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Composition and Distribution of Deep Water Macroalgae Species from the Continental Shelf of Sergipe State, Brazil

SONIA MARIA BARRETO PEREIRA[1,2], JULIANA TORRES[2] & LÍSIA MÔNICA DE SOUZA GESTINARI[2,3]

[1]*Centro Acadêmico de Vitória (CAV), Universidade Federal de Pernambuco. Rua do Alto do Reservatório s/n, Bela Vista, Vitória de Santo Antão, 55.608-680, Pernambuco, Brasil.*

[2]*Programa de Pós-Graduação em Botânica (PPGB) Universidade Federal Rural de Pernambuco*

[3] *Núcleo em Ecologia e Desenvolvimento Socioambiental de Macaé (NUPEM), Universidade Federal do Rio de Janeiro, Campus UFRJ-Macaé Prof. Aloisio Teixeira, Rua São José do Barreto, 764, Barreto, 27965-045, Macaé, Rio de Janeiro, Brasil. lisiagestinari@macae.ufrj.br*

Corresponding author: soniabp@terra.com.br; soniabp@pesquisador.cnpq.br Phone: +55 81 3320-6361 Fax: +55 81 3320-6360

Abstract

This study investigates the deep-water flora of the continental shelf in Sergipe State, Brazil located between 10°36'08" – 11°21'07"S and 36°28'10" – 37°13'47"W. The samples were collected by dragging at 18 sampling sites, between 10 to 30 m depth, from May 1999 to March 2000. A total of 91 taxa of marine benthic macroalgae were identified (56 Rhodophyta, 20 Heterokontophyta and 15 Chlorophyta). Forty-seven (47) of these are new occurrences for Sergipe flora. Rhodophyta dominated, accounting for 61% of the total species collected, with the order *Ceramiales* having the highest number of species present (39.55%), followed by Heterokontophyta (23%), mostly represented by *Dictyotales* (65%). Finally, 15 Chlorophyta taxa were found (16%), mainly composed of *Bryopsidales* (53%).

Key words: biodiversity, benthic macroalgae, subtidal

Introduction

The Brazilian coast is approximately 8.500 km long and can be divided in two phycogeographic regions—Warm Temperate and the Tropical – in accordance with the distribution of seaweeds. These regions are separated by a transition zone that runs along the Espírito Santo coast (Horta *et al*. 2001).

In spite of our relatively deep understanding of Brazilian marine macroalgae flora (Brazil leads other South American nations in these studies), most of our current knowledge has been obtained through intertidal region surveys (Burgos *et al*. 2009, Amado Filho *et al*. 2010). Because of the difficulties involved in gaining access to the subtidal region, little research had been conducted into subtidal flora until the end of the last century. This is the main reason why it has been difficult to establish floristic patterns and, consequently, the origins of Brazilian flora in these regions (Horta *et al*. 2001, Burgos *et al*. 2009).

Among the studies of the phycological flora of the subtidal region, the most prominent have been those carried out by oceanographic vessels such as the *Almirante Saldanha*, *Canopus, Akaroa* and others (Yoneshigue-Valentin *et al*. 2006). This research has predominantly focused on providing species "check lists" (Joly & Yoneshigue-Braga 1966, Guimarães *et al*. 1981), new taxa descriptions (Joly & Oliveira Filho 1968) and new reports of subtidal flora (Joly & Sazima 1971a; b, Joly *et al.* 1976). Equally important has been the research into the subtidal flora of the coast of Espirito Santo (Oliveira Filho 1976), as well as studies undertaken in the Brazilian northeast designed by the Recife Commission (Ugadim & Pereira 1978) and carried out by PROJETO ALGAS (SUDENE) in the subtidal region of Rio Grande do Norte, Paraiba, Alagoas and Pernambuco (Pereira *et al*. 1981, Pereira 1983, Ferreira *et al*. 1988). The results yet another research program were published as part of the REVIZEE Program, which investigated the phycological diversity of the subtidal region of Bahia, Espírito Santo and Rio de Janeiro (Yoneshigue-Valentin *et al.* 2006).

More recent investigations have been conducted into the phycological flora of the subtidal region of Gaibu Beach on the coast of Pernambuco (Pereira *et al.* 2007 b), Arvoredo Island in Santa Catarina (Horta *et al*. 2008), Todos os Santos Bay in Bahia (Marins *et al.* 2008), Cabo Frio island in Rio de Janeiro (Villaça *et al.* 2008), the setentrional coast

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of the Bacia do Potiguar in Rio Grande do Norte (Cocentino *et al.* 2010) and on Santo Aleixo Island in Pernambuco (Carvalho *et al.* 2013). Studies have also been undertaken involving the rhodoliths beds found along the Brazilian coast (Riul *et al*. 2009, Amado-Filho *et al*. 2010, Amado-Filho & Pereira-Filho 2012, and Francini-Filho *et al*. 2013). Francini-Filho *et al*. (2013) have also reported the influence of fleshy macroalgae and turf algae on the dynamics of the coral reef benthic assemblages of the Abrolhos Bank, in eastern Brazil.

The tropical region where the coast of Sergipe is located covers part of the northeastern Brazilian coast. Its northern boundary is at the west of the Ceará littoral and its southern boundary is located in the south of the state of Bahia (Horta *et al*. 2001). This tropical region is characterized by a diverse flora, due to environmental conditions such as high salinity and water transparency and the bountiful consolidated substrate provided by sandstone reefs encrusted with algae and corals - conditions favoring the establishment and development of macroalgae.

The Sergipe state constitutes an exception to the region's general character. Its extensive mangrove ecosystem, combined with the influence of the waters of the São Francisco River, has led the coast to be considered as an area of little floristic representativeness and few phycological surveys have been conducted in this region. Fortes (1992) studied the taxonomic and ecological aspects of red algae in the mangrove swamp of the Santos Island / Piauí-Fundo Real estuarine complex and Fortes-Xavier & Pereira (1994) registered the first occurrence of *Caloglossa ogasawaraensis* Okamura (1897: 12—Delesseriaceae) along the northeastern coast.

