

Species diversity, taxon structure and distribution of the Chlorophytes on Truong Sa archipelago

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Abstract

The results of research on characteristic of distribution and taxa structure of Chlorophytes (Chlorophyta) at nine islands of Truong Sa archipelago (Truong Sa, Da Tay, Thuyen Chai, Toc Tan, Sinh Ton, Nam Yet, Song Tu Tay, Da Nam and Son Ca) indicate that there are 67 species of Chlorophytes, they belong to 4 orders, 14 families and 22 genera. The number of species at the sampling islands ranged from 13 species/island (Toc Tan isd.) to 43 species/island (Nam Yet isd.) with the average of 25.5 species/island. Sorensen similarity coefficient at the sampling sections ranged from 0.24 (between Song Tu Tay and Thuyen Chai) to 0.74 (between Nam Yet and Song Tu Tay) with the average of 0.45. Among 67 species in nine islands, there are 10 species distributed only in the intertidal zone (they are occupying 14.9% of total species), 14 species (31.4%) in subtidal zone only and 43 species (64.2%) in both intertidal zone and subtidal zone. The number of species concentrates on some genera (*Halimeda*: 10 species; *Caulerpa*: 10 species; *Codium*: 6 species,...), they belong to Codiaceae, Siphonales. There are some genera with only 1 species (*Tydemania*, *Anadyomene*, *Microdictyon*,...).

Keywords: Truong Sa archipelago, distribution, species composition.

INTRODUCTION

Chlorophytes, a phylum with a very large number of species (180 species of the Chlorophytes only in Vietnam [1]) is a group of lower plants living in sea and brackish water area [2]. This is an important economic value component of marine resources used for human life. From green algae, many compounds such as Ulvarin, Halimedin, Codianin, amino acids, growth hormones are extracted for common uses in various fields (additives for beverage processing industry, specialized glues, pharmaceutical preparations,...). Nowadays in Vietnam, Chlorophytes is one of the living resources very widely exploited and cultivated (*Caulerpa lentillifera*) for domestic and exporting needs [2, 3].

Truong Sa archipelago is located at 6°30'–12°00'N, 111°30'–117°03'E and belongs to the district of Truong Sa (Truong Sa archipelago), Khanh Hoa province, with hundreds of islands, shoals and coral reefs covering an area of about 594,000 km² [4]. Research results on macro algae in general and Chlorophytes in particular on Truong Sa archipelago are very few and mostly unsystematic. This is mainly because of difficult access to the offshore islands in poor financial conditions and transportation. Surveys and investigation, researches and publication of any scientific results for Truong Sa archipelago take a great significance in contribution to asserting the sovereignty of the Socialist Republic of Vietnam, to supplementing knowledge about species composition, living and natural resources, to making a rational and sustainable plan of living resources exploitation, to protecting the environment and serving food for islanders especially during typhoon season.

MATERIALS AND METHODS

Materials

Materials used for this research are collected from several projects implemented at nine islands of Truong Sa archipelago (Big Truong Sa, Da Tay, Thuyen Chai, Toc Tan, Sinh Ton, Nam Yet, Song Tu Tay, Da Nam and Son Ca) from 1994 to 2019 as follows:

Investigation of biological resources in islands of Truong Sa Archipelago (1994–1995);

Research on biology and economic cultivation of algae on Truong Sa Archipelago (1999–2000);

Research on the scientific basis for establishing marine protected areas on Truong Sa archipelago (2007–2008);

Application of satellite imageries for assessment of some physical and environmental characteristics on several large islands and surrounding waters of Truong Sa archipelago for economic development and national defense and security (2015–2017);

Research and assessment of potential resources and the ability to exploit and cultivate economic seaweed in offshore islands for socio-economic development, coded KC.09.05/16–20;

Scientific basis and comprehensive solution for sustainable development of Truong Sa District, Vietnam, coded KC09.29/16–20.

In addition, data and documents from the Vietnam-Philippines joint survey (JOMSRE-SCS), in April and May 1996 in East Sea and Truong Sa archipelago were referred.

Locations of the Chlorophytes survey sites on Truong Sa archipelago are shown in table 1 and figure 1.

