

Current Status of Seaweed Diversity and Distribution on Tu Thien Intertidal Rocky Platform in Ninh Thuan Province, Vietnam

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ABSTRACT. – The study investigated the diversity and the spatial distribution of seaweed in the intertidal zone during three periods including December 2022, March 2023, and May 2023 at Tu Thien seaweed field, Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province. Samples were hand collected through wading surveys of the intertidal zone during low tide periods. The coverage was assessed based using the line transect-quadrat method of Saito and Atobe. The investigation recorded 59 species of seaweeds belonging to 3 phyla, 3 classes and 34 genera. Among all families, Sargassaceae was the most species-rich with 11 species, followed by Gracilariaceae with 9 species. The Rhodophyta accounted for the highest proportion of species composition. The highest coverage of seaweed was measured in March 2023 (103.36 to 343.19). *Ulva reticulata* was the dominant species, with the Simpson dominance index ranging from 0.7 to 0.9 at most sites in March. Simultaneously, the coverage of this species reached 80% during the March survey period. The Cheney index of 2.28, the Tu Thien seaweed community was classified as temperate. It is inferred that seaweed exhibits substantial diversity and abundance at optimal times of the year, particularly during the first half, before gradually diminishing in the latter half. The baseline data generated in this study will serve as the first foundational reference, not only for the scientific assessment of seaweed coverage but also for documenting the occurrence of seaweed species in the Tu Thien seaweed field, Ninh Thuan.

KEYWORDS: macroalgae, Tu Thien seaweed field, diversity, coverage, intertidal platform

INTRODUCTION

Marine macroalgae, commonly known as seaweed, are multicellular, non-vascular plants lacking basic organs such as roots, stems and leaves. These organisms are capable of autotrophy through photosynthesis (Dawes, 1998), making them important primary producers in marine ecosystems (Lüning, 1991; Graham and Wilcox, 2000; Baweja et al., 2016). Seaweed exhibit wide geographic distribution in coastal areas, particularly in intertidal and sublittoral-to-littoral zones of the seas and oceans. They typically attach to dead corals, rocks, stones, pebbles and other hard substrates (Lüning, 1991; Graham and Wilcox, 2000; Baweja et al., 2016; Norashikin, 2013). These zonation pattern support critical nutritional relationships within coastal ecosystems food web (Lüning, 1991). Seaweed also serves as valuable natural biological resources, providing benefits in food, pharmaceutical, cosmetic and agricultural field (Rao et al., 2018). Based on their thallus color, seaweeds are classified into three major groups: red, green and brown algae (Graham and Wilcox, 2000; Baweja et al., 2016).

A comprehensive checklist of Vietnamese marine macroalgae by Nguyen et al. (2013), documented 827 species belonging 4 major phyla: Chlorophyta (Green algae), Ochrophyta (Brown algae), Rhodophyta (Red algae) and Cyanobacteria (blue-green algae). Of these, 132 marine macroalgal species have been recorded in the littoral zones from Thai An to Ca Na, focusing on the My Hoa, Son Hai, and Ca Na areas in Ninh Thuan

province (Le, 2000). The highest species diversity occurs from February to April, comprising red, brown, and green algae, followed by their gradual decline, with regeneration beginning in late December to January. In general, limited research has been conducted on seaweed diversity in Ninh Thuan over the past decade, particularly in the Tu Thien seaweed field, where species diversity and coverage of seaweed remain unexplored up to the present time.

The Tu Thien seaweed field (*Cánh đồng rong biển*), located in Tu Thien village, Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province (Fig. 1), lies within the Southeast coast of southern Vietnam (Tran, 2015). Following the tidal zonation principles of Pham (1962), this area is classified as an intertidal zone. To date, no scientific studies on the diversity, abundance, and distribution of seaweed have been published in this area.

