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 isl.) to 43 species/island (Nam Yet isl.) 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 Codiacea, Siphonales. There are some genera with only 1 species (Tydemania, Anadyomene, Microdictyon, ...).

Keywords: Truong Sa archipelago, distribution, species composition.

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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, Codanin, 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.

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             |
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 Leliaert 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...
on documents by Nguyen Van Tu et al., [1], Silva, Ermani, 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).

| No. | Taxa                           | Geographical distribution | Vertical distribution |
|-----|--------------------------------|---------------------------|-----------------------|
| 1   | Ulva flexuosa (Wulf.) J. Ag.   | +                         | +                     |
| 2   | U. ralfsii Harv.               | +                         | +                     |
| 3   | U. clathrata (Roth.) Grev.     | +                         | +                     |
| 4   | U. conglobata Kjell.           | +                         | +                     |
| 5   | Anadyomene wrightii Harv.      | +                         | +                     |
| 6   | Microdictyon okamurae Setch.   | +                         | +                     |
| 7   | Boodlea composita (Harv.) Brand| +                         | +                     |
| 8   | B. struveoides Howe            | +                         | +                     |
| 9   | Cladophoropsis sudaensis Reinh.| +                         | +                     |
| 10  | C. vaucheriaeformis (Aresc.) Papenf. | +                 | +                     |
| 11  | Chaetomorpha crassa (C. Ag.) Kuetz. | +                 | +                     |
| 12  | Ch. antennina (Bory) Kützing   | +                         | +                     |
| 13  | Cladophora crispula Vick.      | +                         | +                     |
| 14  | C. catenata (L.) Kuetz.        | +                         | +                     |
| 15  | C. patentiramea (Mont.) Kuetz. | +                         | +                     |
|   | Species            | Family     |
|---|--------------------|------------|
| 16| *C. socialis*       | Pithophoraceae |
| 17| *C. sudanensis*     | Dictyosphaeraceae |
|   |                     | *Dictyosphaeria cavernosa* (Forskål) Boergesen |
| 18| *D. Setchelli*      | Siphonocladaceae |
| 19|                     | *Boergsenia* |
| 20| *Boergsenia forbesii* (Harv.) Feldm. |
| 21| *Struvea deliceatula* Kuetz. |
| 22| *S. enomotoi* Chihara |
|   |                     | Valoniaceae |
| 23| *Valonia aegagropila* (Roth.) C. Ag. |
| 24| *V. utricularis* Ag. |
| 25| *V. ventricosa* J. Ag. |
|   |                     | *Valoniopsis* |
| 26| *V. macrophysa* Kuetz. |
| 27| *V. macrophysa* (Mart.) Boerg. |
|   |                     | Bryopsidales |
| 28| *B. hypnoides* Lamx. |
|   |                     | Caulerpaceae |
| 29| *Caulerpa microphysa* (W. v. Bosse) Feld. |
| 30| *C. brachypus* Harv. |
| 31| *C. cupressoides* (Vahl.) C. Ag. |
| 32| *C. macrodisca* Decne. |
| 33| *C. mexicana f. Vietnamica* Phamh. |
| 34| *C. racemosa* (Forsk.) J. Ag. |
| 35| *C. serrulata* (Forsk.) J. Ag. |
| 36| *C. taxifolia* (Vahl.) C. Ag. |
| 37| *C. webbiana* Mont. |
| 38| *C. ambigua* (Okam.) Prudh. van Rein. & Lokh. |
|   |                     | Dichotomosiphonaceae |
| 39| *Avrainvillea erecta* (Berk.) A. & E. S. Gepp |
| 40| *A. amadelpha* (Mont.) A. Gepp & E. S. Gepp |
| 41| *A. erecta* (Berk.) A. Gepp. & Gepp. |
|   |                     | Udoteaceae |
| 42| *Udotea argentea* Zanard. |
| 43| *U. flabellum* (Ell. & Sold.) Howe |
| 44| *U. velutina* Tseng & Dong |
|   |                     | Tydemaniaceae |
| 45| *Tydemania expeditionis* W. v. Bosse |
|   |                     | Codiaceae |
| 46| *Codium australicum* Kuetz. |
| 47| *C. tenuie* Kuetz. |
null
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 |
|-------------|---------------------|---------------------------------------------|-------|
| High tide belt | Ulva flexuosa, Chaetomorpha crassa, Dictyosphaeria cavernosa,... | The average value of the equator spring tide | 1.7 m |
| Tidal area | Ulva clathrata, Chaetomorpha media, Valonia macrophysa,... | The average value of the equator neap tide | 0.7m |
| Middle tide belt | Boergeria forbesii, Boodlea composita, Struvea deliceatula,... | The average value of the tropical neap tide | 0 m |
| Low tide belt | Neomeris annulata, Udotea javenis, Codium arabicum,... | Mainly species of Halimeda genus | -15 m |
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 (Ulva, Bryopsis, Caulerpa, Udotea, etc.) but others have more than one (Udoteaceae: 3 genera).

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