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Comparison of the diversity and biomass of beach-cast seaweeds from NE and SE Brazil

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ABSTRACT
Stranded seaweeds are reported worldwide; along the Brazilian coast, the occurrence of beach-cast seaweeds is increasing. In this study the diversity, coverage and biomass of beach-cast seaweeds were compared on the north-eastern (NE) and south-eastern (SE) coasts of Brazil. In total 110 taxa were identified: 80 Rhodophyceae, 13 Phaeophyceae and 17 Chlorophyceae. While the NE coast had higher species richness, the SE beaches exhibited higher coverage and biomass, predominantly Phaeophytes within the Dictyotales. The identified taxa were attributed to five functional-form groups and their respective frequencies were calculated and analysed. In Brazil, corticated species displayed the highest frequency at all study sites, especially Emboaca Beach, whereas the corticated foliose group was more frequent on Candeias, Itaoca and Pontal Beaches. A permutational analysis of variance revealed significant differences in coverage and biomass of the macroalgal assemblages across beaches. A homogeneity of multivariate dispersions indicated that these parameters also differed significantly between the NE and SE coasts, with a marked dissimilarity between the beaches studied. Our results will contribute to a better understanding of the biodiversity and biomass of beach-cast seaweeds for possible future economic use (e.g. as fertilizer) in a region where local incomes are low.

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KEYWORDS Macroalgal bloom; macroalgal stranding; marine biodiversity; morphotypes; stranded biomass

Introduction

Patches of stranded macrophytes are a distinctive feature of sandy beaches worldwide (McLachlan & Brown, 2006; MacMillan & Quijón, 2012; López *et al.*, 2017). For example, Zemke-White *et al.* (2005) estimated that up to 25% of annual kelp production, such as *Macrocystis pyrifera* or *Durvillaea antarctica*, may end up as beach-cast seaweeds along temperate coastlines. In tropical areas, there is an increasing trend of massive strandings (mainly pelagic brown seaweeds, such as *Sargassum* spp.), which has been tied to climate change (Sissini *et al.*, 2017; Wang *et al.*, 2019; Johns *et al.*, 2020). Although free-floating pelagic species of *Sargassum* have been studied since at least the 1830s and acknowledged in marine lore by the naming of the Sargasso Sea, these floating communities have only been detected in satellite images recently (Gower *et al.*, 2006; Gower & King, 2011). Pelagic seaweeds identified in the Central Atlantic, Caribbean Sea, North Atlantic and West Africa constitute the Great Atlantic Sargassum Belt (GASB) (Wang *et al.*, 2019). These reportedly monospecific algal blooms most frequently consist of the pelagic *Sargassum* species *S. fluitans* and *S. natans* (Oyesiku & Egunyomi, 2014; Cuevas *et al.*, 2018; Putman *et al.*, 2018; Wang *et al.*, 2019).

Massive floating *Sargassum* blooms, from the GASB, were first reported offshore of northern Brazil in July 2011 by Széchy *et al.* (2012) and again in 2014 and 2015 by Sissini *et al.* (2017). However, the most common unattached seaweed blooms on the tropical Brazilian coast are multispecific, and composed of several species of red, brown and green algae (Câmara-Neto, 1971; Câmara-Neto *et al.*, 1981; Pedrini, 1984; Calado *et al.*, 2003; Santos *et al.*, 2013; Vila Nova *et al.*, 2014). In contrast to the pelagic species of the GASB, these naturally occurring subtidal benthic algae are often attached to rhodoliths and once detached, are pushed onto the beach by wind-induced water motion (Biber, 2007). Various physical and biological factors can influence the detachment of macroalgae from rocky bottoms (Dayton *et al.*, 1992; Pennings *et al.*, 2000). Currents and storm-winds acting together are the main causes of detachment of buoyant seaweeds from rocky habitats, when strong waves break the rock substratum (Zemke-White *et al.*, 2005; Garden *et al.*, 2011; Schreiber *et al.*, 2020).

Greater biomass of beach-cast seaweeds has been observed during the dry season (January–April) at beaches in Candeias and Jaboatão dos Guararapes (Pernambuco, NE Brazil) (Silva, 2019) although

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Barbosa (2010) reported higher volumes of beach-cast seaweeds in SE Brazil from March to July. Considering that the subtidal phycoflora is still poorly known in Brazil, the identification of beach-cast seaweeds and biogeographic studies could potentially shed light on this phenomenon. It has been suggested that the availability and diversity of beach-cast seaweeds are intrinsically related to the benthic phycoflora of each region (Menezes *et al.*, 2015; López *et al.*, 2019).

The Brazilian subtidal phycoflora was partly identified from stranded seaweeds (Pacheco, 2011). However, Schreiber *et al.* (2020) noted that the relationship between benthic populations and stranded seaweeds has received little attention. After detachment, a fraction of floating specimens is returned to shore, resulting in strandings that fluctuate in space and time. Dispersal influenced by currents can modify the distribution pattern of marine species and, according to Batista *et al.* (2018), currents along with storm-generated winds are efficient dispersal mechanisms for floating strategists and associated communities. More frequent and intense storms that are related to global warming have been observed during recent decades in the South Atlantic, and these affect oceanic circulation and migration processes (Sissini *et al.*, 2017; Batista *et al.*, 2018).

Seaweed cast onto beaches negatively affects municipal economies, especially with regard to leisure and tourism. Therefore, removal of beach-cast seaweeds is carried out by local governments to keep beaches in good condition for recreational activities (Cuevas *et al.*, 2018). To most people, beach-cast algae and seagrass are piles of rotting plant material washed up along the high tide line of many beaches. Accumulation of wrack can affect human use and enjoyment of beaches because of the production of hydrogen sulphide gas (Hansen, 1984) and plagues of beach flies (Blanche, 1992) associated with decomposition. On the other hand, beach-cast algae are a livelihood for some as they represent a valuable resource as a raw material for the extraction of phycocolloids (such as alginate and agar) or as cattle feed or garden fertilizers (Kirkman & Kendrick, 1997). Algae can reduce inorganic nutrients and organic matter from coastal waters that have undergone eutrophication (Piriz *et al.*, 2003), by production of compost, biogas (Eyras *et al.*, 1998) and in the cleaning of coastal beaches for recreation and tourism.

The frequent occurrence of beach-cast seaweeds along the Brazilian coastline has been reported (Praciano, 1977; Câmara-Neto *et al.*, 1981; Pedrini, 1984; Santos *et al.*, 2013), however, detailed studies on its taxonomic composition are still insufficient and ecological studies are extremely scarce. In light of this, there is a need for a better understanding of their occurrences in historically poorly studied areas. In this study beaches in NE and SE Brazil were selected based on records of occurrences of beach-cast seaweeds. Theoretically, the diversity and abundance of species should mirror the known phycogeography, which varies across the diversity of environments (Horta *et al.*, 2001). This work is a pioneering study comparing the taxonomic composition and functional-form group (FFG) dominance of beach-cast seaweeds collected in NE and SE Brazil.

