MARIA IRISVALDA LEAL GONDIM CAVALCANTI

Macroalgas arribadas da costa brasileira: biodiversidade e potencial de aproveitamento

Tese apresentada ao Instituto de Botânica da Secretaria de Infraestrutura e Meio Ambiente, como parte dos requisitos exigidos para a obtenção do título de DOUTOR em BIODIVERSIDADE VEGETAL E MEIO AMBIENTE, na Área de Concentração em Plantas Avasculares e Fungos em Análises Ambientais.

SÃO PAULO

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ORIENTADORA: DRA. MUTUE TOYOTA FUJII

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BALÉ NO MAR

Algas dançarinas

Deixaram de ser meninas

Cresceram presas no fundo do mar as algas bailarinas.

Agora, algas soltas marinhas.

Vão por outros caminhos:

À areia ser ninho.

Seguir outros destinos:

Liberar toxina, pobre pequenina.

Ser carragenina, proteína, micosporina.

Ser doce e sê grande menina.

Iris Cavalcanti

Homenagem

Á Dra. Mutue Toyota Fujii, minha orientadora. Professora, um grande encontro, para mim, não é obra do acaso, tem dia e hora certa para acontecer.

Ela é assim..

É como água no mar, não pode parar.

É vai e vem...vai e vem.

É movimento!

É onda perfeita. É talento!

Iris Cavalcanti

Dedicatória

Ao meu querido esposo José Leite,
Aos meus queridos filhos Filipe e Matheus,
Aos meus queridos pais (João e Carmelita),
Aos meus queridos irmãos, sobrinhos e cunhados,
para vocês sempre o melhor de mim.

E tudo que pedirdes em oração, crendo, recebereis.

Mateus 21:22

É trágico ser corajoso nas idéias e tímido nas ações. A prudência que nos castra, não é prudência, nos torna escravos do medo que nos conduz a mediocridade. Sem coragem não é possível ser livre (Samer Agi).

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> "A importância de uma verdadeira amizade não é só quando celebramos! E sim, quando somos abrigo; quando somos amigos; quando somos irmãos; quando estendemos as mãos, quando doamos nosso coração"!

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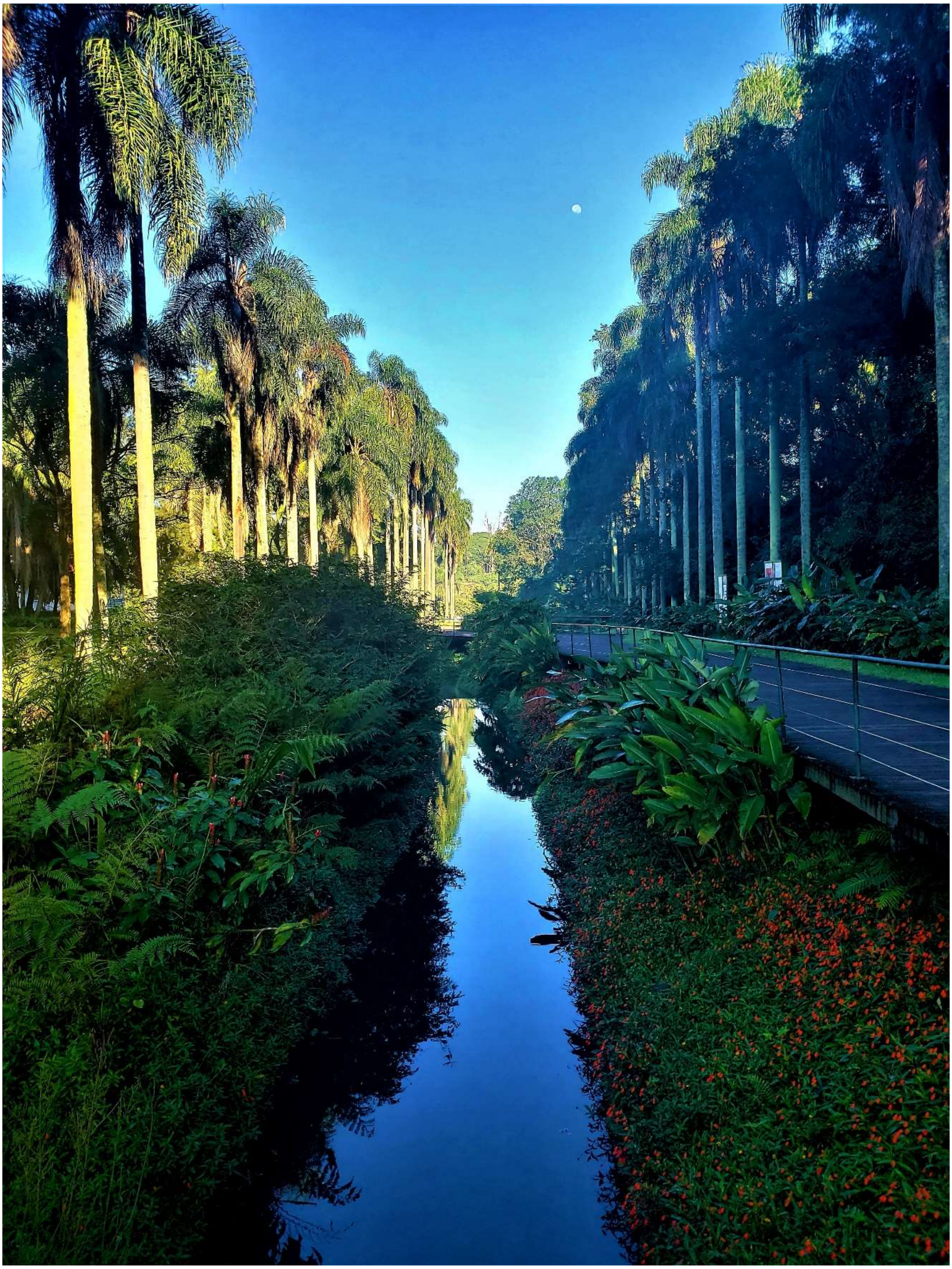

RESUMO

Há um forte consenso de que o mundo está passando por mudanças climáticas globais, e que as tempestades tropicais têm se intensificado, contribuindo para a ocorrência de algas arribadas nas praias do litoral brasileiro com mais frequência. Arribadas de macroalgas é um fenômeno natural onde as algas são arrancadas de seus substratos pelas fortes ações de ondas, correntes e marés, transportando a biomassa flutuante até as praias. No Brasil, as arribadas são compostas por muitas espécies de macroalgas, dentre elas várias com interesse econômico, que podem ser aproveitadas para produção de alimentos, ração animal, fertilizantes, fármacos, entre outros, devido à quantidade significativa de proteínas, vitaminas e minerais, que contêm. No entanto, comumente elas têm sido descartadas, num momento em que há uma demanda crescente por insumos e alimentos e ao mesmo tempo um declínio acentuado dos recursos naturais. Dentro deste contexto, como parte de um projeto de cooperação internacional entre Alemanha e Brasil, intitulado, "SeaFeed: Ingredientes sustentáveis para alimentos e ração animal a partir de macroalgas", desenvolvido no âmbito da "Estratégia de Pesquisa Internacional de Bioeconomia" (BMBF, Alemanha), analisamos a composição específica e comparamos a biomassa de macroalgas arribadas em sete praias do nordeste e sudeste do Brasil, além de avaliar o potencial nutricional das espécies mais representativas nos locais de coleta. Um total de 142 táxons foi identificado e catalogado, sendo 22 Chlorophyta, 102 Rhodophyta e 18 Ochrophyta. A análise comparativa desse material mostrou maior diversidade de espécies no nordeste, enquanto os valores de cobertura e biomassa foram maiores no sudeste, atribuídos principalmente às espécies de Dictyotales. Com base na biomassa disponível durante a coleta, 12 espécies foram selecionadas para análise da composição química: sete espécies de Rhodophyta (*Agardhiella ramosissima*, *Alsidium seaforthii, A. triquetrum, Botryocladia occidentalis*, *Gracilaria domingensis*, *Halymenia brasiliana, Osmundaria obtusiloba*, *Spyridia clavata*), três espécies de Ochrophyta (*Dictyopteris jolyana*, *Spatoglossum schroederi*, *Zonaria tournefortii*) e uma espécie de Chlorophyta (*Codium isthmocladum*). Os resultados revelaram potencial nutricional como fonte de fibras naturais, proteínas, carboidratos, minerais aminoácidos e ácidos graxos. A tese foi organizada em três capítulos e apresentada como: I: Macroalgas arribadas da costa brasileira: biodiversidade e potencial de aproveitamento. II: Beach-cast seaweeds from Itaqui beach, coast of the state of Piauí, northeast of Brazil. III: Comparison of the diversity and biomass of beach-cast seaweeds from Northeastern and Southeastern Brazil. IV: Nutritional composition of beach-cast marine algae from the Brazilian coast: add-value for algal biomass considered as waste.

Palavras-chave: análise nutricional, biodiversidade, composição química, macroalgas.

ABSTRACT

There is a strong consensus that the world is experiencing global climate change, and that tropical storms have intensified, contributing to the occurrence of beach-cast seaweed on the Brazilian coast more frequently. Beach-cast seaweeds is a natural phenomenon where macroalgae are ripped from their substrates by the strong actions of waves, currents and tides, transporting the floating biomass to the beaches. In Brazil, the beach-cast are composed of many species of macroalgae, including several with economic interest, which can be used for the production of food, animal feed, fertilizers, pharmaceutical raw source, among others, due to the significant amount of proteins, vitamins and minerals, that contains. However, they have commonly been discarded at a time when there is a growing demand for inputs and food and at the same time a sharp decline in natural resources. Within this context, as part of an international cooperation project between Germany and Brazil, entitled, "SeaFeed: Sustainable ingredients for food and animal feed from macroalgae", developed under the "International Bioeconomy Research Strategy" (BMBF, Germany), we analyzed the specific composition and compared the biomass of macroalgae landed on seven beaches in northeastern and southeastern Brazil, in addition to evaluating the nutritional potential of the most representative species in the collection sites. A total of 142 taxa were identified and catalogued, being 22 Chlorophyta, 102 Rhodophyta and 18 Ochrophyta. The comparative analysis of this material showed greater species diversity in the northeast, while cover and biomass values were higher in the southeast, mainly attributed to Dictyotales species. Based on the biomass available during collection, 12 species were selected for analysis of chemical composition: seven species of Rhodophyta (*Agardhiella ramosissima*, *Alsidium seaforthii*, *A. triquetrum*, *Botryocladia occidentalis*, *Gracilaria domingensis*, *Halymenia brasiliana*, *Osmundaria obtusiloba*, *Spyridia clavata*), three species of Ochrophyta (*Dictyopteris jolyana*, *Spatoglossum schroederi*, *Zonaria tournefortii*) and one species of Chlorophyta (*Codium isthmocladum*). The results revealed nutritional potential as a source of natural fiber, proteins, carbohydrates, mineral, amino acids and fatty acids. The thesis was organized in four chapters and presented as: I: Macroalgas arribadas da costa brasileira: biodiversidade e potencial de aproveitamento. II: Beach-cast seaweeds from Itaqui beach, coast of the state of Piauí, northeast of Brazil. III: Comparison of the diversity and biomass of beach-cast seaweeds from Northeastern and Southeastern Brazil. IV: Nutritional composition of beach-cast marine algae from the Brazilian coast: add-value for algal biomass considered as waste.

Keywords: biodiversity, chemical composition, macroalgae, nutritional analysis.

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INTRODUÇÃO GERAL

1. INTRODUÇÃO GERAL

1.1. Ambiente Marinho

A terra, apesar do seu nome, é um planeta dominado por água. Os oceanos cobrem 362.000.000 km², o que representa aproximadamente 71% da superfície terrestre, sendo o principal reservatório de água (98% do total), oferecendo 300 vezes mais espaço habitável do que o provido por habitats terrestres e de água doce. Fatores como temperatura, luz, salinidade, nutrientes e outros, interagem para produzir habitats distintos. O ambiente marinho pode ser dividido em dois grandes domínios: o bentônico, que compreende a totalidade do substrato oceânico, e o pelágico, que corresponde a massa d'água total situada acima do leito submarino (Soares-Gomes & Figueredo 2009). Os habitats costeiros bentônicos estão entre os ambientes marinhos mais produtivos do planeta (Coutinho & Zalmon 2009).

O macrofitobentos é a comunidade de organismos vegetais macroscópicos que vivem no fundo do mar ou presos a superfícies sólidas. Isso inclui angiospermas e macroalgas marinhas, que são elementos-chave na estrutura e funcionamento dos ecossistemas costeiros (Suárez 1989). A influência das marés, a ação das ondas e flutuações do nível da água estão entre os fatores mais importantes para o desenvolvimento e distribuição da macrovegetação em áreas marítimas costeiras (Kautsky *et al.* 1999, Boller & Carrington 2006). As macroalgas possuem hábitos bentônicos, mas existem espécies capazes de sobreviverem flutuando na água, durante parte ou a totalidade da sua existência. Um exemplo notável dessa capacidade está no Mar de Sargaço, no qual algumas espécies do gênero *Sargassum* C.Agardh (e outras a elas associadas) flutuam em mar aberto como organismos planctônicos (Lourenço & Marques Junior 2009).

1.2.Biodiversidade

O Brasil é um país marítimo por natureza, possuindo um litoral que é banhado pelo Oceano Atlântico desde o cabo Orange até o Arroio Chuí, com uma faixa litorânea de 8.500 km e uma área oceânica de cerca 5,7 milhões de km² (Marinha do Brasil 2021), onde abriga uma enorme diversidade de espécies, entre elas, as macroalgas. Para as algas marinhas bentônicas, Oliveira Filho (1977), fez a primeira compilação de táxons infragenéricos, relacionando 327 Rhodophyta, 113 Chlorophyta e 64 Ochrophyta, totalizando 504 espécies. Atualmente o número de espécies de algas listadas para o Brasil é de 4.993, e destas aproximadamente 800 espécies correspondem às macroalgas marinhas que inclui os três filos (Chlorophyta, Ochrophyta e Rhodophyta). Estes organismos vivem desde a região entremarés até cerca de 250 m de profundidade em águas brasileiras (Henriques *et al.* 2014, Brasileiro *et al.* 2015, Cocentino *et al.* 2018, Simioni *et al* 2019, Flora do Brasil 2020, Yoneshigue-Valentin *et al.* 2020).

Apesar dos avanços no conhecimento da ficoflora brasileira, acredita-se que esses resultados sejam ainda subestimados, pois as floras brasileiras mais ricas correspondem às mais estudadas, ou seja, àquelas da região sudeste (Espírito Santo, Rio de Janeiro, São Paulo). As regiões nordeste e norte abrangem desde Estados com flora mais bem conhecida (Bahia e Pernambuco), até outras, pobremente inventariadas, tais como Sergipe, Alagoas, Piauí, Pará e Amapá. Outra lacuna existente está relacionada com o conhecimento da ficoflora do infralitoral que durante muito tempo foi negligenciada (Horta *et al.* 2001, Pacheco 2011).

Nos últimos anos esse panorama vem mudando gradativamente, com aumento de investimentos nessa área (Horta 2000, Amado-Filho *et al.* 2006, 2007, 2010, Guimarães *et al.* 2008, 2009, Rocha-Jorge *et al.* 2010, 2012, 2013, Bahia *et al.* 2015, Magalhães *et al.* 2015, Cocentino *et al.* 2018). Os resultados de estudos oriundos do Programa de Avaliação do Potencial Sustentável de Recursos Vivos da Zona Econômica Exclusiva (REVIZEE) também estão sendo divulgados, trazendo novas adições à flora ficológica brasileira de ecossistemas de águas mais profundas, tais como Cassano & Yoneshigue-Valentin (2001), Yoneshigue-Valentin & Loivos (2005), Yoneshigue-Valentin *et al.* (2005, 2006). Em face às diversas intervenções antrópicas na costa litorânea, além das mudanças climáticas que alteram a composição das comunidades, é de extrema relevância a elucidação das lacunas existentes no conhecimento da ficoflora, tanto pela presença das próprias espécies como agentes estruturadores do ambiente, quanto pela participação efetiva na cadeia trófica. Além da importância ecológica, esse conhecimento, aliado a outros (estudo das propriedades químicas, disponibilidade de biomassa etc.) estão intrinsicamente relacionados com a possibilidade de uso econômico e sustentável da biodiversidade.

1.3. Importância econômica

As algas marinhas são um recurso valioso que é usado em muitos países. As algas têm recebido grande atenção como fonte potencial de compostos bioativos, uma vez que são capazes de produzir vários metabólitos secundários com atividades biológicas, incluindo propriedades antioxidantes, antibacterianas, antifúngicas e antivirais (Mayer *et al.* 2007, Plaza *et al.* 2008, Plaza *et al.* 2010, Wang *et al.* 2009, Costa *et al.* 2010, Zhang *et al.* 2010, Stein *et al.* 2011, 2021, Fernandes *et al.* 2014, Gama *et al.* 2014, Machado *et al.* 2014, Nogueira *et al.* 2014, Pardo-Vargas *et al.* 2014, Lira *et al.* 2016, Noseda *et al.* 2018, dentre outros). O grande potencial de aplicação dos metabólitos secundários nas diferentes áreas, tais como medicinais, biológicas ou farmacológicas, ingredientes nutracêuticos e alimentos funcionais, tem estimulado a prospecção de novos compostos bioativos a partir de algas coletadas em vários lugares do mundo. As macroalgas verdes, marrons, e vermelhas contêm vários compostos inorgânicos e orgânicos benéficos para a saúde humana por causa do seu alto valor nutricional e suas propriedades curativas para muitas doenças (Frikha *et al.* 2011, Kuda *et al.* 2002).

Diante da realidade do crescimento populacional mundial, a descoberta por novas áreas de cultivo agrícola para produção de alimentos para o homem e animal tem-se mostrado determinante para assegurar o suprimento global de alimentos. Até o momento, o uso de macroalgas marinhas é limitado ao consumo humano direto e como matéria-prima para aditivos. Um grande impacto na sustentabilidade pode ser alcançado pela substituição de farinhas de origem animal e aditivos funcionais por frações obtidas de macroalgas. Para algumas espécies de macroalgas foram identificados vários benefícios à saúde devido à presença de metabolitos vegetais secundários. Assim, aplicações de tais frações em rações podem trazer benefícios à saúde animal e à qualidade de sua carne. Alguns autores analisaram e quantificaram os teores de proteínas, carboidratos, cinzas, iodo, cálcio, ferro, cloretos, fósforo, sódio e potássio em diversas algas da costa brasileira (Mandelli 1964, Yokoyama & Guimarães 1975, Guedes & Moura 1996, Calado 2003, Noseda *et al.* 2018).

No Brasil, apesar da extensa costa e da presença de habitats variados e rica flora marinha, o uso macroalgas é limitado, seja de cultivo artesanal ou de cultivo comercial, apenas alguns gêneros e espécies foram explorados comercialmente. Entre as espécies que ocorrem no Brasil e identificadas como economicamente importantes na produção de ficocolóides, estão as espécies de Gracilariales, com ampla distribuição, principalmente, na região Nordeste (Simioni *et al.* 2019). Estudos indicam que as algas arribadas da costa brasileira também possuem potencial a ser aproveitado e são promissoras economicamente (Barbosa 2010, Sacramento *et al.* 2013, Vila Nova *et al.* 2014).

1.4. Algas Arribadas

As macroalgas que são arrancadas dos seus substratos, levadas e acumuladas nas praias durante a maré baixa, são chamadas de algas arribadas. Esses acúmulos de algas podem ser formados por espécies bentônicas e/ou por espécies pelágicas, como ocorre com o Mar de Sargaço, em que as arribadas são consideradas monoespecíficas, por serem compostas apenas por espécies pelágicas de *Sargassum* (Areces *et al.* 1993), mas também podem ser multiespecíficas, pertencentes aos filos, Ochrophyta (algas marrons), Rhodophyta (algas vermelhas) e Chlorophyta (algas verdes). A composição das algas arribadas está relacionada com a localização geográfica, ficoclora local e a sazonalidade das espécies (Castillo-Arenas & Dreckmann 1995, Dreckmann & Sentíes 2013). A exposição às ondas também é um fator que influencia na composição das algas arribadas de uma praia, pois algumas espécies se desenvolvem melhor em locais protegidos e outras em locais mais expostos (Druehl 2000, Orr 2005). Vários fatores físicos e biológicos podem influenciar o desprendimento das macroalgas do fundo rochoso (Dayton *et al.* 1992, Pennings *et al.* 2000, Duarte *et al.* 2008). Entre os fatores abióticos, ventos e tempestades, são as principais causas desse desprendimento (Duarte *et al.* 2008). Outro fator biológico importante a ser considerado, porque influencia o desprendimento das algas dos seus substratos, é o dano estrutural produzido nas macroalgas por invertebrados (Dayton *et al.* 1992).

Após o desprendimento as algas são levadas e acumuladas nas praias num processo extremamente dinâmico (Kirkman & Kendrick 1997, Ochieng & Erftemeijer 1999), com eventos frequentes de ressuspensão e redeposição (durante as marés altas e baixas), o que pode dificultar a estimativa de deposição de material arribado. Orr *et al.* (2005) verificaram que as taxas de macroalgas que são depositadas nas praias variam em função do tipo de praia, hidrodinâmica, flutuabilidade das espécies e características do substrato. A velocidade do vento está mais relacionada com a formação das ondas (que geram forças e tensão e atuam no desprendimento das algas), do que na deposição das algas nas praias. que esta, está mais relacionada às correntes, morfologia e aspecto da praia. No entanto há uma necessidade de mais estudos para melhor compreensão desse processo, pois de acordo com Lopez *et al.* (2019) a capacidade de prever padrões temporais de biomassa de macroalgas arribadas ainda é limitada. Quanto ao crescente acúmulo das algas pelágicas do Mar de Sargaço, este tem sido relacionado às mudanças climáticas (Sissini *et al.* 2017, Wang *et al.* 2019, Johns *et al.* 2020) e ainda associado a níveis elevados de nutrientes (Suursaar *et al.* 2014). No entanto, nenhum desses estudos explicou o aparecimento súbito de *Sargassum* nos trópicos ou a recorrência anual e contínua de florações maciças, o que ainda requer monitoramento e pesquisas (Johns *et al.* 2020).

No que se refere, ao tempo de permanência das algas arribadas na praia, Suursaar *et al.* (2014) dizem ser variável, pois a biomassa de cada espécie vai influenciar no tempo de decomposição e que parte de todo material depositado retorna ao mar por ação das ondas, causando uma redução na biomassa e na diversidade do material depositado, principalmente das espécies flutuantes.

No tocante à aparência das macroalgas arribadas às praias, estas podem encontrar-se em estado fresco ou em processo de decomposição. Fatores abióticos, como o tempo de exposição, condições climáticas após o desprendimento e bióticos, como biomassa de cada espécie e ação microbiana vão interferir no estado e na aparência dessas algas (Inglis 1989, Orr *et al.* 2005, Duarte *et al.* 2008, Suursaar *et al.* 2014). Griffiths & Stenton-Dozey (1981) relataram que em uma praia da África do Sul macroalgas encalhadas na zona entremarés perderam aproximadamente 50% da água durante os primeiros dez dias após serem depositadas.

Está bem estabelecido que grandes quantidades de macroalgas são levadas para habitats costeiros e com consequências ecológicas significativas (Duggins *et al.* 1989, Bustamante *et al.* 1995). Contudo, o papel do fitodetrito arribado às praias é um sistema surpreendentemente pouco estudado na interface marinho-terrestre, em termos da noção de subsídios espaciais. Plantas e as algas arribadas são capazes de alterar a estrutura da comunidade fornecendo refúgio, servindo como alimento e habitat para vários invertebrados, aumentando a abundância da fauna na praia (Holmquist 1997, Pennings *et al*. 2000, Dugan *et al*. 2003, Orr *et al*. 2005) e liberando nutrientes após a decomposição bacteriana e, assim, alterando a química do sedimento (Harrison & Mann 1975, Levinton *et al*. 1984, Pellikaan 1984, Tenore *et al*. 1984). O acúmulo de algas arribadas pode também diminuir os efeitos das ondas, contribuindo para a estabilidade da praia e desempenhar um papel importante na formação de novas dunas (Ochieng & Erftemeijer 1999). Todavia, a complexidade desses depósitos, utilização da macrofauna, e os processos de decomposição bacteriana dependem da distribuição, quantidade e composição das espécies depositadas (Valiela *et al*. 1997).

No entanto, o influxo maciço de macroalgas pode potencialmente resultar em uma perturbação da vida marinha nas áreas costeiras. A grande deposição de macrófitas traz impactos negativos à subsistência socioeconômica (pesca e turismo) das comunidades costeiras. Em praias recreativas, a presença das algas arribadas é indesejável, principalmente no que diz respeito ao lazer, ao turismo, pois são vistas como um tipo de poluição, trazem incômodos tanto em termos visuais, quanto pelo odor, e a sua permanência na praia promove o aparecimento de insetos, bactérias e pragas (Hansen 1984, Blanche 1992, Dreckman & Sentíes 2013). A decomposição de algumas espécies, em grandes quantidades podem trazer problemas, a exemplo de *Sargassum* que não é tóxico, mas os grandes volumes de biomassa em decomposição podem levar à anoxia e aumento do sulfeto de hidrogênio, que é prejudicial a muitos animais marinhos e humanos. Isso pode, consequentemente, desencadear a mortalidade de peixes, invertebrados costeiros e pode ser um impacto severo para a pesca local, a aquicultura e turismo, fazendo com que a sua remoção pelas prefeituras seja um manejo usual e necessário a fim de manter as praias em boas condições para atividades recreativas e pesqueira (Zemke-White *et al*. 2005, Bamba *et al*. 2013, Cuevas *et al*. 2018).

Enquanto para algumas pessoas as algas arribadas são vistas como lixo, para outras, podem ser vistas como oportunidade, são meios de subsistência e representam o produto bruto de um recurso valioso. De acordo com Zemke-White *et al.* (2005) a colheita e o aproveitamento das algas arribadas ocorrem desde os tempos pré-históricos, mas o uso comercial é mais restrito a países temperados, como Canadá e Austrália. Para Kirkman & Kendrick (1997) a colheita gerenciada de áreas específicas, onde as algas arribadas são vistas como problemas, pode tanto limpar as praias afetadas, quanto produzir uma variedade de produtos econômicos: como ração para fauna marinha, ração para gado, fertilizante agrícola, corretivo de solo e produção de ficocolóides (alginato e ágar). Outros estudos apontam o uso das macroalgas arribadas, como fontes alternativas na produção de energia e como biossorventes (Bisanz *et al.* 1981, Volesky & Holan 1995, Volesky & Shiewer 1999). De acordo com Moreira *et al.* (2006), as algas arribadas que chegam na zona costeira são um importante recurso a ser considerado, devido aos metabólitos secundários que possuem e sua aplicação na indústria alimentícia, farmacêutica ou agrícola. Além do que evita a exploração das populações naturais de algas bentônicas, o que tem causado o desaparecimento e diminuição em números alarmantes deste recurso (Miranda 1998).

Por outro lado, a colheita de macroalgas arribadas pode impactar os ecossistemas costeiros e terrestres, removendo areia, acelerando o processo de erosão e mudando o perfil da topografia da praia, além de afetar as comunidades do infralitoral através da remoção das estruturas reprodutivas, assim como, a própria matéria orgânica e nutrientes associados. Outro possível impacto da colheita está relacionado à estrutura e dinâmica trófica das comunidades associadas (Kirkman & Kendrick 1997).

Apesar desses impactos, acredita-se que os municípios provavelmente continuarão a realizar a colheita das algas arribadas, principalmente a fim de garantir o lazer nas praias. Para minimizar o impacto prejudicial desta atividade, recomenda-se realizar a coleta usando uma tecnologia mais seletiva, para evitar que grande quantidade de areia seja removida e fazer compostagem das algas arribadas para uso como corretivos de solo, diminuindo as concentrações excessivas de sais solúveis nos solos e recuperando, em parte, o custo da colheita (Piriz *et al.* 2003). Além das perturbações ecológicas associadas à atividade de colheita, a confiabilidade do recurso, o efeito a longo prazo da exportação de nutrientes e carbono da região costeira, a variabilidade e irregularidade da distribuição da biomassa pode tornar esse recurso não viável em nível de produção industrial (Kirkman & Kendrick 1997).

1.5. Algas Arribadas no Brasil

A ocorrência das algas arribadas na costa brasileira é cada vez mais frequente, com maiores volumes e maior abrangência de área. Ocorrem com frequência em muitas praias do nordeste e em algumas do sudeste e sul do Brasil, durante a maré baixa (Câmara-Neto 1971, Câmara-Neto *et al.* 1981, Guedes & Moura 1996, Calado *et al.* 2003, Barbosa 2010, Sacramento *et al.* 2013, Santos *et al.* 2013, Vila Nova *et al.* 2014, Ferreira *et al.* 2020, Cavalcanti & Fujii 2021a, b). Apesar das grandes biomassas de *Sargassum* GASB (*Great Atlantic Sargassum Belt*), que são florações monoespecíficas já terem sido registradas no norte e nordeste do Brasil em julho de 2011 (Széchy *et al.* 2012) e novamente em 2014 e 2015 (Sissini *et al.* 2017), as algas arribadas da costa brasileira são tipicamente multiespecíficas, constituídas assim por espécies de algas vermelhas, marrons e verdes (Câmara-Neto 1971, Praciano 1977, Câmara-Neto *et al.* 1981, Pedrini 1984, Calado *et al.* 2003, Santos *et al.* 2013, Vila Nova *et al.* 2014, Ferreira *et al.* 2020, Cavalcanti & Fujii 2021a, b). Em contraste com as espécies pelágicas do GASB, as algas arribadas encontradas no litoral brasileiro são bentônicas, frequentemente fixas aos rodolitos, que ocorrem naturalmente no infralitoral. Com o crescimento dos talos, as algas flutuam e são empurradas para as praias através do movimento da água induzido pelo vento (Biber 2007). A diversidade taxonômica desse material está intrinsicamente relacionada à ficoflora bentônica conhecida para a região (Menezes *et al*. 2015). Contudo, Sacramento *et al*. (2013), relacionam o aumento de macroalgas arribadas nas praias de Santa Catarina às ações antrópicas de eutrofização das águas litorâneas, impulsionando o crescimento das algas.

Numa análise química de material arribado na costa do Ceará, Ferreira *et al*. (2020), verificaram o potencial nutricional de *Gracilaria cearensis* (A.B.Joly & Pinheiro) A.B.Joly & Pinheiro*, Hypnea pseudomusciformis* Nauer, Cassano & M.C.Oliveira e *Ulva lactuca* Linnaeus (como *U. fasciata*), para produção de fertilizantes orgânicos, devido à maior concentração de macronutrientes como nitrogênio (N), fósforo (P) e potássio (K) do que os fertilizantes comerciais utilizados. Para os micronutrientes, não foram detectadas grandes diferenças entre as concentrações presentes nas algas e no fertilizante.

1.6. Justificativa

Considerando o cenário atual em que há declínio dos recursos naturais, de um lado e um aumento crescente de demanda por alimentos do outro, é fundamental contribuir com a produção de alimento de forma sustentável a partir de recursos naturais renováveis. Dentro desse contexto, a catalogação, a identificação e avaliação do potencial de aproveitamento das macroalgas arribadas na costa brasileira é uma forma criativa e inovadora de utilizar os excedentes produzidos pela natureza e disponíveis para uso imediato, evitando o desperdício e causando um mínimo de impacto na terra. Somam-se a isso, o incremento no conhecimento dos representantes da ficoflora do infralitoral, que ainda é pobremente conhecida.

A presente proposta está inserida num projeto de cooperação internacional no âmbito da "Estratégia de Pesquisa Internacional de Bioeconomia" do Ministério Federal de Educação e Pesquisa (BMBF, Alemanha), intitulado "Ingredientes sustentáveis para alimentos e ração animal a partir de macroalgas – SeaFeed", incluindo algumas Instituições de ensino e pesquisa, como Instituto de Biociências/USP, Instituto de Botânica, Instituto de Pesca/Ubatuba, Instituto de Pesca do Estado do Rio de Janeiro, Departamento de Nutrição Animal – FMVZ/UNESP), além de setores das indústrias alimentícias no Brasil e na Alemanha.

O projeto binacional tem como objetivo identificar as macroalgas arribadas da costa brasileira, viabilizar o cultivo de espécies selecionadas, implementando a maricultura sustentável, gerar novas e amplas fontes biológicas de proteínas com alta funcionalidade para a indústria alimentícia, aproveitar resíduos, que ainda contenham teores de proteínas, óleos de alta qualidade e metabólitos secundários funcionais, como ingredientes de ração.

1.7. Hipóteses e Objetivos

1.7.1. Hipóteses

Hipótese A: O estudo da diversidade de algas arribadas da costa brasileira irá proporcionar um incremento no conhecimento da ficoflora bentônica do infralitoral e, principalmente daquelas de regiões menos estudadas, como do litoral do estado do Piauí.

Hipótese B: Quanto maior a diversidade de macroalgas arribadas conhecida, maior é o potencial biotecnológico, como fonte de fibras, proteínas, óleos e compostos químicos que possam ser aproveitados para alimentação humana e ração animal.

1.7.2. Objetivos

Objetivo geral: Conhecer a diversidade de macroalgas arribadas às praias da costa brasileira e avaliar o potencial para o seu aproveitamento.