Some residents in Tu Thien mentioned that sea lettuce harvesting (*Ulva* spp.) takes place from January to April of the Lunar calendar (February to June of the Solar calendar), during its most abundant period (Viet Quoc and Do Nam, 2024). Simultaneously, aquaculture activities have generally expanded along the coastline of Ninh Thuan over the last 20 years. These anthropogenic activities, including waste discharge and even over-exploitation, may have adverse effects on the seaweed community (Dang and Nguyen, 2022). Additionally, trampling on the rocky flats caused by tourists and harvesters also disturbs seaweed growth, which may reduce coverage and create bare spaces in some communities (Schiel and Taylor, 1999; Tyler-Walters, 2005).



FIGURE 1. Photographs of the study area showing sites with specific macroalgal occurrences located in Tu Thien village, Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province: **(A)** A sampling quadrat placed on the rocky flat; **(B)** A tidal pool with coral reef, live rock, coral debris, and a macroalgal shrub community (occurrence of *Padina* spp. and *Ulva* spp.); **(C)** A person harvesting biomass of *Sargassum* spp.; **(D)** The rocky flat at high tide; **(E)** Recording the coverage of seaweed species in the sampling quadrats; **(F)** The rocky flat covered with a dense layer of green seaweed (dominant species, *Ulva reticulata*).

In this study, the current species diversity, abundance, and spatial distribution of seaweed in the Tu Thien seaweed field were investigated using both qualitative and quantitative methods. This study provides a reference for the list of marine flora in the region and offers scientific evidence for the assessment of seaweed coverage and distribution in the Tu Thien seaweed field.

MATERIALS AND METHODS

Field sampling

Field surveys were conducted during three periods including December 2022, March and May 2023 at Tu Thien village, Phuoc Dinh commune, Thuan Nam

district, Ninh Thuan province (Fig. 2). The sampling design consisted of five parallel transects (A–E), spaced 250 m apart, positioned perpendicular to the shoreline. These lines lied parallel to each other at intervals in one direction. Each transect extended approximately 160 m from the sandy beach-rocky flat boundary (landward) to the intertidal rocky flat margin (seaward). Along each transect, five sampling sites were established at 40 m intervals (Fig. 3), with the first site positioned at the landward boundary.

Sampling was conducted during low tide periods, beginning approximately 2 hours after tide recession. At each site, seaweed coverage was assessed using triplicate randomly placed 50x50cm (2500cm²) PVC quadrats, subdivided into 10x10 cm grid.