Materials and methods

Study area

This study was conducted in two different regions of Brazil. The NE sites were Emboaca Beach (EMB) in Trairi, Ceará (3°12′23.5″S, 39°18′37.1″W) and Candeias Beach (CAN) in Jaboatão dos Guararapes, Pernambuco (8°12′46″S, 34°55′6″W). The NE region is unique because of its oligotrophic waters and abundance of substrata such as sandstone reefs encrusted with algae, limestone and corals that support a rich marine flora (Horta *et al.*, 2001). The coastline is under the influence of highly energetic waves, high temperatures throughout the year (~26°C), strong winds and an intense flow of resuspended sediments, despite the lack of fluvial inputs (Soares *et al.*, 2018). The SE sites were Pontal Beach (PON) in Marataízes (21°00′19″S, 40°48.37′W) and Itaoca beach (ITA) in Itapemirim (20°54’18.0″S, 40°46’42.3″W), both in the state of Espírito Santo. According to Horta *et al.* (2001), this region has a wide diversity of environments, which includes reef formations, rocky substrata, consolidated by concretions of limestone algae and extensive rhodolith banks in waters of the Benguela Current, which originates from the Brazil Current and extends to the north of the state of Espírito Santo. The average temperatures are ~22°C, with predominant trade winds originating from high pressure areas (Guimarães, 1990). The four studied beaches (Fig. 1) are sandy, urbanized and frequently visited by locals and tourists.

Sample collection and processing

Based on records of Barbosa (2010) and Santos *et al.* (2013) on the months with the highest occurrence of beach-cast seaweeds in NE Brazil, algae were collected in February and March 2018 at Candeias and Emboaca Beaches, respectively. In SE Brazil, algae were collected in June 2017 on Pontal and in May 2018 on Itaoca Beach. Seaweeds were collected at each beach during spring tide, using three 20 m long transects, positioned continuously and parallel to the coastline. Transects were positioned in such a way as to cover as much as possible the area where the algae had been deposited. Three 25 x

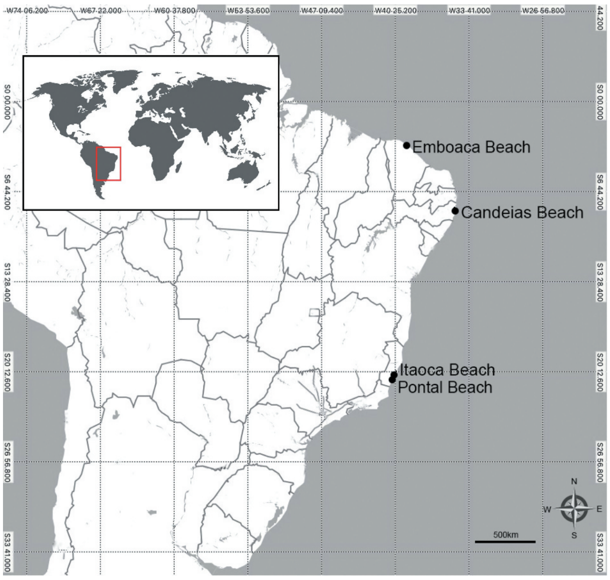

Fig. 1. Map of Brazil showing the sampling sites.

25 cm quadrats were randomly positioned along each transect, in order to estimate the coverage, frequency and biomass of the macroalgae following methods of Barbosa (2010) and Santos *et al.* (2013) (n = 9 per site).

The specimens collected from each quadrat were placed inside individual labelled sealed plastic bags, and immediately frozen at −20°C before being transported to the laboratory at the Institute of Botany, in São Paulo (SP). Although the exposure time of the beach-cast seaweeds was not determined, most of the samples were fresh, in good condition, and not decomposing. At SP the samples were thawed, cleaned and identified using a stereomicroscope and microscope, based on the morphological characteristics according to Wynne (2017) and Guiry & Guiry (2020).

The material collected in each quadrat was analysed and used to calculate species richness, biomass, coverage and frequency at each site. Biomass was calculated by oven-drying the macroalgae at 60°C until a constant dry mass weight was obtained, using a semi-analytical scale (0.001 g) and expressed in g m^{-2} as described by Mafra Jr. & Cunha (2002).

Data analyses

The frequency of each species was expressed as % of the total and used to calculate the number of species present in all of the sampling quadrats at each beach (n = 9 per site). Coverage was estimated by calculating % occupancy of quadrats (divided into four sub-quadrats) at each beach. Coverage and frequency were classified into the following FFGs: filamentous, foliose, corticated foliose, corticated and articulated calcareous (Steneck & Dethier, 1994).

To evaluate the differences in the macroalgal assemblages at each site, non-parametric multi-dimensional scaling (nMDS) based on Bray–Curtis similarities for the coverage and biomass of taxa (untransformed data) was applied (Clarke & Green, 1988; Clarke, 1993). Similarity Percentage procedure (SIMPER) was used to define the taxa that contributed the most to the observed dissimilarities between beaches (Clarke, 1993). Both nMDS and SIMPER were analysed in PRIMER v. 6.1.15 (Clarke & Gorley, 2006).

A permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001) was performed followed by *post hoc* tests (PERMANOVA pairing comparisons), to test the hypothesis that taxa coverage and biomass differed depending on the location. Multivariate data were analysed according to a single factor design (Beaches: four sites, n = 9) using the Bray–Curtis similarity matrix generated from the non-transformed data with 9999 permutations. Differences in multivariate dispersion of the 'beaches' factor were tested using the PERMDISP routine in the PERMANOVA+ v. 1.0.5 statistical software package (Anderson *et al.*, 2008).

Results

A total of 110 algal taxa were identified: 80 Rhodophyceae, 13 Phaeophyceae, 17 Chlorophyceae, in 14 orders and 59 genera. In both NE and SE Brazil, Rhodophyceae genera were the richest, and the most speciose genus was in the order Ceramiales, with 28 taxa. Within the Phaeophyceae, Dictyotales was the most represented (13 taxa), while in Chlorophyta, Bryopsidales was predominant (11 taxa). Of the 110 identified taxa, 42 taxa were only observed at NE sites, 30 were exclusive to SE sites, and 38 taxa were common to both coasts. The greatest species richness was observed in NE Brazil.