Objetivos específicos:

I. Catalogar as espécies de macroalgas arribadas às praias das regiões nordeste e sudeste da costa brasileira e identificá-las por meio de estudos morfológicos, utilizando a técnica molecular, se necessária.

II. Catalogar as macroalgas arribadas no litoral do Piauí para promover o conhecimento da biodiversidade, contemplando locais com ficoflora pobremente inventariada.

III. Analisar e comparar a composição e dominância das macroalgas arribadas no litoral sudeste e nordeste do Brasil.

IV. Selecionar as espécies mais representativas e com biomassa significativa para analisar o perfil nutricional, visando aplicações biotecnológicas.

2. MATERIAL E MÉTODOS

2.1. Locais de estudo, coletas e processamento das amostras

2.1.1. Locais de estudo

As coletas foram realizadas em sete praias das regiões nordeste e sudeste da costa brasileira, conforme assinaladas no mapa (Figura 1). As praias foram selecionadas estrategicamente, com as informações prévias sobre frequência de ocorrência das algas arribadas nas mesmas.

Figura 1. Mapa destacando a costa brasileira, com os locais de coleta.

Descrição dos locais de estudo

A Praia do Itaqui está localizada no município de Luís Correia, no Piauí, nordeste do Brasil (2º54'.6"S e 41º34'28,1"W) (Figura 2). Segundo a classificação de Köppen, o clima litorâneo do Piauí é tropical chuvoso, quente e úmido, tipo (Aw’), com alta pluviosidade, no verão e outono devido à influência da massa atlântica equatorial, entre os meses de janeiro e junho e com temperaturas médias de 27 ºC. O Piauí, com o menor litoral do Brasil (66 Km) (FUNDAÇÃO CEPRO 2004), segundo Horta *et al*. (2001), está inserido em zona tropical que apresenta características ficogeográficas específicas, por apresentar uma flora relativamente rica, estabelecida predominantemente em recifes de arenito incrustados com calcário e algas coralináceas. A região é caracterizada por águas oligotróficas e abundância de substratos duros, propícios ao crescimento de algas bentônicas (Oliveira Filho 1977, Castro-Filho & Miranda 1998).

As praias de Emboaca (3º12'23,5"S e 39º18'37,1"W) e Guajiru (3º14’17.34"S e 39º13'59.1"W) estão localizadas no município de Trairi, Ceará, nordeste do Brasil (Figuras 3 e 4, respectivamente). A costa do Ceará possui uma extensa praia arenosa, localizada no extremo norte do Atlântico sudoeste tropical (Spalding *et al.* 2007). O litoral está sob a influência de ondas altamente energéticas, clima subúmido, altas temperaturas ao longo do ano (~ 26 °C), ventos fortes e um fluxo intenso de sedimentos ressuspensos, apesar da falta de insumos fluviais (Testa & Bosence 1998, Knoppers *et al.* 1999, Vital *et al.* 2010, Soares *et al.* 2018).

A praia de Candeias, está localizada em Jaboatão dos Guararapes, Pernambuco (8º12'46"S e 34º55'6"W), região nordeste do Brasil (Figura 5). Uma região onde o clima é tropical, definido como “AS” pelo critério Köppen-Geiger, com uma estação seca e úmida bem definida. Os recifes são de algas e corais, as correntes na área variam de 0,05 a 0,031 $m.s^{-1}$ com direção predominante de Sul para Norte, e com forte ação dos ventos de NE-SW (Borba 1999). A região nordeste é única pela ocorrência de águas oligotróficas e abundância de substrato, recifes de arenito incrustados com calcário de algas e corais possibilitando o desenvolvimento de uma rica flora marinha (Horta *et al.* 2001).

As praias de Maria Neném, Itaoca e Pontal estão localizadas em Piúma (20°50'33"S e 40°43'52.79"W), Itapemirim (20º54'18"S e 40°46'42,3"W) e Marataízes (21°00'19"S e 40°48,37'W), respectivamente, no sul do Espírito Santo, sudeste do Brasil. Segundo Horta *et al.* (2001), esta região apresenta características peculiares, como uma ampla diversidade de ambientes, que inclui formações recifais, substrato rochoso, fundos de substratos consolidados por concreções de algas calcárias e extensos bancos de rodolitos em águas sob a influência da Corrente Sul Equatorial (Lüning 1990). Esta corrente atinge o norte do estado do Espírito Santo, originando a Corrente do Brasil. A temperatura média (de 22 °C), com predominância de ventos alísios, provenientes de altas pressões. A diversidade de macroalgas marinhas é uma das maiores onde se encontra uma maior biodiversidade (Amado-Filho *et al*. 2007), atribuída a um conjunto de condições climáticas e oceanográficas particulares e à grande diversidade de habitats marinhos (Guimarães 2006). As praias estudadas são arenosas, urbanas, frequentadas por moradores e turistas (Figuras 6 e 8, respectivamente).

Figura 2. Praia de Itaqui, Luís Correia, Piauí, Brasil.

Figura 3. Praia de Guajiru, Trairi, Ceará, Brasil

Figura 4. Praia de Emboaca, Trairi, Ceará, Brasil.

Figura 5. Praia de Candeias, Jaboatão dos Guararapes, Pernambuco, Brasil

Figura 6. Praia de Maria Nenem, Piúma, Espírito Santo, Brasil.

Figura 7. Praia de Itaoca, Itapemirim, Espírito Santo, Brasil.

Figura 8. Praia do Pontal, Marataízes, Espírito Santo, Brasil.

O período de amostragens e os tipos de análise realizados em cada praia estão descritos na tabela 1.

Tabela 1. Período de amostragens e os tipos de análise realizados em cada praia amostrada.

Praia	Tipo de Análise	Data da Coleta
Itaqui – Luís Correia/PI	CE	Julho/ 2018
Emboaca – Trairi/CE	CE, CQ, ABs	Março/2018
Guajiru – Trairi/CE	CE	Dezembro/2018
Candeias – Jaboatão dos Guararapes/PE	CE, CQ, ABs	Fevereiro/ 2018
Maria Nenem – Piúma/ES	CE	Maio/ 2018
Itaoca – Itapemirim/ES	CE, CQ, ABs	Abril/ 2018
Pontal – Marataízes/ES	CE, CQ, ABs	Junho de 2017

Legenda: CE=composição específica, CQ=composição química, ABs=análise de biomassa seca.

2.1.2. Coleta e processamento

Foram realizados quatro tipos de coletas, visando atender aos diferentes objetivos: coleta para análise de composição da diversidade, para análise de biomassa, para análise da composição química, para análise molecular, portanto para cada uma delas foram utilizadas metodologias diferentes.

I - Coleta e processamento para análise da composição da específica das macroalgas arribadas

As amostras foram coletadas aleatoriamente, em vários pontos, de forma a contemplar, ao máximo, a área onde as algas arribadas foram depositadas. No local da coleta as amostras foram lavadas com água do mar para retirar o excesso de areia, em seguida foram acondicionadas em sacos plásticos, posteriormente fechados e identificados com nome da praia, localização geográfica e data da coleta. Depois foram congeladas e armazenadas em caixas térmicas a fim de serem transportadas ao laboratório de Ficologia do Instituto de Botânica de São Paulo, onde permaneceram armazenadas em freezer a -20 ºC, até a data do processamento.

No laboratório as amostras foram descongeladas para processamento. A primeira triagem do material foi feita a olho nu, apenas com o auxílio de luvas e pinça, em seguida procedeu-se a análise morfológica, que foi realizada sob microscópio estereoscópico (Zeiss, Stemi 2000-C), no qual foi observado o aspecto geral do talo, padrão de ramificação, presença de estruturas de reprodução e de epífitas. Para examinar as estruturas internas foram realizados cortes à mão livre com o auxílio de lâmina de aço sob microscópio estereoscópico, os quais foram analisados em microscópio óptico binocular (Zeiss, Primo Star). Quando necessário os cortes anatômicos foram corados com solução aquosa de azul de anilina (Tsuda & Abbott 1985). A descalcificação de espécimes calcificados foi realizada com HCl 1N. Quando necessário, lâminas semipermanentes foram montadas utilizando-se uma solução contendo formol a 4% e xarope de milho Karo®, na proporção de 1:1.

Todas as espécies foram devidamente descritas e ilustradas, sendo abordados aspectos da morfologia geral, e caracteres anatômicos diagnósticos, resultando no catálogo das macroalgas arribadas da costa brasileira. Após todos os estudos morfológicos os exemplares testemunhos foram herborizados e depositados no Herbário “Maria Eneyda P. Kauffman Fidalgo” (SP) do Instituto de Botânica e no Herbário do Instituto Federal do Piauí. As ilustrações das características morfológicas foram feitas através de fotografias e/ou fotomicrografias com câmera Samsung SM-G9600, lentes 4,30 mm (câmera de celular). As algas epífitas foram incluídas nesse estudo, mas não as coralináceas incrustantes.

A sistematização dos táxons foi feita de acordo com Wynne (2017), mas as atualizações taxonômicas após 2017 estão de acordo com AlgaeBase (Guiry & Guiry 2021). A identificação das espécies foi baseada em bibliografia especializada, tais como Joly (1957, 1965, 1967), Taylor (1960), Oliveira Filho (1969a), Pereira (1977), Cordeiro-Marino (1978), Guimarães (1990), Schneider & Searles (1991), Littler & Littler (2000), Nunes (2005), Dawes & Mathieson (2008), Soares (2015). Além destas, outras referências específicas para cada grupo de feofíceas, rodofíceas e clorofíceas também foram utilizadas. Para verificação da distribuição da espécie identificada na costa brasileira, utilizou-se informações da Flora do Brasil (2020).

II - Coleta e processamento das amostras para fins de comparação de biomassa seca

Para fins de comparação da biomassa seca, foi realizada coleta em quatro praias na costa brasileira, sendo duas na região nordeste (Praia de Candeias-PE e Praia de Emboaca-CE) e duas na região sudeste (Praia de Itaoca e Pontal, ambas no ES), utilizando-se um transecto de 20 m, com 3 repetições, que foram posicionados em sequência, de forma contínua e paralelos à linha de arrebentação das ondas, conforme Santos *et al.* (2013). Os transectos foram posicionados de forma que contemplassem, ao máximo a área onde as algas arribadas estavam depositadas. Em cada transecto, três quadrados de 25 cm X 25 cm foram posicionados aleatoriamente, conforme utilizados em trabalhos de aferição de biomassa de macroalgas marinhas, sendo um "n" satisfatório, (Figura 9). Para as amostragens todos os exemplares contidos nos quadrados foram coletados. No local da coleta as amostras, que totalizaram nove por praia, foram lavadas com água do mar, para retirar os detritos biogênicos e areias. Em seguida, foram acondicionadas em sacos plásticos hermeticamente fechados e devidamente identificados com nome da praia, localização geográfica, data da coleta, número do transecto (que foram três por praia) e número do quadrado (que foram três por transecto). Depois foram congeladas e armazenadas em caixas térmicas a fim de serem transportadas ao laboratório de Ficologia, do Instituto de Botânica, em São Paulo, onde permaneceram armazenadas em freezer, com temperatura de -20º até o momento do processamento. Essas amostras foram utilizadas para obtenção e análise de biomassa seca, e complementares à análise de composição específica.

Houve única exceção a essa metodologia, que foi na primeira coleta, na Praia de Pontal, Marataízes, ES, onde ao invés do congelamento, as amostras foram colocadas numa solução de água do mar e formol a 4%. O veículo que utilizávamos nessa coleta, permitiu o transporte desse material nessa condição, sendo de via terrestre. A partir daí, o transporte foi via aérea e a opção foi a acima descrita.

Para obtenção de biomassa seca, as amostras foram sendo descongeladas, triadas e aquelas que ainda não haviam sido identificadas, usou-se a metodologia adotada para a identificação taxonômica. Para as demais amostras, prosseguiram-se, com lavagem para remoção de organismos e/ou detritos e triagem (Figura 10). Após triagem, as amostras foram colocadas em estufa a 60 ºC para secagem de até 48h ou até a obtenção do peso constante. Após a secagem, as amostras foram pesadas em balança semi-analítica e os dados obtidos foram submetidos a testes estatísticos para fins de comparação entre os táxons e entre as regiões nordeste e sudeste brasileiro (Figura 11). Os valores obtidos foram padronizados para as unidades de biomassa como gramas de massa seca por metro quadrado (gms.m^{-2}), de acordo com Mafra Jr. & Cunha (2002).

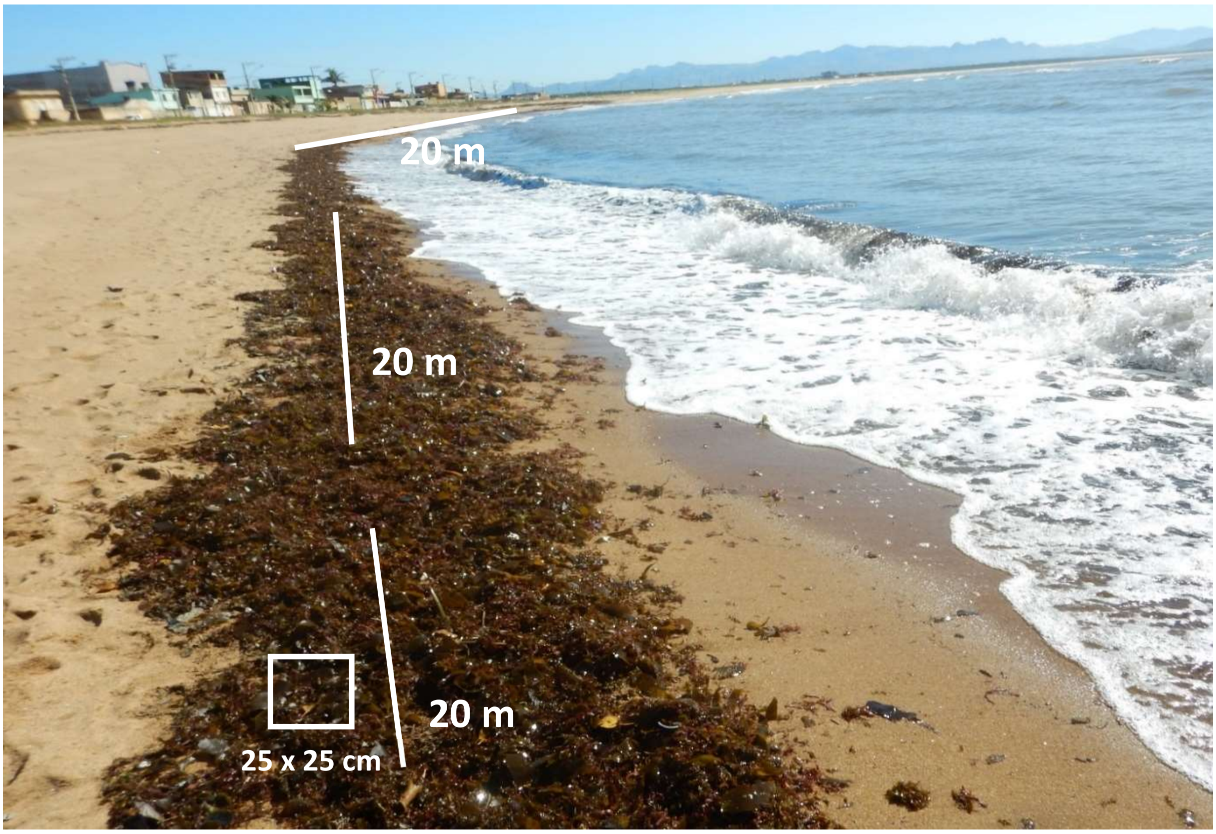

Figura 9. Método do transecto, utilizado para análise de biomassa.

Figura 10. Etapas de coleta e processamento das amostras.

Figura 11. Etapas de processamento das amostras para obtenção de biomassa seca.

III - Coleta e processamento das amostras para obtenção para análise da composição química

Para fins de análise da comparação química, foi realizada coleta em quatro praias na costa brasileira, sendo duas na região nordeste (Praia de Candeias-PE e Praia de Emboaca-CE) e duas na região sudeste (Praia de Itaoca e Pontal, ambas no ES), conforme tabela 1. Durante a coleta, os táxons que apresentaram maiores volumes de biomassa foram selecionados separados para análise de composição química. Nas quatro praias estudadas, doze espécies foram identificadas como promissoras em termos de potencial biotecnológico (Tabela 2, Figura 12). Todas as amostras coletadas foram acondicionadas em sacos plásticos, devidamente identificados com nome do táxon, nome da praia, localização geográfica e data da coleta. Após a coleta, as algas foram triadas, lavadas três vezes em água doce para retirada de detritos, epífitas, organismos incrustantes e excesso de sal, e secas ao ar livre, em média por 48h. Posteriormente, as amostras secas foram embaladas em sacos plásticos devidamente identificados e transportadas ao LAM, Laboratório de Algas Marinhas da USP. No laboratório as amostras foram secas em estufa a 40º C, por 72 horas, com posterior trituração, em moinho de bolas (Figuras 13 e 14). Após a moagem, porções de 4 e 6 mg foram pesadas em balança semi-analítica para a etapa de obtenção dos carboidratos. Paralelamente, amostras de aproximadamente 1 g foram pesadas e enviadas ao Centro Analítico da USP para análise de minerais e metais (Ca, Cd, Cu, Fe, K, Mg e Na). Todas as determinações foram realizadas em triplicatas (n = 3). Além disso, amostras de 40 g de cada espécie foram pesadas e enviadas ao Instituto Fraunhofer IVV, Freising, Alemanha, para serem submetidas a análises de proteína total solúvel e insolúvel, lipídios e ácidos graxos, fibras, cinzas e umidade.

Tabela 2. Algas arribadas identificadas, com base em dados de biomassa, como promissoras em termos de potencial biotecnológico.

Praias	**Táxons**
Emboaca, Trairi, CE	*Alsidium triquetrum* (S.G.Gmelin) Trevisan, *Botryocladia occidentalis* (Børgesen) Kylin, *Gracilaria domingensis* (Kützing) Sonder ex Dickie.
Candeias, PE	*Spatoglossum schroederi* (C.Agardh) Kützing
Itaoca, Itapemirim, ES	*Agardhiella ramosissima* (Harvey) Kylin, *Codium isthmocladum* Vickers, *Halymenia brasiliana* S.M.P.B.Guimarães & M.T.Fujii.
Pontal, Marataízes, ES	*Alsidium seaforthii* (Turner) J.Agardh, *Dictyopteris jolyana* E.C.Oliveira & R.P.Furtado, *Osmundaria obtusiloba* (C.Agardh) R.E.Norris, *Spyridia clavata* Kützing, *Zonaria tournefortii* (J.V.Lamouroux) Montagne.

Figura 12. Espécies que apresentaram os maiores valores de biomassa, e, portanto, selecionadas para análise química. A. *Agardhiella ramosissima;* B. *Alsidium triquetrum;* C. *Botryocladia occidentalis;* D. *Alsidium seaforthii;* E. *Gracilaria domingensis;* F. *Codium isthmocladum;* G. *Halymenia brasiliana;* H. *Spyridia clavata;* I. *Osmundaria obtusiloba;* J. *Dictyopteris jolyana;* K. *Spatoglossum schroederi;* L. *Zonaria tournefortii*. Escalas: 2 cm (A, B, J, F, K); 1 cm (D, E, H, L); 3 cm (G, I); 0,5 cm (C).

Figura 13. Etapas de processamento das amostras para análise de composição química.

Figura 14. Etapas de processamento para moagem das amostras destinadas às análises da composição química.

Extração e estimativa de carboidratos

Os carboidratos totais foram dosados pelo método do ácido fenol-sulfúrico (Dubois *et al.* 1956) e a leitura da absorbância foi realizada em espectrofotômetro, regulado para comprimento de onda de 490 nm. O conteúdo foi calculado em porcentagem por referência à curva padrão de glicose.

Estimativa do conteúdo de minerais

Os conteúdos totais de diferentes elementos foram determinados na solução digerida usando um espectrômetro de plasma acoplado por indução (ICP OES, Radial, Spectro, modelo Arcos) (Allen *et al.* 1997).

IV - Coleta de amostras para fins de análise molecular

Durante as coletas, as amostras que não puderam ser identificadas com base em morfologia do talo e/ou aquelas mais raras, foram separadas e preparadas para molecular com propósito de barcoding. No local de coleta, essas amostras, foram devidamente identificadas (geralmente com o nome do gênero e mais outro nome que fizesse referência a alguma característica observada na amostra), nome da praia, localização geográfica e data da coleta. Foram selecionadas as porções mais jovens dos talos e livre de epibiontes. Foi realizada limpeza e depois foram secas em papel absorvente e colocadas em saquinhos de chá, e imediatamente armazenadas em sílica gel dessecante, para posterior análise no laboratório de molecular do Núcleo de Ficologia do Instituto de Botânica de São Paulo.

Organização da Tese

Após a introdução geral, material e métodos comum, a tese foi desenvolvida em quatro capítulos, atendendo aos objetivos propostos, como seguem:

Capítulo I – MACROALGAS ARRIBADAS DA COSTA BRASILEIRA: BIODIVERSIDADE E POTENCIAL DE APROVEITAMENTO.

Este capítulo, atende ao primeiro objetivo da tese e refere-se à catalogação dos táxons que foram identificados nas sete praias estudadas. O livro foi publicado pela Editora CRV, 2021. 278p. Doi: 1024824/978652510775.2.

Capítulo II - BEACH-CAST SEAWEEDS FROM ITAQUI BEACH, COAST OF THE STATE OF PIAUÍ, NORTHEAST OF BRAZIL

Este capítulo refere-se ao segundo objetivo e traz um levantamento pioneiro das algas arribadas da costa do Piauí, com adições de novos registros e indicação de possibilidades de potenciais novas espécies para a ciência. Foi publicado na revista Pesquisas, Botanica, 2021. 75: 381-414. ISSN-2525-7412.

Capítulo III - COMPARISON OF THE DIVERSITY AND BIOMASS OF BEACH-CAST SEAWEEDS FROM NORTHEASTERN AND SOUTHEASTERN BRAZIL.

O capítulo atende ao terceiro objetivo e refere-se à análise comparativa da diversidade e da biomassa das algas arribadas encontradas em duas praias da região nordeste (Candeias-PE e

Emboaca-CE) e duas da região sudeste (Itaoca e Pontal, ambas do ES). O manuscrito está submetido para publicação na revista European Journal Phycology, e encontra-se em análise.

Capítulo IV - NUTRITIONAL COMPOSITION OF BEACH-CAST MARINE ALGAE FROM THE BRAZILIAN COAST: ADD-VALUE FOR ALGAL BIOMASS CONSIDERED AS WASTE.

Este capítulo atende ao quarto objetivo e traz o perfil nutricional de 12 espécies de macroalgas que apresentaram maiores valores de biomassa, em quatro Praias estudadas, duas da região nordeste (Candeias-PE e Emboaca-CE) e duas da região sudeste (Itaoca e Pontal, ambas do ES). O manuscrito será submetido para publicação na revista Food Chemistry.

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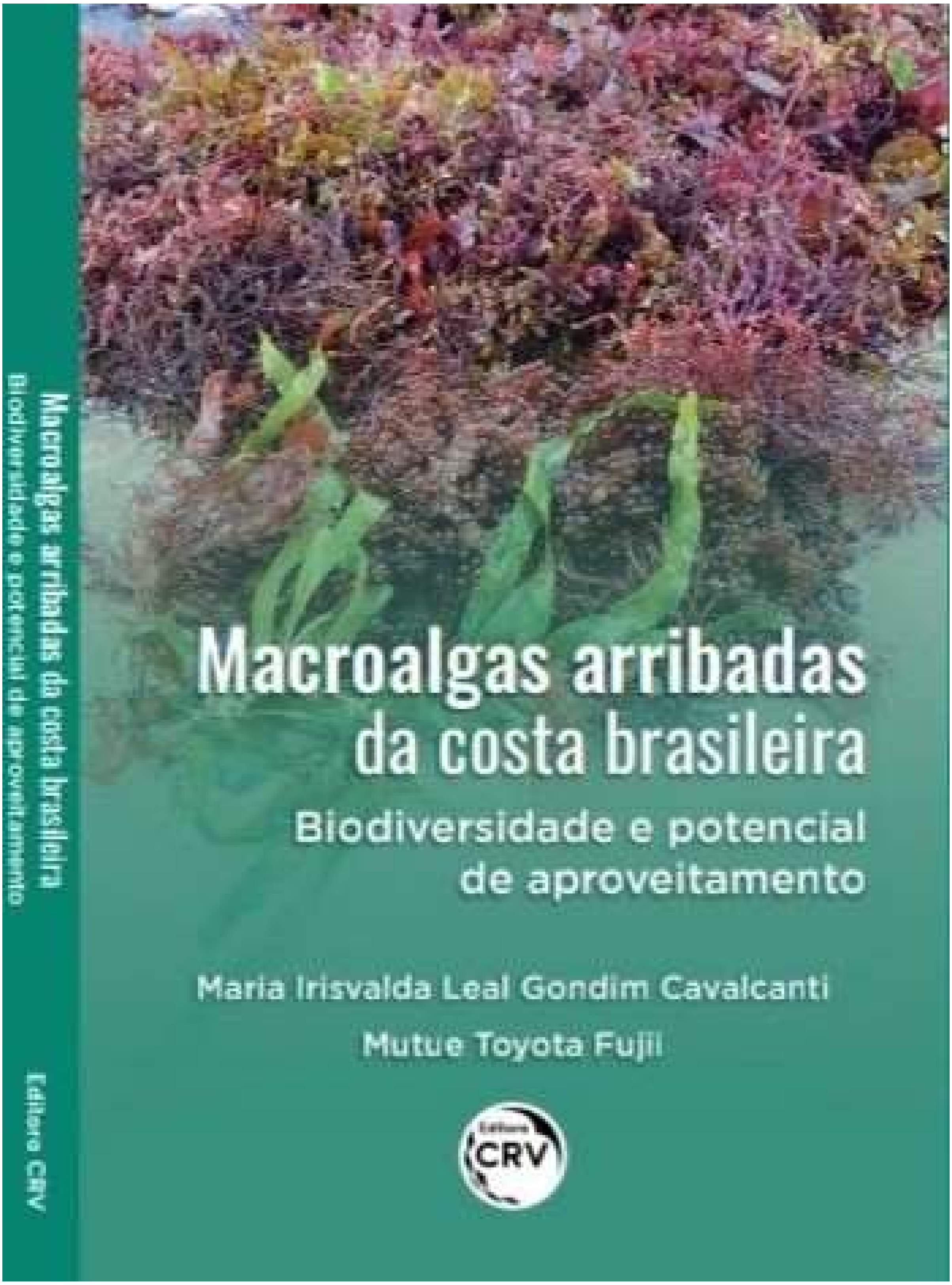
CAPÍTULO I



Macroalgas arribadas da costa brasileira
Biodiversidade e potencial de aproveitamento

Maria Irisvalda Leal Gondim Cavalcanti
Mutue Toyota Fujii

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Aqui apresentamos, na tabela 1, a lista dos táxons que foram catalogados e publicados no Macroalgas Arribadas da Costa Brasileira: biodiversidade e potencial de aproveitamento, na forma e impressa e digital. Foram identificados 142 táxons, destes 18 pertencem ao filo Ochrophyta (1 classe, 3 ordens, 3 famílias e 10 gêneros), 102 ao filo Rhodophyta (1 classe, 10 ordens, 20 famílias e 45 gêneros) e 22 ao filo Chlorophyta (1 classe, 3 ordens, 8 famílias e 9 gêneros). Na publicação, constam, ainda, descrições, ilustrações, ocorrência e distribuição de cada táxon na costa brasileira e potencial biotecnológico com base em literatura consultada, além de uma apresentação, introdução, material e métodos (locais de coleta e processamento das amostras), sinopse taxonômica, registro de novos táxons, constatações adquiridas no estudo, glossário de termos usuais num estudo de algas arribadas e literatura citada.

Tabela 1. Lista dos táxons de macroalgas das praias amostradas.

Táxons	**Praias**						
	PI	**PG**	**PE**	**PC**	**PMN**	**PITA**	**PP**
Filo Ochrophyta							
Classe Phaeophyceae							
Ordem Dictyotales							
Família Dictyotaceae							
Canistrocarpus cervicornis (Kützing) De Paula & De Clerck	x						
Canistrocarpus crispatus (J.V.Lamouroux) De Paula & De Clerck	x						
Dictyota mertensii (C.Martius) Kützing	x	x					
Dictyota menstrualis (Hoyt) Schnetter, Hörning & Weber-Peukert			x				
Dictyota ciliolata Sonder ex Kützing			x				
Dictyopteris jolyana E.C.Oliveira & R.P.Furtado	x	x	x	x	x	x	x
Dictyopteris delicatula J.V.Lamouroux	x	x	x	x	x	x	x

Dictyopteris plagiogramma (Montagne) Vickers		x	x				
Dictyopteris polypodioides (A.P.De Candolle) J.V.Lamouroux				x			
Dictyopteris justii J.V.Lamouroux				x			
Lobophora variegata (J.V.Lamouroux) Womersley ex E.C.Oliveira	x	x	x	x	x	x	x
Padina gymnospora (Kützing) Sonder	x	x	x	x	x	x	x
Stypopodium zonale (J.V.Lamouroux) Papenfuss	x			x		x	x
Spatoglossum schroederi (C.Agardh) Kützing	x	x	x	x	x	x	x
Zonaria tournefortii (J.V.Lamouroux) Montagne	x	x	x	x	x	x	x
Ordem Ectocarpales							
Família Scytosiphonaceae							
Colpomenia sinuosa (Mertens ex Roth) Derbès & Solier	x						
Ordem: Fucales							
Família: Sargassaceae							
Sargassum filipendula C.Agardh	x	x	x	x	x	x	x
Sargassum vulgare C.Agardh	x	x	x	x	x	x	x
Filo Rhodophyta							
Classe Florideophyceae							
Ordem Ceramiales							
Família Callithamniaceae							
Aglaothamnion felipponei (Howe) Aponte, Ballantine & J.N.Norris	x						
Spyridia clavata Kützing					x	x	x

Spyridia filamentosa (Wulfen) Harvey							x
Spyridia hypnoides (Bory) Papenfuss						x	
Familia Ceramiaceae							
Centroceras gasparinii (Meneghini) Kützing							x
Ceramium brasiliense A.B.Joly				x			
Ceramium deslongchampsii Chauvin ex Duby				x			
Ceramium fujiianum Barros-Barreto & Maggs	x						
Ceramium sp1**.**				x			
Família Delesseriaceae							
Dasya rigidula (Kützing) Ardissone	x						
Dictyurus occidentalis J.Agardh	x						
Heterosiphonia crispella (C.Agardh) M.J.Wynne	x						
Família Rhodomelaceae							
Acanthophora muscoides (Linnaeus) Bory			x				
Acanthophora spicifera (M.Vahl) Børgesen			x			x	
Alsidium seaforthii (Turner) J.Agardh	x	x	x	x	x	x	x
Alsidium triquetrum (S.G.Gmelin) Trevisan		x	x	x		x	
Amansia multifida J.V. Lamouroux	x	x	x	x	x	x	x
Dipterosiphonia dendritica (C.Agardh) F.Schmitz						x	
Enantiocladia duperreyi (C.Agardh) Falkenberg				x			

Halopithys schottii (W.R.Taylor) L.E.Phillips & De Clerck						x	x
Heterodasya mucronata (Harvey) M.J.Wynne	x					x	x
Herposiphonia secunda (C.Agards) Ambronn	x						
Laurencia catarinensis Cordeiro-Marino & Fujii			x				
Laurencia dendroidea J.Agardh			x			x	x
Laurencia translucida M.T. Fujii & Cordeiro-Marino			x	x			
Osmundaria obtusiloba (C.Agardh) R.E.Norris	x	x	x	x	x	x	x
Osmundaria sp. 1				x			
Osmundaria sp. 2						x	x
Osmundaria sp. 3							x
Palisada flagellifera (J.Agardh) K.W.Nam			x				x
Palisada furcata (Cordeiro-Marino & M.T.Fujii) Cassano & M.T.Fujii				x			x
Palisada perforata Bory K.W.Nam				x			x
Palisada sp.							x
Yuzurua sp.					x		
Família Wrangeliaceae							
Haloplegma duperreyi Montagne	x	x	x	x	x	x	x
Ordem Corallinales							
Família Corallinaceae							
Corallina panizzoi R.Schnetter & U.Richter				x			

Jania capillacea Harvey	x						x
Jania crassa J.V.Lamouroux			x				
Jania pedunculata var. adhaerens *(J.V.Lamouroux) A.S.Harvey, Woelkerling & Reviers*	x						x
Jania subulata *(Ellis & Solander) Sonder*	x	x	x	x	x	x	x
Ordem Gelidiales							
Família Gelidiaceae							
Gelidium brasiliense Brunelli, Boo & M.T.Fujii in Brunelli & al.							x
Gelidium crinale (Hare ex Turner) Gaillon				x			
Gelidium lineare Iha & Freshwater				x			
Gelidium sp.		x	x				
Família Gelidiellaceae							
Gelidiella acerosa (Forsskål) Feldmann & Hamel			x				
Família Pterocladiaceae							
Pterocladiella beachie Freshwater							x
Ordem Gigartinales							
Família Cystocloniaceae							
Calliblepharis jolyi E.C.Oliveira	x			x		x	x
Calliblepharis occidentalis Joly & Yamaguishi-Tomita	x		x			x	
Hypnea cervicornis J.Agardh	x						