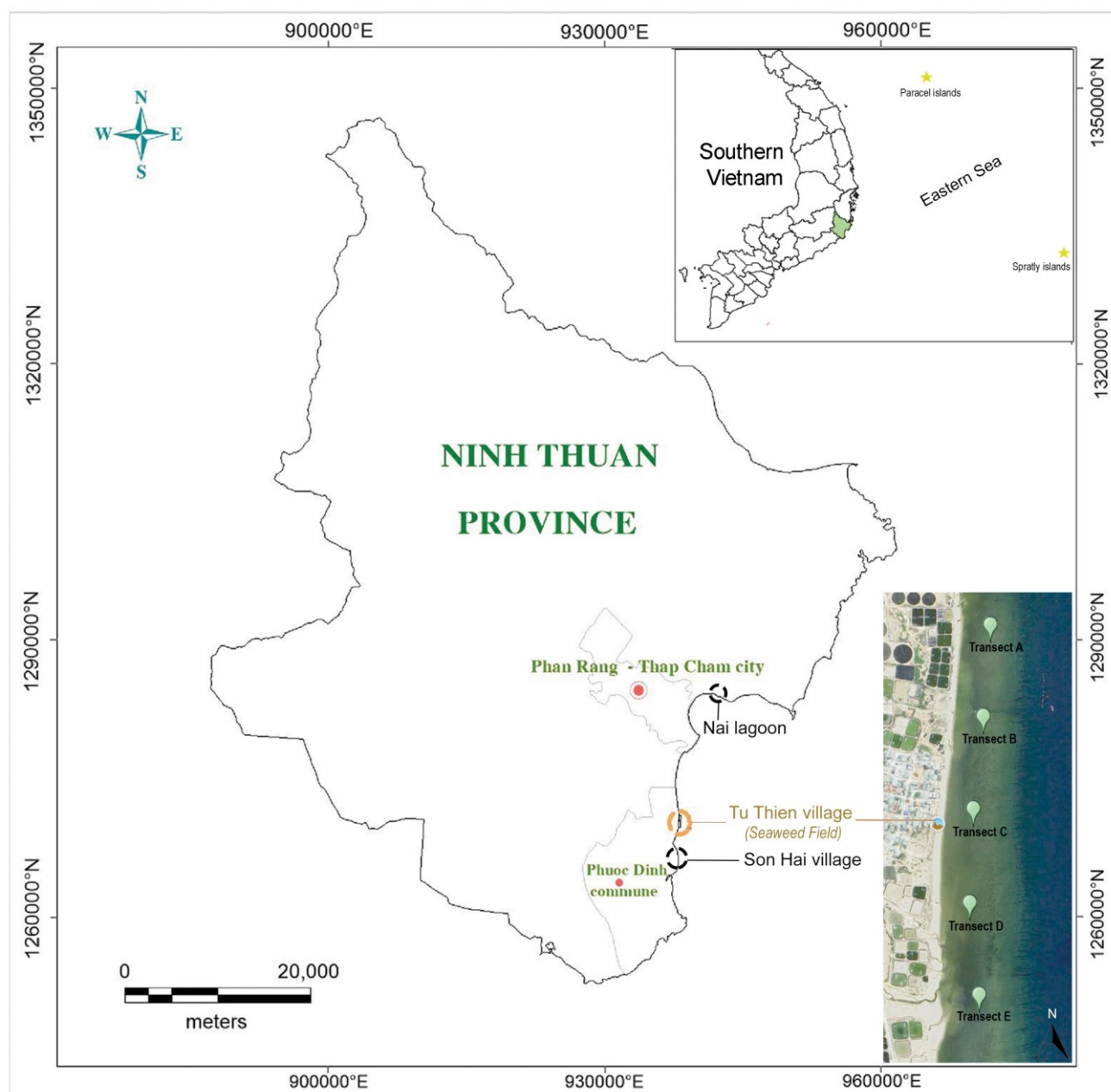


FIGURE 2. Map of Ninh Thuan province which shows location of study area (open orange circle). Tu Thien seaweed field is located at Tu Thien village, Phuoc Dinh commune, Thuan Nam district.

Macroalgae identification and classification

The macroalgae species were identified and classified based on morphological characteristics such as thallus color, stipe, patterns of branching. This study generally followed by taxonomic references of Dawson (1954), Pham (1969), Teo and Wee (1983), Nguyen et al. (1993), Tsutsui et al. (2005) for identifying

specimens up to species level following species identification keys. Algaebase web site <http://www.algaebase.org/> (Guiry and Guiry 2025) were employed to identify the nomenclature and the taxonomic system of each species. The coverage measurement was performed following the description of Saito and Atobe (1970).