Our study has thus made an important contribution to knowledge regarding Brazilian deep-water flora, reporting new records of marine macroalgae from the Continental Shelf of Sergipe State, between the 10 m and 30 m isobaths.

Materials and methods

Study area: Sergipe State (10°36'08'' - 11°21'07''S and 36°28'10'' - 37°13'47''W) is located in Northeast region of Brazil (show in the Figure:1 the Brazil and the northeast region - highlighted). The coast of Sergipe has an approximate extension of 163 km and is characterized by large areas of mangroves, with an almost total absence of consolidated substrate favorable for establishment and development of algae in the littoral areas, low salinity and transparency, due to the influence of the São Francisco River in the north and the Piauí/Real River in the south. According to Kempf (1970) however, rhodoliths beds can be found all along the extent of the South American continental shelf. Rich algal communities are associated with these beds (Riul *et al*. 2009).

The continental shelf is narrower along Brazil's northeastern coast. In this region, it is dominated by biogenic carbonate sediments, with siliciclastic sediments in shallow areas, a consequence of continental run-off (Coutinho 1981, Martins & Coutinho 1981). According to Knoppers *et al*. (2009), Sergipe is located on the East Brazil Shelf Large Marine Ecosystem (LME), where oceanographic conditions are controlled by the Brazilian and Sub-equatorial Currents. The climate is tropical humid (26-28ºC) and has two distinct periods: dry and rainy (April/August).

Sampling and processing: Our survey was carried out along the continental shelf from May 1999 to March 2000. A total of 18 stations were selected along six lines arranged perpendicularly to the coast. The samples were collected through dragging between the isobaths of 10 m and 30 m (Fig. 1). For each station, four samplings with two drags were obtained, totaling 144 drags. In addition to the 18 sampling sites, three supplementary sites (named A, C and CD) were also surveyed. These three sites do not belong to the six lines, but were considered only qualitatively. Their respective taxa were included in the table of occurrence per site (Table 1). Different types of substrata were found at the stations: silt (S), sand (Sd) and clay (C).

The algal material analyzed was selected and fixed in a formalin solution (3%) and then sent to the Phycology Laboratory (LABOFIC) at the Federal University of Rural Pernambuco. Identification was carried out using a stereomicroscope and an optical microscope. Current literature on seaweed taxonomy from Brazil and the Caribbean was consulted (e.g. Taylor 1960, Joly 1965, Pereira 1977, 1983, Littler & Littler 2000). Additionally, comparisons were made with seaweed specimens taken from the Professor Vasconcelos Sobrinho Herbarium of the Federal University of Rural Pernambuco (PEUFR). The taxa are presented according to Wynne (2011). The non-geniculate corallines were not identified by being part of a specific detailed study, taking only their occurrences recorded. After identification, exsiccates were deposited at the PEUFR Herbarium (PEUFR 50634 - 50695). The new occurrences found along the coast of Sergipe State are indicated in Table 1.

TABLE 1. Checklist of Chlorophyta, Heterokontophyta and Rhodophyta per sample station, bathimetry, type of substrate, percentage occurrence at depth and ranking per phyllum on the continental shelf of Sergipe State

Species	Stations																	Depth (m)			Substrate			% Occurrence at Depth	Relative Frequency = % occurrence of the species/ total % occurrence (for all the species)	Ranking
	A	C	C D	1	3	5	6	7	10	11	12	13	14	15	16	17	18	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**			
CHLOROPHYTA																										
Anadyomene stellata (Wulfen in Jacq.) C. Agardh							+													+			+	33.3	6.0	5
**Avrainvillea longicaulis* (Kützing) G. Murray & Boodle														+						+	+			33.3	6.0	5
**Caulerpa lanuginosa* J. Agardh						+													+				+	33.3	6.0	5
C. mexicana Sond. ex Kütz.			+							+	+	+	+	+				+	+	+	+	+	+	100	35.5	2
C. prolifera (Forssk.) J. V. Lamour.							+							+						+	+		+	33.3	17.5	3
**C. sertularioides* (S. G. Gmel.) M. Howe											+	+						+		+			+	66.7	12.0	4
**Chaetomorpha aerea* (Dillwyn) Kütz.										+			+						+			+	+	33.3	6.0	5
**Cladophora ordinata* (Boergesen) C.Hoek						+	+												+	+			+	66.7	6.0	5
**Cladophora vagabunda* (L.) C.Hoek	+	+	+				+			+	+	+	+	+				+	+	+	+	+	+	100	47.0	1
Codium isthmocladum Vickers					+		+													+		+	+	33.3	12.0	4
Halimeda discoidea Decne.														+			+			+	+		+	33.3	6.0	5
**H. gracilis* Harv. ex J. Agardh						+								+					+	+		+	+	66.7	12.0	4
Udotea flabellum (J. Ellis & Sol.) J.V.Lamour.														+						+	+			33.3	6.0	5
Ulva flexuosa Wulfen							+													+			+	33.3	6.0	5
U. lingulata A.P.De Candolle														+						+	+			33.3	6.0	5

……continued to the next page

TABLE 1. (Continued)