Hypnea cornuta (Kützing) J.Agardh	x						
Hypnea pseudomusciformis Nauer, Cassano & M.C.Oliveira	x	x	x	x	x	x	x
Familia Gigartinaceae							
Chondracanthus acicularis (Roth) Fredericq				x			
Chondracanthus saundersii C.W.Schneider & C.E.Lane				x			
Chondracanthus teedei (Mertens ex Roth) Kützing				x			
Família Solieriaceae							
Agardhiella floridana (Kylin) P.W.Gabrielsen ex Guimarães & Oliviera	x	x	x	x	x	x	x
Agardhiella ramosissima (Harvey) Kylin	x	x	x	x	x	x	x
Agardhiella subulata (C.Agardh) Kraft & M.J.Wynne	x						
Meristotheca gelidium (J.Agardh) E.J.Faye & M.Masuda	x		x				x
Solieria filiformis (Kützing) Gabrielson	x			x			
Família Rhizophyllidaceae							
Ochtodes secundiramea (Montagne) M.Howe	x			x			x
Ordem Gracilariales							
Crassiphycus birdiae (E.Plastino & E.C.Oliveira) Gurgel, J.N.Norris & Fredericq		x	x	x			

Crassiphycus caudatus (J.Agardh) Gurgel, J.N.Norris & Fredericq		x	x	x				
Crassiphycus corneus (J.Agardh) Gurgel, J.N.Norris & Fredericq	x	x	x	x				
Gracilaria baiana Lyra, Gurgel, M.C.Oliveira & Nunes				x				
Gracilaria cearensis (A.B.Joly & Pinheiro) A.B.Joly & Pinheiro			x	x				
Gracilaria cervicornis (Turner) J.Agardh	x	x	x	x				
Gracilaria cuneata Areschoug		x	x	x				
Gracilaria curtissiae J.Agardh	x	x	x	x				
Gracilaria domingensis (Kützing) Sonder ex Dickie	x	x	x	x				
Gracilaria hayi Gurgel, Fredericq & J.N.Norris	x		x					
Gracilaria isabellana Gurgel, Fredericq & J.N.Norris				x				
Gracilaria ornata Areschoug			x	x				
Gracilaria sp. 1	x							
Gracilaria sp. 2	x							
Gracilaria sp. 3	x							
Gracilaria sp. 4	x							
Gracilaria sp. 5				x				
Gracilaria sp. 6				x				
Gracilaria sp. 7								x

Gracilariopsis silvana Gurgel, Fredericq & J.N.Norris				x			
Ordem Halymeniales							
Família Halymeniaceae							
Cryptonemia bengryi W.R.Taylor			x				
Cryptonemia crenulata (J.Agardh) J.Agardh			x	x			
Cryptonemia luxurians (C.Agardh) J.Agardh	x	x	x	x	x	x	x
Dermocorynus dichotomus (J.Agardh) Gargiulo, M.Morabito & Manghisi						x	
Grateloupia cuneifolia J.Agardh						x	
Grateloupia filicina (J.V.Lamouroux) C.Agardh						x	
Halymenia brasiliana S.M.P.B.Guimarães & M.T.Fujii					x	x	
Halymenia cearensis C.A.A.Azevedo, Cassano & M.C. Oliveira		x					
Halymenia elongata C.Agardh				x			
Halymenia ignifera C.A.A.Azevedo, Cassano & M.C.Oliveira				x	x		
Halymenia pinnatifida C.A.A.Azevedo, Cassano & M.C.				x	x		
Halymenia integra M.Howe & W.R.Taylor					x	x	
Ordem Nemaliales							
Família Galaxauraceae							

Dichotomaria marginata (J.Ellis & Solander) Lamarck	x						x
Tricleocarpa cylindrica (J.Ellis & Solander) Huisman & Borowitzka							x
Tricleocarpa fragilis (Linnaeus) Huisman & R.A.Townsend							x
Família Scinaiaceae							
Scinaia halliae (Setchell) Huisman				x			
Ordem Peyssonneliales							
Família Peyssonneliaceae							
Sonderophycus capensis (Montagne) M.J.Wynne							x
Ordem Plocamiales							
Família Plocamiaceae							
Plocamium brasiliense (Greville) M.Howe & W.R.Taylor							x
Ordem Rhodymeniales							
Família Champiaceae							
Champia parvula (C.Agardh) Harvey		x					
Família Lomentariaceae							
Ceratodictyon planicaule (Taylor) Wynne	x	x	x	x	x	x	x
Ceratodictyon scoparium (Montagne & Millardet) R.E.Norris			x				
Família Rhodymeniaceae							

Botryocladia occidentalis (Børgesen) Kylin			x			
Filo Chlorophyta						
Classe Ulvophyceae						
Ordem Bryopsidales						
Família Bryopsidaceae						
Bryopsis hypnoides J.V. Lamouroux			x	x		
Bryopsis pennata J.V.Lamouroux	x	x	x	x		x
Bryopsis plumosa (Hudson) C.Agardh			x			
Família Caulerpaceae						
Caulerpa cupressoides var. lycopodium Weber Bosse		x		x		
Caulerpa cupressoides var. serrata (Kützing) Weber Bosse		x				
Caulerpa mexicana Sonder ex Kützing		x				
Caulerpa microphysa (Weber Bosse) Feldmann				x		
Caulerpa prolifera (Forsskål) J.V.Lamouroux		x	x	x		
Caulerpa racemosa (Forsskål) J.Agardh		x	x			x
Caulerpa sertularioides (S.G.Gmelin) M.Howe		x	x	x		x
Família Codiaceae						
Codium decorticatum (Woodward) M.Howe		x				x
Codium intertextum Collins & Hervey		x				
Codium isthmocladum Vickers						x
Familia Halimedaceae						

Halimeda gracilis Harv. ex J. Agardh			x				
Halimeda jolyana Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen & S.M.B.Pereira	x						x
Família Udoteaceae							
Udotea flabellum (J.Ellis & Solander) M.Howe		x					
Ordem Cladophorales							
Família Anadyomenaceae							
Anadyomene stellata (Wulfen) C.Agardh		x					
Família Cladophoraceae							
Cladophora dalmatica Kützing		x					
Cladophora prolifera (Roth) Kützing			x	x			x
Willeella ordinata Børgesen	x	x					
Ordem Ulvales							
Família Ulvaceae							
Ulva lactuca Linnaeus		x	x	x		x	x
Ulva rígida C.Agardh			x				

Legenda: PI=Praia de Itaqui, Luís Correia, PI; PG=Praia de Guajiru, Trairi, CE; PE=Praia de Emboaca, Trairi CE; PC=Praia de Candeias, Jaboatão dos Guararapes, PE; PMN=Praia de Maria Nenem, Piúma, ES; PITA=Praia de Itaoca, Itapemirim, ES; PP=Praia do Pontal, Marataízes, ES.

CAPÍTULO II

BEACH-CAST SEAWEEDS FROM ITAQUI BEACH, COAST OF THE STATE OF PIAUÍ, NORTHEAST OF BRAZIL

Maria Irisvalda Leal Gondim Cavalcanti[1]
Mutue Toyota Fujii[2]

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ABSTRACT

The phycoflora on the coast of Piauí is still among the least studied in Brazil, especially when it comes to knowledge of the infralittoral. The flora of the infralittoral in Brazil is known mainly for the analysis of material stored on the beaches. Beach-cast seaweeds originate from benthic algal banks, mainly from the infralittoral and occur frequently on many beaches in the northeastern, southeastern, and south of Brazil, during low tide. Studies indicate the great biotechnological potential of algae with possibilities of its use, in the production of phycocolloids, such as human food, animal feed, fertilizers, drugs, among others. However, the beach-cast seaweeds have been treated like garbage, commonly incinerated or collected for landfills. Therefore, there is an urgent need for taxonomic identification of its components in order to, from there, know its biotechnological potential, as well as its biogeographic and ecological implications. The identification of the beach-cast seaweeds on the beach on the coast of Piauí is a pioneering study, in addition, this is the first record of a study of macroalgae on the beach of Itaqui. The objective of this study was to identify the beach-cast seaweeds in Itaqui beach, municipality of Luis Correia, Piauí, located in the northeastern of Brazil (2º 54'.6" S 41º 34' 28.1" W). Collections were carried out along the entire length of the wave breaking line, where the seaweeds were present during low tide, in July 2017. Taxonomic identification was performed under a stereomicroscope and microscope, based on morphological characters. 55 taxa were identified, with fourteen new occurrences for the Piauí coast: *Agardhiella ramosissima* (Harvey) Kylin, *Aglaothamnion felipponei* (Howe) Aponte, Ballantine & J.N.Norris, *Canistrocarpus crispatus* (J.V.Lamouroux) De Paula & De Clerck Clerck & al., *Crassiphycus caudatus* (J.Agardh) Gurgel, J.N.Norris & Fredericq, *Dichotomaria marginata* (J.Ellis & Solander) Lamarck, *Halimeda jolyana* Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen & S.M.B. Pereira, *Heterodasya mucronata* (Harvey) M.J.Wynne, *Heterosiphonia crispella* (C.Agardh) M.J.Wynne, *Hypnea cornuta* (Kützing) J.Agardh, *Laurencia translucida* Fujii & Cordeiro-

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Marino, *Meristotheca gelidium* (J.Agardh) E.J.Faye & M.Masuda, *Stypopodium zonale* (J.V.Lamouroux) Papenfuss, *Willeella ordinata* Børgesen, *Zonaria tournefortii* (J.V.Lamouroux) Montagne, in addition to *Gracilaria* spp., *Grateloupia* sp., *Hypnea* sp. that are potential new species.

Keywords: beach-cast seaweeds, marine biodiversity, stranded seaweeds.

RESUMO

A ficoflora no litoral do Piauí ainda está entre as menos estudadas no Brasil, principalmente no que diz respeito ao conhecimento do infralitoral. A flora do infralitoral no Brasil é conhecida principalmente pela análise de material arribado às praias. As algas marinhas arribadas são originárias de bancos de algais bentônicos, principalmente do infralitoral e ocorrem frequentemente em muitas praias do nordeste, sudeste e sul do Brasil, durante a maré baixa. Estudos apontam o grande potencial biotecnológico das algas com possibilidades de seu uso, na produção de ficocolóides, como alimentação humana, ração animal, fertilizantes, medicamentos, entre outros. No entanto, as macroalgas arribadas são tratadas como lixo, comumente incineradas ou coletadas para aterros sanitários. Portanto, há uma necessidade urgente de identificação taxonômica dos seus componentes para a partir daí, conhecer o seu potencial biotecnológico, assim como as suas implicações biogeográficas e ecológicas. A identificação de algas marinhas fundidas na praia do litoral do Piauí é um estudo pioneiro; além disso, este é o primeiro registro de um estudo de macroalgas na praia de Itaqui. O objetivo deste estudo foi identificar as algas encontradas na Praia de Itaqui, município de Luis Correia, Piauí, localizado no nordeste do Brasil (2º 54'.6" S 41º 34' 28.1" W). As coletas foram realizadas ao longo de todo o comprimento da linha de quebra de ondas, onde as algas estavam presentes durante a maré baixa, em julho de 2017. A identificação taxonômica foi realizada sob estereomicroscópio e microscópio, com base em caracteres morfológicos. Foram identificados 55 táxons, com quatorze novas ocorrências para a costa do Piauí: *Agardhiella ramosissima* (Harvey) Kylin, *Aglaothamnion felipponei* (Howe) Aponte, Ballantine e J.N.Norris, *Canistrocarpus crispatus* (J.V.Lamouroux) De Paula e De Clerck Clerck & ca., *Crassiphycus caudatus* (J.Agardh) Gurgel, J.N.Norris & Fredericq, *Dichotomaria marginata* (J. Ellis e Solander) Lamarck, *Halimeda jolyana* Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen e S.M.B. Pereira, *Heterodasya mucronata* (Harvey) M.J.Wynne, *Heterosiphonia crispella* (C.Agardh) M.J.Wynne, *Hypnea cornuta* (Kützing) J.Agardh, *Laurencia translucida* Fujii & Cordeiro-Marino, *Meristotheca gelidium* (J.Agardh) E.J.Faye & M.Masuda, *Stypopodium zonale* (J.V.Lamouroux) Papenfuss, *Willeella ordinata* Børgesen, *Zonaria tournefortii* (J.V.Lamouroux) Montagne, além de *Gracilaria* spp., *Grateloupia* sp., *Hypnea* sp. que são potenciais novas espécies.

Palavras-chave: algas arribadas, algas encalhadas na praia, biodiversidade marinha.

INTRODUCTION

The Brazilian coastline extends across 7367 km, being mostly within the tropical zone, with only the southern region in the subtropical zone (Simioni *et al*., 2019), where it houses great biodiversity of marine organisms. The number of algal species listed for Brazil is 4755, of those 1939 species are marine and about 750 species are benthic macroalgae (Flora do Brasil, 2020), occurring from the intertidal zone to 250 m depths in Brazilian waters (Henriques *et al*., 2014; Yoneshigue-Valentin *et al*., 2020). Despite the advances in the knowledge of the Brazilian algal flora, it is believed that these results are still underestimated. According to Horta *et al*., (2001), there are still gaps in the knowledge of macroalgae alongshore of Brazil, due to the little knowledge of some points on the coast of the northeastern as well as the knowledge of the phycoflora of the infralittoral that has been neglected.

For Pacheco (2011), the flora of the infralittoral in Brazil is known, mainly for the analysis of beach-cast seaweeds and from dredging and diving. Beach-cast seaweeds refer to benthic marine algae, which are pulled from their substrates and brought to the beaches. Considering that the subtidal algal flora is still poorly known in Brazil, the identification of the beach-cast seaweeds and biogeographic studies could perhaps shed light on this phenomenon. Menezes *et al*. (2015) suggested that the availability and diversity of beach-cast seaweeds are intrinsically related to the benthic phycoflora associated with each region.

The occurrence of the beach-cast seaweeds on the beach has been increasingly common. Seaweed strandings occur frequently on many coasts and are particularly important on sandy beaches (McLachlan & Brown, 2006). Patches of stranded macrophytes (wrack, beach-cast) are a distinctive feature of sandy beaches worldwide (McLachlan & Brown, 2006; MacMillan & Quijón, 2012; López *et al*., 2017). As an example, Zemke-White *et al*. (2005) estimated that up to 25% of annual kelp production may end up as beach-cast seaweeds. Kelp forests are very productive communities and one of the dominant species is *Macrocystis pyrifera* (Linnaeus) C. Agardh, commonly known as giant kelp that it occurs in both the North Hemisphere (western coast of North America) and the South Hemisphere (Australia, New Zealand, South Africa, sub-Antarctic islands, and the western and eastern coasts of South America) (Batista *et al*., 2018). In tropical areas, there is an increasing trend of massive strandings (mainly pelagic seaweeds, such as *Sargassum*), which has been related to climate change (Gower *et al*., 2006; Gower & King, 2011). Pelagic seaweeds have been identified in the North and Central Atlantic, Caribbean Sea, and West Africa, and together create the Great Atlantic *Sargassum* Belt (GASB) (Wang *et al*., 2019). These so-called monospecific algal blooms are most frequently related to two pelagic *Sargassum* species: *S. fluitans* (Børgesen) Børgesen and *S. natans* (Linnaeus) Gaillon (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 off the shore of northern Brazil in July 2011 by Széchy *et al*. (2012) and again in 2014 and 2015 (Sissini *et al*., 2017). However, the most common unattached seaweeds observed in the tropical regions along the Brazilian coast are multispecific and typically composed of various 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). Various physical and biological factors can influence the detachment of macroalgae from the rocky bottoms (Dayton *et al*., 1992; Pennings *et al*., 2000). Currents and storm-winds that acting together are the main causes of that detachment of buoyant seaweeds from rocky habitats which occurs mainly during storms when strong waves cause the rock substratum to break or part of the specimens (Santelices *et al*., 1980; Zemke-White *et al*., 2005; Duarte *et al*., 2008; Garden *et al*., 2011).

Due to the frequency of records of occurrence of beach-cast seaweeds along the Brazilian coast, some studies have been carried out in the northeastern (Praciano, 1977; Câmara-Neto *et al*., 1981; Santos *et al*., 2013) and southeastern regions (Pedrini, 1984). However, detailed taxonomic studies are still insufficient and ecological studies are extremely scarce. Schreiber *et al*., (2020) say that the relationship between benthic populations and stranded seaweeds has received little attention, what after detachment, a fraction of floating specimens return to the shore, resulting in strandings that fluctuate in space and time. Factors such possibility of dispersion, influenced by currents, can modify the distribution pattern of marine species. According to Batista *et al.* (2018) currents acting together with storm-winds are efficient dispersal mechanisms for floating strategists and associated communities. In the South Atlantic more frequent and intense storms, related to global warming, have been observed in recent decades, which compromise oceanic circulation and migration processes.

On the other hand, the presence of the beach-cast seaweeds in the beaches brings negative consequences for the municipalities' economy. The presence of these algae is negative for tourism and this biomass, in Brazil, is often underutilized or destined for landfills (Santos *et al.*, 2013). The beach-cast seaweed 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), because the accumulation of these algae can affect human use and beach pleasure, when they decompose, producing hydrogen sulfide gas (Hansen, 1984) and beach fly pests (Blanche, 1992). So, the harvesting of beach-cast seaweeds is carried out by the city halls in order to keep the beaches in good conditions for recreational activities (Cuevas *et al.*, 2018). Therefore, this biomass is being collected without records of its composition, accordingly without knowledge and use of its potential and even more without considering the ecological importance and the environmental impacts promoted by this action. 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.

To most people, beach-cast seaweeds are piles of rotting plant material washed up along the high tide line of many beaches, for other few people, these accumulations are livelihoods and represent the raw product of a valuable resource. According to Kirkman & Kendrick (1997), the managed harvesting of specific areas, where wracks are seen as problems, can produce a variety of economic products: cattle feed, garden fertilizers, soil improvers, mariculture feeds, and such value-added products as alginate and agars, and in adition to reduce inorganic nutrients and organic matter from eutrophicated coastal waters (Piriz *et al.*, 2003), production of biogas (Eyras *et al.*, 1998) and in the cleaning of coastal beaches for recreation and tourism. 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 sound management and utilization strategies, qualitative analyses and quantification of the wrack are necessary. However, few studies have been focused on this area (Piriz *et al.*, 2003).

For the first time, a study is carried out on the beach-cast seaweeds on the beach of the coast of Piauí, moreover, this is the first record of a study of macroalgae on the beach of Itaqui in which species were identified and our results were compared with other existing ones, both for the benthic flora of the coast of Piauí and with studies of the Brazilian infralittoral coast. Our hypothesis was that the study of the beach-cast seaweeds should bring an increase in the knowledge of the benthic marine flora on the infralittoral region to the coast of Piauí. This analysis is considered an important subsidy for expanding knowledge about the algal flora of this region and for providing information about this resource made available by nature with the possibility of being used by the local community.

MATERIAL AND METHODS

Study area

Itaqui Beach is located in the municipality of Luis Correia, Piauí, the northeastern region of Brazil (2º54'.6 "S, 41º34'28.1" W), according to the Köppen classification, the coastal climate in Piauí is rainy, hot and humid (Aw ') tropical type, with high rainfall, in summer and autumn due to the influence of the Equatorial Atlantic mass, between the months of January and June and with average temperatures of 27º C. According to Horta *et al*. (2001), Piauí is inserted in the tropical zone that has specific phychogeographic characteristics, for presenting a relatively rich flora, established predominantly on sandstone reefs encrusted with limestone algae and corals, having as its northern limit the west of Ceará and as the southern limit, the south of the state of Bahia. The region is characterized by oligotrophic waters and an abundance of hard substrates, conducive to the growth of benthic algae (Oliveira Filho, 1977; Castro-Filho & Miranda, 1998) (fig. 1).

Sample processing

Collections were carried out along the entire length of the wave breaking line, where the seaweeds were present during low tide, in July 2017. The collected material was placed in Ziploc plastic bags immediately frozen at -20ºC and transported to the laboratory of the Institute of Botany, in São Paulo, SP, where, then, the species were identified (Barbosa *et al*., 2008; Nunes, 2010; Santos *et al*., 2013). Identification was based on morphological characters and the systematization of the taxa is in accordance with Wynne (2017) and Guiry & Guiry (2020). The confirmation of species registration for the Piauí coast was carried out through Flora do Brasil (2020). As well as through studies already carried out for this region. Samples were deposited in the "Maria Eneyda P. Kauffman Fidalgo" herbarium of the Institute of Botany (SP), São Paulo, Brazil, and in the herbarium of the Institute Federal of Piauí, Piauí, Brazil.

RESULTS

In this study, 55 taxa were identified, among them 33 Rhodophyta, 13 Ochrophyta, and 9 Chlorophyta. 14 new occurrences were recorded for the coast of Piauí (figures 2-15), in addition to four potential new species: *Gracilaria* sp. 1, *Gracilaria* sp. 2, *Grateloupia* sp. and *Hypnea* sp. (Table 1).

Table 1. Updating the flora of benthic marine algae off the coast of the state of Piaui, Brazil.

Taxa	Copertino & Mai 2010.	Batista 2011	Alves & Carvalho 2012	Voltolini *et al.* 2012	Santiago 2016	Assis & Alves 2017	Present Study	Other studies
Ochrophyta Phaeophyceae **Dictyotales**								
Canistrocarpus cervicornis					x		x	
Canistrocarpus crispatus							x	
Dictyopteris delicatula		x		x	x		x	
Dictyota bartayresiana					x			
Dictyota menstrualis		x		x	x			

Dictyota mertensii	x					x	x	
Dictyota pulchella					x			
Lobophora variegata	x	x			x	x	x	
Padina gymnospora	x	x		x	x	x	x	
Spatoglossum schroederi					x		x	
Stypopodium zonale							x	
Zonaria tournefortii							x	
Ectocarpales								
Colpomenia sinuosa					x		x	
Fucales								
Sargassum cymosum						x		
Sargassum filipendula		x					x	
Sargassumstenophyllum		x						
Sargassum vulgare	x	x			x	x	x	
Rhodophyta								
Florideophyceae								
Bangiales								
Pyropia vietnamensis					x			a
Ceramiales								
Acanthophora spicifera	x			x	x	x		
Aglaothamnion felipponei							x	
Alsidium seaforthii	x				x*	x*	x	
Alsidium triquetrum					x			
Amansia multifida					x		x	
Bostrychia tenella						x		
Ceramium brasiliensis						x		
Ceramium sp.							x	
Haloplegma duperreyi				x	x	x	x	
Heterodasya mucronata							x	
Heterosiphonia crispella							x	
Laurencia dendroidea				x		x		
Laurencia translucida							x	
Osmundaria obtusiloba						x	x	
Osmundaria sp.							x	
Palisada flagellifera						x	x	
Palisada perforata				x		x	x	
Spyridia clavata					x			
Corallinales								
Corallina officinalis						x	x	

Corallina panizzoi		x					
Jania capillacea		x				x	
Jania pedunculata var. adhaerens	x				x*		
Jania crassa							
Jania subulata			x		x		
Tricleocarpa cylindrica		x			x		
Tricleocarpa fragilis	x						
Erythropeltidales							
Madagascaria atlantica							d
Gelidiales							
Gelidiella acerosa		x	x		x		
Gelidium calidum							b
Gelidium crinale				x			
Gelidium microdonticum					x*		
Gelidium pusillum		x			x		
Pterocladiella bartlettii							c
Gigartinales							
Agardhiella ramosíssima						x	
Calliblepharis occidentalis				x		x	
Hypnea pseudomusciformis	x	x	x*	x	x*	x	
Hypnea cornuta						x	
Hypnea spinella		x	x		x		
Hypnea sp.						x	
Meristotheca gelidium						x	
Ochtodes secundiramea				x			
Solieria filiformis		x		x		x	
Gracilariales							
Crassiphycus birdiae			x*	x*	x*		
Crassiphycus caudatus						x	
Crassiphycus corneus				x*	x*		
Gracilaria cearensis				x			
Gracilaria cervicornis	x			x	x		
Gracilaria cuneata					x		
Gracilaria curtissiae				x		x	
Gracilaria domingensis			x	x	x	x	
Gracilaria ferox				x			
Gracilaria flabelliformis				x			

Gracilaria hayi				x			
Gracilaria intermedia				x			
Gracilaria sp. 1						x	
Gracilaria sp. 2						x	
Gracilariopsis silvana				x			
Halymeniales							
Cryptonemia crenulata	x			x	x	x	
Cryptonemia seminervis				x	x	x	
Grateloupia sp.						x	
Nemaliales							
Dichotomaria marginata						x	
Dichotomaria obtusata					x		
Tricleocarpa cylindrica					x		
Rhodaclyales							
Rhodachlya westii							e
Rhodymeniales							
Botryocladia franciscana				x			
Botryocladia occidentalis				x	x	x	
Sebdeniales							
Sebdenia flabellata				x			
Chlorophyta, Ulvophyceae **Bryopsidales**							
Avrainvillea longicaulis		x					
Bryopsis pennata		x				x	
Caulerpa ashmeadii		x					
Caulerpa cupressoides var. *elegans*							
Caulerpa cupressoides var. *lycopodium*	x	x		x			
Caulerpa cupressoides var. *serrata*		x		x			
Caulerpa denticulata				x			
Caulerpa floridana				x			
Caulerpa mexicana	x	x	x	x	x		
Caulerpa prolifera	x	x		x	x	x	
Caulerpa racemosa	x			x	x	x	
Caulerpa racemosa var. *occidenatalis*		x			x		
Caulerpa racemosa var. *uvifera*		x			x		
Caulerpa scalpelliformis		x			x		
Caulerpa sertularioides	x	x		x	x		

Caulerpa sertularioides f. *longiseta*					x		
Codium intertextum			x				
Codium isthmocladum	x				x	x	x
Codium taylorii			x		x	x	
Halimeda jolyana							x
Cladophorales							
Cladophora dalmatica		x					
Cladophora prolifera						x	x
Cladophora vagabunda		x	x*			x	x
Cladophoropsis membranacea				x*			
Chamaedoris peniculum					x		
Pseudorhizoclonium africanum			x*				
Rhizoclonium riparium		x					
Valonia aegagropila				x	x	x	
Willeella ordinata							x
Dasycladales							
Acetabularia calyculus	x	x	x	x	x		
Acetabularia crenulata		x		x			
Ulvales							
Gayralia oxysperma		x		x*			
Ulva compressa			x			x	
Ulva flexuosa		x					
Ulva intestinales			x				
Ulva lactuca	x	x	x*	x*	x	x	x
Ulva rigida					x		

*Nomenclatural updates made based on AlgaeBase (https://www.algaebase.org/).
a = Milstein *et al.* (2015); b = Jamas *et al.* (2017); c = Iha *et al.* (2017); d = Soares *et al.* (2019); e = Soares *et al.* (2020).

DESCRIPTION OF NEW OCCURRENCES:

Phylum Ochrophyta

Canistrocarpus crispatus (J.V.Lamouroux) De Paula & De Clerck. Fig. 2 (A-F).

Basionym: *Dictyota crispata* J.V.Lamouroux

Type locality: Antilles, Caribbean Sea

Description: Greenish-brown thallus, up to 30 cm high, attached to the substrate by rhizoids emerging from the base and proximal portions of the base. Blade with a smooth margin, in the form of a narrow row, 4-6 mm in the middle portion of the tape. Dichotomous branching and alternating closed-angle, with sharp, beveled, or rounded apexes. The medullary region consisting of a layer of small, quadratic, and pigmented cells. Medullary region by a layer of colorless, large, quadratic to rectangular cells. Sporangia isolated or grouped, surrounded by a ring of sterile cells. Antheridial sori often found in every thallus.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Stypopodium zonale* (J.V.Lamouroux) Papenfuss**. Fig. 3 (A-C).

Basionym: *Fucus zonalis* J.V.Lamouroux

Type locality: Dominican Republic

Description: Yellowish-brown to dark brown thallus, up to 45 cm high, fixed to the substrate by a discoid holdfast, composed of rhizoidal filaments. The thallus of malleable consistency, often split longitudinally into segments of wedged apexes, with cross hairlines and growth by unrolled apical cell margins. In cross-section, a thallus formed by a layer of pigmented cortical cells and four layers of colorless medullary cells, larger than the cortical ones, in the median region. Sporangia distributed irregularly throughout the thallus.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Zonaria tournefortii* (J.V.Lamouroux) Montagn .** Fig. 4 (A-E).

Basionym: *Fucus tournefortii* J.V.Lamouroux

Type locality: Corsica; southern France; Italy

Description: The thallus of shrubby habit, dense, greenish-brown in color, up to 20 cm high, fixed to the substrate by an holdfast composed of strongly intertwined rhizoidal filaments. Flabeliform thallus of rigid consistency, with central rib, restricted to more developed portions, smooth margins, and radial streaks. Laminar portion with dichotomous to irregular branching. Appendages wedged and not rolled, formed by rows of cells longitudinally split and expanded. In a superficial view, cortical cells are quadratic to rectangular, perfectly aligned longitudinally two by two. In cross-section, thallus formed by a layer of pigmented cortical cells and four layers of colorless cells, larger than the cortical ones.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

Phylum Rhodophyta

***Agardhiella ramosissima* (Harvey) Kylin.** Fig. 5 (A-B).

Basionym: *Chrysymenia ramosissima* Harvey

Type locality: Key West, Florida

Description: Intense red thallus, erect, isolated, slippery, leathery texture, up to 46 cm high, fixed to the substrate by a discoid base. Flat ribbon-shaped axes, up to 1.3 cm in diameter, abundantly branched, in a dystic manner. Branches with a constricting base, usually dissected by numerous short, spinous branches. In cross-section, the internal cortical region with 3 to 4 layers of small, pigmented cells, rounded to oval and external cortical region with 3 to 4 layers of large, colorless, rounded to quadratic cells. Medullary region composed of branched filaments, interlaced, loosely arranged. Zoned tetrasporangia, scattered over the last order branches.

Distribution on Brazilian coast: Northeastern, Southeastern and South coast**.**

***Aglaothamnion felipponei* (Howe) Aponte, Ballantine & J.N.Norris.** Fig. 6 (A-B).

Basionym: *Callithamnion felipponei* Howe

Type locality: Cabo de Santa Maria, Rocha, Uruguay.

Description: Thallus filamentous, pinkish-reddish, forming delicate tufts of shrublike aspect, up to 4 mm high, fixed to the substrate by typed multicellular rhizoids. Uninucleate cells. Evident main axis, 50-75 µm in diameter, with alternating, dense branching in several planes. Narrower branches towards the apex and branches of last order are typically curved. Basal cells are quadratic, while apical cells are thin and elongated, up to 12.5 × 75 µm in diameter.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Crassiphycus caudatus* (J.Agardh) Gurgel, J.N.Norris & Fredericq**. Fig. 7 (A-C).

Basionym: *Gracilaria caudata J.Agardh*

Type locality: Gulf of Mexico

Description: Red to reddish-brown Thallus, cylindrical, forming curved tufts, up to 10 cm high, attached to the substrate by a small discoid holdfast. Shafts up to 1.5 mm in diameter, with branching generally unilateral to irregular. Branches decreasing in diameter towards the apex. Some branches with constrained bases. In cross-section, 1 to 2 layers of small cortical cells, the outermost being oval and with up to 11 layers of rounded medullary cells, with numerous floridean starch grains. Gradual transition between the cortical and medullary regions. When present, cruciate tetrasporangia, spread on the surface of the thallus.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Dichotomaria marginata* (J.Ellis & Solander) Lamarck .** Fig. 8 (A-D).

Basionym: *Corallina marginata* J.Ellis & Solander

Type locality: Bahamas

Description: Erect, reddish-brown, flattened thallus, up to 15 cm high, fixed to the substrate through a holdfast. Dichotomous to pseudodichotomic branching, with mild calcification. Branches with rounded apices. In cross-section, the gametophytic thallus has a filamentous medulla and cortex with three layers of cells and apiculate cells that are formed mainly at the margins of the thalli, from external cortical cells. There are no apiculate cells in the tetrasporophytic thalli**.**

Distribution on Brazilian coast: Northeastern, Southeastern, and South coast.

***Heterodasya mucronata* (Harvey) M.J.Wynne.** Fig. 9 (A-D).

Basionym: *Dasya mucronata* Harvey

Type locality: Key West, South Florida

Description: Thallus shrubby, feathery, erect, red to pinkish red, up to 20 cm high, with one or more axes fixed to the substrate by a small discoid base. Cylindrical and cross-sectional branches have five pericentral cells. The branching is radial to irregular. The upper branches are covered by branches (trichoblasts), giving the thallus a shrublike appearance. The molds are mucronated and uniseriate and show apical and monopodial growth, arranged in a spiral pattern alternate or subdichotomous. When present, sporangia are tetrahedrally divided and cystocarps are ostiolated.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

Heterosiphonia crispella **(C.Agardh) M.J.Wynne .** Fig. 10 (A-E).

Basionym: *Callithamnion crispellum* C.Agardh

Type locality: Cádiz, Spain

Description: Rosy-reddish, corticated thallus, up to 1 cm high, forming delicate rugs on the host. Main cylindrical shaft, branched every 2 segments, in an alternating and abundant manner. Monosiphonic branches with subdichotomous branching, at an open angle, formed by approximately quadratic cells. Acuminated apices. Tetrahedral *tetrasporangia*, up to 3 per segment, organized in *stichidium*, usually originating from the median region of the lateral branches. Gametophytes were not observed.

Distribution on Brazilian coast: Northeastern, Southeastern and South coast**.**

Hypnea cornuta **(Kützing) J.Agardh.** Fig. 11 (A-F).

