria cervicornis (Turner) J. Agardh	+	-	+	-	-	-
Gracilaria domingensis (Kütz) Sond. Ex Dickie	+	+	-	-	+	-
Hydropuntia caudata (J. Agardh) Gurgel & Fredericq	-	+	-	-	+	+
Halymeniales						
Halymeniaceae						
Grateloupia dichotoma J. Agardh	-	-	-	-	+	+
Grateloupia doryphora (Montagne) M.A. Howe	+	+	+	-	+	-
Grateloupia filicina (J.V. Lamouroux) C. Agardh	-	+	-	+	-	-
Halymenia C. Agardh	-	-	+	+	-	-
Hildenbrandiales						
Hildenbrandiaceae						
Hildenbrandia rubra (Sommerf.) Menegh	-	-	+	-	+	-
Nemaliales						
Galaxauraceae						
Tricleocarpa cylindrica (J. Ellis & Sol.) J. V. Lamour.	-	-	+	-	+	-
Peyssonneliales						
Peyssoneliaceae						
Peyssonnelia armorica (P.L.Crouan & H.M.Crouan) Weber-van Bosse	-	-	+	-	-	-
Plocamiales						
Plocamiaceae						
Plocamium brasiliense (Greville) M.A. Howe & W.R. Taylor	+	-	+	-	-	-
Rhodymeniales						
Champiaceae						
Champia parvula (C. Agardh) Harvey	-	-	+	+	-	-
Lomentariaceae						
Ceratodictyon intricatum (C. Agardth) R.E. Noaris	-	+	-	+	-	-
Ceratodictyon variabile (J.Agardh) R.E.	-	-	+	-	-	-
Lomentaria corallicola Børgesen	+	-	-	-	-	-

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Table 1. Continued.

TAXA	Ilha do Mel		Currais Archipelago		Ilha do Farol	
Rhodymeniaceae						
Rhodymenia pseudopalmata (J. V. Lamour.) P. C. Silva	+	-	+	+	-	-
Sebdeniales						
Sebdeniaceae						
Sebdenia flabellata (J. Agardh) P.G. Parkinson	-	-	-	+	-	-
Total 90	42	40	47	38	32	16

index between summer and winter; however, this community is different when compared to that of Ilha do Farol or Ilha do Mel. On the other hand, seasonal diversity patterns between Ilha do Mel and Ilha do Farol are quite defined showing similarity during the summer but differences during the winter.

Considering the morphofunctional groups, the filamentous group comprised the majority of the taxa of Chlorophyta, Phaeophyceae, and Rhodophyta, followed by terete and corticated foliose groups. On the other hand, the less representative group was crustose calcareous (Figure 4).

Discussion

This study reports the occurrence of 139 taxa of seaweeds in insular areas from the Paraná coast, comprising 52 species as new records for that state. The diversity found in Paraná in this survey is 33% higher than data reported over the last decade (Oliveira et al. 2013). However, diversity of benthic marine algae from the Paraná coast and nearby islands is lower when compared to other Brazilian states, corresponding to 44% and 70% of phycoflora from the States of São Paulo and Santa Catarina, respectively (following Horta et al. 2001). This difference could be explained by the shorter coastline and lower availability of rocky shores in Paraná State. Furthermore, the Paraná coast is located between estuarine systems (Paranaguá and Guaratuba Bays), thus receiving runoff and a large input of continental water, resulting in high concentrations of suspended particulate matter and low seawater transparency.

The differences in diversity between Currais Archipelago and the other islands (Ilha do Mel and Ilha do Farol) are probably associated with the distance from the coast, resulting in changes of temperature, salinity, nutrient input, anthropic influence, and hydrodynamics.

Ten species previously reported to the Paraná coast in a literature compilation (Oliveira et al. 2013) were not found in the present study: *Ulvella (*formerly *Entocladia) viridis* Reinke, *Acrochaetium globosum* Borgensen, *Bangiopsis dumontioides* (P.L. Crouan & H.M. Crouan) V. Krishnmurthy, *Cryptopleura ramosa* (Hudson) Kylin ex L. Newton, *Gelidium spinosum* (S.G. Gmelin) P.C. Silva, *Heterosiphonia gibbesi* (Harvey) Falkenberg, *Hydrolithon farinosum* (J.V. Lamouroux) Penrose & Y.M. Chamb, *Leptofauchea brasiliensis* A.B. Joly, *Pneophyllum fragile* Kützing and *Stylonema alsidii* (J.V. Lamouroux) P.C. Silva.