Table 1. Coordinates of survey points

No.	Island	Coordinates
1	Big Truong Sa	08°38'2"N - 114°55'00"E
2	Da Tay	08°52'00"N - 112°15'30"E
3	Thuyen Chai	08°13'00"N - 113°20'50"E
4	Toc Tan	08°50'50"N - 114°00'00"E
5	Sinh Ton	09°52'30"N - 114°19'00"E
6	Nam Yet	10°11'06"N - 114°21'30"E
7	Song Tu Tay	11°25'30"N - 114°00'00"E
8	Da Nam	11°23'00"N - 114°18'00"E
9	Son Ca	10°23'00"N - 114°28'38"E

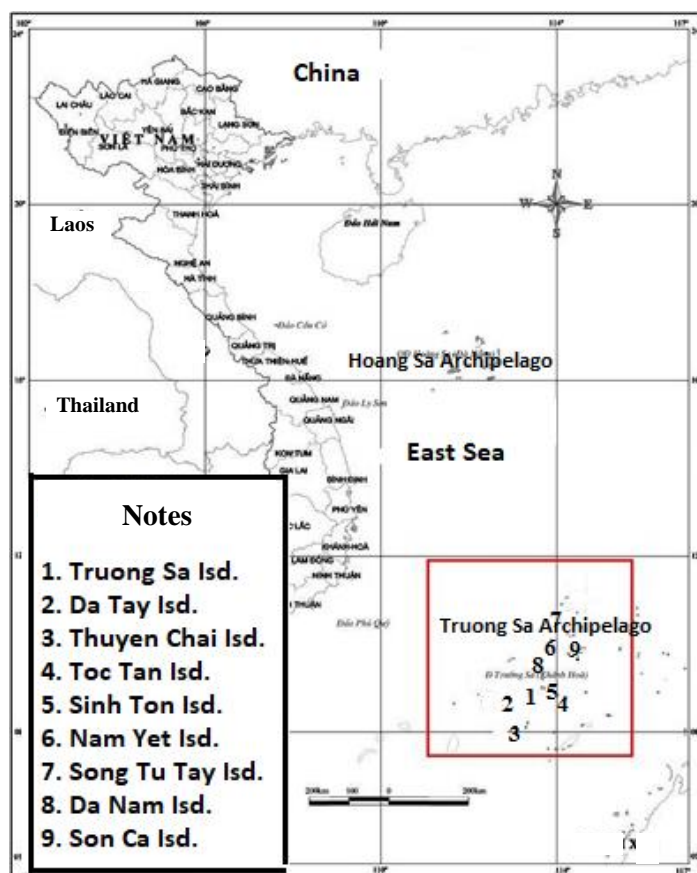


Figure 1. Locations of Chlorophytes survey sites on Truong Sa archipelago

Sampling

Sample collecting follows the Provisional Regulations for Field Survey issued by the State Committee for Science and Technology (Vietnam) in 1981 applied for tidal zone [2], and standard methods by English et al., (1997) [3] for subtidal zone with SCUBA devices, underwater digital cameras (Sea & Sea and NIKONOS V of Japan, and PENTAX WG 5 from Indonesia). At each island, four north, south, east and west surveying main sections and some additional sections between the main sections were set up in perpendicular shoreline and stretched out to the depth without seaweeds (normally at 40 m deep). The depths of sampling sites were figured out using SCUBA depth gauges.

The fresh macroalgal samples were soaked in a solution of formaldehyde 5%, then put on Croki paper, compressed into blotting papers, dried naturally and analyzed.

Species identification

The Chlorophytes specimens were analyzed at the laboratory of Marine Botanical Ecology and Resources Department, Institute of Marine Environment and Resources (Vietnam Academy of Science and Technology).

Specimens were classified based on criteria relating to the morphology and anatomy of specimens under a LEICA microscope. The scientific names used follow national and international authors [7].

Document classification based on the authors such as: Taylor [8], Segawa [9], Pham Hoang Ho [10], Tseng [11], Nguyen Huu Dinh et al., [12].

The order of taxa is based on Pham Hoang Ho [10], Frederik Leliart et al., [13]; Guiry, M. D., Guiry, G. M., [14]. Names of taxa are used according to the general standard provisions of the Tokyo nomenclature [15]. Some additional information is searched based

on documents by Nguyen Van Tu et al., [1], Silva, Ernani, Menez & Richard [16] and some other research results on seaweed [17–23].