Species	Stations																	Depth (m)			Substrate			% Occurrence at Depth	Relative Frequency = % occurrence of the species/ total % occurrence (for all the species)	Ranking
	A	C	C D	**1**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**			
HETEROKONTOPHYTA																										
**Asteronema breviarticulatum* (J. Agardh) Ouriques & Bouzon	+	+	+	+	+		+				+	+	+	+			+	+	+	+	+	+	+	100	64.5	3
**Bachelotia antillarum* (Grunow) Gerloff											+									+			+	33.3	6.0	12
Canistrocarpus cervicornis (Kützing) De Paula & De Clerck		+					+			+							+		+	+			+	66.7	23.5	9
Colpomenia sinuosa (Roth) Derbès & Solier							+				+									+			+	33.3	6.0	12
Dictyopteris delicatula J.V.Lamour.	+		+			+	+	+				+		+				+	+	+	+		+	100	47.0	5
**D. jamaicensis* W.R.Taylor										+				+			+		+	+	+		+	66.7	12.0	11
D. justii J.V.Lamour.	+	+	+	+	+	+	+	+	+			+	+	+			+	+	+	+	+	+	+	100	88.0	1
D. plagiogramma (Montagne) Vickers	+		+			+			+	+	+			+				+	+	+	+		+	100	35.5	7
D. polypodioides (DC. in Lam.) J.V. Lamour.	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	100	88.0	1
**Dictyota bartayresiana* J.V.Lamour.						+	+			+	+	+						+	+	+			+	100	29.5	8
D. mertensii (Mart.) Kütz.	+	+	+		+	+	+	+		+		+	+				+	+	+	+	+	+	+	100	70.5	2
D. pulchella Hörning & Schnetter	+		+				+	+		+	+			+				+	+	+	+		+	100	29.5	8
Lobophora variegata (J.V.Lamour.) Womersley ex E.C. Oliveira	+	+	+	+	+	+	+		+	+	+		+	+				+	+	+	+	+	+	100	70.5	2
Padina gymnospora (Kütz.) Sond.									+	+	+	+						+	+	+			+	100	23.5	9
Sargassum hystrix J. Agardh	+				+								+						+	+		+		66.7	17.5	10
S. platycarpum Mont.			+				+													+			+	33.3	12.0	11
Sargassum vulgare C. Agardh var. *vulgare*								+	+	+								+	+		+			100	17.5	10
Spatoglossum schroederi (C. Agardh) Kütz.	+					+			+		+							+	+	+			+	100	29.5	8
Sporochnus bolleanus Mont.			+			+	+	+			+	+	+	+			+	+	+	+	+	+	+	100	53.0	4
Stypopodium zonale (J.V.Lamour.) Papenf.	+						+				+	+	+	+			+	+	+	+	+	+	+	100	41.0	6

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TABLE 1. (Continued)

Species	Stations																	Depth (m)			Substrate			% Occurrence at Depth	Relative Frequency = % occurrence of the species/ total % occurrence (for all the species)	Ranking
	A	C	C D	**1**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**			
RHODOPHYTA																										
**Acanthophora spicifera* (Vahl) Boergesen	+									+		+	+					+	+			+	+	66.7	23.5	8
**Aglaothamnion felliponei* (M. Howe) Aponte, D.L. Ballant. & J.N. Norris					+															+		+		33.3	6.0	11
**A. uruguayense* (W. R. Taylor) Aponte, D.L. Ballant. & J.N. Norris											+									+			+	33.3	6.0	11
Amansia multifida J.V. Lamour.						+							+				+		+	+		+	+	66.7	12.0	10
Antithamnion antillanum Boergesen					+															+		+		33.3	12.0	10
Asparagopsis taxiformis (Delile) Trevis.		+	+		+									+						+	+	+		33.3	12.0	10
**Bryothamnion seaforthii* (Turner) Kütz.					+	+		+		+	+						+	+	+	+	+	+	+	100	35.5	6
B. triquetrum (S.G. Gmel.) M.Howe						+													+				+	33.3	6.0	11
**Callithamniella tingitana* (Schousb. ex Bornet) Feldm.Maz.					+															+		+		33.3	6.0	11
* *Ceramium brevizonatum* var. *caraibicum* H.E.Petersen & Boergesen							+				+									+			+	33.3	12.0	10
**C. comptum* Boergesen		+			+	+		+			+	+	+	+		+		+	+	+	+	+	+	100	59.0	2

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TABLE 1. (Continued)

Species	Stations																	Depth (m)			Substrate			% Occurrence at Depth	Relative Frequency = % occurrence of the species/ total % occurrence (for all the species)	Ranking
	A	C	C D	**1**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**			
**C. luetzelburgii* O.C. Schmidt var. *australis* A.B. Joly			+		+	+	+	+				+	+	+			+	+	+	+	+	+	+	100	53.0	3
C. tenerrimum (G.Martens) Okamura								+										+			+			33.3	6.0	11
*Corallinaceae (non-geniculate corallines)						+								+			+		+	+	+		+	66.7	23.5	8
**Crouania pleonospora* W.R. Taylor							+				+	+	+	+				+	+	+	+	+	+	100	29.5	7
**Cryptonemia bengryi* W.R. Taylor		+				+	+	+		+	+							+	+	+	+		+	100	29.5	7
**C. crenulata* (J. Agardh) J. Agardh		+			+	+				+		+	+	+		+	+	+	+	+	+	+	+	100	53.0	3
C. seminervis (C. Agardh) J. Agardh					+	+				+			+		+			+	+	+		+	+	100	29.5	7
**Dasya rigidula* (Kütz.) Ardiss.												+	+	+	+	+	+	+	+	+	+	+	+	100	35.5	6
**Dictyurus occidentalis* J. Agardh						+	+			+		+		+				+	+	+	+		+	100	29.5	7
**Erythrotrichia carnea* (Dillwyn) J. Agardh							+							+						+	+		+	33.3	12.0	10
**Gayliella flaccida* (Harvey ex Kützing) T.O.Cho & L.J.McIvor.						+	+												+	+			+	66.7	6.0	11
Gracilaria cearensis (A.B. Joly & Pinheiro in A.B.Joly et al.) A.B. Joly & Pinheiro in Pinheiro & A.B.Joly									+									+					+	33.3	6.0	11
**G. cervicornis* (Turner) J. Agardh					+	+		+					+					+	+	+	+	+	+	100	23.5	8
**G. cuneata* Aresch.						+										+		+	+			+	+	66.7	12.0	10