Nutrient pulses are higher and more conspicuous in urban environments compared to less urbanized or pristine areas (Scherner et al. 2012). The seaweed community structure from Currais Archipelago, a Marine State Park, showed the greatest difference among the sampling sites, and it was also the location with the highest number of new records on seaweed diversity for the state. These results reinforce the need to maintain the conservation status of this park. The marine flora here was dominated by turf algae (Littler & Littler 1980;

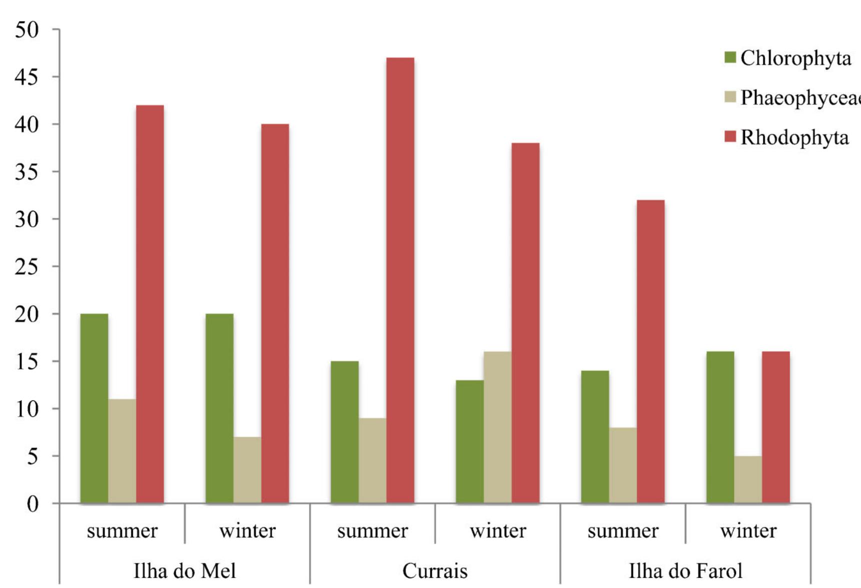

Figure 2. Variation in species number of Chlorophyta, Phaeophyceae and Rhodophyta during the summer and winter in the sampling sites (Ilha do Mel, Currais Archipelago and Ilha do Farol) along the Paraná coast, southern Brazil.