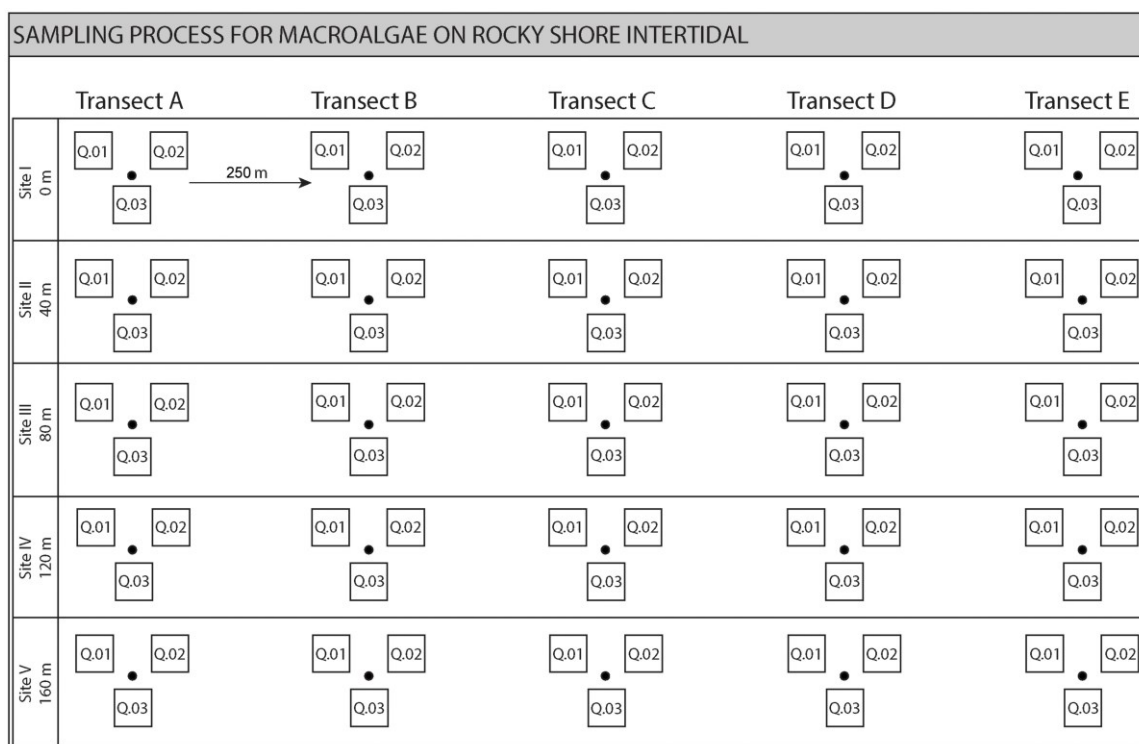


FIGURE 3. Layout of transects at intertidal rocky shore extending from the boundary between sandy beach and intertidal rocky flat to margin of intertidal rocky. Transects had an extension of 250m.

Analysis of indices for community structure and diversity

The Bray-Curtis similarity index (Bray and Curtis, 1957) was used to compare seaweed coverage among sites in March.

$$BC = \frac{\sum_{i=1}^S \min(n_{i1}, n_{i2})}{N}$$

Where N is the total sum of coverage in two sites, n_{i1} and n_{i2} are the coverage values of species i in site 1 and 2 respectively, $\min(n_{i1}, n_{i2})$ represents the minimum coverage value of species i between two sites (1 and 2), and S is the total number of species.

The Sorensen similarity index (Sorensen, 1948) was used to compare species composition between communities across three sampling periods.

$$S = \frac{2C}{A+B}$$

Where C is the number of species present in both periods A and B, A represents the number of species in period A, and B represents the number of species in period B.

The Simpson dominance index (Simpson, 1949) was calculated as:

$$D = 1 - \sum_{i=1}^S \left(\frac{n_i}{N}\right)^2$$

Where n_i is the coverage of species i , N is the total coverage of all species and S is the total number of species. The index ranges from 0 to 1, with 0 indicating no dominance species and 1 indicating complete dominance of a single species within the community.

The Cheney index (Cheney, 1977) is used for ascertaining and showing the geographic characteristics of the study area.

$$\text{Floristic affinity} = \frac{(R + C)}{P}$$

Where R represents the number of Rhodophyta species; C represents the number of Chlorophyta species, and P represents the number of Phaeophyceae species. A value less than 3.0 indicates temperate flora, a value greater than 6.0 indicates tropical flora, and intermediate values indicates mix floristic affinity.

Data analysis

One-way and two-way analysis of variance (ANOVA) were employed to test differences in total coverage between the sampling periods, with statistical significance set at a p-value of ≤ 0.05 . Prior to analysis, the homogeneity of variance was examined using Levene's test. The ecological indices, including the Bray-Curtis similarity index, Sorensen similarity index, Simpson dominance index, and Cheney index, were calculated by PRIMER 6 (version 6.1.6). Distribution contour line graphs of the seaweed coverage in Tu Thien seaweed field were created using Surfer 18.1.186 (Golden Software, Golden, CO, USA). All data were recorded and stored in Microsoft Excel (Microsoft 365), and statistical analyses were performed using Rstudio (version 4.3.1). Results were shown in both tabular and graphical forms.