… … *continued to the next page*

TABLE 1. (Continued)

Species	Stations																	Depth (m)			Substrate			% Occurrence at Depth	Relative Frequency = % occurrence of the species/ total % occurrence (for all the species)	Ranking
	A	C	C D	**1**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**			A
**G. domingensis* (Kütz.) Sond. ex Dickie													+						+			+		33.3	6.0	11
**G. mammillaris* (Mont.) M.Howe						+													+				+	33.3	6.0	11
**Gracilariopsis lemaneiformis* (Bory de SaintVincent) Dawson, Acleto & Foldvik			+		+					+		+	+					+	+	+		+	+	100	29.5	7
**Griffithsia schousboei* Mont. in Webb			+			+	+				+	+		+				+	+	+	+		+	100	35.5	6
**Gymnothamnion elegans* (Schousb. ex C.Agardh) J.Agardh						+													+				+	33.3	6.0	11
**Halopithys schottii* (W.R.Taylor) L.E.Phillips & De Clerck						+	+												+	+			+	66.7	12.0	10
**Haloplegma duperreyi* Mont.						+	+	+		+				+				+	+	+	+		+	100	29.5	7
**Halymenia elongata* C. Agardh									+									+					+	33.3	6.0	11
**H. pseudofloresii* Collins & M.Howe													+						+			+		33.3	6.0	11
**H. rosea* M.A.Howe & W.R.Taylor											+									+			+	33.3	6.0	11
Herposiphonia secunda (C. Agardh) Ambronn	+					+	+												+	+			+	66.7	17.5	9
Herposiphonia tenella (C. Agardh) Ambronn	+	+	+		+	+	+	+				+	+	+			+	+	+	+	+	+	+	100	70.5	1
Heterosiphonia crispella (C. Agardh) M.J.Wynne					+	+	+	+			+	+	+	+		+		+	+	+	+	+	+	100	53.0	3

… …*continued to the next page*

TABLE 1. (Continued)

Species	Stations																	Depth (m)			Substrate			% Occurrence at Depth	Relative Frequency = % occurrence of the species/ total % occurrence (for all the species)	Ranking
	A	C	C D	**1**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**			A
**H. gibbesii* (Harv.) Falkenb.						+	+							+					+	+	+		+	66.7	17.5	9
**Hypnea musciformis* (Wulfen in Jacq.) J.V.Lamour.	+		+	+	+	+	+	+		+	+	+	+	+				+	+	+	+	+	+	100	70.5	1
**Jania adhaerens* J.V.Lamour.						+														+			+	33.3	6.0	11
**Jania cubensis* Mont. ex Kütz.					+															+		+		33.3	6.0	11
J. rubens (L.) J.V.Lamour.						+	+	+										+	+	+	+		+	100	17.5	9
**J. subulata* (J.Ellis & Sol.) Sond.						+	+	+				+	+				+	+	+	+	+	+	+	100	35.5	6
**Leptofauchea brasiliensis* A.B. Joly													+						+			+		33.3	6.0	11
* *Meristotheca gelidium* (J.Agardh) E.J.Faye & Masuda in E.J.Faye et al.									+									+					+	33.3	6.0	11
**Neosiphonia ferulacea* (Suhr ex J. Agardh) S.M. Guim. & M.T. Fujii					+															+		+		33.3	6.0	11
* *Palisada flagellifera* (J.Agardh) K.W.Nam						+	+												+	+			+	66.7	12.0	10
**Pneophyllum fragile* Kütz.						+	+	+		+	+	+			+	+		+	+	+	+	+	+	100	41.0	5
* *Polysiphonia saccorhiza* (Collins & Herv.) Hollenb.							+													+			+	33.3	6.0	11
P. subtilissima Mont.							+				+	+		+				+		+	+		+	66.7	29.5	7
**Sahlingia subintegra* (Rosenvinge) Kornmann							+	+			+							+		+	+		+	66.7	17.5	9

… …*continued to the next page*

TABLE 1. (Continued)

Stations	Depth (m)																	Substrate			% Occurrence at Depth			Relative Frequency	Ranking	Stations
	A	C	C D	**1**	**3**	**5**	**6**	**7**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**10**	**20**	**30**	**S+Sd/ S+C**	**S+C**	**Sd**		= % occurrence of the species/ total % occurrence (for all the species)	A
**Solieria filiformis* (Kützing) P.W.Gabrielson					+		+	+									+	+		+	+		+	66.7	23.5	8
Spyridia filamentosa (Wulfen) Harv. In Hook			+			+	+	+		+	+	+	+	+				+	+	+	+	+	+	100	53.0	3
**Vidalia obtusiloba* (C.Agardh) J.Agardh		+		+	+	+	+	+		+					+			+	+	+	+	+	+	100	47.0	4
Wrangelia argus (Mont.) Mont.						+													+				+	33.3	6.0	11
Total	**16**	**13**	**19**	**6**	**25**	**43**	**44**	**24**	**9**	**25**	**28**	**28**	**29**	**35**	**5**	**7**	**18**	**47**	**60**	**75**	**46**	**41**	**76**			