Basionym: *Chondroclonium cornutum* Kützing

Type locality: "ad oras Guineae"

Description: Erect thallus, cartilaginous texture, brownish-yellow color, up to 15 cm high, fixed to the substrate by primary cutting disc or rhizoidal branches. Little or unbranched thallus. Main cylindrical and evident branch, 937–1350 µm in diameter. Apice erect and acute, 371–435 µm in diameter. Alternatively arranged modules with a logistical tendency. Axial cells much smaller than as peiraxial, as which are rounded to ovals, in a number of 5 or 6, 2 or 3 layers of medial hyaline cells, 1 or 2 layers of cortical cells. Abundant lenticular thickening in the walls of the periaxial and or medullary cells. Cut very thick around the entire thallus. Tetrasporangia, surrounding a basal and median part of the shafts. Examples of gametophytes not found.

Distribution on Brazilian coast: Northeastern (Piauí, Maranhão, Bahia), Southeastern (Rio de Janeiro, São Paulo) and South (Paraná) coast.

Laurencia translucida **Fujii & Cordeiro-Marino.** Fig. 12 (A-D).

Type locality: Praia do Padre, Aracruz, Espírito Santo, Brazil

Description: Vinous-red to greenish-red thallus, erect, forming isolated, delicate tufts, up to 12 cm high, attached to the substrate by one or more aggregated discoid holdfasts. Dense branching, alternating the spiral, producing rulers in up to 3 orders. In a superficial view, translucent external cortical cells, without secondary connections between them and pigmented internal cortical cells, with secondary connections. In a longitudinal section, cortical cells not projected beyond the surface of the thallus. In cross section, 2 layers of cortical cells, the outermost composed of translucent cells, with a slightly triangular outline and the innermost composed of the square to irregular cells. Medullary region composed of 4 to 5 layers of cells. Each vegetative axial segment produces 2 pericentral cells.

Distribution on Brazilian coast: Northeastern, Southeastern and South coast**.**

Nordeste (Bahia, Ceará, Paraíba, Pernambuco)

Sudeste (Espírito Santo)

Sudeste (Espírito Santo)

Nordeste (Bahia, Ceará, Paraíba, Pernambuco)
Sudeste (Espírito Santo)

***Meristotheca gelidium* (J.Agardh) E.J.Faye & M.Masuda**. Fig. 13 (A-D).

Basionym: *Sphaerococcus gelidium* J.Agardh

Type locality: Brazil

Description: Vinous red to greenish-yellow thallus, firm texture, subcartilaginous, with flattened branches, up to 60 cm high, attached to the substrate by a small discoid holdfast. Branching alternates the sub-opposite, most of the time couplet, with branches in up to 3-6 orders. Branches up to 2 cm wide, from sub-cylindrical to flat, tapered towards the apex. Branches of last order short and spinous or elongated and flexible. Multiaxial apex, pit-connection between adjacent axial filaments. Interconnection of missing cells and filaments. In cross-section, cortex with 3-4 layers of pigmented cells and medulla with filaments and rhizoid. Tetrasporangia zoned over the entire surface of the thallus, except the base and cystocarps in the last order branches with spinning projections.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

Phylum Chlorophyta

***Halimeda jolyana* Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen & S.M.B.Pereira** Fig. 14 (A-C).

Type locality: Castelhanos beach, Anchieta, Espírito Santo, Brazil

Description: Green to dark green thallus up to 2.5 cm high, fixed to the substrate by a large discoid holdfast. Thallus with mild calcification, composed of very thick segments, 1.7-3.0 mm, coined to discoid. In a superficial view, the primary utricles appear in a polygonal pattern (mainly hexagonal), firmly pressed against each other. Branching often forked.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Willeella ordinata* Børgesen.** Fig. 15 (A-D).

Type locality: Port Okha, Gujarat, India

Description: Dark green, filamentous thallus approximately 2.5-7.5 cm long. Opposite branching in one plane, opposite at the apex of the thallus and conical apical cells, giving a pinched appearance to the stem. Main axis cells are longer than wide. Chloroplasts in polygonal cells, interconnected, forming a parietal network with a central pyrene.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

DISCUSSION

After compiling and analyzing the results of previous studies of phycoflora from the coast of Piauí (Copertino & Mai, 2010; Batista, 2011; Alves & Carvalho, 2012; Voltolini *et al*., 2012; Santiago, 2016; Assis & Alves, 2017) the present study revealed an algal flora extremely rich, concentrated in a reduced area if we take into account that it was carried out on a single beach, where 14 new occurrences were recorded, increasing to 122 the number of taxa in the Piauí coast. Red algae group presented higher richness (60%) followed by brown (23.6%) and green algae (16.4%). This result is in agreement with other studies carried out in subtidal region (Horta, 2000; Yoneshigue-Valentin *et al*., 2006; Cocentino, 2009).

Based on the richness data and the frequent association between beach-cast seaweeds and rhodoliths, common substrates present in constantly submerged regions, lends support in favor of the subtidal origin of these algae. The number of species recorded in the present study is similar to that reported for other locations in the North Atlantic (Barbera *et al*., 2003) and in the South Atlantic (Riul *et al*., 2009) in studies of phycoflora associated with rhodoliths. 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).

The predominance of the orders Ceramiales, Dictyotales and Bryopsidales among the red, brown and green algae, respectively also in relation to the others in other studies of benthic phycoflora (Pedrini, 1984; Altamirano & Nunes, 1997; Nunes & Paula, 2002; Barata, 2004; Marins *et al*., 2008; Barbosa, 2010; Santos *et al*., 2013) in the southeastern and northeastern of Brazil.

The results found in this study confirm our hypothesis regarding the contribution of increased knowledge of the flora of the benthic algae, since 14 new occurrences were identified on the coast of Piauí, which was surprising since the study was carried on a single beach. As for the origin, these species had already been identified in other studies of the infralittoral, both in the northeastern region (Riul *et al*., 2009) and in the southeastern (Pacheco, 2011) of Brazil, confirming the origin of a beach-cast seaweeds, in fact, is related to the subtidal region.

Bell & Hall (1997) suggested that less active environments favor the growth of benthic macroalgae than those with higher current speeds and/or extensive exposure to waves. While Berglund *et al*. (2003) suggested that the occurrence of beach-cast seaweeds was affected by exposure to the waves and that the greater the exposure the greater the accumulation. Several studies indicate that the biomass of the beach-cast seaweeds is influenced by currents, storms, substrates, nutrients, seasonality, light, competition, near floristic stock (Orr *et al*., 2005; Biber, 2007; Barbosa *et al*., 2008), although our ability to predict temporal patterns of stranded macroalgae biomass is still limited (López *et al*., 2018).

The presence of beach-cast seaweeds to the coastal zone is an important resource to be considered, due to the secondary metabolites they have and their application in the food, pharmaceutical or agricultural industries (Conde, 2019). The use of beach-cast seaweeds avoids the exploitation of natural algae populations (pruning in situ), which causes the disappearance and alarming decrease of this resource (Areces *et al*., 1993; Moreira *et al*., 2006). Studies indicate that beach-cast seaweeds of the Brazilian coast are promising as fertilizers (Barbosa, 2010; Sacramento *et al*., 2013; Vila Nova *et al*., 2014). However, before collection for commercial purposes, it must be determined what environmental impacts might be caused by this harvest. Kirkham & Kendrick (1997) pointed out that it is necessary to understand the link between the living resource offshore and the beach-cast seaweed. This information should be obtained at least for the main species and areas 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 relating to biomass and availability of the resource followed by the effects of its removal on coastal ecosystems (Zemke-White *et al.*, 2005).

This was the first beach-cast seaweeds study carried out on the coast of Piauí and it provided an opportunity to expand the biodiversity of the algae known for this coast. Such new findings indicate that biodiversity and marine flora is still underestimated. Additional phycological studies in this beach, particularly in deepwater habitats and other less collected environments, are likely to further increase the biodiversity of known algae in the region. The diversity of seaweed found in this study calls attention to this potential for renewable energy that has been disregarded or underutilized throughout the Brazilian coast. In conclusion, despite the apparent biotechnological potential of beach-cast seaweeds, this area of research and development is still relegated or underused. Further studies monitoring the occurrence, chemical composition, and taxonomic identification of beach-cast seaweeds are necessary for understanding how to utilize this biomass, a potential source of alternative biofunctional products when natural resources are being depleted.

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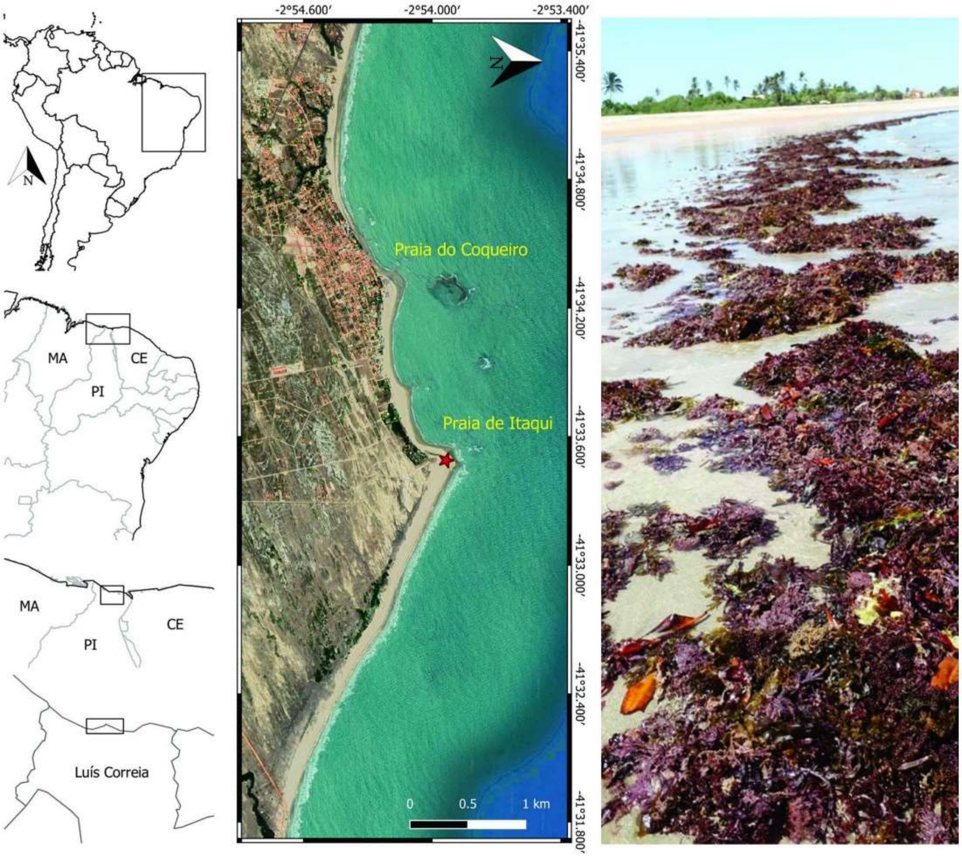

Figure 1. Map of Brazil with collection site at Praia de Itaqui, Luís Correia, Piaui, northeastern Brazil.

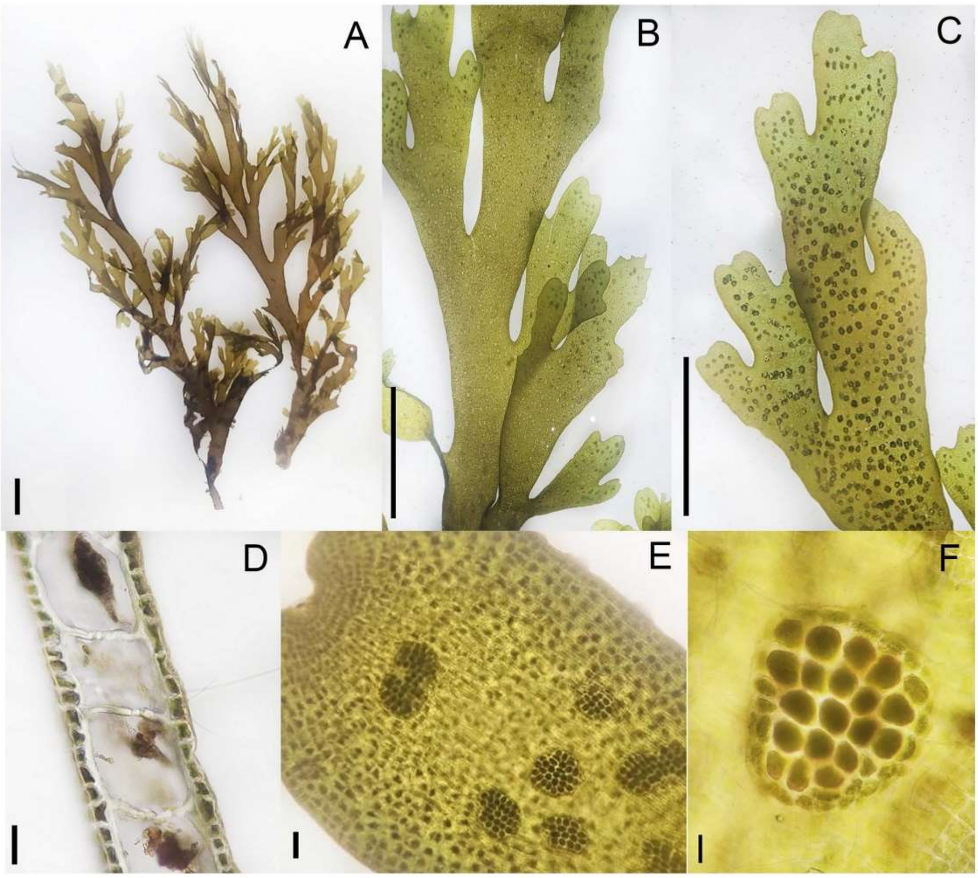

Figure 2. *Canistrocarpus crispatus.* A. General aspect of the thallus. B-C. Superficial view of the thallus. Branch showing alternating dichotomous branching. D. Cross-section of the branch. E. Superficial view of the branch with sporangia (dark spots). F. Superficial view of sporangia surrounded by a ring of vegetative cells. Scales: A=1 cm; B-C=0,5 cm; D, F=25 µm; E=100 µm.

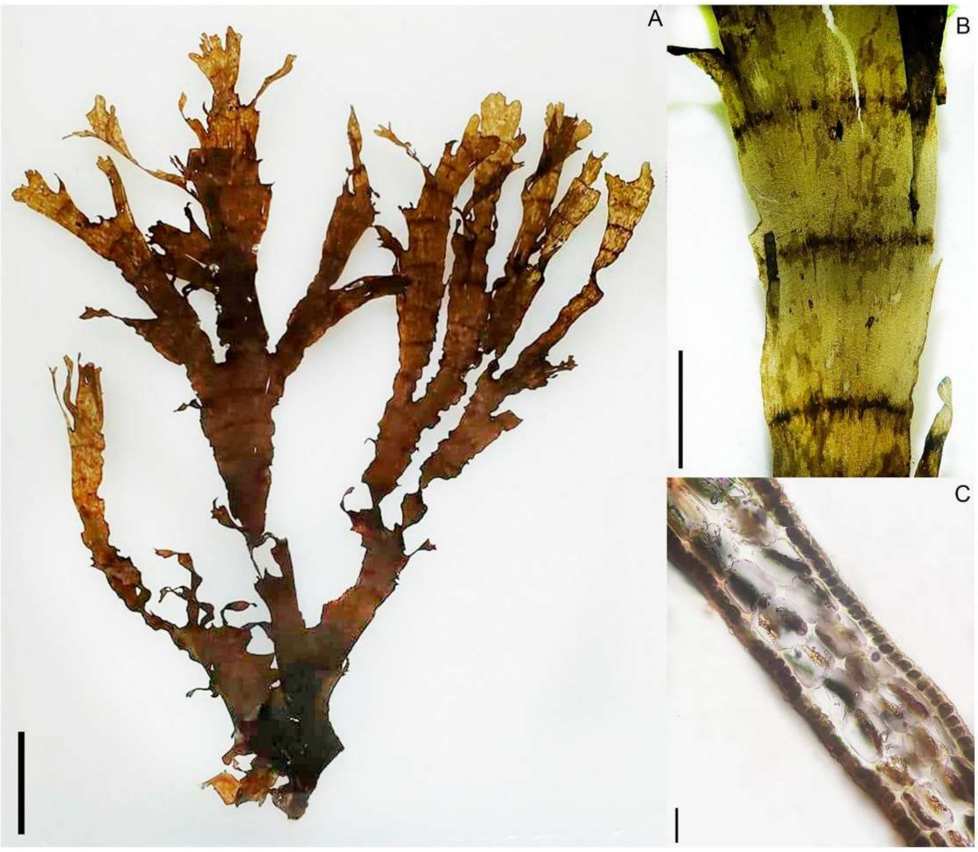

Figure 3. *Stypopodium zonale.* A. General aspect of the thallus. B. Superficial view of the branch. Branch showing cross hair lines C. Cross-section of the thallus apical region. Scales: A-B=1 cm; C=2 µm.

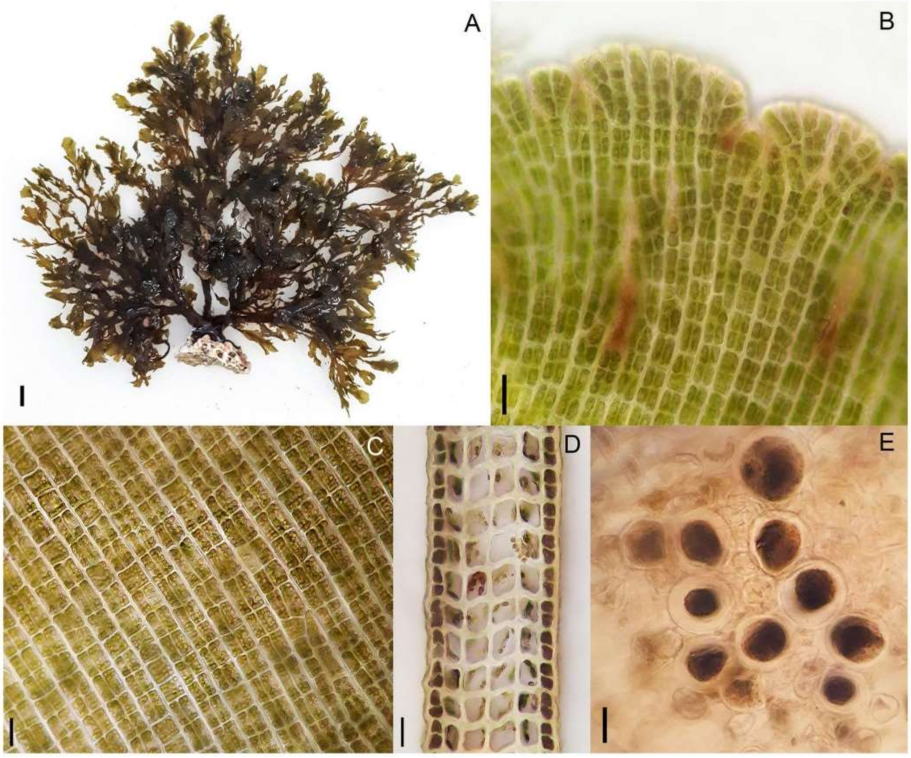

Figure 4. *Zonaria tournefortii.* A. General aspect of the thallus. B-C. Superficial view of the apical and median region of the thallus. Cortical cells perfectly aligned two by two. D. Cross-section of the thallus. E. Superficial view of the thallus. Branch showing oogonium. Scales: A=1 cm; B-C =100 µm; D-E=25 µm.

Figure 5. *Agardhiella ramosissima***.** A. General aspect of the thallus. B. Cross-section of the thallus. Scales: A=1 cm D=100 µm.

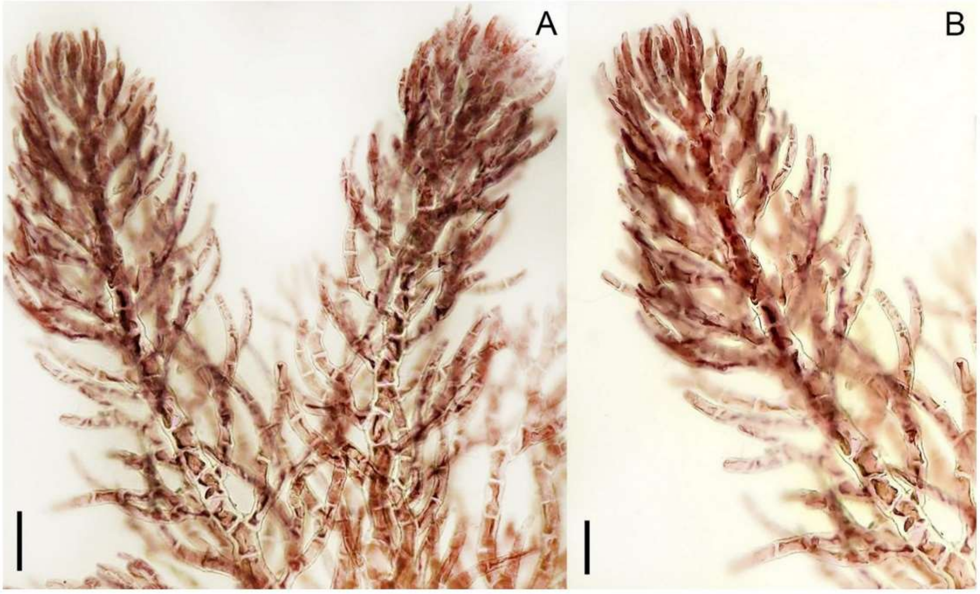

Figure 6. *Aglaothamnion felipponei*. A. General aspect of the thallus. B. Detail of the branching pattern and evident main axis. Scales: A-B= 100 µm.

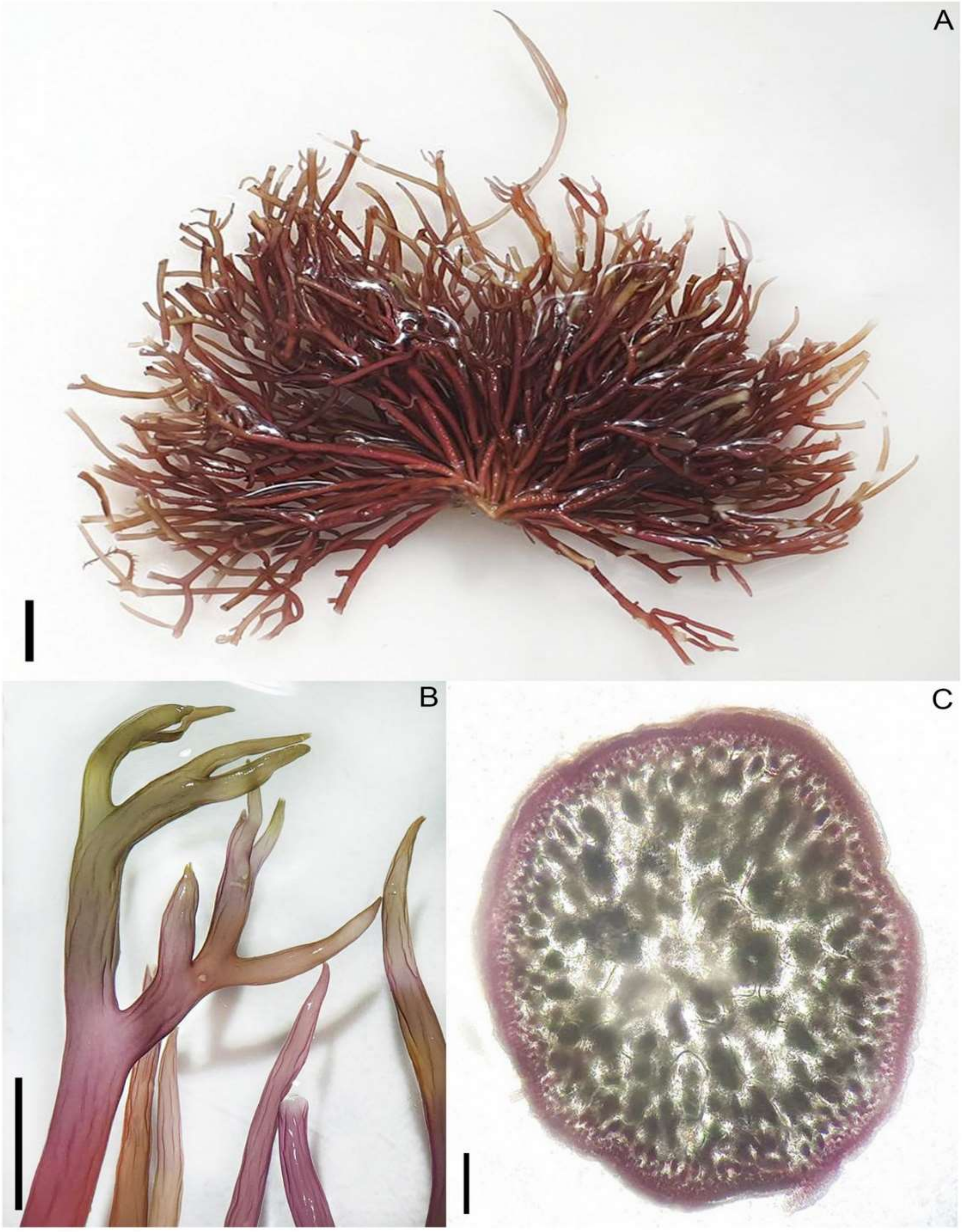

Figure 7. *Crassiphycus caudatus*. A. General aspect of the thallus. B. Detail of the Apice of the Branches. C. Cross-section of the thallus. Scales: A= 1 cm; B=0,5 cm; C=100 µm.

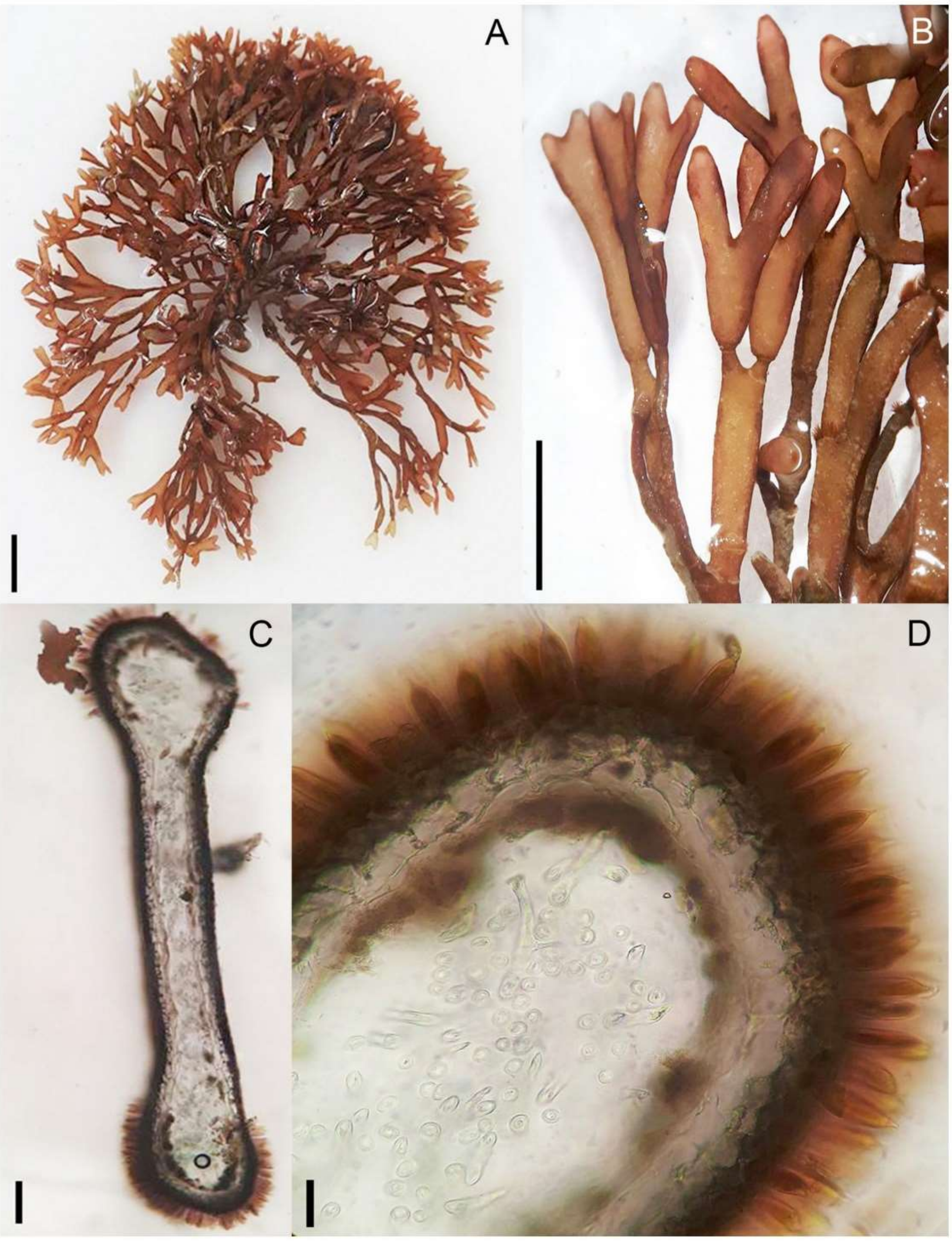

Figure 8. *Dichotomaria marginata.* A. General aspect of the thallus. B. Detail of the apex of the branches. C. Cross section of the gametophytic thallus. D. Detail of apiculate cells. Scales : A= 1 cm; B= 0,5 cm; C=100 µm; D= 25 µm.

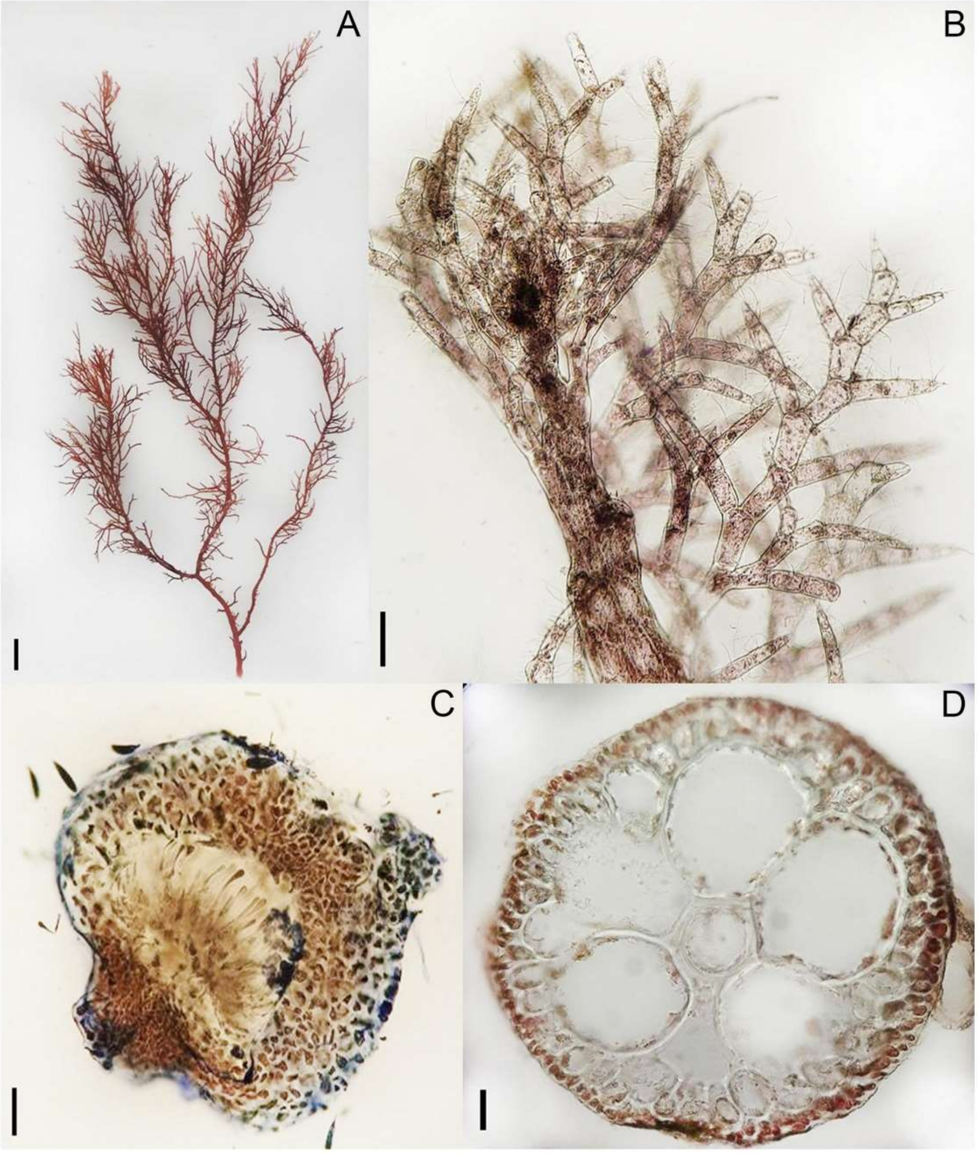

Figure 9. *Heterodasya mucronata*. A. General aspect of the thallus. B. Superficial view of the thallus with mucronate branchlets. C. Cystocarp. D. Cross-section of the thallus, showing 5 pericentral cells. Scales: A=1 cm; B-C=100 μm; D=25 μm.