Lobophora variegata and *Alsidium seaforthii* were the best represented species at all beaches. All five FFGs were present in all samples, but variations in group frequency were detected. Corticated algae were the most represented FFG at all study sites, with high frequencies of *A. seaforthii* and *Osmundaria obtusiloba* in all samples. Corticated foliose was the second most dominant FFG observed at all sites, with high frequencies of *L. variegata* at all beaches. *Dictyopteris jolyana* and *Zonaria tournefortii* were frequently observed at PON and ITA, while *Spatoglossum schroederi* was found at CAN and *D. delicatula* at EMB. Among the filamentous algae, *Cladophora prolifera* was found more frequently at EMB and *Codium isthmocladum* at ITA. *Haloplegma duperreyi* and *Ulva lactuca* were foliose algae recorded at all of the sites. In contrast, articulated calcareous was the least representative FFG at all of the study sites (Supplementary table S1).

The average coverage values for both regions were very similar, and EMB and ITA beaches had the highest values. SE Brazilian beaches had higher average biomass (1041.2 g m^{-2}) than the NE ones (732.0 g m^{-2}). The PERMANOVA demonstrated a significant difference in the coverage and biomass of the algal groups at the four study sites (Coverage: pseudo-F = 41.142, p = 0.0001; Biomass: pseudo-F = 32.549, p = 0.0001) and pairwise comparisons indicated significant differences in all of the combinations performed. PERMDISP showed a significant difference in coverage and biomass among the four beaches (Coverage: F = 4.9783, p = 0.0268; Biomass: F = 4.9659, p = 0.0259), indicating differences in the location and dispersion of coverage and biomass between the analysed groups (Fig. 3). Based on the species coverage and biomass, corticated foliose algae were the FFG group best represented followed by corticated algae on the four beaches (Table 1, Fig. 2).

Non-metric multidimensional scaling plots (nMDS) showed a marked dissimilarity between the beaches and regions studied for both coverage and biomass (Fig. 3). SIMPER analysis identified the 10 species that contributed the most (> 9%) to the observed dissimilarities between the recorded macroalgae for coverage and biomass on the beaches (Table 2, Fig. 3). *Spatoglossum schroederi*, *Codium isthmocladum* and *D. jolyana* were important for cover and biomass, other species appearing in only one of the analyses.

Corticated foliose brown algae were the dominant functional-form in the study area for both coverage and biomass. In NE Brazil, the distribution patterns of the groups analysed for coverage and biomass were

Table 1. Main representatives in biomass and coverage in the studied sites.

Study area	FFG group	Species
SE Brazil	Corticated foliose	*Zonaria tournefortii*, *Dictyopteris jolyana*, *Dictyopteris polypodioides* and *Padina gymnospora*
	Corticated	*Alsidium seaforthii* and *Osmundaria obtusiloba*
NE Brazil	Corticated foliose	*Spatoglossum schroederi*, *Sargassum filipendula* and *Lobophora variegata*
	Corticated	*Gracilaria domingensis*, *Cryptonemia crenulata*, *Botryocladia occidentalis* and *Alsidium triquetrum*

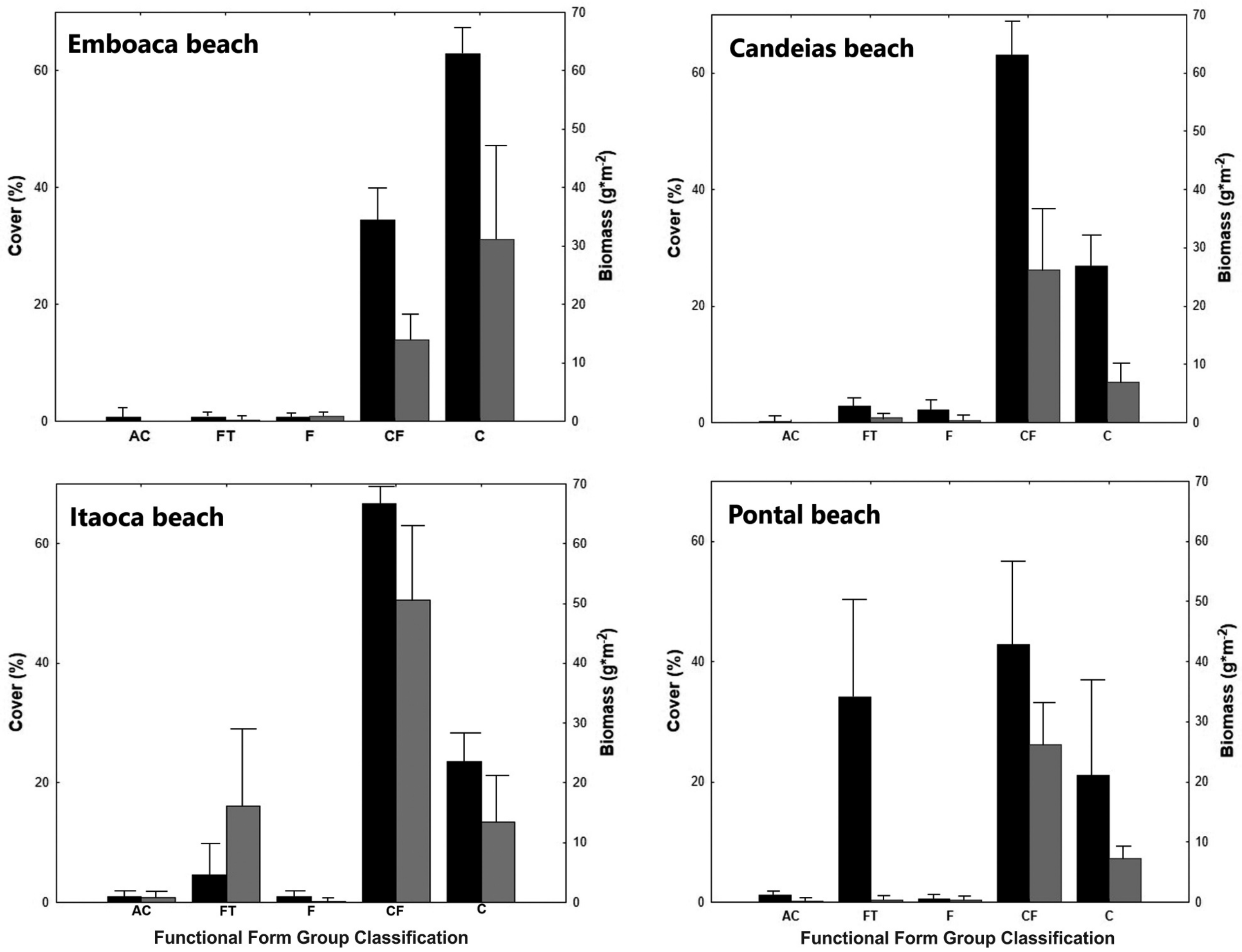

Fig. 2. Coverage and biomass of functional-form groups in the studied beaches: Emboaca Beach, Candeias Beach, Itaoca Beach, Pontal Beach. AC, articulated calcareous algae; FT, filamentous algae; F, foliose algae; CF, corticated foliose algae; C, corticated algae. Cover (black bars), biomass (grey bars). Data are mean ± SD (n = 9).