+ = presence
S = silt; Sd = sand; C = clay
* = new record for Sergipe State

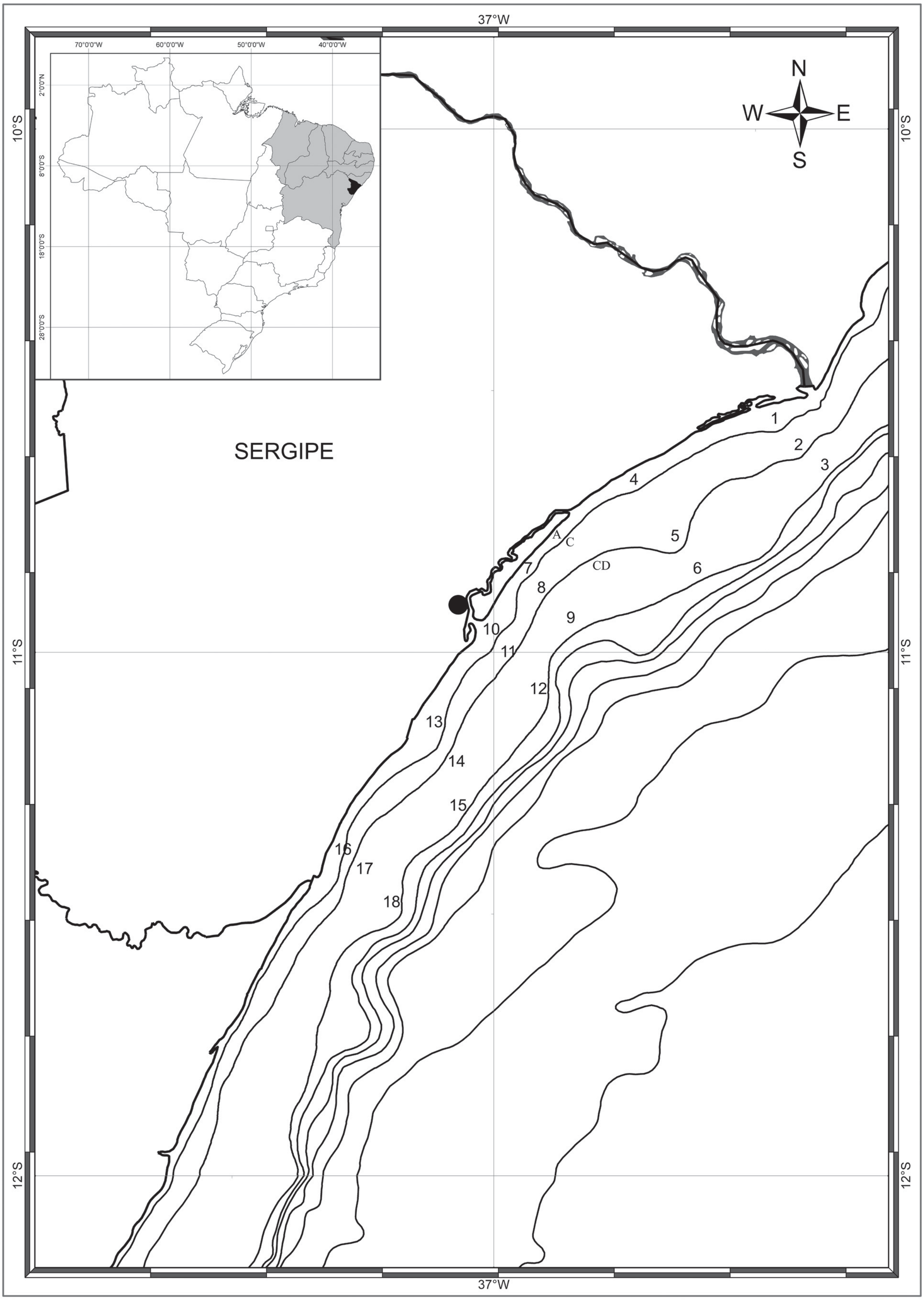

FIGURE 1. Map of Continental Shelf of Sergipe State showing the 18 sampling sites.

Data Analyses: Correspondence analysis (CA) was employed to ordinate samples and species based on their occurrence patterns. Sampling stations 10 and 11 were excluded from the species presence-absence matrix due to the occurrence of the rare species whose frequency was less than 0.2%. CA resulted in an arch effect and, therefore, only the first axis was retained for ecological interpretation. The relationship between depth and patterns of algae species composition summarized in the CA1 axis was investigated via Spearman correlation, because even after transformation, depth values did not presented a normal distribution. The possible effects of the substrate on algae species composition was investigated by comparing the mean CA1 scores of the three substrate categories with a one-way variance analysis. Normality of data and homoscedasticity of variances were tested with Shapiro-Wilk and Levenne tests, respectively. The multivariate analysis was carried out using PC-Ord 4.10 (McCune & Mefford 1999) while univariate analysis was conducted with StatisticaTM (Statsoft Inc. 2007). The assumed significance level in all tests was $P<0.05$.

The R/P (Feldmann 1937) and (R+C)/P (Chenney 1977) indexes were used for describing geographical patterns according to seaweed phylum ratios (Figueiredo *et al*. 2008, Villaça *et al*. 2010).

Results

Floristic composition

A total of 91 infrageneric taxa of benthic marine macroalgae were identified, of which 47 were new references in the State (Table 1, Fig. 2). The R/P and (R+C)/P indexes were 2.8 and 3.55, respectively.

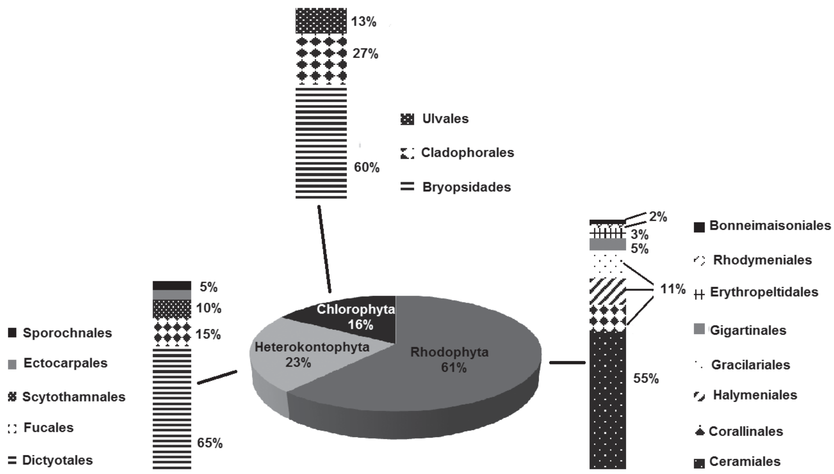

FIGURE 2. Percentage of Rhodophyta, Heterokontophyta and Chlorophyta and their respective orders, recorded on the continental shelf of Sergipe State.