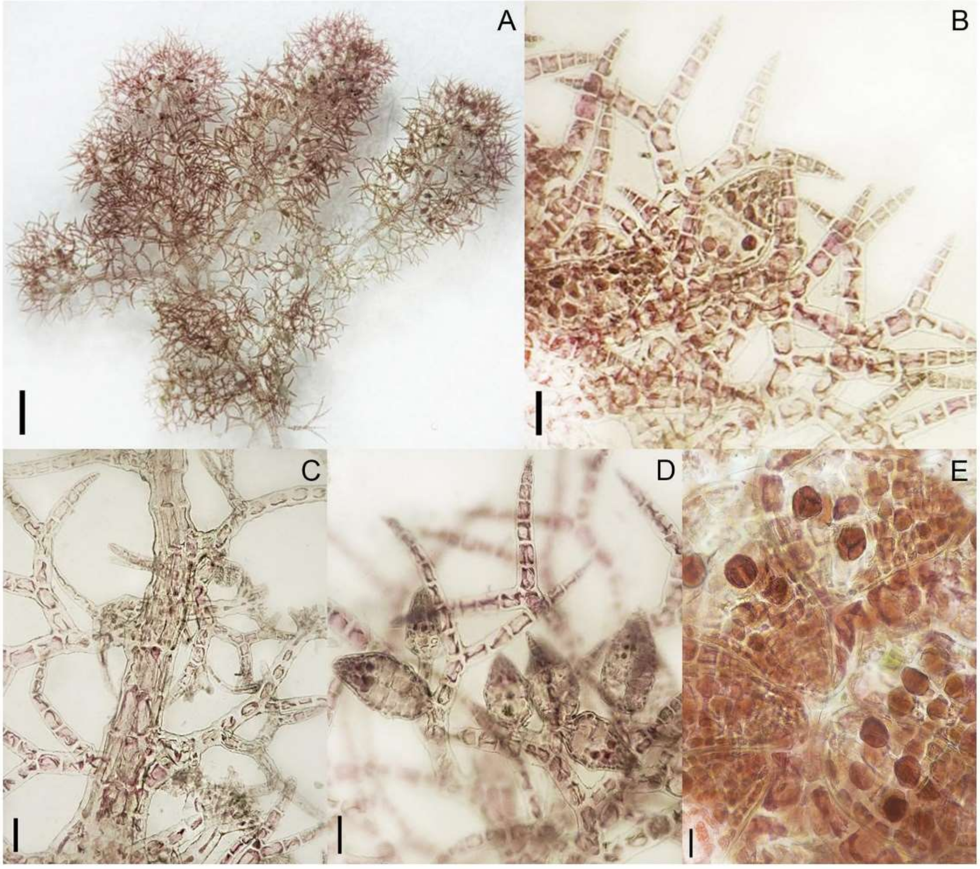

Figure 10. *Heterosiphonia crispella*. A. General aspect of the thallus. B. Superficial view of the thallus with acuminated apex and open-angle. C. Superficial view of the main axis. D-E. Superficial view of estiquidios and tetrasporangia. Scales: A=1 mm; B-C=100 µm; D-E=25 µm.

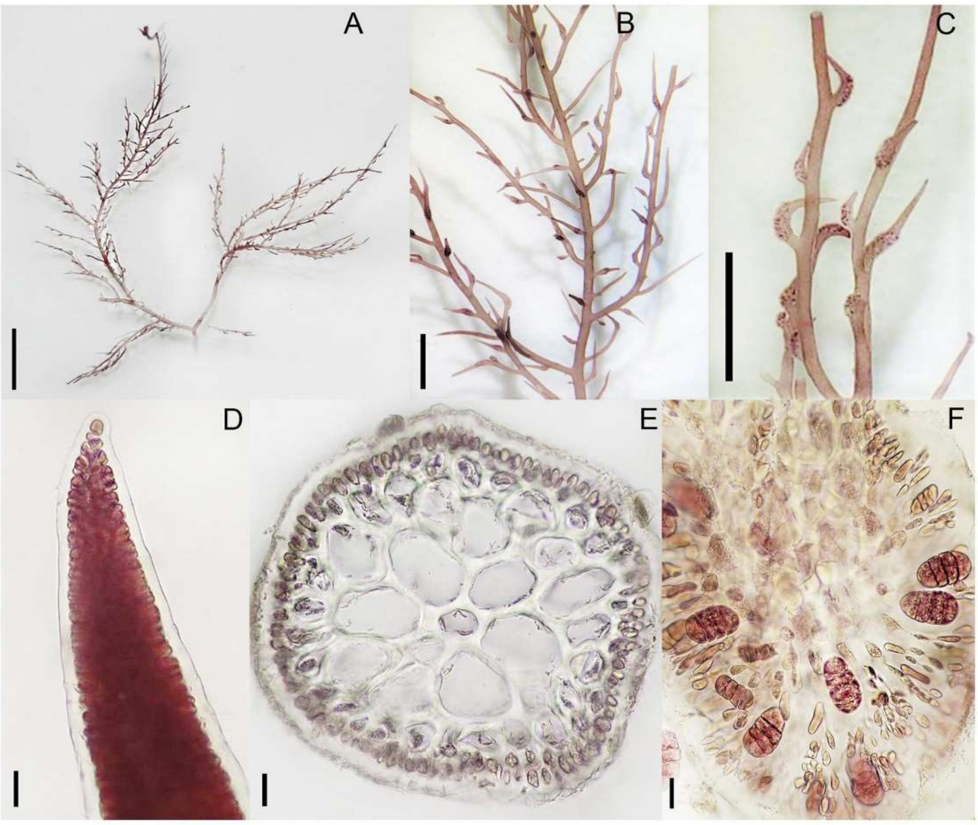

Figure 11. *Hypnea cornuta*. A. General aspect of the thallus. B. Detail of the branch. C. Superficial view of the branches with the arrangement of tetrasporangia. D. Superficial view of the apical cell. E. Cross-section of the thallus. D. Zoned tetrasporangia. Scales: A=1 cm; B-C=0,2 cm; D=100 µm; E-F=25 µm.

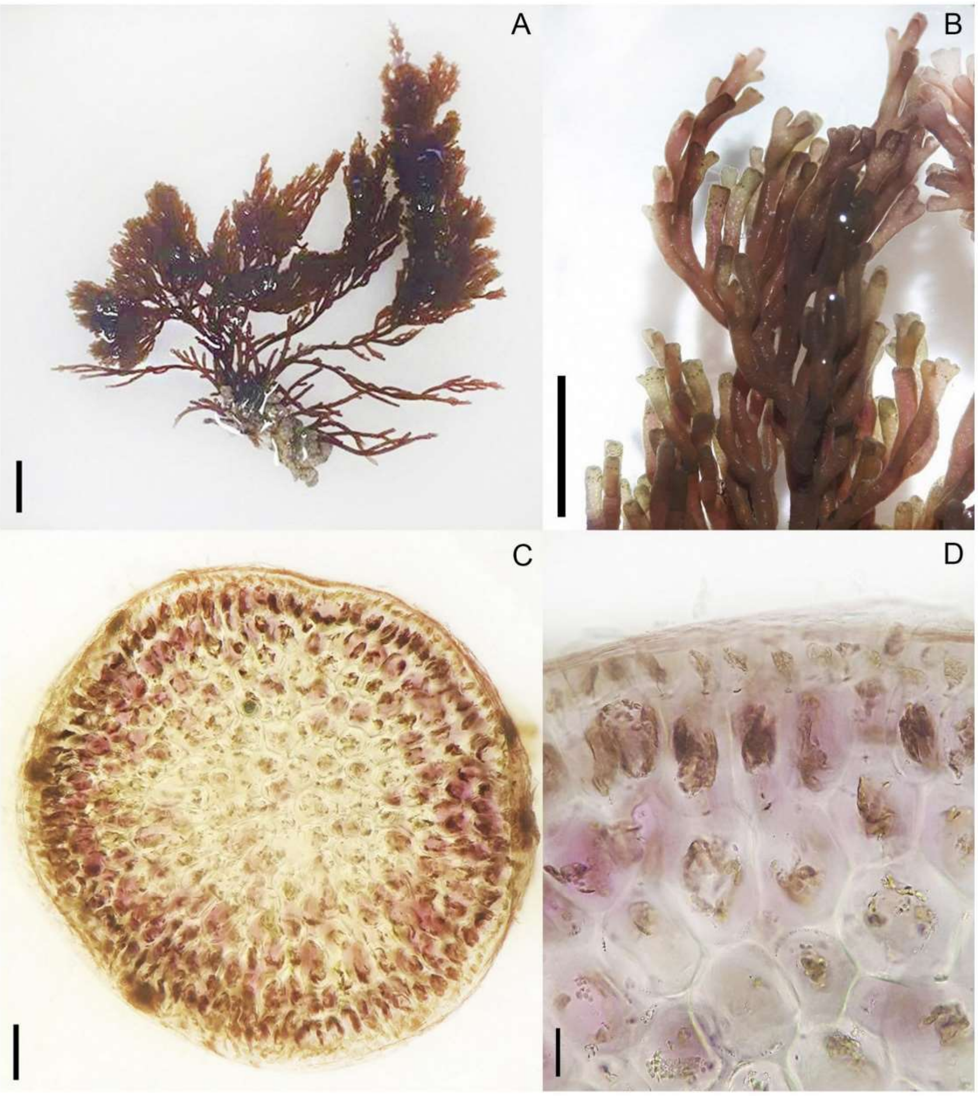

Figure 12. *Laurencia translucida*. A. General aspect of the thallus. B. Detail of the thallus branch. C. cross-section of the thallus, showing translucent cortical cells. D. Detail of the cross-section of the thallus, showing the cortex. Scale: A= 1 cm; B=0,5 cm; C=100 µm; D=25 µm.

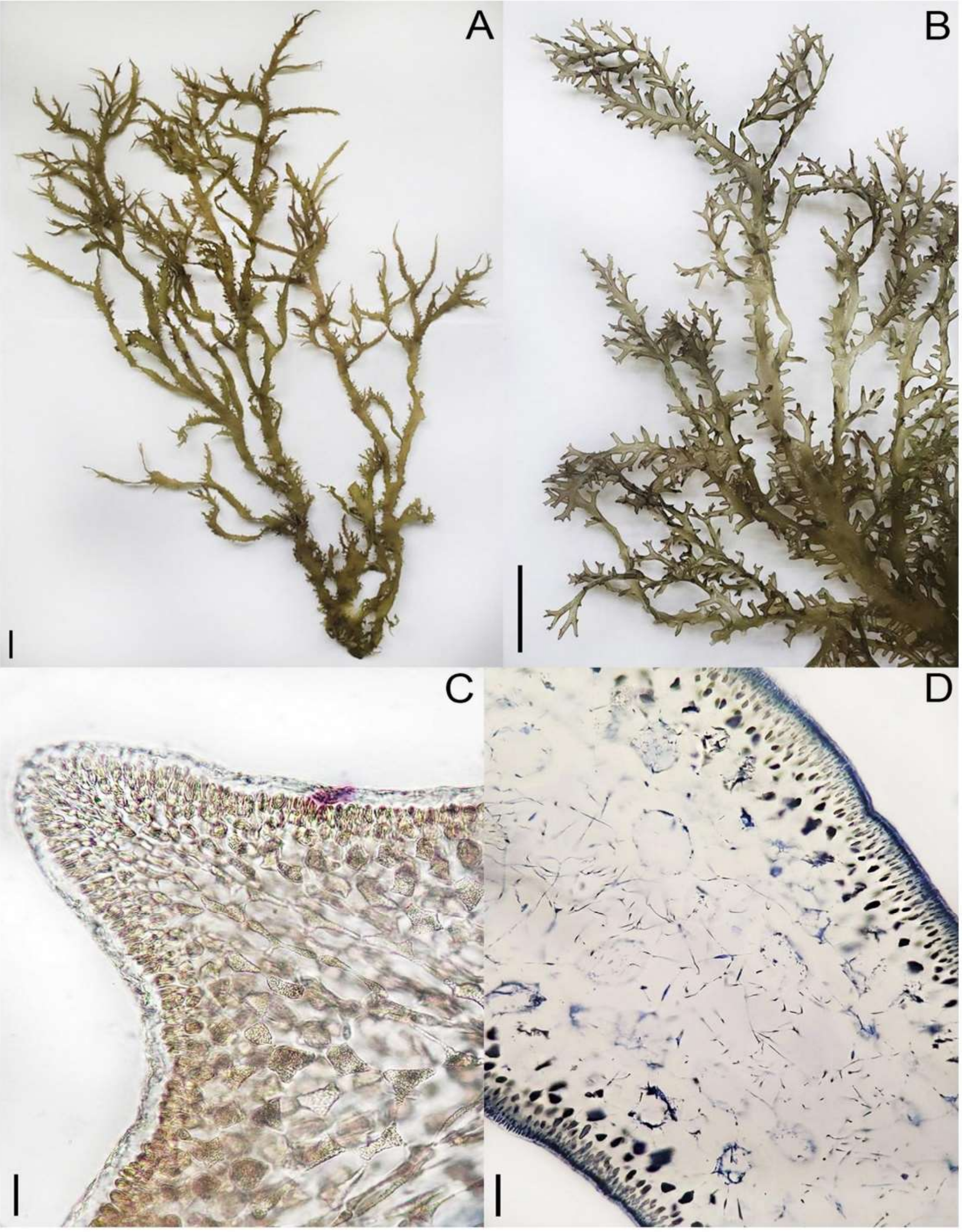

Figure 13. *Meristotheca gelidium*. A. General aspect of the thallus. B. Detail of the Cystocarpic branches. C. Longitudinal section of the apex. D. Cross-section of the thallus. Scale: A-B= 2 cm; C-D=100 µm.

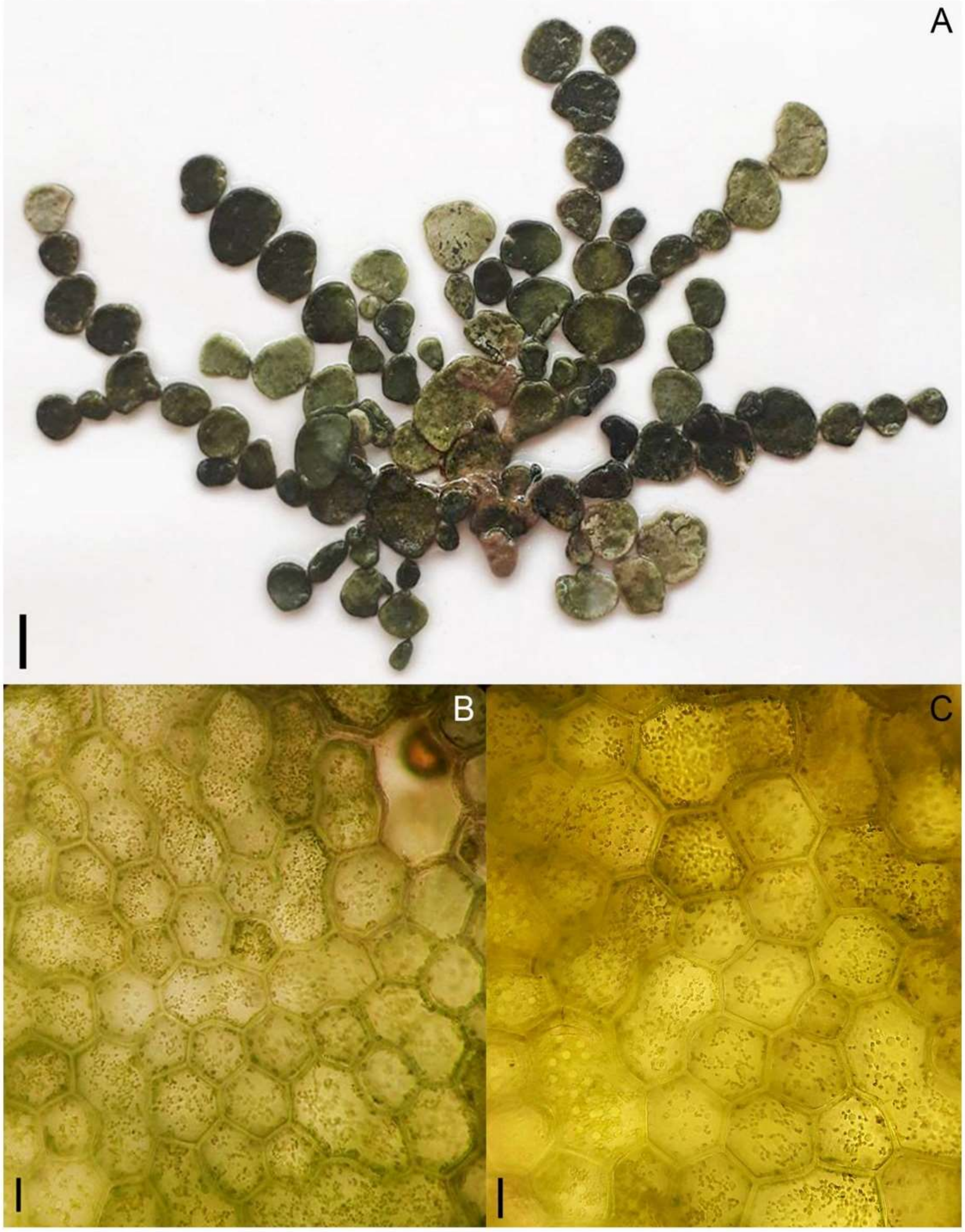

Figure 14. *Halimeda jolyana*. A. General aspect of the tallus. B-C. Superficial view of the thallus, a polygonal and hexagonal pattern of the utricles. Scales: A=1 cm; B-C=25 µm.

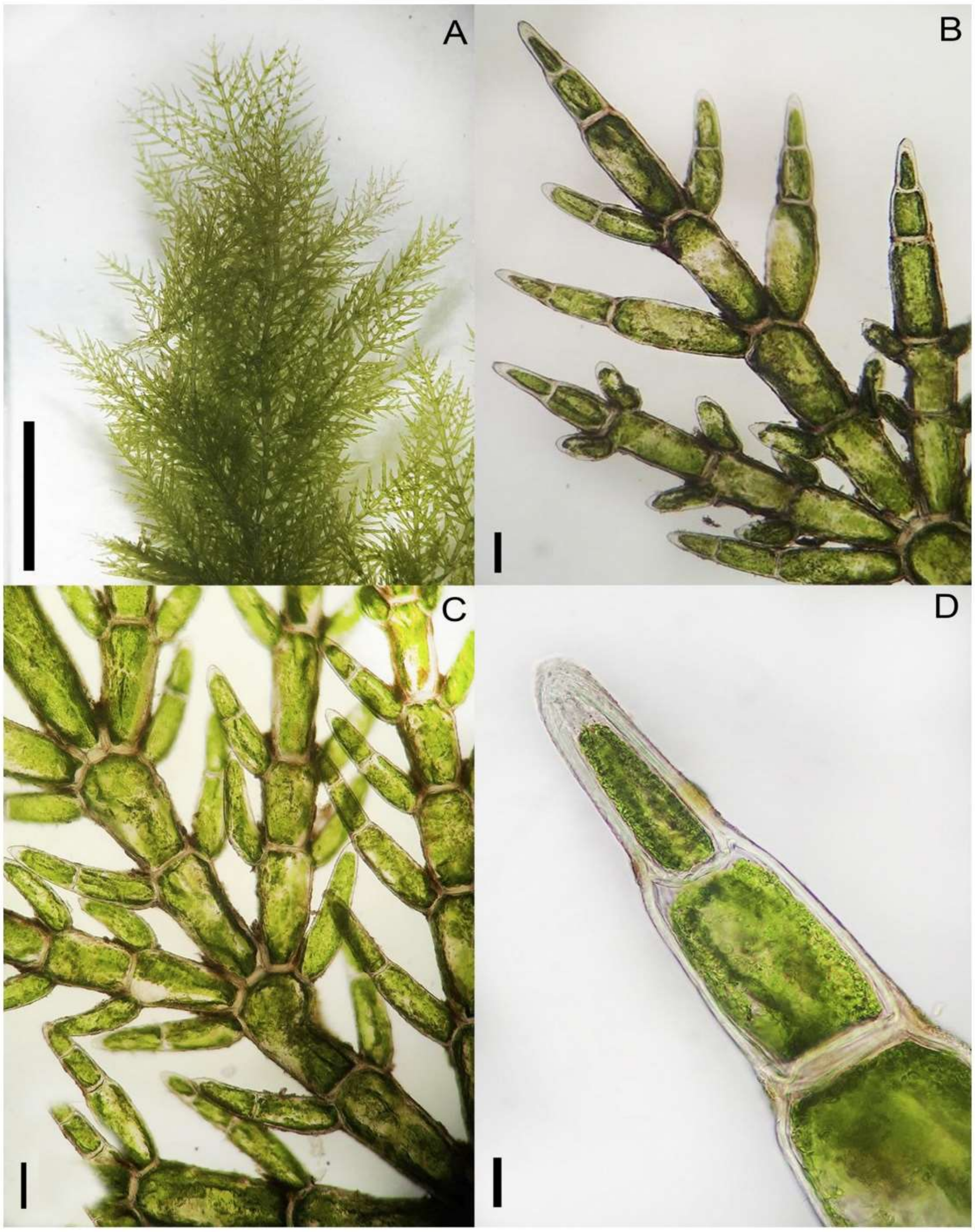

Figure 15. *Willeella ordinata*. A. General aspect of the thallus. B. Detail of the pinnate appearance of the branch. C. Branch detail in one plane. D. Detail of the conical apical cell. Scales: A=0,5 cm; B-C=100 µm; D=25 µm.

CAPÍTULO III

MANUSCRITO SUBMETIDO PARA PUBLICAÇÃO NA REVISTA EUROPEAN JOURNAL PHYCOLOGY.

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Abstract

Stranded seaweeds have been 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 northeastern (NE) and southeastern (SE) coasts of Brazil. In total 110 taxa were identified: 80 Rhodophyta, 13 Phaeophyceae and 17 Chlorophyta. While the NE coast had higher species richness, the SE beaches exhibited higher coverage and biomass, mainly Dictyotales. The identified taxa were attributed to five functional-form groups and their respective frequencies were calculated and analysed. The corticated group displayed the highest frequency at all study sites, especially at Emboaca Beach, whereas the corticated foliose group was more frequent on Candeias, Itaoca and Pontal Beaches. PERMANOVA revealed significant differences in coverage and biomass of the macroalgal assemblage between beaches. PERMDISP (homogeneity of multivariate dispersions) showed that these parameters also differed significantly between the coasts, with a marked dissimilarity between the beaches and regions 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.

Key words: beach-cast seaweeds; 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 may end up as beach-cast seaweeds. Kelp forests are very productive communities. One of the dominant species is *Macrocystis pyrifera,* giant kelp, which occurs both in the Northern (western coast of North America) and Southern Hemispheres (Australia, New Zealand, South Africa, sub-Antarctic islands, and the western and eastern coasts of South America) (Batista *et al*., 2018). In the Southern Hemisphere, *Durvillaea antarctica* is one of the most common floating seaweeds (López *et al*., 2017).

In tropical areas, there is an increasing trend of massive strandings (mainly pelagic brown seaweeds, such as *Sargassum* spp.), which has been related 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, they have been detected in satellite images only 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 Jr., 2019) although 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 acting together with storm-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 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, cast algae on the beach 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, and for 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.

Here, studies were carried out on beaches in NE and SE Brazil selected based on records of occurrences of beach-cast seaweeds. According to Horta et *al*. (2001), these sites differ phycogeographically mainly due to the diversity of their environments and their range of temperatures. Thus, the hypothesis of this research is that the differences observed in the distribution of benthic marine algae should be reproduced in a study with beach-cast seaweeds from the two regions, both in terms of richness and abundance. 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 consisted of Emboaca beach (EMB) in Trairi, Ceará (3º12'23.5"S, 39º18'37.1"W) and Candeias beach (CAN) in Jaboatão dos Guararapes, Pernambuco (8º12'46"S, 34º55'6"W). The NE region is unique because of its oligotrophic waters and the abundance of substrates, 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 characteristics peculiar to it, such as a wide diversity of environments, which includes reef formations, rocky substrate, substrate consolidated by concretions of limestone algae and extensive rhodolith banks in waters under the influence of the Benguela Current, which reaches the north of the state of Espírito Santo, originating from the Brazil Current. Its 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 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. Along each transect, three 25 X 25 cm quadrats were randomly positioned, totaling 9 quadrats per sampling site as previously described by Barbosa (2010) and Santos et al. (2013). The specimens collected from each quadrat were placed inside individual labeled sealed plastic bags, and immediately frozen at -20ºC 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.

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 estimate the richness, biomass, coverage and frequency of the taxa present. Biomass was estimated by oven-drying the macroalgae at 60ºC 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). Coverage was estimated by calculating % occupancy of quadrats (divided into 4 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 applied to define the taxa that contributed the most to the observed dissimilarities between beaches (Clarke, 1993). Both nMDS and SIMPER were calculated using PRIMER v. 6.1.15 (Clarke & Gorley, 2006).

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 taxa were identified: 80 Rhodophyta, 13 Phaeophyceae, 17 Chlorophyta, in 14 orders and 59 genera. In both NE and SE Brazil, Rhodophyta had the highest number of representative genera in terms of richness 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 richness of species was observed in NE Brazil.

Lobophora variegata and *A. 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 *Alsidium 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 (Appendix 1).

The average coverage values for both regions were very similar (NE 97%; SE 98%), 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}). 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 determined by the species *S. schroederi* and *S. filipendula*, and by *D. delicatula* for coverage. 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

There are differences in richness, frequency, coverage and biomass values of beach-cast macroalgae among the studied regions. 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. In this study, notably, there was a high diversity of Rhodophyta taxa, which is indicative of subtidal origin. The origin of the beach-cast seaweeds seems to be related to the subtidal regions because the results found in our study are in agreement with studies carried out in the subtidal regions of SE (Horta, 2000; Cocentino, 2009; Yoneshigue *et al.*, 2006) and NE Brazil (Riul *et al.*, 2009). Based on the richness data and the frequent association between beach-cast seaweeds and rhodoliths, common substrates 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).

Of the five FFGs evaluated, corticated algae were more frequent in all beaches. Corticated algae, are mainly 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). 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. 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 differences in coverage and biomass of the macroalgal assemblage found in the studied areas as seen by the nMDS were further confirmed by the PERMANOVA and PERMDISP tests. *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, though not yet in Brazil, have indicated its potential in the production of alginate gels and high viscosity solutions of great economic interest, for example 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 richness values, 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 quantified 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 Northeast 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 these algae is negative for tourism. The 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. 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 refuges (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 et al., 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 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. Kirkham & Kendrick (1997) pointed out that it is necessary to understand the link between the living resource 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, a potential source of alternative biofunctional products as-natural resources are being depleted.

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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.*

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.

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

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 (gray 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.

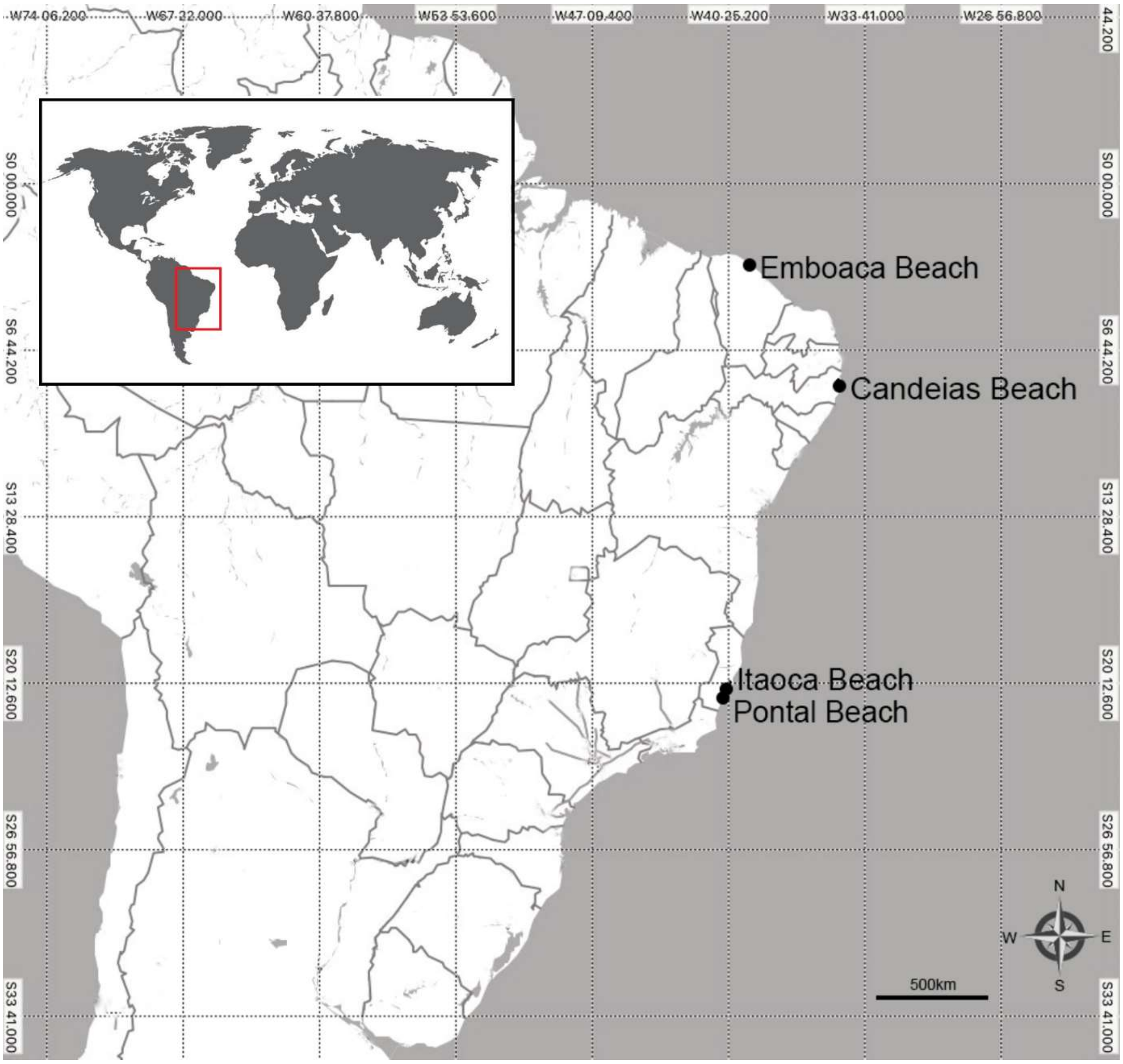

Figure 1. Map of Brazil showing the sampling sites.

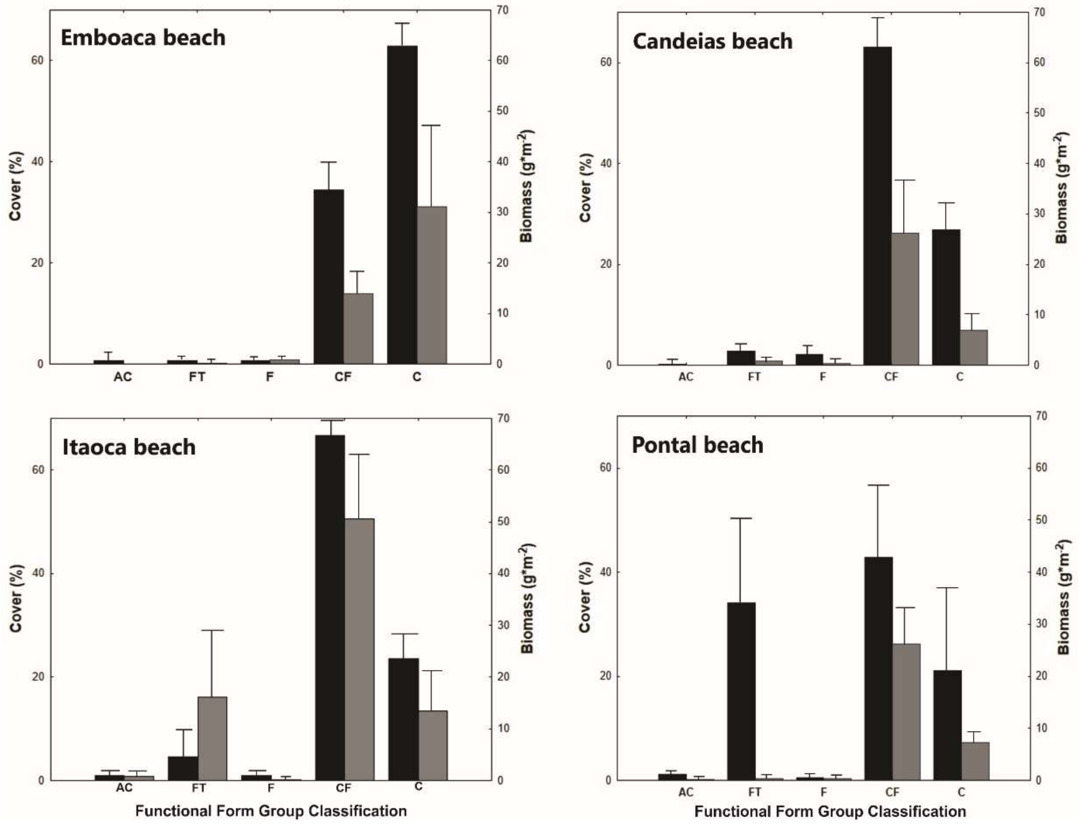

Figure 2. Coverage and biomass of functional-form groups in the studied beaches. Emboaca beach; Candeias beach; Itaoca beach; Pontal beach. AC: articulated calcareous algae; FT: filamentous algae; F: foliose algae; CF: corticated foliose algae; C: corticated algae. Cover (black bars), biomass (gray bars).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

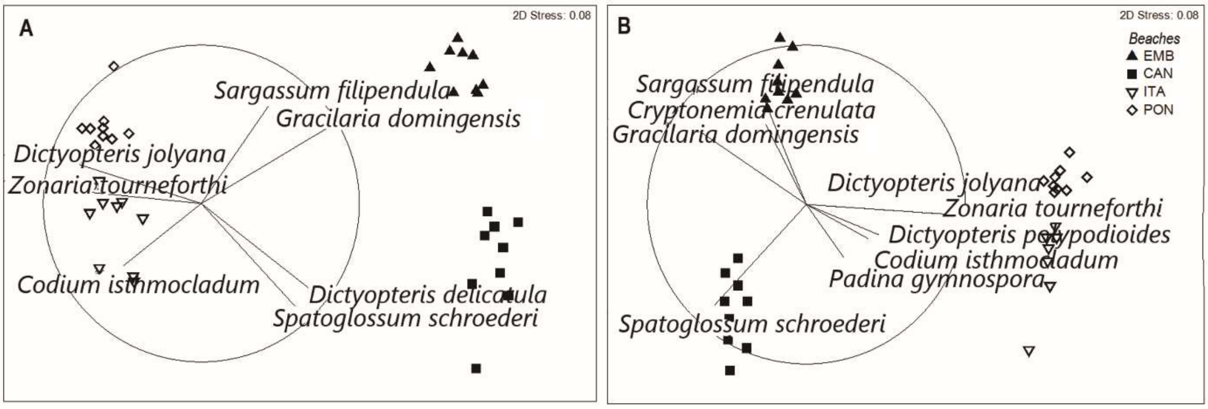

Figure 3. nMDS biplot of sampling units (9), based on the (A) coverage and (B) biomass of macroalgal species recorded in the four beaches. The vector plots represent the species obtained in the SIMPER analysis that contributed more than 9% to the differences between beaches.