RESULTS AND DISCUSSIONS

Species composition

A total of 59 macroalgal species were identified from the study area (Table 1). These species belong to three macroalgal groups: the phylum Chlorophyta (green seaweed), the class Phaeophyceae (brown seaweed) of the phylum Ochrophyta and the phylum Rhodophyta (red seaweed). In total, these seaweeds were classified into three divisions, three classes, 15 orders, 25 families and 34 genera. Among the identified species, 52 species were successfully identified to the species level, while seven species were identified only to the genus level. The highest species richness was observed in Rhodophyta with 29 species accounting for 49.15% of the total recorded species, followed by Phaeophyceae (Ochrophyta), with 18 species (30.51%) (Fig. 4). Chlorophyta had the lowest species richness, with 12 species accounting for 20.34% of the total species recorded (Fig. 4). The family Sargassaceae exhibited the highest number of species (11 species), including three genera *Hormophysa*, *Sargassum* and *Turbinaria*, followed by Gracilariaceae, which comprised nine species across two genera *Gracilariopsis* and *Gracilaria*. Within Chlorophyta, the genus *Ulva* exhibited the highest species richness, with three species. For brown seaweed, specifically *Sargassum*, some of the collected samples, whether young or old, lacked certain distinguishing structures such as vesicles, receptacles, and holdfasts. Hence, these samples were identified only to the genus level. Common genera found consistently across all three surveys included *Ulva*, *Boergesenia*, *Valonia*, *Sargassum*, *Gracilaria*, *Amphiroa*. Figure 5 displays some common seaweeds from the intertidal zone of Tu Thien.

Ninh Thuan province has historically received little attention from researchers, with very few studies having been conducted regarding seaweed biodiversity in this region. In the present study, the total number of recorded seaweed species was 59 species, which can be compared Le (2000), which recorded 65 species in Son Hai (a location near Tu Thien village, approximately 5 km to the South). In the intertidal zone of Son Hai, there were 19 species of green seaweed, 15 species of brown seaweed, and 24 species of red seaweed, representing the highest number of species (Le, 2000). Our study identified 17 species that also appear in the species composition list of Son Hai seaweeds recorded in Le (2000)'s study. Both studies employed the same qualitative method based on external morphological descriptions by Dawson (1954), Pham (1969), and Nguyen et al. (1993), which partially explains the similarity in species composition between the Tu Thien and Son Hai regions. This similarity may be considered well-founded. These 17 identified species are as follows: *Ulva reticulata*, *Boergesenia forbesii*, *Valonia fastigiata*, *Caulerpa racemosa* var. *macrophyssa*, *Padina australis*, *Colpomenia sinuosa*, *Turbinaria ornata*, *Sargassum polycystum*, *Gelidiella acerosa*, *Amphiroa foliacea*, *Amphiroa fragilissima*, *Gracilaria eucheumatoides*, *Gracilaria arcuata*, *Gracilaria canaliculata*, *Gracilaria salicornia*, *Asparagopsis taxiformis*, and *Palisada perforata*. Furthermore, the two studies confirmed that the phylum Rhodophyta had the highest number of species compared to other seaweed groups. Geographically, these two locations are approximately 5 km apart, a relatively short distance (Fig. 2). Both areas lie along the coastline and exhibit similar environmental conditions, including water temperature, salinity, tides, and swell. Both were recognized as intertidal zones according to Pham (1962)'s description of rocky coast settlements. Moreover, the two zones not only share similar substrates, primarily composed of coral, live rock, coral debris, gravel, and pebbles from a geomorphological perspective, but also have the same climate, particularly a semi-arid climate (Le, 2000; Thai, 1965). As Wondzell et al. (1996) had indicated, there is a close correlation between geomorphology and the distribution of ecological communities. Hence, the aforementioned explanations suggest that the development of the two seaweed communities in these regions, characterized by overlapping species composition, is an expected phenomenon. This explanation was also elaborated in the study by Dam et al. (2020), which attributed the resemblance in species composition to conditions such as spatial proximity, bottom pattern, and coastal hydrodynamic dynamics.