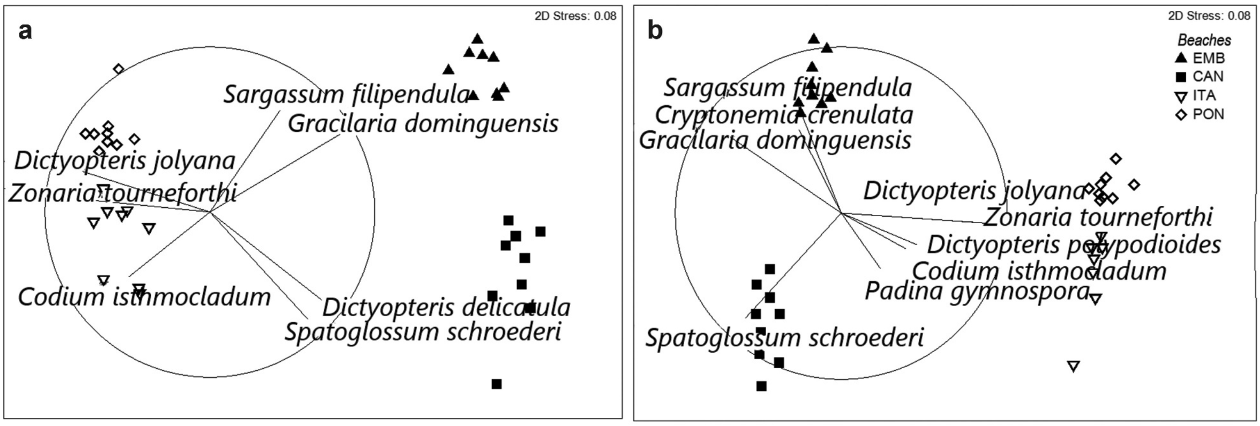

Fig. 3. nMDS biplot of sampling units (9), based on the (A) coverage and (B) biomass of macroalgal species recorded in the four beaches (NE beaches = EMB and CAN; SE beaches = ITA and PON). The vector plots represent the species obtained in the SIMPER analysis that contributed more than 9% to the differences between beaches.

determined by the species *S. schroederi* and *S. filipendula*, and by *D. delicatula*. In the SE, the species that predominated for coverage and biomass were *Z. tournefortii* and *D. jolyana*, and also for biomass, *D. polypodioides* and *P. gymnospora* stood out (Fig. 3).

Discussion

In NE and SE Brazil, there are differences in species richness, frequency, coverage and biomass of beach-cast macroalgae. Beach-cast seaweeds from the Brazilian coast are multispecific, although a few species are dominant in terms of biomass. The study also revealed that corticated algae FFG was the most frequent on all beaches and, except at EMB, was also responsible for the highest coverage and biomass values.

In the present study, the number of Rhodophyta species (74%) was greater than those of green (14%) and brown seaweeds (12%). As for species richness, the results obtained show that a higher number of taxa inhabit the NE region, with Rhodophyta contributing greatly to this result. The species of beach-cast seaweeds reflect studies describing the subtidal flora of SE (Horta, 2000; Cocentino, 2009; Yoneshigue-Valentin *et al.*, 2006) and NE Brazil (Riul *et al.*, 2009). Based on species richness, and the frequent association between beach-cast seaweeds and rhodoliths, common substrata present in constantly submerged regions also support the sublittoral origin of these algae. The rhodolith beds are one of the most important benthic communities in the Brazilian continental shelf, providing a three-dimensional structure that transforms homogeneous backgrounds and unconsolidated sediments into heterogeneous hard substrates, consequently expanding the available niches and promoting increased species diversity, including commercially important and endemic species (Riul *et al.*, 2009; Amado-Filho *et al.*, 2010; Nunes & Andrade, 2017).

Table 2. Contributions of taxa to the dissimilarities among beaches, determined by SIMPER analysis (n = 9). Only those taxa that contributed more than 9% to dissimilarities between beaches are shown.

Groups	Coverage		Biomass	
CAN & PON (97.23, 96.55)	**Contr. %**	**Cum. %**	**Contr. %**	**Cum. %**
Spatoglossum schroederi	20.87	20.87	25.97	25.97
Dictyopteris jolyana	17.37	38.25	17.78	61.85
Zonaria tournefortii	16.18	54.43	18.1	44.08
CAN & ITA (96.24, 95.39)				
Spatoglossum schroederi	20.74	20.74	16.05	16.05
Codium isthmocladum	17.2	37.94	13.04	29.09
Dictyopteris polypodioides	-	-	12.45	41.54
Zonaria tournefortii	-	-	10.83	52.37
EMB & PON (94.02, 91.32)				
Dictyopteris jolyana	17.54	17.54	16.18	33.13
Zonaria tournefortii	16.34	33.88	16.95	16.95
Gracilaria domingensis	13.26	47.14	9.23	42.36
Sargassum filipendula	9.95	57.09	-	-
EMB & ITA (93.90, 90.71)				
Codium isthmocladum	17.16	17.16	12.58	12.58
Gracilaria domingensis	12.84	30	-	-
Sargassum filipendula	10.11	40.12	-	-
Dictyopteris polypodioides	-	-	12.05	24.62
Zonaria tournefortii	-	-	10.46	35.08
EMB & CAN (79.83, 83.09)				
Spatoglossum schroederi	24.95	24.95	26.98	26.98
Sargassum filipendula	12.18	37.13	10.2	37.17
Dictyopteris delicatula	9.44	46.57	-	-
Cryptonemia crenulata	-	-	9.31	46.48
PON & ITA (66.67, 63.64)				
Codium isthmocladum	24.63	24.63	19.47	19.47
Dictyopteris jolyana	16.52	41.15	-	-
Zonaria tournefortii	14.49	55.64	-	-
Dictyopteris polypodioides	-	-	18.6	38.07
Padina gymnospora	-	-	10.78	48.85

Average dissimilarities for coverage and biomass among sites in parentheses. 'Contr. %' refers to the contribution of each species to differences between sites, and 'Cum. %' is a running total of the contribution to the observed dissimilarity.