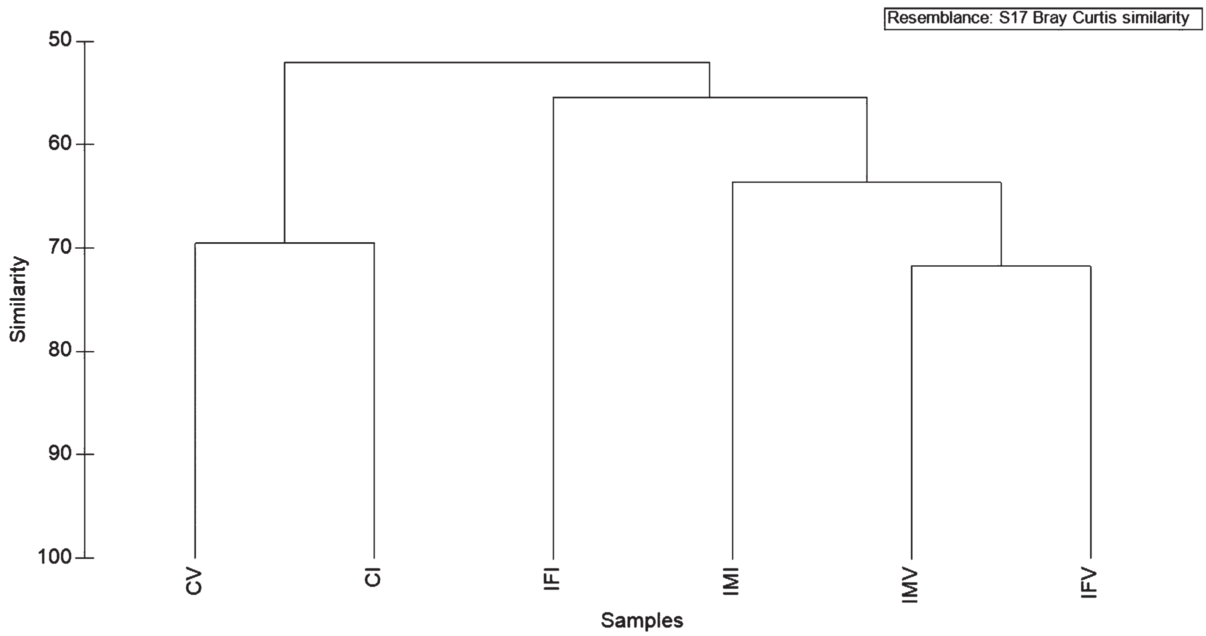

Figure 3. Similarity dendrogram of quadrants based on the Bray-Curtis similarity index among seaweed diversity data from samples collected at *Ilha do Mel* during the summer (IMV) and winter (IMI), *Ilha do Farol* during the summer (IFV) and winter (IFI), and *Currais* during the summer (CV) and winter (CI); islands along the Paraná coast, southern Brazil.

Steneck & Dethier 1994) composed of articulated Corallinaceae on the base and filamentous red algae as an epiphyte, in addition to crustose Corallinales found up to depths of 10m. Turfs are ecologically important in that they retain sand. Furthermore, geniculate coralline algae can act as 'anchor' taxa for other species, as well as maintain surface stability along exposed shores. Among sampling sites, infralittoral zone was sampled only at Currais Archipelago, and this area also showed the highest degree of hydrodynamics, been the farthest island from the coast. These could explain the peculiar phycoflora where seaweeds recruitment is limited by shortage of consolidated substrate and intensive fouling. Currais belongs to the Marine State Park category among Brazilian Conservation Units, and it is a target control site for coastal monitoring studies based on its high degree of conservation. On the other hand, Ilha do Mel and Ilha do Farol are located near estuarine mouths, Paranaguá and Guaratuba Bays, respectively, and also near urban and harbor areas, thus receiving different sediment and nutrient inputs compared to Currais Archipelago, what could explain the distinct patterns in diversity, biomass and distribution of macroalgae assemblages.

Estuarine systems flow into the open sea, adding continental sediments and nutrients. This nutrient input may favor seaweed growth. However, constant sediment input can also increase water turbidity, decrease light penetration, and impair photosynthetic rates, resulting in the dominance of a few

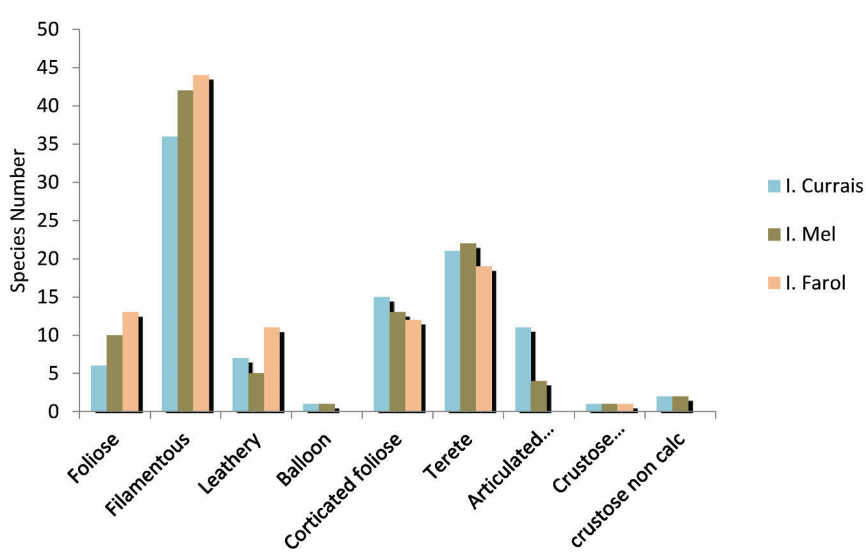

Figure 4. Variation in species number belonging to different morphofunctional groups in the sampling sites (Ilha do Mel, Currais Archipelago and Ilha do Farol) along the Paraná coast, southern Brazil.

opportunistic taxa adapted to high turbidity zones. The lowest diversity, which was observed at Ilha do Farol, could also be associated with anthropic influence on eutrophication in addition to lower salinity and higher water turbidity.