Additionally, a study on the biodiversity of seaweed species in Nai Lagoon (Ninh Hai District, Ninh Thuan Province, approximately 20 km north of Tu Thien Village) conducted between 2013 and 2014 recorded

47 species. Among these, green seaweed had the highest diversity, with 22 species, followed by 15 red seaweed species and 5 brown seaweed species (Dam, 2016). The number of seaweed species in Tu Thien

TABLE 1. The species composition of Tu Thien seaweed field was recorded from Tu Thien village, Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province.

No.	Species composition	Period of study		
		12/2022	3/2023	5/2023
	Phylum CHLOROPHYTA			
	Class Ulvophyceae			
	Order Bryopsidales			
	Family Caulerpaceae			
1	<i>Caulerpa chemnitzia</i> (Esper) J.V. Lamouroux, 1809		+	
2	<i>Caulerpa racemosa</i> var. <i>macrophysa</i> (Forsskål) J. Agardh		+	
	Family Halimedaceae			
3	<i>Halimeda discoidea</i> Decaisne, 1842	+		
	Order Cladophorales			
	Family Cladophoraceae			
4	<i>Lychaete herpestica</i> (Montagne) M.J. Wynne, 2017			+
5	<i>Pseudorhizoclonium africanum</i> (Kützing) Boedeker, 2016			+
	Family Siphonocladaceae			
6	<i>Boergesenia forbesii</i> (Harvey) Feldmann, 1938	+	+	+
7	<i>Dictyosphaeria versluisii</i> Weber-van Bosse, 1905			+
	Family Valoniaceae			
8	<i>Valonia fastigiata</i> Harvey ex J. Agardh, 1887	+	+	+
	Order Ulvales			
	Family Ulvaceae			
9	<i>Ulva intestinalis</i> Linnaeus, 1753	+	+	
10	<i>Ulva lactuca</i> Linnaeus, 1753	+	+	+
11	<i>Ulva reticulata</i> Forsskål, 1775	+	+	+
	Order Ulotrichales			
	Family Monostromataceae			
12	<i>Monostroma nitidum</i> Wittrock, 1866	+	+	
	Phylum OCHROPHYTA			
	Class Phaeophyceae			
	Order Dictyotales			
	Family Dictyotaceae			
13	<i>Padina australis</i> Hauck, 1887		+	+
14	<i>Padina boryana</i> Thivy, 1966		+	+
15	<i>Padina undulata</i> Ni-Ni-Win, S. Arai & H. Kawai, 2010			+
	Order Ectocarpales			
	Family Scytosiphonaceae			
16	<i>Colpomenia peregrina</i> Sauvageau, 1927		+	+
17	<i>Colpomenia sinuosa</i> (Mertens ex Roth) Derbès & Solier, 1851		+	+
18	<i>Hydroclathrus clathratus</i> (C. Agardh) M. Howe, 1920		+	+
19	<i>Hydroclathrus tenuis</i> C.K. Tseng & Lu Baroen, 1983		+	+
	Order Fucales			
	Family Sargassaceae			
20	<i>Hormophysa cuneiformis</i> (J.F. Gmelin) P.C. Silva, 1987			+
21	<i>Hormophysa</i> sp.	+		
22	<i>Sargassum feldmannii</i> Pham-Hoàng Hồ, 1967		+	+
23	<i>Sargassum henslowianum</i> C. Agardh, 1848		+	+
24	<i>Sargassum ilicifolium</i> (Turner) C. Agardh, 1820		+	+
25	<i>Sargassum polycystum</i> C. Agardh, 1824		+	+
26	<i>Sargassum</i> sp.1			+
27	<i>Sargassum</i> sp.2			+
28	<i>Sargassum vietnamense</i> A.D. Zinova & Dinh	+	+	+
29	<i>Turbinaria conoides</i> (J. Agardh) Kützing, 1860	+	+	+
30	<i>Turbinaria ornata</i> (Turner) J. Agardh, 1848	+	+	

TABLE 1. (Continue).