Distribution study

Vertical distribution

Determining the vertical distribution of marine macroalgae is based on the principle of the partitioning (zonation) of the tidal zone as used by Feldmann (1937) [24], Stephenson (1949) [25] and Pham Hoang Ho (1962) [26]. Under this scheme, the coastal zone is arbitrarily partitioned into many different areas depending on tidal levels such as high tide, mid-tide and low tide. Water level and tidal data were derived from the tidal regime measured at Da Nang in 2014 and 2015 [27–35].

Geographical distribution

Geographical distribution of marine macroalgae referred as its geographical distribution is indicated by a similarity index

(Sorensen similarity index) that is calculated according to the formula $S = 2C/A+B$, where A and B are the numbers of species in sample sites A and B, respectively, and C is the number of species shared by the two sampling sites (A and B). In the range from 0 (zero) to 1 (one), when the coefficient (S) value approaches one (1), these sampling sites show a strong similarity; and when the coefficient value gets down to zero (0), these sampling sites are less similar.

The spatial distribution data were processed using Excel to obtain the final values.

RESULTS AND DISCUSSION

Species composition

Based on the analysis results from marine macroalgal surveyed samples on Truong Sa archipelago and references [30, 31], a total of 67 species of Chlorophytes are recorded, belonging to three (3) orders, fourteen (14) families and twenty-two genera (table 2).

Table 2. Species composition and distribution of Chlorophytes on Truong Sa archipelago

No.	Taxa	Geographical distribution								Vertical distribution		
		1	2	3	4	5	6	7	8	9	TZ	SZ
	Chlorophytes											
	Ulvales											
	Ulvaceae											
	Ulva											
1	<i>Ulva flexuosa</i> (Wulf.) J. Ag.						+	+	+	+		+
2	<i>U. ralfsii</i> Harv.						+	+	+	+		+
3	<i>U. clathrata</i> (Roth.) Grev.							+	+			+
4	<i>U. conglobata</i> Kjell.							+	+			+
	Cladophorales											
	Anadyomenaceae											
	Anadyomene											
5	<i>Anadyomene wrightii</i> Harv.		+				+	+		+	+	
	Microdictyon											
6	<i>Microdictyon okamurae</i> Setch.						+	+			+	
	Boodleaceae											
	Boodlea											
7	<i>Boodlea composita</i> (Harv.) Brand	+	+	+			+	+		+	+	+
8	<i>B. struveoides</i> Howe	+		+				+				+
	Cladophoropsis											
9	<i>Cladophoropsis sudaensis</i> Reinb.					+		+	+			+
10	<i>C. vaucheriaeformis</i> (Aresc.) Papenf.						+				+	
	Cladophoraceae											
	Chaetomorpha											
11	<i>Chaetomorpha crassa</i> (C. Ag.) Kuetz.			+			+	+			+	+
12	<i>Ch. antennina</i> (Bory) Kützing			+		+		+			+	+
	Cladophora											
13	<i>Cladophora crispula</i> Vick.					+		+	+	+		+
14	<i>C. catenata</i> (L.) Kuetz.							+	+			+
15	<i>C. patentiramea</i> (Mont.) Kuetz.		+	+	+					+		+