Appendix 1: Macroalgal species recorded at the four sampling sites with their frequency of occurrence and functional-form group according to Steneck & Dethier (1994).

Taxa	FFG	Northeastern		Southeastern	
Ochrophyta (Phaeophyceae)		**EMB**	**CAN**	**ITA**	**PON**
Dictyotales					
Dictyopteris delicatula	FC	100	88.89	11.11	-
Dictyopteris jolyana	FC	22.22	11.11	100	100
Dictyopteris justii	FC	88.88	44.44	-	-
Dictyopteris polypodioides	FC	-	44.44	100	-
Dictyota ciliolata	FC	88.88	-	-	-
Lobophora variegata	FC	100	100	100	88.89
Padina gymnospora	FC	11.11	44.44	88.89	11.11
Sargassum filipendula	FC	44.44	44.44	88.89	44.44
Sargassum vulgare	FC	88.89	55.56	-	-
Sargassum sp.	FC	-	-	44.44	44.44
Spatoglossum schroederi	FC	55.56	100	33.33	11.11
Stypopodium zonale	FC	-	-	100	77.78
Zonaria tournefortii	FC	22.22	11.11	100	100
Rhodophyta					
Bangiales					
Pyropia spiralis	F	-	-	-	11.11
Corallinales					
Corallina panizzoi	CA	-	-	22.22	-
Jania pedunculata var. *adhaerens*	CA	-	-	11.11	11.11
Jania rubens	CA	11.11	-	-	-
Jania subulata.	CA	11.11	11.11	11	11.11
Nemaliales					
Scinaia halliae	C	-	11.11	-	-

Tricleocarpa cylindrica	CA	11.11	11.11	11.11	11.11
Ceramiales					
Acanthophora muscoides	C	11.11	-	-	-
Acantophora spicifera	C	22.22	11.11	11.11	22.22
Alsidium seaforthii	C	77.78	100	88.89	100
Alsidium triquetrum	C	100	66.67	11.11	-
Amansia multifida	C	88.89	11.11	22.22	-
Centroceras clavulatum	FT	11.11	11.11	11.11	-
Ceramium sp.	FT	11.11	22.22	11.11	-
Dasya rigidula	C	-	-	-	22.22
Dipterosiphonia dendritica	C	-	-	11.11	44.44
Enantiocladia duperreyi	C	-	-	-	11.11
Halopithys schottii	C	-	-	88.89	77.78
Haloplegma duperreyi	F	100	11.11	44.44	100
Herposiphonia sp.	FT	-	11.11	-	-
Heterodasya mucronata	C	-	-	88.89	-
Heterodasya sp.	C	-	-	-	44.44
Laurencia dendroidea	C	22.22	-	-	11.11
Laurencia sp.	C	-	-	-	11.11
Osmundaria obtusiloba	C	88.89	22.22	88.89	100
Osmundaria sp. (form 1)	C	11.11	11.11	22.22	22.22
Osmundaria sp. (form 3)	C	100	11.11	88.89	100
Osmundaria sp.	C	100	11.11	-	-
Palisada flagellifera	C	55.56	11.11	22.22	-
Palisada furcata	C	11.11	-	-	77.78
Palisada perforata	C	55.56	11.11	-	-
Spyridia clavata	FT	-	-	55.56	88.89
Spyridia filamentosa	FT	-	-	-	11.11
Spyridia hypnoides	FT	-	-	22.22	-

Yuzurua sp.	C	-	-	11.11	-
Gelidiales					
Gelidiella acerosa	C	100	11.11	11.11	-
Gelidiella sp.	C	22.22	44.44	-	-
Gelidium lineare	C	-	66.67	-	-
Gelidium sp.	C	-	33.33	-	-
Pterocladiella sp.	C	-	11.11	-	-
Gigartinales					
Agardhiella floridana	C	-	-	55.56	-
Agardhiella ramosissima	C	66.67	-	88.89	-
Calliblepharis occidentalis	C	88.89	-	22.22	-
Chondracanthus acicularis	C	-	77.78	-	-
Chondracanthus teedei	C	-	-	22.22	-
Hypnea pseudomusciformis	C	22.22	100	66.67	-
Hypnea yokoyana	C	-	11.11	-	-
Hypnea sp.	C	-	-	-	66.67
Meristotheca gelidium	C	-	-	88.89	-
Ochtodes secundiramea	C	-	11.11	-	11.11
Rhodophyllis gracilarioides	C	-	-	33.33	-
Solieria filiformis	C	-	-	33.33	-
Gracilariales					
Crassiphycus birdiae	C	44.44	22.22	-	-
Crassiphycus caudatus	C	100	22.22	-	-
Crassiphycus corneus	C	88.89	22.22	-	-
Gracilaria cearensis	C	22.22	22.22	-	-
Gracilaria cervicornis	C	11.11	66.67	-	-
Gracilaria cuneata	C	11.11	44.44	-	-
Gracilaria curtissiae	C	88.89	11.11	-	-
Gracilaria domingensis	C	100	100	66.67	11.11

Gracilaria ornata	C	77.78	44.44	-	-
Gracilaria sp.	C	-	33.33	-	-
Gracilariopsis silvana	C	-	77.78	-	-
Halymeniales					
Cryptonemia bengryi	C	11.11	-	-	-
Cryptonemia crenulata	C	100	33.33	-	-
Cryptonemia seminervis	C	77.78	11.11	44.44	100
Dermocorynusdichotomus	C	-	-	11.11	-
Grateloupia gibbesii	C	-	-	11.11	-
Grateloupia sp.	C	-	11.11	-	-
Halymenia brasiliana	C	-	-	55.56	-
Halymenia cearensis	C	-	11.11	-	-
Halymenia elongata	C	-	11.11	22.22	-
Halymenia ignifera	C	-	-	11.11	-
Halymenia pinnatifida	C	-	-	100	-
*Halymenia*s sp.	C	-	-	33.33	-
Plocamiales					
Plocamium brasiliense	C	-	-	-	66.67
Rhodymeniales					
Botryocladia occidentalis	C	100	33.33	22.22	44.44
Ceratodictyon planicaule	C	11.11	22.22	33.33	66.67
Ceratodictyon scoparium	C	77.78	-	-	-
Ceratodyction variabile	C	11.11	22.22	-	-
Chlorophyta					
Bryopsidades					
Bryopsis hypnoides	FT	11.11	22.22	-	-
Bryopsis pennata	FT	11.11	11.11	22.22	-
Bryopsis plumosa	FT	11.11	-	-	-

Caulerpa cupressoides	C	11.11	22.22	-	-
Caulerpa microphysa	C	77.78	-	-	-
Caulerpa prolifera	C	55.56	22.22	-	-
Caulerpa racemosa	C	33.33	44.44	11.11	-
Caulerpa sertularioides	C	22.22	11.11	-	-
Codium decorticatum	FT	-	-	-	88.89
Codium isthmocladum	FT	33.33	11.11	100	11.11
Halimeda jolyana	CA	-	22.22	33.33	88.89
Cladophorales					
Anadyomene stellata	F	11.11	11.11	-	-
Cladophora prolifera	FT	11.11	100	22.22	11.11
Cladophora vagabunda	FT	11.11	11.11	-	-
Willeella ordinata	FT	44.44	11.11	-	-
Ulvales					
Ulva lactuca	F	55.56	55.56	66.66	11.11
Ulva rigida	F	88.89	-	-	-

CAPÍTULO IV

MANUSCRITO A SER SUBMETIDO À REVISTA FOOD CHEMISTRY

Nutritional composition of beach-cast marine algae from the Brazilian coast: add-value for algal biomass considered as waste

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HIGHLIGHTS

- Beach-cast seaweeds are available and suitable underused biomass with similar chemical properties to edible seaweeds or vegetables or seaweed-based feed.
- The nutritional profiling of 12 seaweeds (red, brown, and green taxa) from the Brazilian coast is shown.
- All beach-cast seaweeds exhibited different nutritional properties, some species combining several characteristics while others with a specific attribute.
- Our data show that beach-cast seaweeds can be suitable underused biomass that should be best known for valorization, exploitation, and bioprospecting purposes.

ABSTRACT

It is common practice to dispose of beach-cast marine algae as urban waste. However, there is a huge potential for these seaweeds as a new source of feedstock due to their nutritional properties, similar to those found in edible seaweeds, vegetables, or seaweed-based feed as well as their biofunctional profile. We characterize the nutritional profile of 12 beach-cast algal species from the Brazilian coast, aiming for the evaluation of its potential valorization. The algae showed significant amounts of nutritional features like ash (6.5 to 59.3%), total dietary fibers (22.1 to 65.8%), proteins (5.1 to 21.5%), and carbohydrates (31.4 to 81%), with expressive composition and abundance of minerals, free amino, and acids fatty acids. The overall profile suggests the suitability of beach-cast seaweeds for nutritional and other bioeconomical purposes like feed, food, cosmeceutical, biomaterials, and farmaceutical industries, in which different species contribute with diverse traits.

Keywords: Amino acids, Fatty acids, Feed, Food, Functional ingredient, Seaweeds

1. Introduction

Population growth combined with increasingly limited or overused resources of arable lands and freshwater have resulted in a need for alternative protein sources and feedstocks with nutritional attributes. At present, plant protein is primarily produced by land crops. Marine algae do not compete with traditional food crops for space and resources, therefore they can be seen as underexploited marine vegetable crops providing nutritious components with high productivity (Bolton, Robertson-Andersson, Shuuluka, & Kandjengo, 2009; Angell, Angell, de Nys, & Paul, 2016; Mata, Magnusson, Paul, & de Nys, 2016; Angell, Paul, & de Nys, 2017). Several studies on edible seaweeds showed interesting nutritional chemical composition; in particular, red and green seaweed species are gaining interest as protein-rich foods for human consumption and sources of proteinaceous biofunctional peptide ingredients (Fleurence, Le Coeur, Mabeau, Maurice, & Landrein, 1995; Fleurence, 1999a, 1999b; Domínguez, 2013). To our knowledge, the composition and properties of macroalgae from the Brazilian coast had not been investigated so far, in contrast to other countries such as Japan, China, and Western countries (Gressler et al., 2010; Yaich et al., 2011). However, the Brazilian coast is rich in macroalgae regarding biomass and biodiversity (Gressler et al., 2011) suitable as nutritional and functional feedstock.

Nevertheless, there are few market macroalgae species by aquaculture production, and predatory extractivism from natural beds is no longer a globally accepted practice. Therefore, the search for alternative biomass including new aquacultured species, natural bed management, or other available seaweed material has been the focus of many researchers and industries. As a large amount of available and suitable underused biomass, the harvest of beach-cast marine algae for various applications, usually consider as waste can generate ecosystem services contributing to the blue bioeconomy and seaweed valorization that currently lack market price attractiveness. In addition to commercial uses, annually tons of beach-cast seaweeds are removed as part of beach cleaning operations by local authorities and are discarded into landfill sites as part of urban waste or have valorization for cosmetic purposes in some few countries (López-Mosquera et al., 2011; Barbot, Al-Ghaili, & Benz, 2016). The inappropriate management of marine macroalgae waste accumulated at the coastal regions represents a loss of resources and an opportunity to add value to the economic sector (Russo, 2015; Pardilhó et al., 2021). Either wild pelagic growing or beach-cast seaweeds are currently harvested for direct consumption or processed into food additives and nutraceuticals, feed, biofuels, agricultural fertilizers, cosmetics, and medicines or used as a source of potassium and iodine production or to hydrocolloid extraction (Buschmann et al., 2017). As a consequence, the determination of the biochemical composition and abundance is the first step in assessing the nutritional value or biofunctional ingredient properties of beach-cast seaweeds used as a potential food product or other biofunctional application. For these reasons, we selected 12 abundantly biomass of beach-cast algal species from the Brazilian coast and characterized the nutritional profile aiming the evaluation of its potential utilization as food or other supplements that could be explored as a regional and sustainable biomass source.

2. Materials and methods

2.1. Sample collection and species identification

Twelve different abundant biomass species of red, brown, and green beach-cast macroalgae were collected from the southeast and northeast beaches of the Brazilian coast (Table S1). The seaweeds were collected by systematic sampling, in which only visible healthy individuals were selected. The material was cleaned of macroepiphytes, washed with abundant tap water, and air-dried under shaded local. The pre-dried samples were transported to the laboratory, air circulation oven-dried at 40 °C, and then powdered in a ball mill. Three fresh individuals for each species were separated for exsiccate and deposited in the SPF Herbarium (Phycological

Section) at the University of São Paulo and the Herbarium of the Instituto de Botânica, São Paulo (SP), Brazil (Table S1). Maria Irisvalda Leal Gondim Cavalcanti and Dr. Mutue T. Fujii, both from the Instituto de Botânica, confirmed taxonomic identity.

2.2. Bromatological characterization

Dry matter was determined according to AOAC methods 925.10 in a TGA 601 thermogravimetric system at 105 °C. Ash and protein contents were determined using a protein analyzer (LECO TGA 601 Corp., St. Joseph, MI, USA) based on the Dumas combustion method according to the AOAC method 968.06 (AOAC, 1990). The samples were burned according to DIN EN ISO 14891 at 550 °C and 950 °C until complete incineration. The organic nitrogen content was quantified and the total crude protein was estimated by using the factor 6.25 (Lourenço, Barbarino, De-Paula, Pereira, & Marquez, 2002; Barbarino & Lourenço, 2005). Although this conversion factor is high for algae material, it was used to allow comparison to previous studies.

Soluble (SDF), insoluble (IDF), and total (TDF) dietary fibers were determined according to the enzymatic-gravimetric method AOAC 993.19 and 991.43 (AOAC, 2016) as provided by Megazymes (Megazymes International Irland, Bray County Wicklow, Irland) using Fibertec.

Crude carbohydrates were calculated by the difference of 100 minus ash and crude proteins. Soluble carbohydrates were obtained by three-time aqueous extraction for 2 h each at 70 °C and determined using the phenol-sulfuric acid method (Masuko et al. 2005) by absorbance read at 490 nm. Soluble carbohydrates were calculated by referring to the galactose standard curve.

2.3. Mineral composition

Macro (N, P, Ca, K, Mg, Na) and micro (Fe) elements and trace metals (Cd, Cu) were determined using concentrated HNO_3 and H_2O_2 30% (v/v) digestion in a thermal digester block

(DigiPrep, SCP Science, USA) and an Inductively Coupled Plasma Optical Emission Spectrometry technique (ICP-OES, Arcos, USA) according to Allen et al. (1997).

2.4. Free amino acids

Free amino acid profile was analyzed according to Santa-Catarina et al. (2006), with modifications. Samples were extracted with 6 mL of ethanol 80% for 2 h and the supernatant concentrated in speed-vacuum. The concentrated sample was re-suspended in 2 mL of ultrapure water and the supernatant was filtrated with a 0.2 µm Millipore membrane. Amino acids were derivatized with *o*-phthaldialdehyde (OPA) and identified by HPLC (Shimadzu Shin-pack CLC ODS) using a C18 reverse-phase column (Supelcosil LC-18, 25 cm × 4.6 mm/L × i.d.). The gradient was developed by mixing increasing proportions of methanol 65% to a buffer solution (50 mM sodium acetate, 50 mM sodium phosphate, 20 mL/L methanol, 20 mL/L tetrahydrofuran, and pH 8.1 adjusted with acetic acid). The gradient of methanol 65% was programmed according to Egydio et al. (2013). Fluorescence excitation and emission wavelengths were 250 nm and 480 nm, respectively. Peak areas and retention times were measured by comparison with known quantities of standard amino acids (Sigma-Aldrich, USA).

2.5. Fatty acids

Lipid content was determined by the Büchi Caviezel method, where the measurements of the fatty acid were based on a gas chromatographic separation (Agilent 7890A) and detection by a flame ionization detector. The method takes into consideration all free and bonded fatty acids from C4 to C24 with a content of 0.1 to 100% regarding the total content of fatty acids in the sample expressed as triglycerides.

2.6. Protein solubility

Protein solubility was determined by a standardized method based on Morr et al. (1985) by using the Megazyme Kit (AOAC Method 991.43). Protein solubility is understood to mean the determined amount of protein, which has dissolved again after stirring into a 0.1 mol/L sodium chloride solution at a corresponding pH. The undissolved portion is separated by centrifugation and the remaining protein in solution is calculated by nitrogen analysis and multiplied by the respective total crude protein. Protein solubility was carried out at pH values from 2 to 13.

2.7. Statistical analysis

All analytical determinations were performed at least in triplicate as technical replication, except for protein solubility. Values were expressed as mean ± standard deviation (SD). One-way Analysis of Variances (ANOVA) was performed followed by Student-Newman-Keuls (SNK) test to determine the significant differences ($p < 0.05$) among the samples by the software Statistic v.10. Additionally, pairwise multiple comparisons by mean Euclidean cluster based on Pearson's correlation were carried out for the global integration of nutritional composition and compare the best score for each species by the software PAST v.2.17.

3. Results and discussion

3.1. Samples collection and species identification

There was a broad species diversity of abundant biomass of beach-cast seaweed selected for our study, eight correspondings to red macroalgae (Rhodophyta), three brown macroalgae (Phaeophyceae, Ochrophyta), and one green macroalga (Chlorophyta) (Table S1) collected from the Brazilian northeast and southeast coasts.

3.2. Bromatological characterization

Bromatological characterization is summarized in Table 1 and supplementary Figure S1. Dry matter showed slight magnitude variation ranging from 89.0 ± 0.1% (*H. brasiliana*) to 94.9 ± 0.3% (*G. domingensis*). Ash content exhibited the highest amount in *C. isthmocladum* (59.3 ± 1.5%), in which the brown beach-cast seaweeds showed the lowest percentage of ash (6.5 to 20.4%) and the red beach-cast seaweeds ranged from 25.8 ± 0.2% to 58.3 ± 0.4%. The ash content in seaweed is high compared to vegetables and includes macro-minerals and trace elements that show seasonal and environmental variation in the composition as described in Holdt, and Kraan (2011).

Seaweeds are rich in dietary fibers (> 50% DW), particularly in the soluble form (Lahaye, 1991; Lahaye & Kaeffer, 1997; Deniaud, Fleurence, & Lahaye, 2003; Dawczynski, Schubert, & Jahreis, 2007; Wells et al., 2017). Total dietary fiber (TDF) was variable among the species and taxa studied here. The highest TDF content was found in *D. jolyana* with 65.8 ± 1.1 g/100 g regarding 46.4 ± 1.0 g/100 g soluble dietary fibers (SDF), whereas *C. isthmocladum* had the lowest content of TDF, 22.1 ± 0.2 g/ 100 g regarding 4.7 ± 0.5 g/100 g SDF. The TDF content agreed with the values previously reported for seaweeds (Lahaye, 1991; Mabeau & Fleurence, 1993; Ruperez & Saura-Calixto, 2001; Ortiz et al., 2006).

The insoluble dietary fiber (IDF) abundance ranges between 5.1 ± 0.9 and 46.2 ± 0.3 g/100 g (Table 1, Fig. S1). Cornish, Mouritsen, and Critchley (2019) showed that utilization of non-digestible soluble fibers (polysaccharides/oligosaccharides), in the large intestine, can produce short-chain fatty acids (SCFAs) (e.g., butyrate, propionate, and acetate), which are important host health-promoting products of beneficial gut bacteria.

In this study, almost all species showed higher values of SDF than insoluble forms, ranging from 4.7 ± 0.5 g/100 g to 46.4 ± 1.0 g/100 g (Table 1, Fig. S1), which are higher than values determined in fruits and vegetables (Abdel-Fattah & Sary, 1987; Pak, 2000; Ortiz et al., 2006). For macroalgae, the main components of SDF are alginates for brown seaweeds and carrageenans and agars for red seaweeds (Lahaye & Kaeffer, 1997; Rupérez & Saura-Calixto, 2001), which are constituents of the amorphous external cell wall matrix, including minor amounts of cellulose, xylans, galactans, hydroxyproline glycosides, mannans, and fucoidans depending the taxa. High SDF content is a desirable nutritional value as is considered a consuming benefit effect for any medical reason (Ortiz et al., 2006).

Some species displayed more SDF than IDF, whereas for other species the opposite was observed, representing a variable ratio of SDF/TDF and IDF/TDF.

Seaweeds are known for their low protein content, regarding 27% for red macroalgae, 12% for brown macroalgae, and 24% for green macroalgae (Wells et al., 2017; Tenorio, Kyriakopoulou, Suarez-Garcia, van den Berg, & van der Goot, 2018). Our data show crude proteins differences among the species, ranging from 7.3 ± 0.1 g/100 g to 19.7 ± 0.1 g/100 g for red specimens, 10.9 ± 0.4 g/100 g to 21.5 ± 0.2 g/100 g for brown specimens, and 5.1 ± 0.1 g/100 g for the green alga *C. isthmocladum* (Table 1, Fig. S1). *Codium isthmocladum* presented the lowest concentration of crude proteins and carbohydrates and soluble carbohydrates. It is important to note that *A. seaforthii* (red alga) and *S. schroederi* (brown alga) reached protein contents close to 20%, an expressive protein amount once it has been estimated 27% and 12% for red and brown seaweeds, respectively by Tenorio et al. (2018). The protein content from beach-cast *S. schroederi* is similar than the reported by Rice (1982), 16-24%. Additionally, the agarophyte *G. domingensis* is locally exploited as raw material for agar industry; however, the beach-cast *G. domingensis* showed 16.8 ± 0.1% of proteins that could open an alternative possibility for valuable by-product when compared to the value of 6.2% soluble protein reported from Gressler et al. (2010). In summary, the red and green beach-cast macroalgae were within the range as reported by different authors (Fleurence, 1999b; Angell et al., 2017; Wells et al., 2017).

Crude carbohydrate contents of beach-cast algae were expressive with levels from 31.4 ± 0.5 g/100 g to 81.0 ± 0.7 g/100 g (Table 1, Fig. S1). A large amount of polysaccharides in seaweeds from 4-76% DW is a feature of marine algae and reported by several authors as Holdt and Kraan (2011). Tenorio et al. (2018) described carbohydrate abundance of 12% for red algae, 21% for brown algae, and 8% for green algae. Carbohydrate amounts, as well as dietary fibers, are the two major metabolites of marine macroalgae. The cell wall and storage carbohydrates depend on the macroalga taxa and imply on their osmoregulation (Stiger-Pouvreau, Bourgougnon, & Deslandes, 2016). While mono- and disaccharides characteristically have low molecular weight and are water-soluble, polysaccharides have high molecular weight and are insoluble in water, except in hot water, and have numerous applications in industrial products. These polysaccharides represent the main nutritive storage in seaweeds, but also polysaccharide-rich cell wall, a major deposit of photosynthetically fixed carbon represents at least 50% of the dry weight of macroalgae, and undergo structural changes during their life cycle (Stengel, Connan, & Popper, 2011). The carbohydrate content of *H. brasiliana* is comparable to that reported by three *Halymenia* species from the Philippines reported by Hurtado, Magdugo, and Critchley (2020). Soluble carbohydrates were also assessed, with notable species like *G. domingensis* (113.5 ± 0.1 µg galactose/mg) and *D. jolyana* (146.0 ± 0.1 µg galactose/mg) (Table 1, Fig. S1). *Gracilaria domingensis* is an agarophyte species with high agar yield and low agar strength explored in the Brazilian northeast as a source for agar industry. On the other hand, *D. jolyana* is a known species with high polyphenol levels.

3.3. Mineral composition

Seaweeds are known to be high in mineral content, even 10-100 times higher than traditional vegetables (Rupérez, 2002; Holdt & Kraan, 2011; Gelli & Barbieri, 2015). Also, the ash content in seaweeds is high compared to vegetables. This high level of ash, basically minerals and trace elements, is attributed to the capacity to retain inorganic marine substances due to the characteristics of cell surface polysaccharides (Domínguez, 2013). Most of the macroalgae have high Ca, Mg, K, Na, and Fe contents (Rupérez, 2002; Kumar, Ganesan, Suresh, & Bhaskar, 2008). In this study Ca, K, Mg, Na, Fe, Cd and Cu were determined in all collected species (Table 2, Fig. S2). A wide variation in mineral content was observed among samples. A higher Ca content was observed in *A. triquetum* 7.24 ± 0.01% and for *A. seaforthii* 5.94 ± 0.05%.

All red algae offer an extraordinary level of K from 4.39 ± 0.01% for *A. seaforthii* to 11.18 ± 0.06% for *A. ramosissima*, which is very similar to our natural plasma level. However, the linkage of certain minerals with anionic polysaccharides (alginate, agar, or carrageenan) might limit the absorption of these minerals (Kumar et al., 2008). Notably, *C. isthmocladum* posses high Mg content of 2.11 ± 0.01% and high Na content of 14.90 ± 0.01%. The average content of Fe followed the order Phaeophyceae (316.57 ± 1.88 ppm to 2306.33 ± 15.58 ppm) > Rhodophyta (112.72 ± 0.60 ppm to 1879.26 ± 24.36 ppm) > Chlorophyta (310.40 ± 10.84 ppm). The level of minerals detected (Table 2) also fit within the ranges observed in previous reports in seaweeds (Rupérez, 2002). Some of the analyzed seaweed species may be seen as good sources of Ca, K, Mg, and Fe.

Non detected amount of Cd and Cu were registered, that could be an interesting feature as they can be toxic at high levels.

3.4. Free amino acids

Most seaweeds contain all the essential amino acids at proportions comparable to traditional protein sources, such as soybean meal and fishmeal (Domínguez, 2013; Angell, Mata, de Nys, & Paul, 2016). These amino acids occur as protein constituents and as free amino acids or salts. As widely described aspartic and glutamic acids constitute a large part of the amino acid fraction in seaweeds, while tryptophan is the first limiting amino acid in alga proteins. In general amino acid composition fluctuates seasonally affected by environmental conditions, and can also vary interspecifically (Fleurence, 1999b; Fleurence, 2004; Dawczynski et al., 2007; Harnedy & FitzGerald, 2011). Content, as well as the type of proteinaceous molecules such as peptides and free amino acids, depends on several factors such as available light, wave force, temperature, salinity, nutrient and mineral availability, and carbohydrate levels. Free amino acids and peptides are key determinants in food taste, like L-glutamate, which is recognized for *Umami* taste and is rich in cheese, tomato, and kelps. Other amino acids (alanine and glycine) also contribute to the distinctive flavors of some marine algae (Holdt & Kraan, 2011). The characteristic taste of many marine foods is elicited by free amino acids (Kato, Rhue, & Nishimura, 1989).

Table 3 and Figure S3 present the mean values from the analysis by HPLC of the free amino acid content. The seaweed samples contained all the essential amino acids (in different proportions). While Asp, Cit, Glu, Orn, Ser, Orn, and Trp seems to be the most abundant in brown seaweeds, red seaweeds possess a high amount of Arg, Asp, Cit, Glu, Orn, Ser, and Trp. While the green species *C. isthmocladum* showed a high amount of Arg, Asp, Cit, Glu, Leu, Ser, and Trp. The most significant observation pertains to the content of Cit that for most species are significantly higher than the contents of the remaining free amino acids. Citrulline is a common by-product of other amino acids like Orn and Arg, and like other amino acids, they play many vital functional roles, including the building of proteins, synthesis of hormones and neurotransmitters, and boost athletic performance. Arginine can be considered a nonessential amino acid, but it can be needed when fighting against certain diseases like cancer. Asparagine plays an important role in glycoproteins synthesis and liver health, associated also with fatigue. Glutamic acid is well known as a precursor to GABA, which acts as an excitatory neurotransmitter. Leucine is a branched-chain amino acid, critical for protein synthesis, muscle repair, and regulating blood sugar levels; also stimulates wound healing and produces growth hormones. Ornithine plays a role in the urea cycle by disposing of nitrogen excess. Serine participates in creatine, epinephrine, DNA and RNA synthesis, neuromodulation, and it has also been associated with breast cancer cell growth. Tryptophan is needed to maintain proper nitrogen balance and is a precursor of serotonin that regulates appetite, sleep, and mood. Total free amino acids found in the beach-cast algae ranged from 290.4 ± 122.6 µg/g to 11307.5 ± 4631.8 µg/g with a considerable wide variety of composition profile and abundance characteristic for each material. The highest content of all total amino acids was detected in three red species *A. seaforthii*, *A. triquetrum*, *O. obtusiloba*, and for the brown alga *D. jolyana*. Therefore, considering the functional role of free amino acids, the immediate availability, and the possible seaweed supplementation as a natural source, some species studied here can be proposed as natural amino acid stock.

3.5. Fatty acids

Lipids represent up to 5% of the seaweed on a dry weight basis, which is lower than that of other marine organisms. Generally, lipid levels and composition, including fatty acid profiles, vary according to a taxonomic entity, season, geographic regions, and growth conditions. Algae contain a wide variety of fatty acids and their oxidized products (oxylipins), as well as sterols of nutritional and chemo-taxonomic importance. Numerous studies have confirmed that the occurrence of fatty acids, oxylipins, and sterols in macroalgae are highly specific to their respective taxa and evolutionary history (Domínguez, 2013). It is generally known that algae can accumulate polyunsaturated fatty acids (PUFAs) when there is a decrease in environmental temperature. Marine lipids contain substantial amounts of long-chain PUFAs, with n-3 fatty acids as the significant component and mono-unsaturated fatty acids (Holdt & Kraan, 2011). Since humans are incapable of synthesizing PUFAs with more than 18 carbons, n-3 PUFAs are of nutritional importance and must be added as a dietary supplement or as part of a balanced diet. PUFAs greater than C18 are abundantly found in marine species, with green algae being rich in C18 PUFAs (ALA, STA, and LA) and red algae being rich in C20 PUFAs (AA and

EPA), while brown algae exhibit both in appreciable amounts (MacArtain, Gill, Brooks, Campbell, & Rowland, 2007; Kumari, Kumar, Gupta, Reddy, & Jha, 2010; Domínguez, 2013). The fatty acid composition of the seaweeds under study is shown in Table 4 and Figure S4. In all analyzed seaweed, palmitic acid (C16:0) was the single most abundant saturated fatty acid (SFA). The content of C16:0 was highest in *A. ramosissima* with 62.77 ± 10.63 g/100 g and lower levels were in *D. jolyana* with 21.05 ± 1.05 g/100 g. Furthermore, the macroalgae varieties tested had minor levels of myristic acid (C14:0) from 1.92 ± 0.21 g/100 g to 14.01 ± 0.77 g/100 g. In agreement with reports of other studies the most abundant fatty acid in the algae studied in this work, apart from C16:0, were generally C18:1, which was not detected in *A. ramosissima* (Sánchez-Machado, López-Cervantes, López-Hernández, & Paseiro-Losada, 2004; Gressler et al., 2010; Harrysson et al., 2018). Eight seaweeds also contained the essential fatty acids C18:2 (linoleic acid) and C18:3 (linolenic acid). The occurrence of the C18 PUFAs is important in human nutrition and for fish, which are not able to synthesize them (Sánchez-Machado et al., 2004).