No.	Species composition	Period of study		
		12/2022	3/2023	5/2023
	Phylum RHODOPHYTA			
	Class Florideophyceae			
	Order Bonnemaisoniales			
	Family Bonnemaisoniaceae			
31	<i>Asparagopsis taxiformis</i> (Delile) Trevisan de Saint-Léon, 1845	+	+	
	Order Ceramiales			
	Family Rhodomelaceae			
32	<i>Amansia glomerata</i> C. Agardh, 1822	+	+	
33	<i>Acanthophora muscoides</i> (Linnaeus) Bory de Saint-Vincent, 1828			+
34	<i>Palisada paniculata</i> (Kützinger) J.N. Norris, 2014	+	+	+
35	<i>Palisada perforata</i> (Bory) K.W. Nam, 2007		+	+
36	<i>Laurencia obtusa</i> (Hudson) J.V. Lamouroux, 1813	+		
	Order Corallinales			
	Family Corallinaceae			
37	<i>Jania spectabile</i> (Harvey ex Grunow) J.H. Kim, Guiry & H.-G. Choi, 2007	+		
38	<i>Jania unguata</i> (Yendo) Yendo, 1905	+		
	Family Lithophyllaceae			
39	<i>Amphiroa foliacea</i> J.V. Lamouroux, 1824		+	+
40	<i>Amphiroa fragilissima</i> (Linnaeus) J.V. Lamouroux, 1816	+	+	
	Order Gigartinales			
	Family Cystocloniaceae			
41	<i>Hypnea cervicornis</i> J. Agardh, 1851		+	+
	Family Gigartinaceae			
42	<i>Chondracanthus acicularis</i> (Roth) Fredericq, 1993			+
	Family Rhizophyllidaceae			
43	<i>Portieria hornemannii</i> (Lyngbye) P.C. Silva, 1987	+	+	+
	Family Solieriaceae			
44	<i>Betaphycus gelatinus</i> (Esper) Doty ex P.C. Silva, 1996	+		
	Order Gelidiales			
	Family Gelidiaceae			
45	<i>Gelidium</i> sp.			+
	Family Gelidiellaceae			
46	<i>Gelidiella acerosa</i> (Forsskål) Feldmann & Hamel, 1934	+	+	+
	Family Gracilariaceae			
47	<i>Gracilariopsis rhodotricha</i> E.Y. Dawson, 1949			+
48	<i>Gracilaria arcuata</i> Zanardini, 1858	+	+	
49	<i>Gracilaria canaliculata</i> Sonder, 1871	+	+	
50	<i>Gracilaria incurvata</i> Okamura, 1931			+
51	<i>Gracilaria salicornia</i> (C. Agardh) E.Y. Dawson, 1954		+	+
52	<i>Gracilaria eucheumatoides</i> (Harvey) Gurgel & Fredericq, 2004	+	+	+
53	<i>Gracilaria</i> sp.1			+
54	<i>Gracilaria</i> sp.2	+		
55	<i>Gracilaria</i> sp.3	+		
	Order Nemaliales			
	Family Galaxauraceae			
56	<i>Tricleocarpa fragilis</i> (Linnaeus) Huisman & R.A. Townsend, 1993	+	+	
	Family Liagoraceae			
57	<i>Neoizziella divaricata</i> (C.K. Tseng) S.-M. Lin, S.-Y. Yang & Huisman, 2011			+
	Order Rhodymeniales			
	Family Hymenocladaceae			
58	<i>Asteromenia anastomosans</i> (Weber-van Bosse) G.W. Saunders, C.E. Lane, C.W. Schneider & Kraft, 2006	+		
	Family Lomentariaceae			
59	<i>Ceratodictyon scoparium</i> (Montagne & Millardet) R.E. Norris, 1987	+		
Total		29	35	39

showed a moderate difference from Nai lagoon, differing by more than 12 species. However, the proportion of species composition was different from

the present study. The results revealed that red algae dominated in Tu Thien intertidal flat, whereas green seaweed was most abundant in Nai lagoon. This