16	<i>C. socialis</i> Kuetz.				+	+					
17	<i>C. sudanensis</i> Reinb.						+	+	+		+
	Pithophoraceae										
	Dictyosphaeria										
18	<i>Dictyosphaeria cavernosa</i> (Forsk.) Boergesen	+	+	+	+	+	+	+	+	+	+
19	<i>D. Setchellii</i> Boerg.				+	+	+	+			+
	Siphonocladaceae										
	Boergsenia										
20	<i>Boergsenia forbesii</i> (Harv.) Feldm.						+	+		+	+
	Struvea										
21	<i>Struvea delicatula</i> Kuetz.	+	+	+			+	+			+
22	<i>S. enomotoi</i> Chihara							+			+
	Valoniaceae										
	Valonia										
23	<i>Valonia aegagropila</i> (Roth.) C. Ag.	+					+	+	+		+
24	<i>V. utricularis</i> Ag.	+	+	+				+	+	+	+
25	<i>V. macrophysa</i> Kuetz.	+				+	+	+	+		+
26	<i>V. ventricosa</i> J. Ag.	+							+		+
	Valoniopsis										
27	<i>Valoniopsis pachynema</i> (Mart.) Boerg.	+	+	+			+	+	+	+	+
	Bryopsidales										
	Bryopsidaceae										
	Bryopsis										
28	<i>Bryopsis Bryopsis pennata</i> var. <i>secunda</i> (Harvey)						+	+	+		+
	Collins et Hervey										
29	<i>B. hypnoides</i> Lamx.						+	+	+		+
	Caulerpaceae										
	Caulerpa										
30	<i>Caulerpa microphysa</i> (W. v. Bosse) Feld.	+					+	+		+	+
31	<i>C. brachypus</i> Harv.							+			+
32	<i>C. cupressoides</i> (Vahl.) C. Ag.	+		+	+	+			+		+
33	<i>C. macrodisca</i> Decne.							+			+
34	<i>C. mexicana</i> f. <i>Vietnamica</i> Phamh.								+		+
35	<i>C. racemosa</i> (Forsk.) J. Ag.	+		+			+	+		+	+
36	<i>C. serrulata</i> (Forsk.) J. Ag.				+	+	+		+		+
37	<i>C. taxifolia</i> (Vahl.) C. Ag.			+							+
38	<i>C. webbiana</i> Mont.				+					+	+
39	<i>C. ambigua</i> (Okam.) Prudh. van Rein. & Lokh.	+								+	+
	Dichotomosiphoniaceae										
	Avrainvillea										
40	<i>Avrainvillea erecta</i> (Berk.) A. & E. S. Gepp	+	+	+			+	+	+	+	+
41	<i>A. amadelpa</i> (Mont.) A. Gepp & E. S. Gepp							+		+	
42	<i>A. erecta</i> (Berk.) A. Gepp. & Gepp.							+		+	
	Udoteaceae										
	Chlorodesmis										
43	<i>Chlorodesmis fastigiata</i> (C. Agardh) Ducker							+		+	
	Udotea										
44	<i>Udotea javensis</i> (Mont.) Gepp	+	+	+	+	+	+	+	+	+	+
45	<i>U. xishaensis</i> Tseng et Dong				+		+	+	+		+
46	<i>U. argentea</i> Zanard.						+		+		+
47	<i>U. flabellum</i> (Ell. & Sold.) Howe							+	+		+
48	<i>U. velutina</i> Tseng & Dong				+		+	+	+		+
	Tydemania										
49	<i>Tydemania expeditionis</i> W. v. Bosse				+		+			+	+
	Codiaceae										
	Codium										
50	<i>Codium arabicum</i> Kuetz.						+		+		+
51	<i>C. tenuie</i> Kuetz.						+		+	+	+

52	<i>C. bartletti</i> Tseng & Gibb.							+	+	+			+
53	<i>C. repens</i> (Crouan) Frat in Vick.							+	+	+			+
54	<i>C. tomentosum</i> (Huds.) Stack.							+	+	+			+
55	<i>C. geppiorum</i> O. C. Schmidt		+					+	+	+	+	+	+
	Halimediaceae												
	Halimedia												
56	<i>Halimedia discoidea</i> Decne.	+	+					+	+				+
57	<i>H. serrulata</i> (Forsk.) J. Ag.	+	+	+	+	+	+			+			+
58	<i>H. micronesia</i> Yam.	+	+	+	+			+	+	+	+		+
59	<i>H. incrassata</i> (Ell.) Lamx.							+	+		+		+
60	<i>H. opuntia</i> (L.) Lamx. f. <i>triliba</i> (Dec.) Barton				+								+
61	<i>H. macroloba</i> Dec.	+						+		+			+
62	<i>H. cuneata</i> Hering									+	+		+
63	<i>H. velasquezii</i> Taylor	+						+					+
64	<i>H. opuntia</i> (L.) Lamx.				+					+			+
65	<i>H. tuna</i> (Ell. & Soland.) Lamx.									+			+
	Dasyacladales												
	Dasycladaceae												
	Bornetella												
66	<i>Bornetella nitida</i> (Harv.) Mun. et Chai.					+							+
	Neomeris												
67	<i>Neomeris annulata</i> Dick.	+	+	+	+	+	+			+	+		+
	Total: 67 species	21	15	24	13	16	43	38	34	25	38		55

Notes: 1: Big Truong Sa; 2: Da Tay; 3: Thuyen Chai; 4: Toc Tan; 5: Sinh Ton; 6: Nam Yet; 7: Song Tu Tay; 8: Da Nam; 9: Son Ca; TZ: Tidal zone; SZ: Subtidal zone.