The Rhodophyta phylum (red algae) dominated, represented by 56 taxa (61%). Within this phylum, the *Ceramiales* order was the most abundant with 39 taxa (55%), among which the family Ceramiaceae dominated with 19 taxa - 48.5% of the occurring order (Table 1, Figs. 2, 3).

The Heterokontophyta phylum (brown algae) was the second most dominant, with 20 taxa (23%). *Dictyotales*, with 13 taxa, accounted for 65% of the occurrences of brown algae. *Dictyopteris* J.V. Lamouroux (1809: 332) and *Dictyota* J.V. Lamouroux (1809: 38), with six and five taxa, respectively, were the most abundant within this order (Table 1, Figs. 2, 3).

The Chlorophyta phylum (green algae) had the lowest number of occurrences among all phyla, with 15 taxa, corresponding to 16% of all occurring phyla. The *Bryopsidales* order was the most commonly encountered within this phylum, with nine species (53%). *Caulerpa* J. V. Lamouroux (1809: 332) accounted for four species, or 45% of the occurring genera, although the dominance of a particular genus was not observed (Table 1, Figs. 2,3).

Distribution of macroalgae

Correspondence analysis (Fig. 4) showed the stations were grouped as function of flora composition (CA1). Two groups were weakly formed: one with sand as substrate (SDSD), and other with sand, silt and clay as substrate (SSDC and SCSC). Stations were observed with different substrata in both groups, however. One-way ANOVA determined that the substrate type was not statistically important in the separation of the flora (f=2.82; gl=2; 12; p=0.10), due to high standard error. However, the species composition of the stations with SSDC and SCSC substrata (according to the values of the CA1 axis) was more similar than those stations with SDSD substrate.

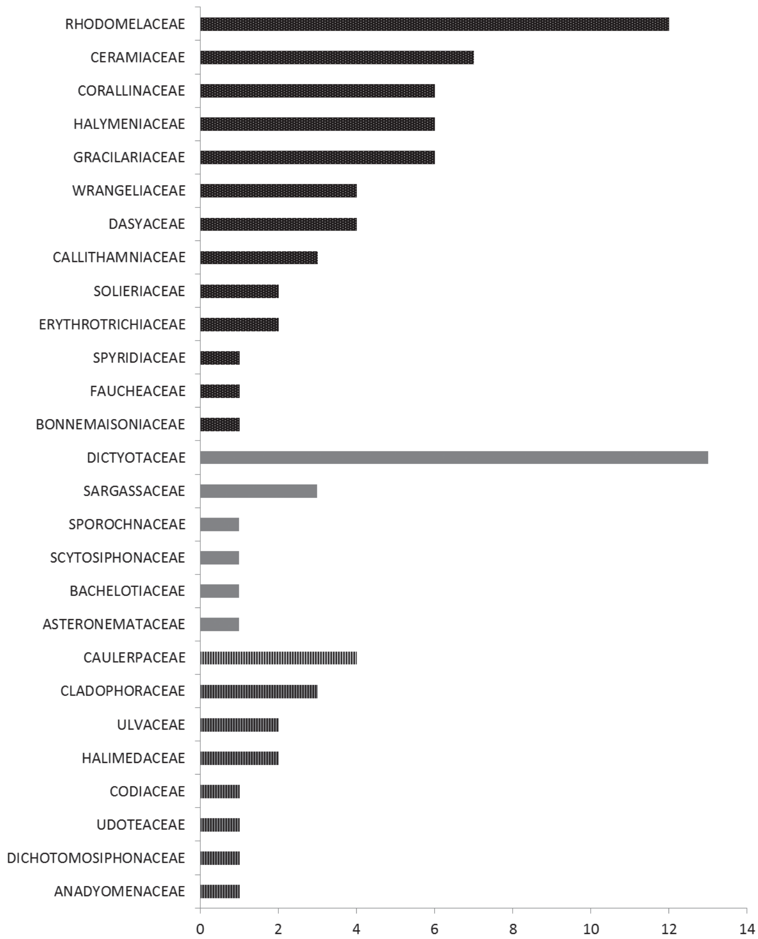

FIGURE 3. Number of infrageneric taxa of benthic marine macroalgae, distributed by families, registered on the continental shelf of Sergipe State.

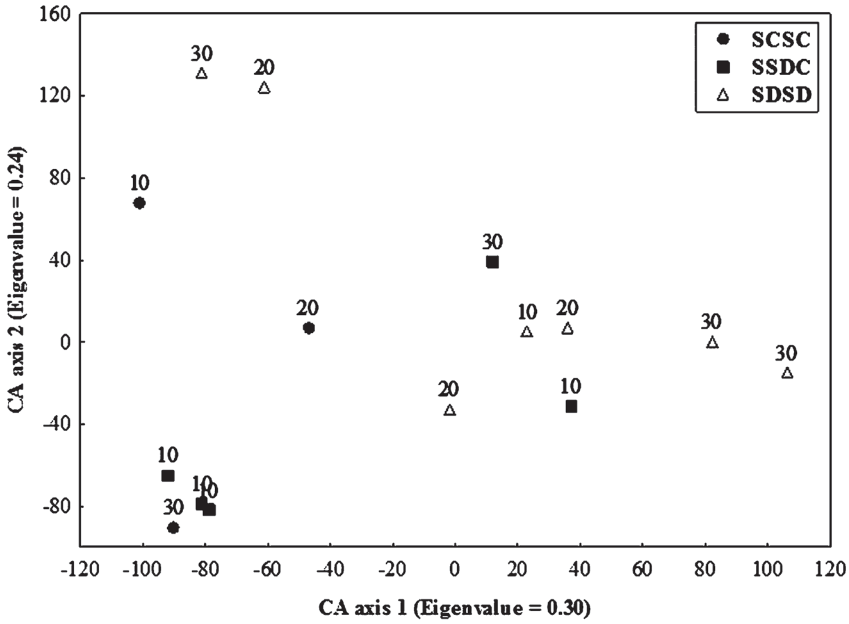

FIGURE 4. Distribution of the sampling sites as function of flora composition.