3.6. Protein solubility

Macroalgae have a very robust polysaccharide-rich cell wall and the cell wall mucilage reduces the extractability of proteins. The extractability of proteins is influenced both by the ionic interactions between the cell wall and the proteins and by the high viscosity exerted via the polysaccharides in a water solution (Fleurence, Massiani, Guyader, & Mabeau, 1995). Hence the pH had a significant influence effect on the solubility of the seaweed proteins. Several studies have shown that the extractability and recovery of seaweed proteins could be increased with the pH-shift process, using alkaline protein solubilization followed by isoelectric precipitation, an efficient way to produce extracts with high protein concentrations (Harrysson et al., 2019). Protein solubility is also one of the most important parameters of a food ingredient because it influences other functional properties such as water-binding or foaming properties. The protein solubility in water at different pH values was adjusted between pH 2 and pH 13 as indicated in Table 5. The solubility of proteins increased for all species with increased pH as is reported by Vilg and Undeland (2017) and Harrysson et al. (2018). Maximum solubility achieved was 54.8 ± 1.8% at pH 13 for *A. seaforthii* with a second peak with 42.2 ± 0.9% at pH 12 and around 40% at pH 12 and pH 6, and for *G. domingensis* 52.5 ± 1.5% at pH 13 (Table 4, Fig. S5. Both red algae species showed maximum protein contents (respectively 19.7% and 16.8%) as well the brown alga *S. schroederi* with a crude protein content of 21.5 ± 0.2% and a peak with 26.3 ± 1.3% at pH 13. The solubility was decreasing with decreasing pH values, eventually plateauing at pH 6–8 where the solubility was only about 20 to 40%. Minimum solubility was observed at pH 13 for *D. jolyana* (25.3%), *S. schroederi* (26.3%), and *S. clavata* (26.0 %), while the solubility was about 34 to 54.8% for the rest of the species. The pattern of protein solubility of macroalgal biomass differs from those for example nuts (Ramos & Bora, 2004), whey (Mulcahy et al., 2016), and fish (Undeland et al., 2003), whose curves were U-shaped around pH 4-6 showing dip insolubility. It is, however, in accordance to other studies of marine algal proteins, with the same slope-shaped solubility curves (Vilg & Undeland, 2017).

4. Conclusion

This study investigated the nutritional composition of Brazilian beach-cast seaweeds and revealed important results in what concerns bromatological characterization and protein solubility, including similar chemical properties to edible seaweeds or vegetables or seaweed-based feed. It can be concluded that, particularly, some of the red and brown algae varieties represent an important source of proteins, which contain all free amino acids. Furthermore, this investigation of beach-cast macroalgae verified the presence of several health-promoting and beneficial nutrients, such as essential free amino acids, important fatty acids (C18 PUFAs), and dietary fiber with spotlighting some species. All species expressed similar suitable amounts of ash, fibers, crude proteins, and carbohydrates compared with other edible seaweeds, with emphasis of *D. jolyana* that exhibited the highest values for most of these descriptors. Minerals and free amino acids were also similar or higher than the common edible products, in which the studied beach-cast seaweeds showed attractive features and composition depending on the species. In turn, *O. obtusiloba*, *D. jolyana*, *C. isthmocladum*, *S. schroederi*, *A. seaforthii* and *Z. tournefortii* stood out regarding fatty acid contents, in which the first four were impressive in PUFAs.

Overall, it can be concluded that as the first complete bromatological characterization of beach-cast seaweeds the obtained results have clearly shown the potential of nutritional availability of this underused biomass as a source of natural fibers, proteins, carbohydrates, minerals, amino acids, and fatty acids. As represented in the integrated cluster analysis, each species has particular properties evidencing broad diversity of benefit, with species showing a greater diversity of components and abundance, while other species have less diversity and stand out for only a few characteristics. Therefore, beach-cast seaweeds can be suitable underused biomass that should be best known for valorization, exploitation, and bioprospecting purposes.

Credit authorship contribution statement

Andrea Mandalka: Conceptualization, Investigation, Formal and statistical analysis, Writing – original draft, review and editing. Maria Irisvalda L.G. Cavalcanti: Collection and identification, Soluble carbohydrate analysis. Talissa B. Harb: Collection, Statistical analysis. Mutue T. Fujii: Collection and identification. Peter Eisner: Funding acquisition, Project administration. Ute Schweiggert-Weisz: Supervision. Fungyi Chow: Conceptualization, Collection, Methodology, Statistical analysis, Writing – review and editing, Funding acquisition, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1. Bromatological characterization of beach-cast macroalgae (g/100 g = % and *µg galactose/mg on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). Crude carbohydrates calculated by difference = 100-crude protein-ash.

Species	Dry Matter	Ash	Total Dietary Fibers (TDF)	Soluble Fibers (SDF)	Insoluble Fibers (IDF)	SDF/TDF	IDF/TDF	Crude Proteins	Crude Carbohydrates*	Soluble Carbohydrates
Rhodophyta (red algae)										
Agardhiella ramosissima	92.2 ± 0.2 ^{cd}	57.3 ± 0.2 ^{a}	40.1 ± 1.5 ^{cd}	31.5 ± 2.1 ^{d}	8.6 ± 0.7 ^{d}	0.79	0.21	7.3 ± 0.1 ^{i}	35.4 ± 0.3 ^{i}	25.9 ± 0.1 ^{de}
Alsidium seaforthii	94.5 ± 0.3 ^{a}	34.7 ± 1.0 ^{c}	61.7 ± 4.9 ^{a}	33.5 ± 0.6 ^{d}	28.2 ± 4.7 ^{b}	0.54	0.46	19.7 ± 0.1 ^{b}	45.6 ± 0.9 ^{g}	11.9 ± 0.1 ^{de}
Alsidium triquetrum	92.7 ± 0.1 ^{bc}	46.5 ± 0.4 ^{b}	45.2 ± 4.8 ^{c}	19.3 ± 2.4 ^{e}	25.9 ± 2.3 ^{b}	0.43	0.57	12.8 ± 0.2 ^{f}	40.7 ± 0.5 ^{h}	32.3 ± 0.1 ^{d}
Botryocladia occidentalis	92.7 ± 0.1 ^{bc}	58.3 ± 0.4 ^{a}	25.0 ± 0.2 ^{e}	6.2 ± 0.4 ^{h}	18.8 ± 0.6 ^{c}	0.25	0.75	10.3 ± 0.2 ^{g}	31.4 ± 0.5 ^{j}	15.8 ± 0.1 ^{de}
Gracilaria domingensis	94.9 ± 0.3 ^{a}	35.2 ± 0.9 ^{c}	45.9 ± 0.8 ^{c}	37.5 ± 0.9 ^{c}	8.3 ± 0.1 ^{d}	0.82	0.18	16.8 ± 0.1 ^{c}	47.9 ± 0.8 ^{f}	113.5 ± 0.1 ^{b}
Halymenia brasiliana	89.0 ± 0.1 ^{h}	33.7 ± 1.0 ^{c}	46.8 ± 0.3 ^{c}	41.8 ± 1.1 ^{b}	5.1 ± 0.9 ^{d}	0.89	0.11	8.2 ± 0.4 ^{h}	58.1 ± 1.4 ^{d}	30.0 ± 0.1 ^{d}
Osmundaria obtusiloba	92.9 ± 0.1 ^{b}	31.2 ± 0.1 ^{d}	36.9 ± 3.5 ^{d}	19.8 ± 1.7 ^{e}	17.1 ± 1.7 ^{c}	0.54	0.46	14.6 ± 0.2 ^{d}	54.1 ± 0.2 ^{e}	58.9 ± 0.1 ^{c}
Spyridia clavata	90.8 ± 0.2 ^{g}	25.8 ± 0.2 ^{e}	33.7 ± 0.2 ^{d}	16.0 ± 0.9 ^{ef}	17.8 ± 0.9 ^{c}	0.47	0.53	13.6 ± 0.2 ^{e}	60.6 ± 0.3 ^{c}	15.8 ± 0.1 ^{cde}
Phaeophyceae (brown algae)										
Dictyopteris jolyana	92.0 ± 0.2 ^{de}	6.5 ± 0.6 ^{g}	65.8 ± 1.1 ^{a}	46.4 ± 1.0 ^{a}	19.4 ± 0.2 ^{c}	0.71	0.29	12.5 ± 0.2 ^{f}	81.0 ± 0.7 ^{a}	146.0 ± 0.1 ^{a}
Spatoglossum schroederi	91.3 ± 0.4 ^{fg}	19.4 ± 0.4 ^{f}	59.2 ± 0.4 ^{ab}	13.1 ± 0.3 ^{fg}	46.2 ± 0.3 ^{a}	0.22	0.78	21.5 ± 0.2 ^{a}	59.1 ± 0.2 ^{cd}	16.6 ± 0.1 ^{de}
Zonaria tournefortii	91.6 ± 0.4 ^{ef}	20.4 ± 0.8 ^{f}	54.5 ± 2.3 ^{b}	10.2 ± 1.8 ^{g}	44.3 ± 1.1 ^{a}	0.19	0.81	10.9 ± 0.4 ^{g}	68.7 ± 0.5 ^{b}	19.5 ± 0.1 ^{de}
Chlorophyta (green algae)										
Codium isthmocladum	93.1 ± 0.1 ^{b}	59.3 ± 1.5 ^{a}	22.1 ± 0.2 ^{e}	4.7 ± 0.5 ^{h}	17.4 ± 0.3 ^{c}	0.21	0.79	5.1 ± 0.1 ^{j}	35.6 ± 1.5 ^{i}	5.3 ± 0.1 ^{e}

Table 2. Macro (N, P, Ca, K, Mg, Na) and micro (Fe) elements and trace metals of beach-cast macroalgae (g/100 g = % and *ppm on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). nd = not detected.

Species	**Ca**	**K**	**Mg**	**Na**	**Fe***	**Cd**	**Cu**
Rhodophyta (red algae)							
Agardhiella ramosissima	0.50 ± 0.01 ^{cd}	11.18 ± 0.06 ^{a}	0.96 ± 0.01 ^{cd}	2.83 ± 0.01 ^{d}	112.72 ± 0.60 ^{d}	nd	nd
Alsidium seaforthii	5.94 ± 0.05 ^{a}	4.39 ± 0.01 ^{c}	0.81 ± 0.01 ^{a}	1.72 ± 0.01 ^{d}	1879.26 ± 24.36 ^{b}	nd	nd
Alsidium triquetrum	7.24 ± 0.01 ^{bc}	7.76 ± 0.03 ^{b}	1.03 ± 0.01 ^{c}	2.44 ± 0.01 ^{e}	509.17 ± 2.99 ^{b}	nd	nd
Botryocladia occidentalis	2.82 ± 0.03 ^{bc}	5.90 ± 0.01 ^{a}	1.74 ± 0.01 ^{e}	7.17 ± 0.06 ^{h}	1613.59 ± 12.54 ^{c}	nd	nd
Gracilaria domingensis	2.29 ± 0.03 ^{a}	10.80 ± 0.01 ^{c}	0.45 ± 0.01 ^{c}	0.65 ± 0.01 ^{c}	941.38 ± 14.01 ^{d}	nd	nd
Halymenia brasiliana	0.54 ± 0.01 ^{h}	7.24 ± 0.03 ^{c}	1.12 ± 0.02 ^{c}	1.62 ± 0.06 ^{b}	153.21 ± 0.49 ^{d}	nd	nd
Osmundaria obtusiloba	3.84 ± 0.03 ^{b}	6.25 ± 0.02 ^{d}	0.44 ± 0.01 ^{d}	0.29 ± 0.01 ^{e}	832.60 ± 2.24 ^{c}	nd	nd
Spyridia clavata	1.70 ± 0.03 ^{g}	5.43 ± 0.01 ^{e}	1.51 ± 0.01 ^{d}	1.04 ± 0.01 ^{ef}	878.81 ± 14.26 ^{c}	nd	nd
Phaeophyceae (brown algae)							
Dictyopteris jolyana	0.58 ± 0.01 ^{de}	0.56 ± 0.01 ^{g}	0.33 ± 0.01 ^{a}	0.54 ± 0.01 ^{a}	316.57 ± 1.88 ^{c}	nd	nd
Spatoglossum schroederi	4.31 ± 0.05 ^{fg}	0.26 ± 0.01 ^{f}	0.30 ± 0.01 ^{ab}	0.15 ± 0.01 ^{fg}	2021.13 ± 28.13 ^{a}	nd	nd
Zonaria tournefortii	2.75 ± 0.01 ^{ef}	1.28 ± 0.01 ^{f}	0.86 ± 0.01 ^{b}	0.81 ± 0.01 ^{g}	2306.33 ± 15.58 ^{a}	nd	nd
Chlorophyta (green algae)							
Codium isthmocladum	0.93 ± 0.01 ^{b}	0.54 ± 0.01 ^{a}	2.11 ± 0.01 ^{e}	14.90 ± 0.01 ^{h}	310.40 ± 10.84 ^{c}	nd	nd

Table 3. Amino acids composition of beach-cast macroalgae (µg/g on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). nd = not detected.

Species	Ala	Arg	Asn	Asp	Cit	Gln+His	Glu	Gly	Ile	Leu
Rhodophyta (red algae)										
Agardhiella ramosissima	0.4 ± 0.1^{d}	15.4 ± 0.3^{c}	8.5 ± 0.8^{b}	12.0 ± 0.8^{g}	65.8 ± 1.7^{d}	14.5 ± 0.2^{c}	11.8 ± 1.1^{e}	3.2 ± 0.2^{c}	6.8 ± 0.3^{b}	30.3 ± 0.2^{b}
Alsidium seaforthii	36.8 ± 14.9^{b}	4.9 ± 1.5^{c}	35.7 ± 0.1^{b}	42.7 ± 6.4^{ef}	2878.4 ± 211.5^{a}	8.2 ± 3.3^{d}	327.1 ± 44.2^{b}	19.0 ± 7.9^{a}	2.4 ± 0.5^{cd}	2.1 ± 0.6^{de}
Alsidium triquetrum	1.2 ± 0.4^{d}	1682.6 ± 76.7^{a}	2.6 ± 1.1^{b}	190.8 ± 5.5^{a}	0.9 ± 0.5^{d}	41.1 ± 4.7^{b}	513.4 ± 9.9^{a}	16.0 ± 1.7^{a}	23.7 ± 2.0^{a}	1.8 ± 0.4^{e}
Botryocladia occidentalis	1.9 ± 0.4^{d}	2.2 ± 0.4^{c}	6.3 ± 0.2^{b}	13.9 ± 1.5^{g}	9.1 ± 0.9^{d}	17.6 ± 3.3^{c}	46.3 ± 3.4^{e}	3.9 ± 0.6^{c}	1.4 ± 0.3^{d}	4.0 ± 0.6^{de}
Gracilaria domingensis	4.0 ± 1.2^{d}	293.0 ± 78.7^{b}	4.4 ± 0.9^{b}	26.3 ± 5.7^{fg}	8.5 ± 1.6^{d}	3.9 ± 0.6^{c}	42.7 ± 9.7^{e}	8.1 ± 1.9^{bc}	5.3 ± 0.9^{bc}	4.3 ± 1.5^{d}
Osmundaria obtusiloba	56.1 ± 5.7^{a}	2.1 ± 0.2^{c}	6788.1 ± 751.8^{a}	139.8 ± 17.4^{b}	67.4 ± 15.2^{d}	59.7 ± 8.3^{ab}	45.8 ± 8.6^{e}	6.1 ± 1.3^{bc}	4.1 ± 0.1^{bcd}	9.9 ± 0.7^{c}
Spyridia clavata	13.6 ± 3.6^{cd}	2.0 ± 0.5^{c}	5.9 ± 0.6^{b}	96.8 ± 5.4^{c}	416.4 ± 16.7^{c}	40.8 ± 1.1^{b}	103.3 ± 3.1^{d}	1.5 ± 1.9^{c}	0.9 ± 0.2^{d}	2.0 ± 0.6^{de}
Phaeophyceae (brown algae)										
Dictyopteris jolyana	5.8 ± 0.6^{d}	2.4 ± 0.01^{c}	51.7 ± 1.0^{b}	96.0 ± 3.2^{c}	1832.7 ± 0.1^{b}	8.8 ± 0.01^{c}	184.8 ± 0.1^{c}	13.6 ± 0.01^{ab}	1.7 ± 0.2^{d}	2.8 ± 1.3^{de}
Spatoglossum schroederi	4.6 ± 0.1^{d}	1.3 ± 0.4^{c}	5.0 ± 0.3^{b}	44.6 ± 0.1^{c}	9.0 ± 4.5^{d}	15.0 ± 0.01^{c}	41.2 ± 0.1^{e}	3.7 ± 0.9^{c}	2.3 ± 1.5^{cd}	3.6 ± 0.7^{de}
Zonaria tournefortii	24.9 ± 5.7^{bc}	1.0 ± 0.3^{c}	4.9 ± 2.0^{b}	66.4 ± 0.1^{d}	24.2 ± 0.1^{d}	69.0 ± 20.6^{a}	24.5 ± 0.1^{e}	1.7 ± 0.4^{c}	2.0 ± 0.8^{cd}	2.8 ± 1.2^{de}
Chlorophyta (green algae)										
Codium isthmocladum	0.9 ± 0.2^{d}	20.7 ± 0.1^{c}	5.9 ± 2.3^{b}	55.8 ± 2.8^{de}	78.0 ± 0.1^{d}	18.2 ± 0.9^{c}	49.6 ± 0.5^{e}	4.8 ± 1.2^{c}	6.3 ± 2.5^{b}	33.7 ± 0.1^{a}

(continued…)

Table 3 (continued…)

Species	Lys	Met	Orn	Phe	Ser	Thr	Trp	Tyr+GABA	Val	Total aa
Rhodophyta (red algae)										
Agardhiella ramosissima	15.7 ± 2.7 ^{bcd}	0.8 ± 0.2 ^{b}	19.8 ± 1.9 ^{e}	1.3 ± 0.2 ^{de}	46.7 ± 1.6 ^{cde}	1.1 ± 0.1 ^{bc}	45.8 ± 1.6 ^{cde}	2.7 ± 0.3 ^{b}	0.7 ± 0.3 ^{e}	346.5 ± 158.1 ^{b}
Alsidium seaforthii	2.2 ± 0.6 ^{f}	1.0 ± 0.2 ^{b}	42.8 ± 3.5 ^{de}	7.6 ± 0.4 ^{de}	43.9 ± 9.1 ^{cde}	nd	43.9 ± 9.1 ^{cde}	1.8 ± 0.1 ^{b}	6.7 ± 1.3 ^{c}	4718.9 ± 2154.0 ^{b}
Alsidium triquetrum	24.6 ± 1.1 ^{b}	3.3 ± 1.3 ^{b}	67.3 ± 3.9 ^{de}	1.0 ± 0.1^{dea}	1128.3 ± 5.2 ^{a}	10.1 ± 5.5 ^{a}	128.3 ± 5.2 ^{a}	0.2 ± 0.1 ^{b}	13.0 ± 1.4 ^{b}	3669.7 ± 1561.4 ^{b}
Botryocladia occidentalis	18.0 ± 2.9 ^{bc}	0.5 ± 0.2 ^{b}	361.7 ± 27.2 ^{b}	70.2 ± 9.2 ^{b}	2.1 ± 0.5 ^{f}	0.2 ± 0.1 ^{c}	2.1 ± 0.5 ^{f}	1.8 ± 0.5 ^{b}	5.8 ± 1.5 ^{cd}	761.6 ± 342.5 ^{b}
Gracilaria domingensis	5.4 ± 0.6 ^{ef}	732.3 ± 212.7 ^{a}	10.8 ± 2.1 ^{e}	0.5 ± 0.1 ^{de}	91.6 ± 34.6 ^{b}	0.9 ± 0.6 ^{bc}	91.6 ± 34.6 ^{b}	0.8 ± 0.1 ^{b}	5.1 ± 1.5 ^{cd}	1781.9 ± 645.3 ^{b}
Osmundaria obtusiloba	37.9 ± 8.3 ^{a}	1.2 ± 0.2 ^{b}	814.6 ± 68.2 ^{a}	156.2 ± 17.0 ^{a}	29.9 ± 4.9 ^{ef}	5.6 ± 1.3 ^{ab}	29.9 ± 4.9 ^{ef}	8.4 ± 1.6 ^{a}	22.4 ± 1.0 ^{a}	11307.5 ± 4631.8 ^{a}
Spyridia clavata	4.6 ± 1.4 ^{f}	0.5 ± 0.2 ^{b}	108.7 ± 0.9 ^{d}	18.6 ± 3.9 ^{d}	4.2 ± 0.4 ^{f}	0.7 ± 0.4 ^{bc}	4.2 ± 0.4 ^{f}	1.5 ± 0.2 ^{b}	3.6 ± 0.6 ^{d}	1114.1 ± 491.7 ^{b}
Phaeophyceae (brown algae)										
Dictyopteris jolyana	9.0 ± 0.5 ^{cdef}	0.7 ± 0.1 ^{b}	289.5 ± 21.4 ^{c}	46.8 ± 5.6 ^{c}	32.7 ± 5.0 ^{def}	1.9 ± 0.1 ^{bc}	32.7 ± 5.0 ^{def}	1.0 ± 0.1 ^{b}	6.0 ± 0.7 ^{cd}	3463.5 ± 1520.2 ^{b}
Spatoglossum schroederi	7.1 ± 4.3 ^{def}	1.3 ± 0.7 ^{b}	7.3 ± 5.1 ^{e}	0.4 ± 0.3 ^{e}	64.5 ± 0.0 ^{bcd}	0.4 ± 0.3 ^{c}	64.5 ± 0.1 ^{bcd}	2.0 ± 2.5 ^{b}	0.3 ± 0.1 ^{e}	290.4 ± 122.6 ^{b}
Zonaria tournefortii	3.1 ± 0.8 ^{f}	0.2 ± 0.1^{b}	50.9 ± 15.9 ^{de}	12.7 ± 0.6 ^{de}	2.6 ± 1.2 ^{f}	1.2 ± 0.2 ^{bc}	2.6 ± 1.2 ^{f}	4.1 ± 0.5 ^{b}	6.7 ± 0.1 ^{c}	419.0 ± 224.8 ^{b}
Chlorophyta (green algae)										
Codium isthmocladum	15.0 ± 4.8 ^{bcde}	3.6 ± 3.3 ^{b}	17.6 ± 8.5 ^{e}	0.7 ± 0.7 ^{de}	74.8 ± 5.3 ^{bc}	1.0 ± 0.5 ^{bc}	74.8 ± 5.3 ^{bc}	1.3 ± 0.8 ^{b}	0.5 ± 0.4 ^{e}	528.6 ± 245.4 ^{b}

Table 4. Fatty acids composition of beach-cast macroalgae (g/100 g on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). Statistical analysis was performed only for amounts over 10. nd = not detected.

Species	14:0	16:0	17:0	18:0	22:0	24:0	18:1	18:2	18:3
Rhodophyta (red algae)									
Agardhiella ramosissima	nd	62.77 ± 10.63 ^{a}	nd	nd	nd	nd	nd	nd	nd
Alsidium seaforthii	1.92 ± 0.21 ^{g}	21.65 ± 0.47 ^{d}	3.56 ± 1.43	2.63 ± 0.20	nd	nd	10.40 ± 0.87^{bcd}	4.68 ± 1.05	nd
Alsidium triquetrum	nd	27.36 ± 0.33 ^{cd}	nd	nd	nd	nd	7.50 ± 0.31 ^{d}	3.24 ± 0.10	nd
Botryocladia occidentalis	7.32 ± 0.08 ^{bc}	53.58 ± 0.78 ^{b}	nd	1.11 ± 1.93	nd	nd	20.09 ± 0.63 ^{a}	nd	nd
Gracilaria domingensis	5.53 ± 0.19 ^{d}	68.16 ± 1.15 ^{a}	nd	nd	nd	nd	8.38 ± 0.10 ^{cd}	nd	nd
Halymenia brasiliana	3.32 ± 0.13 ^{f}	35.32 ± 1.08 ^{c}	nd	nd	nd	nd	6.62 ± 0.34 ^{d}	nd	2.01 ± 1.74
Osmundaria obtusiloba	4.11 ± 0.64 ^{e}	21.27 ± 2.50 ^{d}	3.52 ± 1.50	4.67 ± 1.05	5.18 ± 2.04	3.14 ± 1.63	9.82 ± 1.69 ^{cd}	4.21 ± 1.41	5.86 ± 0.48
Spyridia clavata	4.13 ± 0.32 ^{e}	35.50 ± 3.81 ^{c}	nd	2.45 ± 2.27	3.64 ± 0.00	nd	13.99 ± 1.45 ^{abcd}	nd	nd
Phaeophyceae (brown algae)									
Dictyopteris jolyana	6.89 ± 0.35 ^{c}	21.05 ± 1.05 ^{d}	0.34 ± 0.58	0.91 ± 0.05	nd	0.37 ± 0.63	17.67 ± 0.90 ^{bcd}	7.89 ± 0.40	2.69 ± 0.13
Spatoglossum schroederi	7.86 ± 0.25 ^{b}	30.44 ± 1.19 ^{c}	nd	1.16 ± 0.25	3.54 ± 0.00	0.19 ± 0.16	18.26 ± 0.86 ^{ab}	3.93 ± 0.18	2.01 ± 0.06
Zonaria tournefortii	14.01 ± 0.77 ^{a}	22.49 ± 1.17 ^{d}	0.44 ± 0.75	1.69 ± 0.09	nd	nd	15.58 ± 1.24 ^{abc}	5.40 ± 0.39	nd
Chlorophyta (green algae)									
Codium isthmocladum	2.20 ± 0.18 ^{g}	28.03 ± 2.67 ^{cd}	nd	1.50 ± 0.12	nd	6.09 ± 0.69	13.66 ± 1.35 ^{abcd}	2.36 ± 0.18	2.10 ± 0.19

Table 5. Solubility of crude protein from beach-cast macroalgae (%) at different pH levels. Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). nd = not detected.

Species	**pH 2**	**pH 4**	**pH 6**	**pH 8**	**pH 10**	**pH 12**	**pH 13**	**Crude Proteins**
Rhodophyta (red algae)								
Agardhiella ramosissima	27.3 ± 2.5 ^{c}	22.4 ± 2.5 ^{cde}	34.7 ± 0.1 ^{b}	40.9 ± 8.7 ^{a}	33.5 ± 1.3 ^{cd}	29.8 ± 2.5 ^{d}	51.0 ± 1.2 ^{a}	7.3 ± 0.1 ^{i}
Alsidium seaforthii	27.4 ± 4.0 ^{c}	39.5 ± 0.9 ^{a}	40.4 ± 0.9 ^{a}	38.6 ± 0.9 ^{a}	40.8 ± 2.2 ^{a}	42.2 ± 0.9 ^{b}	54.8 ± 1.8 ^{a}	19.7 ± 0.1 ^{b}
Alsidium triquetrum	23.7 ± 0.01 ^{cd}	25.9 ± 2.1 ^{cd}	25.9 ± 0.7 ^{c}	27.3 ± 0.7 ^{b}	29.3 ± 0.1 ^{cd}	35.6 ± 0.6 ^{c}	nd	12.8 ± 0.2 ^{f}
Gracilaria domingensis	32.8 ± 0.5 ^{b}	33.9 ± 0.5 ^{a}	37.4 ± 0.1 ^{ab}	35.9 ± 0.5 ^{a}	38.0 ± 1.6 ^{cd}	38.5 ± 0.1 ^{bc}	52.5 ± 1.5 ^{a}	16.8 ± 0.1 ^{c}
Halymenia brasiliana	18.2 ± 0.1 ^{e}	19.4 ± 1.1 ^{de}	22.7 ± 0.1 ^{cd}	19.3 ± 1.1 ^{cd}	20.5 ± 2.3 ^{e}	21.6 ± 1.1 ^{e}	34.0 ± 2.3 ^{bc}	8.2 ± 0.4 ^{h}
Osmundaria obtusiloba	39.8 ± 1.6 ^{a}	37.2 ± 2.1 ^{a}	35.0 ± 3.2 ^{b}	39.9 ± 0.5 ^{a}	32.4 ± 2.7 ^{cd}	33.4 ± 3.7 ^{cd}	34.0 ± 0.1 ^{bc}	14.6 ± 0.2 ^{d}
Spyridia clavata	27.2 ± 0.7 ^{c}	33.2 ± 0.1 ^{ab}	42.0 ± 3.3 ^{a}	37.2 ± 1.3 ^{a}	35.2 ± 3.3 ^{abc}	48.6 ± 2.0 ^{a}	26.0 ± 0.8 ^{c}	13.6 ± 0.2 ^{e}
Phaeophyceae (brown algae)								
Dictyopteris jolyana	3.6 ± 0.7 ^{fg}	4.3 ± 0.1 ^{f}	6.5 ± 0.7 ^{ef}	7.3 ± 0.1 ^{ef}	6.5 ± 0.7 ^{f}	7.2 ± 0.1 ^{f}	25.3 ± 0.8 ^{c}	12.5 ± 0.2 ^{f}
Spatoglossum schroederi	0.8 ± 0.1 ^{g}	nd	2.9 ± 2.1 ^{f}	4.2 ± 0.1 ^{ef}	5.8 ± 0.8 ^{f}	6.3 ± 0.4 ^{f}	26.3 ± 1.3 ^{c}	21.5 ± 0.2 ^{a}
Zonaria tournefortii	6.7 ± 0.1 ^{f}	15.9 ± 5.9 ^{e}	9.2 ± 0.8 ^{e}	11.7 ± 1.7 ^{de}	24.2 ± 2.5 ^{de}	29.2 ± 2.5 ^{d}	40.0 ± 6.7 ^{b}	10.9 ± 0.4 ^{g}
Chlorophyta (green algae)								
Codium isthmocladum	nd	1.8 ± 1.8 ^{f}	3.5 ± 0.1 ^{f}	1.8 ± 1.8 ^{f}	3.5 ± 0.1 ^{f}	7.0 ± 0.1 ^{f}	nd	5.1 ± 0.1 ^{j}

SUPPLEMENTARY MATERIAL

Table S1. Summary of the beach-cast algae collected from southeast and northeast beaches, Brazil. CE: Ceará State, northeast coast. ES: Espírito Santo State, southeast coast. PE: Pernambuco State, northeast coast.

Species	Beach (State)	Localization	Nº Voucher (herbarium)	Data of collection
Rhodophyta (red algae)				
Agardhiella ramosissima (Harvey) Kylin	Itaoca Beach (ES)	20°54'18.0"S; 40°46'42.3"W	SP470206	04/30/2018
Alsidium seaforthii (Turner) J. Agardh	Piúma Beach (ES)	20°50'31.5"S; 40°43'46.0"W	SPF58253	06/11/2018
Alsidium triquetrum (S.G. Gmelin) Trevisan	Emboaca Beach (CE)	3°12'23.5"S; 39°18'37.1"W	SPF58318	03/30/2018
Botryocladia occidentalis (Børgesen) Kylin	Emboaca Beach (CE)	3°12'23.5"S; 39°18'37.1"W	SPF58317	03/30/2018
Gracilaria domingensis (Kützing) Sonder ex Dickie	Emboaca Beach (CE)	3°12'23.5"S; 39°18'37.1"W	SPF58316	03/30/2018
Halymenia brasiliana S.M.P.B. Guimarães & M.T. Fujii	Itaoca Beach (ES)	20°54'18"S; 40°46'42.3"W	SP470204	30/04/2018
Osmundaria obtusiloba (C. Agardh) R.E. Norris	Piúma Beach (ES)	20°50'31.5"S; 40°43'46.0"W	SPF58344	06/11/2018
Spyridia clavata Kützing	Pontal Beach (ES)	20°58'22.5"S; 40°48'38.6"W	SPF58251	06/09/2017
Phaeophyceae (brown algae)				
Dictyopteris jolyana E.C. Oliveira & R.P. Furtado	Pontal Beach (ES)	20°58'22.5"S; 40°48'38.6"W	SPF58249	04/30/2018
Spatoglossum schroederi (C. Agardh) Kützing	Candeias Beach (PE)	8°12'46"S; 34°55'6"W	SP470200	25/02/2018
Zonaria tournefortii (J.V. Lamouroux) Montagne	Pontal Beach (ES)	20°58'22.5"S; 40°48'38.6"W	SPF58252	06/09/2017
Chlorophyta (green algae)				
Codium isthmocladum Vickers	Itaoca Beach (ES)	20°54'18.0"S; 40°46'42.3"W	SP470207	04/30/2018

Supplementary Figure captions

Figure S1. Bromatological characterization of beach-cast macroalgae (% or g/100 g = % and *µg galactose/mg on dry mass basis) including dry matter, ash, total dietary fibers, soluble fibers, insoluble fibers, crude proteins and carbohydrates, soluble carbohydrates, and total lipids. Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). Crude carbohydrates calculated by difference = 100-crude protein-ash.

Figure S2. Macro (Ca, K, Mg, Na) and micro (Fe) elements and trace metals of beach-cast macroalgae (g/100 g = % and *ppm on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$).

Figure S3. Amino acids composition of beach-cast macroalgae (µg/g on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$).

Figure S4. Fatty acids composition of beach-cast macroalgae (g/100 g on dry mass basis). Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$).

Figure S5. Solubility of crude protein from beach-cast macroalgae (%) at different pH levels. Values represent the average of three technical replicates (mean ± SD) and letters indicate the statistical significance ($p < 0.05$). nd = not detected.