Taxon structure

Table 1 shows that in the order, the number of families varies from one (1) to seven (7) families/order. In fourteen (14) families, the number of genus varies from one (1) to three (3) genera/family with a total of 67 species. The number of species is in dissimilarity. Some genera have only one species (*Valoniopsis*,

Boergsenia, *Anadyomene*,...) but some others have a larger number of species (*Halimedia*: 10 species, *Caulerpa*: 10 species; *Codium*: 6 species,...). Among families, several families consist of only one genus (Ulvaceae, Bryopsidaceae, Caulerpacae,...) but others have more than one (Udoteaceae: 3 genera) (table 3).

Table 3. The taxon structure of Chlorophytes on Truong Sa archipelago

The sort order of order	Quantity and percentage (%)					
	Family		Genus		Species	
	Quantity	Percentage (%)	Quantity	Percentage (%)	Quantity	Percentage (%)
1	1	7.2	1	4.5	4	6.0
2	6	42.8	11	50.0	23	34.3
3	4	28.6	6	27.3	22	32.8
4	3	21.4	4	18.2	18	26.9
Total	14	100	22	100	67	100

Geographical distribution

The species number of Chlorophytes at nine small islands ranged from 13 sp. (Toc Tan) to 43 (Nam Yet), averaging 25.5 species/island (table 1). The lowest species number in Toc Tan island is perhaps due to a lack of surveys, only one survey was carried out on the island (1999). On some other

islands, species were much more recorded because several surveys (e.g. four surveys on Nam Yet) were conducted over time.

The Sorensen similarity index (SSI) of marine macroalgae at different sites ranged from 0.24 (between Song Tu Tay and Thuyen Chai) to 0.74 (between Nam Yet and Song Tu Tay), averaging 0.45. The SSI of 0.24 (lowest)

between Song Tu Tay and Thuyen Chai can be explained by the long distance and their differences in physical conditions and structures of the two islands. A pair of islands (Nam Yet and Thuyen Chai) reached average SSI of 0.45 thanks to their specific characteristics of tidal zones and bottom substrates. Nam Yet is a small island with an intertidal corridor of coral reefs interspersed with coarse sand, and Thuyen Chai is a coral atoll submerged at high tide and exposed at low tide, structured with reef surface

interspersed with sandy bottom. The highest SSI (0.74) between Nam Yet and Song Tu Tay is possibly explicated by their close locations and similar physical conditions and substrates particularly.

The average SSI (0.45) shows that the isotropy of Chlorophytes species in the nine studied islands is not high. This may be because the studied islands are atolls, small area and located quite far apart, not convenient for spreading seed sources and growth of Chlorophytes species (table 4).

Table 4. Matrix of Sorensen similarity index values between islands

Island	1	2	3	4	5	6	7	8	9
9	0.57	0.55	0.45	0.42	0.44	0.59	0.51	0.47	
8	0.36	0.37	0.41	0.30	0.28	0.65	0.64		
7	0.51	0.45	0.52	0.24	0.26	0.74			
6	0.44	0.41	0.45	0.29	0.27				
5	0.49	0.32	0.45	0.41					
4	0.35	0.43	0.43						
3	0.58	0.56							
2	0.61								
1									

Notes: 1: Big Truong Sa; 2: Da Tay; 3: Thuyen Chai; 4: Toc Tan; 5: Sinh Ton; 6: Nam Yet; 7: Song Tu Tay; 8: Da Nam; 9: Son Ca.

Vertical distribution

On Truong Sa archipelago, there are two substrate types related to Chlorophytes vertical distribution. They are rocky intertidal areas (mostly dead and cohesive corals) and soft-bottom intertidal areas (mainly coarse sandy bottom with other foreign objects such as shells, empty cans). However, the soft substrate type with less Chlorophytes is not large. Therefore, Chlorophytes vertical distribution is

mainly surveyed and studied in the rocky intertidal areas.

Based on tidal level data (1994, 1995, 1996, 1999, 2007, 2008 and 2018–2019), among 67 species on Truong Sa archipelago there were 10 species (accounting for 14.9% of total species) found only in intertidal zone, 14 species (20.9%) in subtidal zone, and 43 species (60.0%) recorded in both intertidal and subtidal zones.