Macroalgae were found at the great majority of sampling sites (except at sites 2, 4, 8 and 9) and at all the supplementary sites (A, C and CD). A different pattern was observed, however, with respect to occurrence by Phylum (Table 1). Chlorophyta was present in approximately 70% of the 18 sampling sites. Sites 15 and 6 were the most representative for this phylum, showing occurrences of eight and six species, respectively. Heterokontophyta was present at all sampling sites, giving a 100% rate of occurrence. Site 6 was the most representative, with 13 species. However, other sampling stations also presented species richness ranging from 11 (A and 12) and 10 (CD, 11, 15). Sites 16 and 17 presented the lowest number of occurring taxa, with only one species *Dictyopteris polypodioides* (A.P. De Candolle) J.V.Lamouroux (1809: 332) recovered. Rhodophyta also obtained a 100% rate of occurrence at the sampling sites. The sites with the greatest number of occurrences were 5 (31 species) and 6 (25 species).

Setting aside sites A, C, CD, where no information about depth and type of substrate was obtained, the sampling sites that recorded the highest numbers of species presented sandy bottom (Sd = 6, 5) and silt + clay / silt/sand (S+Sd/ S+C = 15) (Table 1).

With respect to occurrence percentages, it was observed that Heterokontophyta was the most commonly occurring, followed by Rhodophyta and Chlorophyta (Table 1). Among the brown algae, the greatest percentages were between 64.5% and 88% achieved by *Dictyopteris justii* J.V. Lamouroux (1809: 332) (88%), *D. polypodioides* (88%), *Dictyota mertensii* Kützing (1859: 15-70.5%), *Lobophora variegata* (J.V. Lamouroux) Womersley ex E.C. Oliveira (1977: 217 -70.5%) and *Asteronema breviarticulatum* (J. Agardh) Ouriques & Bouzon (2000: 271 - 64.5%). All of these species, with the exception of the last, belong to the *Dictyotales* order. Among the Rhodophyta, the largest percentages were between 59% and 70.5%, with *Hypnea musciformis* J.V.Lamouroux (1813: 43) and*, Herposiphonia secunda* (C.Agardh) Ambronn (1880: 197) achieving 70.5%, and *Ceramium comptum* Børgesen (1924: 28-29-59%) (Table 1). Along the continental shelf of Sergipe, macroalgae were found in a bathymetric range of 10 m to 30 m (Table 1). In general, species of green algae occurred at a constant depth (30 m), except *Caulerpa lanuginosa* J.Agardh (1873: 28) and *Chaetomorpha aerea* (Dillwyn) Kützing (1849: 379) which occurred at 20m depth (Table 1). Conversely, brown algae presented a predominance of species that occurred between 10 m and 30 m. Only six species of brown algae remained at a constant depth of 30 m, while two ranged between 10 m and 20 m. Among the red algae, 38 species varied with respect to depth, with 29 occurring between 10 m and 30 m and nine occurring between 20 m and 30 m. The 32 remaining species occurred at constant depths of 30 m (13 species), 20 m (15 species) and 10 m (4 species). Rhodophyta thus presented the highest number of species with the widest vertical distribution among the studied phyla, while Chlorophyta presented the narrowest bathymetric distribution (Table 1).

Discussion

The present study identified 91 taxa of benthic marine algae, 47 of which are new occurrences for this area. These organisms occurred in 90% of the sampling sites, which may indicate that the area is suitable for their development. Conversely, studies of the intertidal flora of this region previously recorded only 22 Rhodophyceae (Moura *et al.* 2014), 3 Phaeophyceae (Széchy & de Paula 2014) and 7 Ulvophyceae (Branco *et al.* 2014), totaling 32 species.

The R/P (Feldmann 1937) and (R+C)/P (Chenney 1977) indexes, commonly used for describing geographical patterns by seaweed phylum ratios, were 2.8 and 3.55, respectively. Our values were similar than those found by Villaça *et al*. (2010) on Atol das Rocas. According to these authors phytogeographic Feldmann and Cheney index values of <4 are low for tropical regions, principally in our study area, which is subject to continental runoff and higher turbidity. However, Figueiredo *et al*. (2008) emphasized that these indexes should be used with caution in small scale studies because they should be applied in a large spatial scale.