Of the five FFGs evaluated, corticated algae were more frequent in all beaches. Corticated algae are predominantly red algae which are better adapted to high water turbidity, as they have a broad spectrum of light absorption in relation to the other classes

(Kain & Norton, 1990). According to Steneck & Dethier (1994), corticated macrophytes are larger, have longer life, making these algae more susceptible to the forces of ocean currents that in part are responsible for the presence of stranded seaweeds (Santos *et al*., 2013). The greatest coverage of corticated algae was found in EMB, with *G. domingensis, C. crenulata* and *A. triquetrum*, which also showed the highest biomass values on this beach. *S. schroederi, D. jolyana, D. polypodioides, Z. tournefortii* and *P. gymnospora* are among the species that contributed most to these results. These species are grouped by their morphological characteristics in foliose corticated algae, which are larger and thicker frondose species with the ability to be more resistant and more adapted to hydrodynamics. Also, these species are important for community structure, as they may affect light availability, promoting stratification of the surrounding flora (Eston & Bussab, 1990). The order Dictyotales has the highest values of biomass on the Brazilian coast and studies elsewhere have indicated its potential in the production of alginate gels and high viscosity solutions of great economic interest (e.g. in the food, cosmetic, chemical and textile industries; Noseda *et al*., 2018).

The results obtained confirm the hypothesis that there are differences between the two regions of the Brazilian coast. NE Brazil showed higher species richness, whereas coverage and biomass were higher in SE Brazil. Contrary to what was observed here, previous phycological studies (Guimarães, 1990, 2006; Horta, 2000; Pacheco, 2011) identified Espírito Santo as having the highest diversity of macroalgae in the SE region and attributed this to climatic and oceanographic conditions and diversity of marine habitats (Horta *et al*., 2001; Guimarães, 2006; Amado-Filho *et al*., 2007). Nonetheless, our results could be related to other factors. First, biomass deposition is an extremely dynamic process, both in space and in time, with frequent suspension and redeposition events during the various tidal cycles (Orr *et al*., 2005). Therefore, according to Duarte *et al*. (2009), this may be a point measure of these stranded macroalgae rather than the actual amount that reaches the beach. Therefore, it is suggested that temporal analyses of the stranded seaweeds in the study areas, followed by qualitative and quantitative analyses, be carried out in future. Benthic flora studies are needed to link the beach-cast seaweeds to the nearby floristic stock and the seasonality of the species (Castillo-Arenas & Dreckmann, 1995).

Bell & Hall (1997) suggested that less active environments are more favourable to the growth of benthic macroalgae than those with higher current speeds and/or extensive exposure to waves. Berglund *et al*. (2003) suggested that the occurrence of beach-cast seaweeds was affected by wave exposure and that the greater the exposure the greater the accumulation. Several studies have indicated that the biomass of the beach-cast seaweeds is influenced by currents, storms, substrates, nutrients, seasonality, light, competition and near floristic stock (Orr *et al*., 2005; Biber, 2007; Barbosa *et al*., 2008; Riul *et al*., 2009), although our ability to predict temporal patterns of stranded macroalgae biomass is still limited (López *et al*., 2019).

This study found some species which were previously identified in the local benthic flora (Nunes & Paula, 1999) as well as some with high dispersal capacity due to their floats, e.g. *S. vulgare, S. filipendula* and other *Sargassum* spp. Pelagic species were not found but beach-cast seaweeds are a form of monitoring, taking into account the biogeographic importance of these organisms that function as rafts loaded with many species. Floating marine algae are important dispersal vectors in marine ecosystems, facilitating the dissemination and population connectivity of many associated species (Thiel & Fraser, 2016; Batista *et al*., 2018). In addition, Oliveira Filho *et al*. (1979) drew attention to the effect of the Brazil Current, which would be a route for the introduction of species from the north-east towards higher latitudes of the Brazilian coast. Therefore, beach-cast seaweeds may be an indicator of rafting seaweeds (Schreiber *et al*., 2020).

The occurrence of beach-cast seaweeds has been frequent on many beaches in NE and SE Brazil. The four beaches studied have local economies tied to tourism and fishing activities. The presence of this algal biomass interferes with recreational uses of the beaches and therefore must be periodically collected and disposed of (Piriz *et al*., 2003; Cuevas *et al*., 2018). It is often underutilized or destined for landfills (Santos *et al*., 2013), gathered without recording its composition or potential value, nor considering the ecological importance and the environmental impacts promoted by this action on the beaches. According to Gavio *et al*. (2015), the fact that these events have become recurrent is alerting scientists as well as the affected communities, where tourism, fishing, and other economic activities have been disrupted. It is urgent to understand the causes of these events, which may disrupt shallow ecosystems like seagrass and macroalgal beds and affect local communities disrupting their economic activities. In order to establish management and utilization strategies, qualitative analyses and quantification of the wrack are necessary. However, few studies have been focused in this area (Piriz *et al*., 2003).

On the sandy beaches one of the main sources of organic matter is stranded seaweed (Griffiths *et al*., 1983; Dugan *et al*., 2003; Duarte *et al*., 2008). These macrophytes can influence the community and population structure of the macrofauna, serving as food and/or refuge (Griffiths *et al*., 1983; Pennings *et al*., 2000). Therefore, harvesting of the beach-cast seaweeds can cause an environmental imbalance in these ecosystems. Several studies (Griffiths *et al*., 1983; Dugan *etal*., 2003; Duarte *et al*., 2008, 2009) have provided evidence that in regions with high marine macrophyte production the community structure of sandy beach macrofauna is closely linked with the input and fate of macrophyte wrack. Macrophyte drift or wrack represents an important allochthonous source of carbon and organic material to the intertidal zone of exposed sandy beaches in many parts of the world. According to Dugan *et al.* (2003), direct studies on the effects of grooming (to remove drift macrophytes, debris, and trash) with heavy equipment (which is a widespread practice on populated sandy beaches) on macrofaunal communities are scarce.

Seaweeds are a valuable resource that is used in many countries. In Brazil, despite the extensive coast, and the presence of varied habitats and rich marine flora, there has been limited use of macroalgae. Only a few genera and species have been exploited commercially (Simioni *et al*., 2019). Previous studies have indicated that beach-cast seaweeds of the Brazilian coast are promising as fertilizers (Barbosa, 2010; Sacramento *et al*., 2013; Vila Nova *et al*., 2014). Gracilariales are economically important for production of phycocolloids, with wide distribution, mainly in the NE region (Simioni *et al*., 2019). This was confirmed by collecting beach-cast seaweeds from the states of Ceará and Pernambuco, both in NE Brazil. However, before gathering them for commercial purposes, the environmental impacts of harvesting them must be determined. Kirkman & Kendrick (1997) pointed out that it is necessary to understand the link between the living off-shore and the beach-cast seaweed. This information should be obtained at least for the main species that are as subject to commercial harvest. There are several key research gaps that need to be addressed in order to make decisions on the management of this resource or to determine the effects of removal. These gaps fall into two classes that are related to biomass and availability of the resource followed by the effects of its removal on coastal ecosystems (Zemke-White *et al*., 2005).