Table 5. Distribution of green seaweed in tidal areas of rocky Truong Sa archipelago
[Source: Truong Sa archipelago regime: 1994, 1995, 1996, 1999, 2007, 2008 and 2018–2019]

On the tide		There is no seaweed	
		The average value of the tropical spring tide	2.8 m
Tidal area	High tide belt	<i>Ulva flexuosa</i> , <i>Chaetomorpha crassa</i> , <i>Dictyosphaeria cavernosa</i> ,...	1.7 m
		The average value of the equator spring tide	
	Middle tide belt	<i>Ulva clathrata</i> , <i>Chaetomorpha media</i> , <i>Valonia macrophysa</i> ,...	0.7m
		The average value of the equator neap tide	
Subtidal area	Low tide belt	<i>Boergsenia forbesii</i> , <i>Boodlea composita</i> , <i>Struvea delicatula</i> ,...	0 m
		The average value of the tropical neap tide	
	High belt	<i>Neomeris annulata</i> , <i>Udotea javensis</i> , <i>Codium arabicum</i> ,...	-15 m
	Low belt	Mainly species of <i>Halimeda</i> genus	

On sea hard bottoms, Chlorophytes composition is very abundant and common with most species discovered in the study area. In some closed areas (shoal lakes like Thuyen Chai) or semi-closed lakes (in the heart of Toc Tan shoals), representatives of the genera such as *Caulerpa*, *Avrainvillea*, *Udotea*,... are often growing (table 5).

Most of Truong Sa archipelago that are often small in size, narrow in intertidal areas, structured with tidal sandy substrates are not favorable for seaweed growth. Meanwhile, large subtidal areas (especially in shallow or submerged islands) with hard bottoms and clear water are good conditions for seaweed growth. That is why Chlorophytes grows mainly in subtidal areas of Truong Sa archipelago.

Discussion

Surveys conducted at nine islands of the Truong Sa archipelago present natural conditions of hard bottoms, high temperature and salinity, which are favorable for the growth of Chlorophytes species. However, so far the number of recorded species is relatively low, only 67 species. This is because species sampling from all surveys was conducted in one season (Southwest monsoon) of a year (except for the one in 2019). Species number is likely to be greater when surveys are conducted at more sites and islands, especially submerged islands of very large area (e.g. Thuyen Chai), and in Northeast monsoon in the area.

A factor of SSI low average value (0.42) is affected by the long distance between islands (e.g. Song Tu Tay and Thuyen Chai). In many cases of strong ocean currents, seaweed seeds are not spread far out from one island to the others.

Forty three of 67 (64.2%) recorded species found in both tidal and subtidal areas show normal distribution on Truong Sa archipelago with very clear water and semi-diurnal tide regime of low range. These favorable conditions allow Chlorophytes to grow at deeper sea on Truong Sa archipelago. Meanwhile Chlorophytes regularly grows in tidal zones in other areas.

Despite the limitations, this is the most updated documentation on species composition and taxon structure of Chlorophytes on Truong Sa archipelago.

CONCLUSION

At nine islands of Truong Sa archipelago, 67 species of Chlorophytes recorded belonged to 4 orders, 14 families and 22 genera of seaweed.

The number of Chlorophytes species at nine small islands ranged from 13 sp. (Toc Tan) to 43 (Nam Yet), averaging 25.5 species/island. The Sorensen similarity index of Chlorophytes at different islands ranged from 0.24 (between sites of Song Tu Tay and Thuyen Chai) to 0.74 (between Nam Yet and Song Tu Tay), averaging 0.45.

Among 67 species on Truong Sa archipelago, 10 species occupying 14.9% of total species were found in intertidal zone, 14 species (20.9%) in subtidal zone and 43 species (60.0%) in both intertidal and subtidal zones.

Regarding taxon structure, in the order, the number of families varied from one (1) to seven (7) families/order. In fourteen (14) families, the number of genus ranged from one (1) to three (3) genera/family with a total of 67 species. The number of species is in dissimilarity. Some genera have only one species (*Valoniopsis*, *Boergsenia*, *Anadyomene*, etc.) but some others have a larger number of species (*Halimeda*: 10 species, *Caulerpa*: 10 species; *Codium*: 6 species, etc.). Among families, several families consist of only one genus (Ulvaceae, Bryopsidaceae, Caulerpacae, etc.) but others have more than one (Udoteaceae: 3 genera).

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