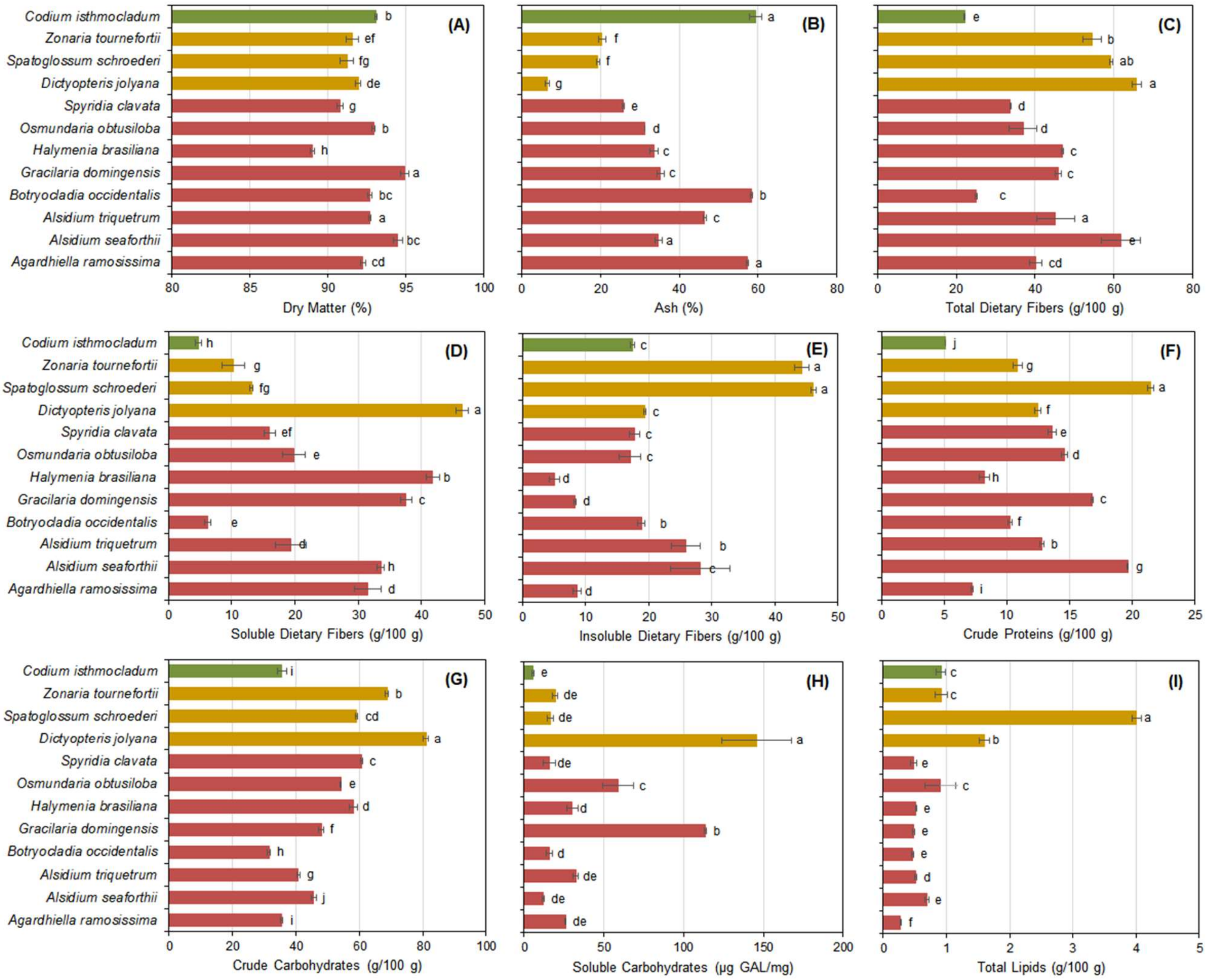

Codium isthmocladum
Zonaria tournefortii
Spatoglossum schroederi
Dictyopteris jolyana
Spyridia clavata
Osmundaria obtusiloba
Halymenia brasiliana
Gracilaria domingensis
Botryocladia occidentalis
Alsidium triquetrum
Alsidium seaforthii
Agardhiella ramosissima
(A)
b
ef
fg
de
g
b
h
a
bc
a
bc
cd
80
85
90
95
100
Dry Matter (%)
(B)
a
f
f
g
e
d
c
c
b
c
a
a
0
20
40
60
80
Ash (%)
(C)
e
b
ab
a
d
d
c
c
c
a
e
cd
0
20
40
60
80
Total Dietary Fibers (g/100 g)
(D)
h
g
fg
a
ef
e
b
c
e
d
h
d
0
10
20
30
40
50
Soluble Dietary Fibers (g/100 g)
(E)
c
a
a
c
c
c
d
d
b
b
c
d
0
10
20
30
40
50
Insoluble Dietary Fibers (g/100 g)
(F)
j
g
a
f
e
d
h
c
f
b
g
i
0
5
10
15
20
25
Crude Proteins (g/100 g)
(G)
i
b
cd
a
c
e
d
f
h
g
j
i
0
20
40
60
80
100
Crude Carbohydrates (g/100 g)
(H)
e
de
de
a
de
c
d
b
d
de
de
de
0
50
100
150
200
Soluble Carbohydrates (µg GAL/mg)
(I)
c
c
a
b
e
c
e
e
e
d
e
f
0
1
2
3
4
5
Total Lipids (g/100 g)

FIGURE S1

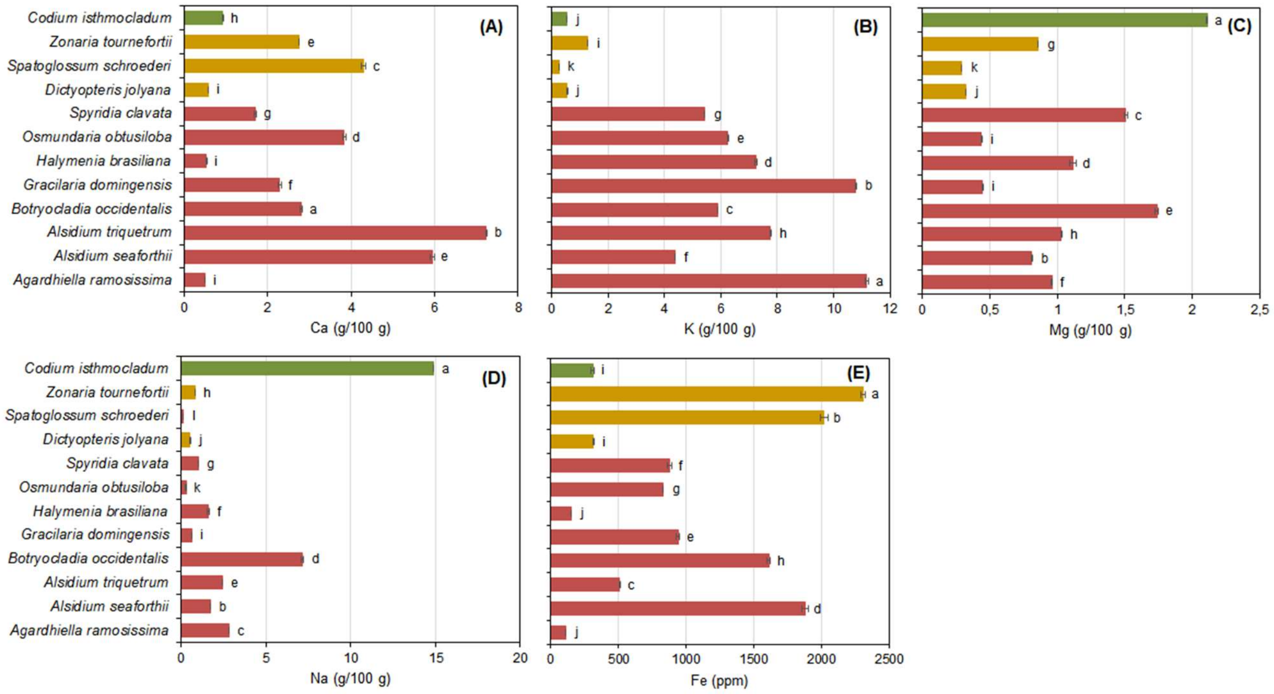

(A)
(B)
(C)
(D)
(E)
Codium isthmocladum
Zonaria tournefortii
Spatoglossum schroederi
Dictyopteris jolyana
Spyridia clavata
Osmundaria obtusiloba
Halymenia brasiliana
Gracilaria domingensis
Botryocladia occidentalis
Alsidium triquetrum
Alsidium seaforthii
Agardhiella ramosissima
Ca (g/100 g)
K (g/100 g)
Mg (g/100 g)
Na (g/100 g)
Fe (ppm)
0
2
4
6
8
10
12
0,5
1
1,5
2
2,5
5
15
20
500
1000
1500
2000
2500
h e c i g d i f a b e i
j i k j g e d b c h f a
a g k j c i d i e h b f
a h l j g k f i d e b c
i a b i f g j e h c d j

FIGURE S2

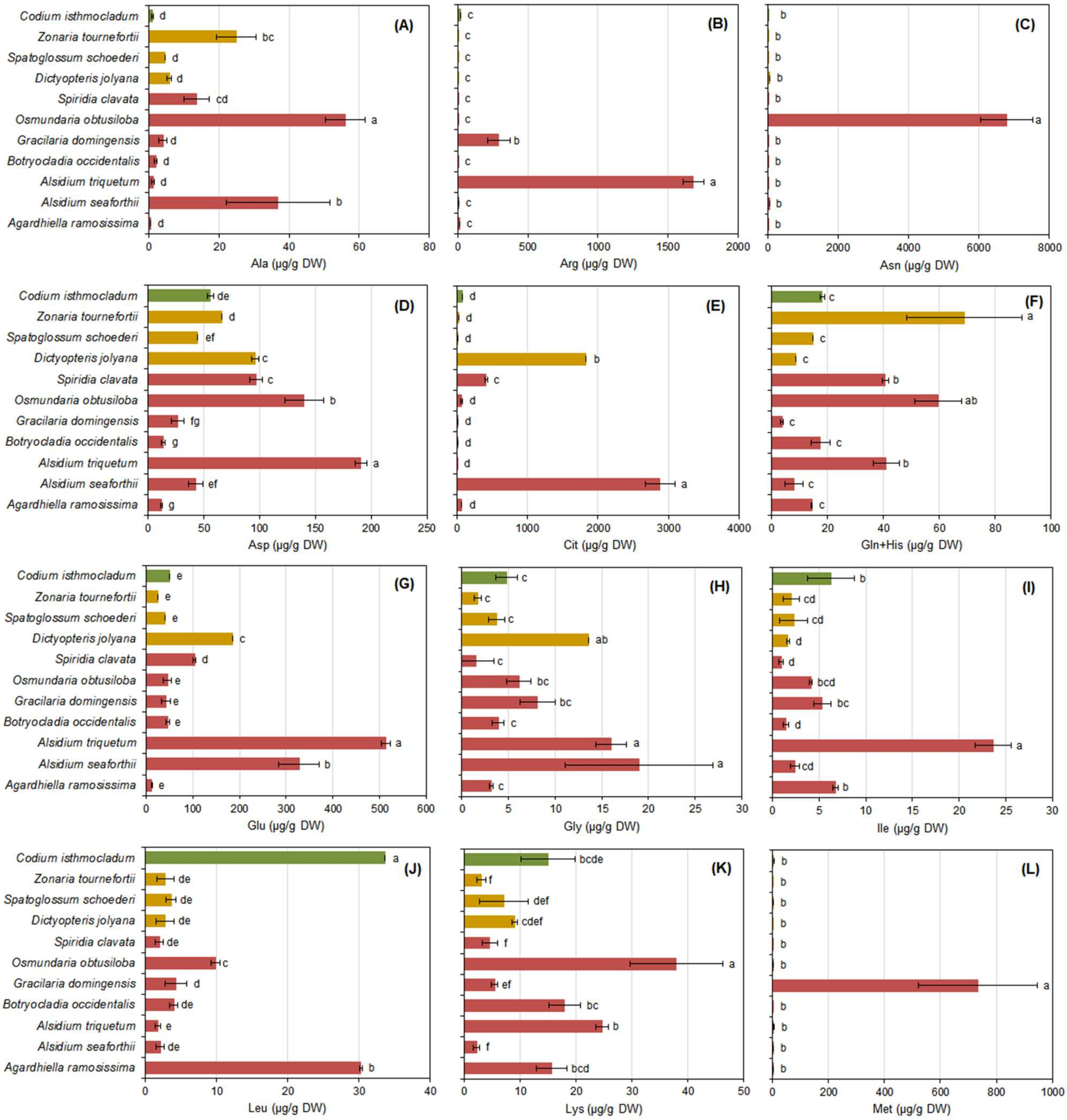
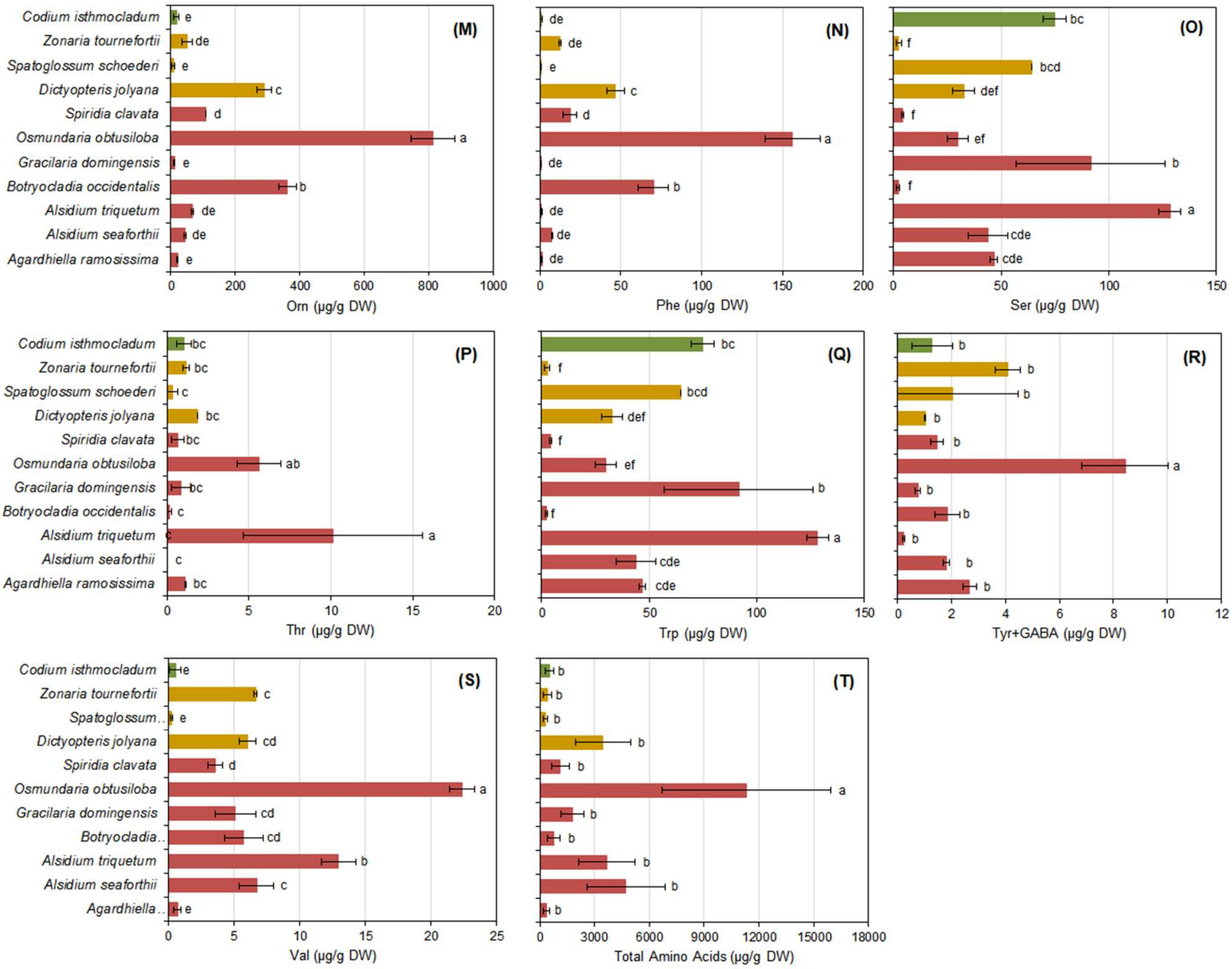


FIGURE S3 (continued...)

FIGURE S3 (continued...)



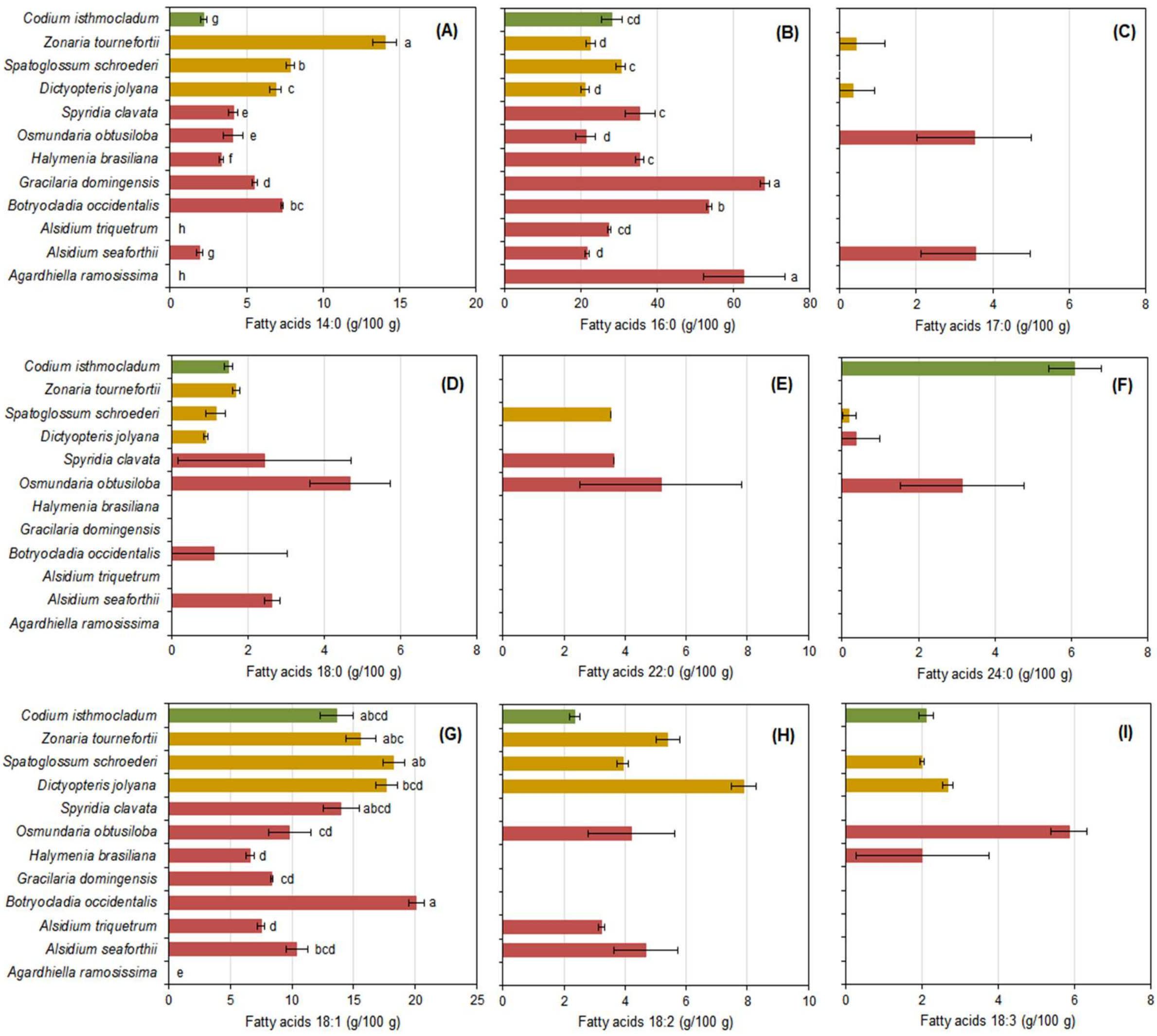

Codium isthmocladum
Zonaria tournefortii
Spatoglossum schroederi
Dictyopteris jolyana
Spyridia clavata
Osmundaria obtusiloba
Halymenia brasiliana
Gracilaria domingensis
Botryocladia occidentalis
Alsidium triquetrum
Alsidium seaforthii
Agardhiella ramosissima
(A)
g
a
b
c
e
e
f
d
bc
h
g
h
0
5
10
15
20
Fatty acids 14:0 (g/100 g)
(B)
cd
d
c
d
c
d
c
a
b
cd
d
a
0
20
40
60
80
Fatty acids 16:0 (g/100 g)
(C)
0
2
4
6
8
Fatty acids 17:0 (g/100 g)
(D)
0
2
4
6
8
Fatty acids 18:0 (g/100 g)
(E)
0
2
4
6
8
10
Fatty acids 22:0 (g/100 g)
(F)
0
2
4
6
8
Fatty acids 24:0 (g/100 g)
(G)
abcd
abc
ab
bcd
abcd
cd
d
cd
a
d
bcd
e
0
5
10
15
20
25
Fatty acids 18:1 (g/100 g)
(H)
0
2
4
6
8
10
Fatty acids 18:2 (g/100 g)
(I)
0
2
4
6
8
Fatty acids 18:3 (g/100 g)

FIGURE S4

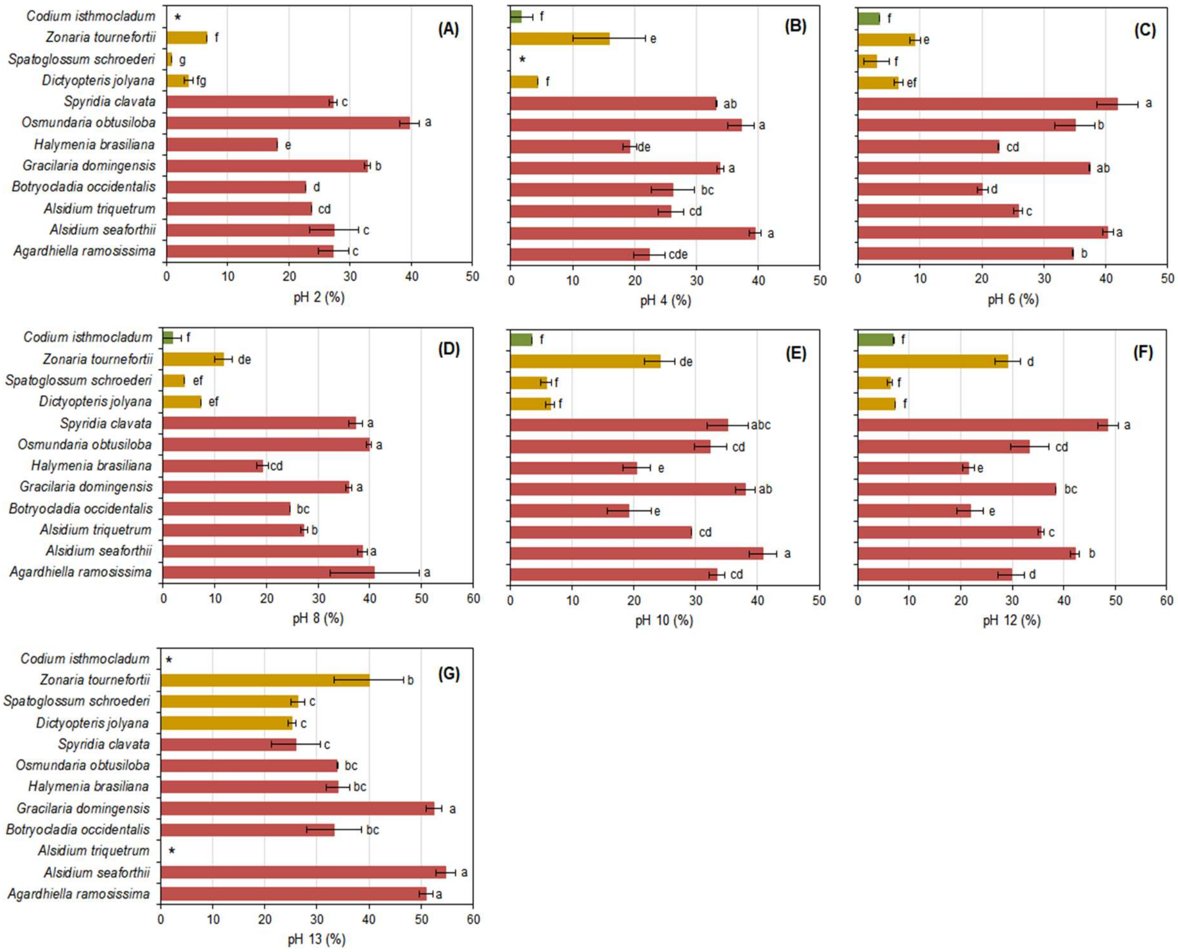

Codium isthmocladum
Zonaria tournefortii
Spatoglossum schroederi
Dictyopteris jolyana
Spyridia clavata
Osmundaria obtusiloba
Halymenia brasiliana
Gracilaria domingensis
Botryocladia occidentalis
Alsidium triquetrum
Alsidium seaforthii
Agardhiella ramosissima
(A)
* f g fg c a e b d cd c c
0 10 20 30 40 50
pH 2 (%)
(B)
f e * f ab a de a bc cd a cde
0 10 20 30 40 50
pH 4 (%)
(C)
f e f ef a b cd ab d c a b
0 10 20 30 40 50
pH 6 (%)
(D)
f de ef ef a a cd a bc b a a
0 10 20 30 40 50 60
pH 8 (%)
(E)
f de f f abc cd e ab e cd a cd
0 10 20 30 40 50
pH 10 (%)
(F)
f d f f a cd e bc e c b d
0 10 20 30 40 50 60
pH 12 (%)
(G)
* b c c c bc bc a bc * a a
0 10 20 30 40 50 60
pH 13 (%)

FIGURE S5

Considerações finais

Considerações finais

O presente estudo está inserido no contexto atual de bioeconomia mundial, que surge num momento em que se tem um enorme desafio de fornecer alimentos a uma população que, até meados do século XXI, deve ultrapassar 9 bilhões de pessoas (FAO 2018). Para que a bioeconomia seja mantida é necessária a utilização do potencial do mar para o desenvolvimento de outras fontes de fornecimento de recursos. Cisneros-Montemayor et al. (2021) relacionam a economia global oceânica ou economia azul a indústrias oceânicas socialmente equitativas, ambientalmente sustentáveis e economicamente viáveis. A Marinha do Brasil (2019) afirma que a economia azul, ou “Amazônia azul”, no Brasil, é tão promissora e estratégica quanto a “Amazônia verde”, e emerge trazendo reflexões sobre a contribuição dos oceanos à economia e a necessidade

A organização das Nações Unidas (ONU) declarou 2021-2030 como sendo a década da ciência oceânica, que visa aprimorar a disponibilidade de dados e fortalecer a gestão sustentável do oceano. de garantir a sustentabilidade ambiental e ecológica dos espaços marítimos. Para o Brasil, o uso sustentável dos oceanos por meio de atividades econômicas marítimas não é apenas uma possibilidade, mas uma oportunidade. Dada a importância estratégica desse espaço marítimo, das riquezas nele contidas e da imperiosa necessidade de sua proteção e preservação (Marinha do Brasil 2021).

Entende-se que conhecer a biodiversidade do mar é o primeiro passo a ser dado tanto para desvendar o potencial que ele possui e fazer uso sustentável do mesmo, quanto para protegê-lo juntamente como as diferentes formas de vida que o habitam. Nesse sentido, considera-se que os resultados produzidos neste estudo, sobre algas arribadas às praias da costa brasileira, trazem informações relevantes acerca de composição específica, distribuição de espécies, disponibilidade de biomassa e indicação de táxons para bioprospecção, baseada em dados de biomassa e análise da composição centesimal.

A evidência relacionada à composição multiespecífica das algas arribadas na costa brasileira foi fortalecida neste estudo, assim como a relação da origem, das mesmas, com a flora bentônica do infralitoral observada para a região. Nesse sentido, a presença de rodolitos presos aos apressórios dos táxons, a prevalência das algas vermelhas em relação às pardas e verdes, a similaridade com a ficoflora do infralitoral descrita para a região reforçam e validam essa observação.

A hipótese de que o estudo da diversidade de algas arribadas da costa brasileira irá proporcionar um incremento no conhecimento da ficoflora bentônica do infralitoral e, principalmente daquelas de regiões menos estudadas, como o litoral do estado do Piauí, foi comprovada, pois este estudo trouxe 18 novos registros para a flora bentônica do Piauí, com possibilidade de 3 potenciais novas espécies, 9 novas ocorrências para a costa pernambucana com 3 potenciais novas espécies e a possibilidade de 2 novas espécies para o Espírito Santo. Portanto a importância das algas arribadas também se torna evidente quando se almeja conhecer a biodiversidade das macroalgas que habitam determinado ambiente, pois refletem a biodiversidade de algas bentônicas de locais próximos, conforme afirmam Suursaar *et* al. (2014). Corroboram também o conceito do uso de espécies arribadas como um método simples para avaliação da biodiversidade, conforme foi testado anteriormente com moluscos (Warwick & Light 2002).

Em relação à composição específica das algas arribadas, a região nordeste apresentou maior número de espécies que o Espírito Santo (sudeste), ao contrário dos estudos realizados por Horta *et al.* (2001), Guimarães (2006), Amado-Filho *et al*. (2007), que incluíram espécimes coletados no infralitoral e mesolitoral. Esses autores se referem o estado do Espírito Santo como a região de maior biodiversidade do litoral brasileiro. Entretanto, são necessários novos estudos com maior número de coletas nas regiões estudadas a fim de que essa informação seja melhor elucidada. Quanto à biomassa, a região sudeste apresentou maior volume, atribuído à ordem Dictyotales, que apresentam várias espécies com talos de tamanhos maiores, o que coincide com resultados de outros estudos com macroalgas bentônicas (Oliveira-Filho 1977, Santos *et al.* 2013, Rodrigues *et al.* 2020). Porém, na praia de Emboaca, CE, região nordeste, os resultados encontrados foram diferentes, pois nessa praia os maiores valores de biomassa foram atribuídos às algas vermelhas, com grande contribuição de Gracilariales.

Em relação ao período e a frequência da ocorrência, observa-se que as algas arribadas não ocorrem somente em períodos anteriormente definidos pela literatura (Barbosa 2010, Silva Jr. 2019), que seriam de janeiro a abril no nordeste e de março a julho no sudeste. Ao longo desses quatro anos, verificou-se que o período chuvoso coincidiu, de fato, com o maior volume de algas arribadas no nordeste, mas não está restrito a esse período. Verificou-se também a ocorrência de algas arribadas em períodos e localidades que ainda não haviam sido registrados anteriormente, como é o caso da Praia de Itaqui, no litoral piauiense, com menor volume em 2018 e aumento significativo em 2021. As causas do aumento e dos novos registros de algas arribadas podem estar relacionadas a ações antrópicas ou às mudanças climáticas (Sacramento *et al.* 2013, Lapointe *et al.* 2021).

Outra observação foi acerca da qualidade das algas arribadas encontradas e coletadas neste estudo, pois a grande maioria apresentava-se fresca e o processo de decomposição não havia iniciado. Além disso, não houve um padrão de permanência das algas nas praias.

Num momento em que há um esgotamento de uso dos recursos naturais não renováveis para atender uma demanda energética crescente, o uso dos excedentes pode apresentar-se como oportunidades para aproveitar localmente uma forma renovável de energia, partindo de uma perspectiva moderna que vê os desperdícios como recursos e oportunidades. Este estudo, através de análises da composição química das espécies coletadas com potencial para bioprospecção em termos de biomassa, revelou que as algas arribadas da costa brasileira possuem potencial para uso econômico para fins de alimentação, pois possuem propriedades químicas semelhantes às algas já identificadas como comestíveis, pois todas as espécies analisadas exibiram propriedades nutricionais, corroborando assim, a hipótese de que quanto maior a diversidade de macroalgas arribadas conhecida, maior é o potencial biotecnológico como fonte de fibras, proteínas, óleos e compostos químicos que possam ser aproveitados para alimentação humana e para ração animal. É imperativo que antes da colheita das algas arribadas para fins comerciais, sejam analisados quais impactos essa atividade pode causar ao meio ambiente, como sugerem Kirkmam & Kendrick (1997), visto que é necessário compreender a ligação entre o recurso vivo no mar e as algas arribadas na praia. Esta informação deve ser obtida pelo menos para as principais espécies que estão sujeitas à colheita comercial. Existem várias lacunas de pesquisas importantes que precisam ser abordadas a fim de tomar decisões sobre a gestão deste recurso ou para determinar os efeitos da remoção. Essas lacunas se enquadram em duas classes relacionadas à biomassa e à disponibilidade do recurso, seguidas pelos efeitos de sua remoção nos ecossistemas costeiros (Zemke-White *et al*. 2005).

Por fim, acreditamos que esta tese contribui significativamente com o conhecimento importante sobre diversidade e potencialidade do ambiente marinho, pois constam aqui informações que elucidam questões ainda abertas no conhecimento e trazem novas reflexões sobre algas arribadas na costa brasileira. Estudos adicionais como os de monitoramento, de impacto ambiental causados pela colheita das algas arribadas, o impacto na economia do turismo causado pela permanência das algas arribadas nas praias, as causas do aumento no volume de biomassa, o tempo de permanência nas praias e de educação e conscientização ambiental, são necessários, a fim de que o potencial do mar possa ser aproveitado de forma sustentável e na sua totalidade, através da ciência que precisamos para o oceano que queremos (Marinha do Brasil 2021).

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