In conclusion, despite the global relevance of the subject and the apparent biotechnological potential of beach-cast seaweeds, this area of research and development is still relegated to the background or underexplored. Further studies that monitor the occurrence, explore the chemical composition, and consolidate the taxonomic diversity of beach-cast seaweeds are necessary to understand how to utilize this biomass, which is a potential source of natural products.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Supplementary material

The following supplementary material is accessible via the Supplementary Content tab on the article’s online page at https://doi.org/10.1080/09670262.2021.2003867

Supplementary table S1. Macroalgal species recorded at the four sampling sites with their frequency of occurrence and functional-form group according to Steneck & Dethier (1994).

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References

Amado-Filho, G.M., Maneveldt, G., Manso, R.C.C., Marins-Rosa, B.V., Pacheco, M.R. & Guimarães, S.M.P. B. (2007). Estructura de los mantos de rodolitos de 4 a 55 metros de profundidad en la costa sur del estado de Espírito Santo, Brasil. *Ciencias Marinas*, **33**: 399–410.

Amado-Filho, G.M., Maneveldt, G., Pereira-Filho, G.H., Manso, R.C.C., Barros-Barreto, M.B. & Guimarães, S. M.P.B. (2010). Seaweed diversity associated with a Brazilian tropical rhodolith bed. *Ciencias Marinas*, **36** (**4**): 371–391.

Anderson, M.J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, **26**: 32–46.

Anderson, M.J., Gorley, R.N. & Clarke, K.R. (2008). *PERMANOVA for PRIMER: Guide to Software and Statistical Methods*. PRIMER-E, Plymouth.

Barbosa, S.O. (2010). Potencial agrícola das algas marinhas arribadas no litoral norte fluminense. Dissertação de Mestrado em Ciências Biológicas – Botânica. Universidade Federal do Rio de Janeiro, Rio de Janeiro. pp. 52.

Barbosa, S.O., Figueiredo, M.A.O. & Testa, V. (2008). Estrutura e dinâmica de comunidades bentônicas dominadas por macrófitas na zona intramareal da praia de Jacaraípe, Espírito Santo, Brasil. *Hoehnea*, **35**: 563–575.

Batista, M.B., Batista, A., Franzan, P., Simionatto, P., Lima, T.C., Velez-Rubio, G.M. & Horta, P.A. (2018). Kelps' long-distance dispersal: role of ecological/oceanographic processes and implications to marine forest conservation. *Diversity*, **10**: 1–11.

Bell, S.S. & Hall, M.O. (1997). Drift macroalgal abundance in seagrass beds: investigating large-scale associations with physical and biotic attributes. *Marine Ecology Progress Series*, **147**: 277–283.

Berglund, J., Mattila, J., Rönnberg, O., Heikkilä, J. & Bonsdorff, E. (2003). Seasonal and inter-annual variation in occurrence and biomass of rooted macrophytes and drift algae in shallow bays. *Estuarine and Coastal Shelf Science*, **56**: 1167–1175.

Biber, P.D. (2007). Transport and persistence of drifting macroalgae (Rhodophyta) are strongly influenced by flow velocity and substratum complexity in tropical seagrass habitats. *Marine Ecology Progress Series*, **343**: 115–122.

Blanche, K.R. (1992) Preliminary observations on the distribution and abundance of seaweed flies (Diptera: Coelopidae) on beaches in the Gosford district of New South Wales. *Australian Journal of Ecology*, **17**: 27–34.

Calado, S.C.S., Silva, V.L., Passavante, J.Z.O., Abreu, C. A.M., Lima Filho, E.S., Duarte, M.M.M.B. & Diniz, E. V.G.S. (2003). Cinética e equilíbrio de biossorção de chumbo por macroalgas. *Tropical Oceanography*, **31**: 53–62.

Câmara-Neto, C. (1971). Contribuição ao conhecimento qualitativo e quantitativo das "arribadas" da Redinha. *Boletim do Instituto de Biologia Marinha*, **5**: 3–30.

Câmara-Neto, C., Araújo, R.A., Melo Filho, N.R., Soares, M.L. & Costa, P.N. (1981). *Composição e estimativa da biomassa das algas arribadas em praias do Rio Grande do Norte*. SUDENE – *Estudos de Pesca, ser.*, **9**: 85–95.

Castillo-Arenas, G. & Dreckmann, K.M. (1995). Composición taxonómica de las arribazones algales en el Caribe mexicano. *Cryptogamie Algologie*, **16**: 115–123.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology*, **18**: 117–143.

Clarke, K.R. & Gorley, R.N. (2006). *PRIMERv6: User Manual/Tutorial*. PRIMER-E, Plymouth.

Clarke, K.R. & Green, R.H. (1988). Statistical design and analyses for a "biological effects" study. *Marine Ecology Progress Series*, **46**: 213–226.

Cocentino, A. de. L.M. (2009). Flora ficológica da plataforma continental do litoral setentrional da baciapotiguar (RN), com ênfase em chlorophyta. Tese de doutorado. Universidade Federal do Pernambuco. 127 pp.

Cuevas, E., Uribe-Martínez, A. & Liceaga-Correa, M.A. (2018). A satellite remote-sensing multi-index approach to discriminate pelagic *Sargassum* in the waters of the Yucatan Peninsula, Mexico. *International Journal of Remote Sensing*, **39**(**11**): 3608–3627.

Dayton P.K., Tegner, M.J., Parnell, P.E. & Edwards, P.B. (1992). Temporal and spatial patterns of disturbance and recovery in a kelp forest community. *Ecological Monographs*, **62**: 421–445.

Duarte, C., Jaramillo, E. & Contreras, H. (2008). Stranded algal wracks on a sandy beach of south central Chile: feeding and habitat preferences of juveniles and adults of *Orchestoidea tuberculata* (Nicolet), (Amphipoda, Talitridae). *Revista Chilena de Historia Natural*, **81**(**1**): 69–81.

Duarte, C., Jaramillo, E., Contreras, H., Acuña, K. & Navarro, J.M. (2009). Importance of macroalgae subsidy on the abundance and population biology of the amphipod *Orchestoidea tuberculata* (Nicolet) in Sandy beaches of south central Chile. *Revista de Biologia Marina y Oceanografia*, **44**(**3**): 691–702.