In the present study, Rhodophyta was the most abundantly occurring algae, with 56 taxa. *Ceramiales* showed the highest number of species (31), with the Ceramiaceae and Rhodomelaceae families and genera such as *Acanthophora* J.V. Lamouroux (1813: 132), *Bryothamnion* Kützing (1843: 433), *Ceramium* Roth (1797: 146), *Halopithys* Kützing (1843: 433), *Spyridia* Harvey in Hook (1833:259,336) and *Vidalia* J.V. Lamouroux ex J. Agardh (1863: 1117) being prominent. Despite the fact that this is an expected pattern for the eastern region, it should be noted that the number of red algae decreased compared to nearby locations such as the states of Pernambuco, Paraíba and Rio Grande do Norte (Pereira 1977; 1983, Pereira *et al.* 1981, Cocentino *et al.* 2010). However, it must be remarked that the number of *Ceramiales* found in this study was higher than at the sites previously cited. *Herposiphonia tenella* (C.Agardh) Ambronn (1880: 197) was the sole taxon of this order found among the highest percentages of frequency (75.5%). At the same frequency level, we found *Hypnea musciformis* (*Gigartinales*): a carrageenophyte of great importance in the Brazilian Northeast. Although there were several representatives of *Gracilariales*, the material was quite fragmented and, for that reason, a reliable identification at the species level was not possible. Among the Rhodophyta, we must consider the very low occurrence of species of Melobesoideae that are characteristic of the northeast shelf bottom. The non-articulated Corallinaceae obtained a greater qualitative occurrence, although much smaller than those normally observed in other places along the northeastern coast (Riul *et al*. 2009, Amado-Filho *et al*. 2012).

Regarding Heterokontophyta (brown algae), a great number of taxa were found among the local flora. It should be noted that, as expected, the *Dictyotales* order provided the greatest qualitative occurrence. This is characteristic of tropical regions. Oliveira Filho (1977) has emphasized the quali-quantitative importance of this order along the Brazilian northeastern coast. *Dictyopteris justii* and *D. polypodioides* showed a large frequency (88%) among the studied samples. 20 Heterokontophyta have been recorded for the states of Alagoas and Pernambuco, 15 for Paraíba and 20 for Rio Grande do Norte (Guimarães *et al*. 1981, Ferreira *et al*. 1988, Pereira 1983, Pereira *et al*. 1981, Cocentino *et al.* 2010). Different from the green algae, brown algae were well represented, including species considered to be limited to the Brazilian coast such as *Dictyopteris polypodioides* (recorded only in the states of Pernambuco, Bahia and Espírito Santo) and *Sporochnus bolleanus* Montagne (1856: 393) found in the states of Bahia, Espírito Santo, Rio de Janeiro and São Paulo (Széchy & de Paula 2014).

Some authors (Steneck & Dethier 1984, Littler & Littler 1984) suggest that the structure of a community can be better understood when we employ a form-functional group approach, because each group will respond differently to the abiotic (such as substrate) and biotic (such as biomass production) factors of the environment. Although the biomass of the more abundant species has not been examined, we have the predominance of three form-functional groups: filamentous (36 species), foliose (21 species) and coarsely branch group with 19 species. Thus, there is evidence in the diversity of species discovered (especially by Heterokontophyta and Rhodophyta) that they play an important role in neritic system productivity. These organisms are responsible for local fauna diversity including species of economic interest which depend on macroalgae for food and/or shelter (Pereira 1996, Horta *et al.* 2001).

The distribution pattern of macroalgae differs from that of the deep-water flora of the Brazilian Northeast due to a decrease in the number of green algae and a slight increase in brown algae. Ugadim and Pereira (1978) have reported 36 Chlorophyta taxa occurring in the subtidal region of the Brazilian Northeast, which were collected by the Recife Commission and Ferreira *et al*. (1988), observed 21 taxa of green algae in the states of Paraíba, Pernambuco and Alagoas.

Comparing the results of this work with Pereira *et al.* (1981), Pereira (1983) and Cocentino *et al.* (2010) for the subtidal flora (10 and 45 m) of the States of Rio Grande do Norte and Paraíba, one can observe a decrease in the number of species, mostly green algae. In these works, 32, 28 and 54 Chlorophyta were found along the continental shelf of Paraíba and Rio Grande do Norte states, respectively. Along the continental shelf of the state of Sergipe, the number of species of typical tropical genera such as *Caulerpa*, *Codium* Stackhouse (1797: 24, 26), *Halimeda* J.V. Lamouroux (1812: 186), *Udotea* J.V. Lamouroux (1812: 186) and *Valonia* C. Agardh (1823: 428) was limited. Only four species of *Caulerpa*, for example, were found in the state of Sergipe, while seven and ten species have been recorded in Paraíba and Rio Grande do Norte states, respectively. Similar observations can be made regarding the *Halimeda* genera; for instance, the absence of *H. incrassata* (J.Ellis) J.V. Lamouroux (1816: 307), *H. opuntia* (L.) J.V. Lamouroux (1816: 308), and *H. tuna* (J.Ellis & Soll.) J.V. Lamouroux (1816: 309). Therefore, we believe that a considerable reduction of Chlorophyta occurs in Sergipe. As pointed out by Pereira (1996), the coast of Sergipe is characterized by low transparency and salinity due to the influence of the São Francisco River. This fact leads to a decrease in green algae flora because the taxa of this group occupy the shallower regions, which are more subjected to the action of these factors.

Similar results to this study were obtained in other surveys of subtidal flora performed by Yoneshigue-Valentin *et al*. (2006) for the REVIZEE Program for benthic diversity of the Brazilian continental shelf, as well by Marins *et al.* (2008) for Todos os Santos Bay, in the state of Bahia. In these studies, the *Ceramiales*, *Dictyotales* and *Bryopsidales* orders were the most abundant. Recently, Carvalho *et al*. (2013) surveyed the benthic Chlorophytes of Santo Aleixo Island (Pernambuco) and found 23 infrageneric taxa, with the *Bryopsidales* order being the most abundant.

The most significant sampling sites in terms of algae were sites 5 and 6, located on line 2. This may be due to the type of substrate in these areas: the coarse sand, which enables better algae fixation. It appears that no reefs occur in the region, contrary to the characteristic presence of these substrata along the Brazilian Northeast coast (Pereira and Eskinazi-Leça 1999).

This study represents a first attempt towards improving our knowledge of deep-water flora in Sergipe State, filling the gap in our understanding of the distribution of marine macroalgae along the Brazilian coast.

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