Ilha do Mel showed higher species similarity between seasons, while Ilha do Farol showed higher biomass (data not shown), mainly *Ulva fasciata* Delile during the summer and *Pyropia* spp. during the winter. Some green algae are cosmopolitan and show opportunistic behavior. In some cases, low diversity and/or high biomass of some opportunistic taxa suggests eutrophication, input of pollutants and/or high herbivory activity in the area, as reported by Yoneshigue-Valentin & Valentin (1992). Also, filamentous Ulvales and other orders of foliose seaweeds could dominate areas with high continental water discharge. Thus, algal blooms could be explained as a result of an impact that had already occurred. This fact corroborates the stress sensitivity of some species that suffer from the adverse effects of short- and long-term exposure to urban-derived contaminants. However, these same species, which respond quickly to organic pollution, may also be good bioindicators in coastal monitoring plans (Pellizzari & Kawaii 2010).

Green seaweed beds found at Ilha do Farol mainly during the summer could be associated with urbanization and eutrophication from the discharge of organic effluents from rivers or even sewage on the beaches during the summer tourist season. Eutrophication also probably results from the location of this island at the mouth of Guaratuba Bay. During the summer months, the precipitation is higher, increasing continental runoff and resulting in lower seaweed diversity and biomass dominated by opportunistic taxa. Several reports have described the ephemeral *Ulva* species as opportunistic taxa and as pollution-tolerant species (Scherner et al. 2013). These authors also report that the photosynthetic response of the perennial, canopy-forming seaweed *Sargassum stenophyllum* Martius declines after pollution stress. Studying the impact of coastal urbanization on the structure of phytobenthic communities in southern Brazil, Martins et al. (2012) suggest that pristine-like environments are characterized by an increase of Rhodophyta species and that urbanized environments are dominated by opportunistic algae, including such green algae as *Ulva* and *Cladophora*. Amado-Filho et al. (2006) studied the infralittoral seaweeds from Laje de Santos, São Paulo State, identifying *Cladophora vagabunda, Padina gymnospora, Hypnea spinella* (C. Agardh) Kütz., *Centroceras clavulatum* and *Amphiroa beauvoisii* J.V. Lamour as conspicuous species during the summer and winter. According to our study, these taxa were also found in all sampling sites in the Paraná islands and could be used as bioindicators or proxies of seasonal variation.

Considering the advances in molecular analysis, seaweed diversity along the Brazilian coastline, including insular ecosystems, needs to be further investigated. Moreover, the subtidal regions remain a gap in phycoflora knowledge in some Brazilian states (Horta et al. 2001; Nunes 2005). Since the present study comprises subtidal samplings along the Paraná coast at Currais Archipelago, the survey, as detailed in Table 1, should serve to fill this gap. However, many places of the Paraná coast are still unexplored below depths of 15 m.

The knowledge of seaweed diversity through updated surveys is essential to conservation studies. Significant seasonal changes that affect diversity, both short and long term, can be detected through proxies as new occurrences. Changes in the ecosystem can also be indicated by the identification of new species, the invasion of alien species, and blooms of opportunistic taxa. Thus, the development of a database, such as that provided in the present study, can help in the identification of bioindicators for monitoring coastal waters, which is an essential component of conservation. This database serves to detect impacts that can affect the patterns of biogeographical distribution, suggesting, in turn, gradual or abrupt changes in coastal communities. Furthermore, the increase in algal utilization in many countries, including Brazil, may result in unsustainable seaweed resources and even depletion of natural beds, suggesting that diversity in association with water quality monitoring should be included as a mandatory tool for conservation initiatives.

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