Dugan, J., Hubbard, D.M., McCrary, M.D. & Mopierson, M.O. (2003). The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. *Estuarine Coastal and Shelf Science*, **58**: 25–40.

Eston, V.R. & Bussab, W.O. (1990). An experimental analysis of ecological dominance in a rocky subtidal macroalgal community. *Journal of Experimental Marine Biology and Ecology*, **36**: 170–195.

Eyras, M.C., Rostagno, C.M. & Defossé, G.E. (1998). Biological evaluation of seaweed composting. *Compost Science and Utilization*, **6**: 74–81.

Garden, C.J., Craw, D., Waters, J.M. & Smith, A. (2011). Rafting rocks reveal marine biological dispersal: a case study using clasts from beach-cast macroalgal holdfasts. *Estuarine, Coastal and Shelf Science*, **95**: 388–394.

Gavio, B., Rincón-García, M.N. & Santos-Martínez, A. (2015). Massive quantities of pelagic *Sargassum* on the shores of San Andres Island, Southwestern Caribbean. *Acta Biologica Colombiana*, **20**: 239–241.

Gower, J., Hu, C., Borstad, G. & King, S. (2006). Ocean color satellites show extensive lines of floating *Sargassum* in the Gulf of Mexico. *IEEE Transactions on Geoscience and Remote Sensing*, **44**: 3619–3625.

Gower, J. & King, S.A. (2011). Distribution of floating *Sargassum* in the Gulf of Mexico and the Atlantic Ocean mapped using MERIS. *International Journal of Remote Sensing*, **32**: 1917–1929.

Griffiths, C.L., Stenton-Dozey, J.M.E. & Koop, K. (1983). Kelp wrack and the flow of energy through a sandy beach ecosystem. In *Sandy Beaches as Ecosystems* (McLachlan, A. & Erasmus, T., editors), Vol. 19, pp. 547–556. Springer, Dordrecht.

Guimarães, S.M.P.B. (1990). Rodofíceas marinhas bentônicas do Estado do Espírito Santo: ordem Cryptonemiales. Tese de Doutorado. Universidade de São Paulo, São Paulo.

Guimarães, S.M.P.B. (2006). A revised checklist of benthic marine Rhodophyta from the state of Espírito Santo, Brazil. *Boletim do Instituto de Botânica*, **17**: 143–194.

Guiry, M.D. & Guiry, G.M. (2020). *AlgaeBase*. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org (last accessed 6 October 2020).

Hansen, G. (1984). Accumulations of macrophyte wrack along sandy beaches in Western Australia: biomass, decomposition rate and significance in supporting near-shore production. PhD thesis, University of Western Australia, 93 pp.

Horta, P.A. (2000). Macroalgas do Infralitoral do Sul e Sudeste do Brasil: taxonomia e biogeografia. Tese de Doutorado. Universidade de São Paulo, 301 pp.

Horta, P.A., Amâncio, E., Coimbra, C.S. & Oliveira, E.C. (2001). Considerações sobre a distribuição e origem da flora de macroalgas marinhas brasileiras. *Hoehnea*, **28**: 243–265.

Johns, M.E., Lumpikin, E., Putman, N.F., Smith, R.H., Muller-Karger, F.E., Rueda-Roa, D.T., Hu, C., Wang, M., Brooks, M.T., Gramer, L.J. & Werner, F.E. (2020). The establishment of a pelagic *Sargassum* population in the tropical Atlantic: biological consequences of a basin-scale long distance dispersal event. *Progress in Oceanography*, **182**: 1–26.

Kain, J.M. & Norton, T.A. (1990). Marine ecology. In *Biology of the Red Algae* (Cole, K.M. & Sheath, R.G.), 377–422. Cambridge University Press, New York.

Kirkman, H. & Kendrick, G.A. (1997). Ecological significance and commercial harvesting of drifting and beach-cast macro-algae and seagrasses in Australia: a review. *Journal of Applied Phycology*, **9**(**4**): 311–326.

López, B.A., Macaya, E.C., Jeldres, R., Valdivia, N., Bonta, C.C., Tala, F. & Thiel, M. (2019). Spatio-temporal variability of strandings of the southern bull kelp *Durvillaea antarctica* (Fucales, Phaeophyceae) on beaches along the coast of Chile-linked to local storms. *Journal of Applied Phycology*, **31**(**3**): 2159–2173.

López, B.A., Macaya, E.C., Tala, F., Tellier, F., & Thiel, M. (2017). The variable routes of rafting: stranding dynamics of floating bull kelp *Durvillaea antarctica* (Fucales, Phaeophyceae) on beaches in the SE Pacific. *Journal of Phycology*, **53**(**1**): 70–84.

MacMillan, M.R. & Quijón, P.A. (2012). Wrack patches and their influence on upper-shore macrofaunal abundance in an Atlantic Canada sandy beach system. *Journal of Sea Research*, **72**: 28–37.

Mafra, Jr., L.L & Cunha, S.R. (2002). Bancos de *Sargassum cymosum* (Phaeophyceae) na Enseada de Armação do Itapocoroy, Penha, SC: biomassa e rendimento em alginato. *Notas Técnicas Facimar*, **6**: 111–119.

McLachlan, A. & Brown, A.C. (2006). *The Ecology of Sandy Shores*. Academic Press, Burlington, MA.

Menezes, M. *et al.* (2015). Update of the Brazilian floristic list of Algae and Cyanobacteria. *Rodriguésia*, **66**(**4**): 1–16.

Noseda, M.D., Gonçalves, A.G., Ferreira, L.G., Ducatti, D. R.B., Viana, A.G., Cassolato, J.E.F., Faria-Tischer, P.C.S., Zibetti, R.G.M. & Duarte, M.E.R. (2018). Polissacarídeos e macroalgas marinhas: estrutura química e atividade biológica. In *Polissacarídeos da biodiversidade brasileira* (DePaula, R.C.M., DePaula, H.C.B. & Feitosa, J.P.A., editors), 52–104. Imprensa Universitária, Fortaleza.

Nunes, J.M.C. & Andrade, N.A. (2017). *Estudo de bancos de rodolitos do litoral norte do estado da Bahia: aspectos econômicos e ecológicos*. Novas Edições Acadêmicas, Mauritius. v, 1. 135 pp.

Nunes, J.M. de C. & Paula, E.J. de. (1999). Phaeophyta da região metropolitana de Salvador, Bahia, Brasil. Universidade de São Paulo, São Paulo.

Oliveira Filho, E.C., Ugadim, Y. & Paula, E.J. (1979). Comunidades associadas a plantas de Sargassum flutuantes em águas da corrente do Brasil — considerações biogeográficas. *Boletim de Botánica*, **7**: 5–9.

Orr, M., Zimmer, M., Jelinski, D.E. & Mews, M. (2005). Wrack deposition on different beach types: spatial and temporal variation in the pattern of subsidy. *Ecology*, **86**: 1496–1507.

Oyesiku, O.O. & Egunyomi, A. (2014). Identification and chemical studies of pelagic masses of *Sargassum natans* (Linnaeus) Gaillon and *S. fluitans* (Borgesen) Borgesen (brown algae), found offshore in Ondo State, Nigeria. *African Journal of Biotechnology*, **13**(**10**): 1188–1193.

Pacheco, M.R. (2011). Macroalgas marinhas associadas a bancos de rodolitos do infralitoral do Espírito Santo, Brasil. Tese de Doutorado em Botânica. Instituto de Biociências, Universidade de São Paulo, São Paulo. 371 pp.

Pedrini, A.G. (1984). Algas marinhas bentônicas do litoral norte Fluminense. I – lista preliminar das algas arribadas da praia de Manguinhos (Guaxindiba), São João da Barra, Rio de Janeiro. *Atas da sociedade Botânica do Brasil*, RJ, **2**(**17**): 143–144.

Pennings, S.C., Carefoot, T.H., Zimmer, M., Danko, J.P. & Ziegler, A. (2000). Feeding preferences of supralittoral isopods and amphipods. *Canadian Journal of Zoology*, **78**: 1918–1929.

Piriz, M.L., Eyras, M.C., M.C. & Rostagno, C.M. (2003). Changes in biomass and botanical composition of beach-cast seaweeds in a disturbed coastal area from Argentine Patagonia. *Journal of Applied Phycology*, **15**: 67–74.

Praciano, P.R.S. (1977). Composição e estimativa das algas depositadas em praias do Estado do Ceará, no período de julho de 1976 a junho de 1977. Monografia de Bacharelado em Engenharia de Pesca, Universidade Federal do Ceará, 14 pp.

Putman, N.F., Goni, G.J., Gramer, L.J., Hu, C., Johns, E.M., Trinanes, J. & Wang, M. (2018). Simulating transport pathways of pelagic *Sargassum* from the Equatorial Atlantic into the Caribbean Sea. *Progress in Oceanography*, **165**: 205–214.

Riul, P., Lacouth, P., Pagliosa, P.R., Christoffersen, M.L. & Horta, P.A. (2009). Rhodolith beds at the easternmost extreme of South America: community structure of an endangered environment. *Aquatic Botany*, **90**: 315–320.

Sacramento, R.M. de O., Seidler, E., Souza, M. & Yoshimura, C.Y. (2013). Utilização de macroalgas arribadas do litoral catarinense na adubação orgânica de olerícolas. *Scientia Prima*, **1**(**1**): 55–59.

Santos, G. do N., Nascimento O.S., Pedreira A., Rios, G. I., Vasconcelos,& Nunes, J.M.C. (2013). Análise quali-quantitativa das algas arribadas no norte do estado da Bahia, Brasil. *Acta Botanica Malacitana*, **38**: 13–24.

Schreiber, L., López, B.A., Rivadeneira, M.M. & Thiel, M. (2020). Connections between benthic populations and local strandings of the southern bull kelp *Durvillaea antarctica* along the continental coast of Chile. *Journal of Phycology*, **56**(**1**): 185–197.

Silva Jr., C.P. (2019). Dinâmica sazonal e influência das marés na ocorrência de algas arribadas em praia urbana de Pernambuco. Trabalho de conclusão de curso de Bacharrelado em ciências biológicas. Faculdade Frassinetti do Recife, Recife, PE.

Simioni, C., Hayashi, L. & Oliveira, M.C. (2019). Seaweed resources of Brazil: what has changed in 20 years? *Botanica Marina*, **62**: 433–441.

Sissini, M.N., De Barros Barreto, M.B.B., Széchy, M.T.M., De Lucena, M.B., Oliveira, M.C., Gower, J., Liu, G., De Oliveira Bastos, E., Milstein, D., Gusmão, F., Martinelli-Filho, J.E., Alves Lima, C., Colepicolo, P., Ameka, G., de Graft-Johnson, K., Gouvea, L., Torrano-Silva, B., Nauer, F., de Castro Nunes, J.M., Barufi, J.B., Rorig, L., Riosmena-Rodríguez, R., Mello, T.J., Lotufo, L.V.C. & Horta, P.A. (2017). The floating *Sargassum* (Phaeophyceae) of the South Atlantic Ocean – likely scenarios. *Phycology*, **56**: 321–328.

Soares, L.P., Carneiro, P.B.(2018). New records of red seaweeds to the coast of Ceará State, **45**(**2**): 323–347.

Steneck, R.S. & Dethier, M.N. (1994). A functional group approach to the structure of algal-dominated communities. *Oikos*, **69**: 476–498.

Széchy, M.T. de., Guedes, P.M., Baeta-Neves, M.H. & Oliveira, E.N. (2012). Verification of *Sargassum natans* (Linnaeus) Gaillon (Heterokontophyta: Phaeophyceae) from the Sargasso Sea off the coast of Brazil, western Atlantic Ocean. *CheckList*, **8**(**4**): 638–641.

Thiel, M. & Fraser, C. (2016). The role of floating plants in dispersal of biota across habitats and ecosystems. In *Marine Macrophytes as Foundation Species* (Ólafsson, E., editor), 76–94. Taylor & Francis Group, Boca Raton, FL.

Vila Nova, L.L.M., Costa M.M.S., Costa, J.G., Amorim, E.C. S. & Guedes, E.A.C. (2014). Utilização de "algas arribadas" como alternativa para adubação orgânica em cultivo de *Moringa oleifera* Lam. *Revista Ouricuri*, **4**(**3**): 68–81.

Wang, M., Hu, C., Barnes, B.B., Mitchum, G., Lapointe, B. & Montoya, J.P. (2019). The great Atlantic *Sargassum* belt. *Science*, **365**: 83–87.

Wynne, M.J. (2017). A checklist of benthic marine algae of the tropical and subtropical western Atlantic: fourth revision. *Nova Hedwigia Beiheft*, **145**: 1–202.

Yoneshigue-Valentin, Y., Gestinari, L.M.S. & Fernandes, D.R.P.(2006). Macroalgas. In *Biodiversidade bentônica da Região Central da Zona Econômica Exclusiva Brasileira* (Lavrado, H.P. & Ignácio, B.L., editors). n.18: 67–105. Rio de Janeiro, Museu Nacional, Série Livros.

Zemke-White, W.L., Speed, S.R. & McClary, D.J. (2005). Beach-cast seaweed: a review. *New Zealand Fisheries Assessment Report*. 47 pp.