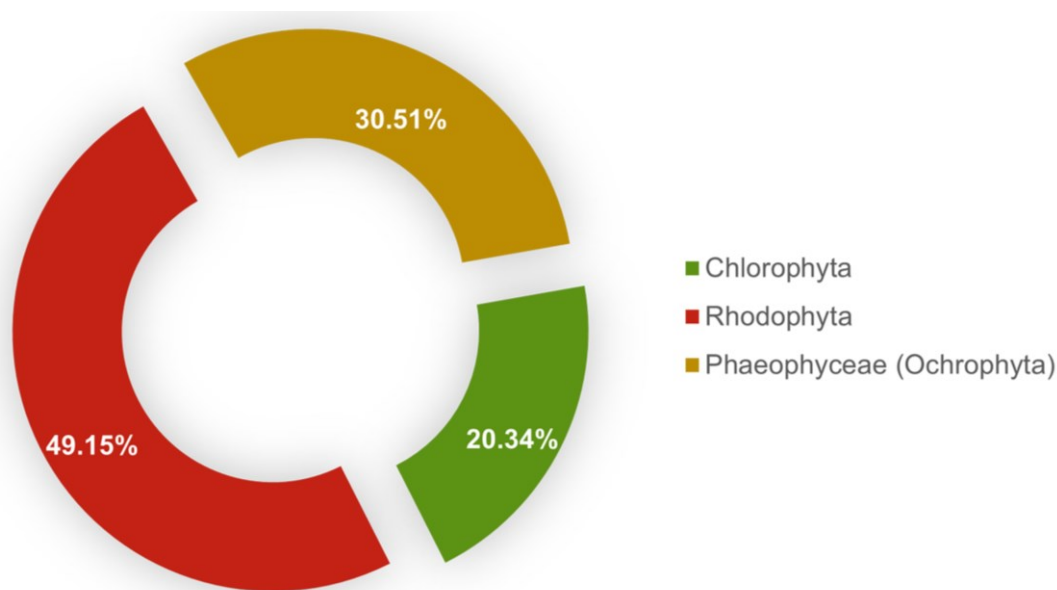


FIGURE 4. Percentage of seaweed species composition of the study area.

variation may be attributed to different geomorphological characteristics as well as substrate composition in the two study areas. Such geomorphological features have a significant influence on the distribution of seaweed species composition in coastal areas, particularly substrate types (Coelho et al., 2000; Kostina et al., 2016; Ramos et al., 2016). The substrate plays an important role in the growth and presence of macroalgae species due to its ability to impact organisms living on its surface (Dawes, 1998). Based on our investigations, the intertidal flat of Tu Thien village is predominantly composed of boulders and dead corals, which create favorable conditions for the growth of seaweed species compared to sandy or sandy-mud substrates (Anggadiredja, 2017; Sabri et al., 2021; Taylor and Littler, 1982; Zainee et al., 2019). In contrast, the substrate in Nai Lagoon consisted mainly of sandy mud (Dam, 2016), which was relatively unstable for seaweed growth, as many species struggle to anchor themselves (Anggadiredja, 2017; Zainee et al., 2019). However, Nai Lagoon recorded a higher diversity of green seaweed compared to the others (Dam, 2016). Among them, certain green algae, such as *Avrainvillea*, *Caulerpa*, and *Udotea*, were able to anchor and grow on unconsolidated sediments like sand and mud using their rhizoids (Anggadiredja, 2017; Fagerberg et al., 2012; Zainee et al., 2019). *Caulerpa*, in particular, possesses root-like holdfasts that can penetrate deeply into sandy or muddy sediments (Anggadiredja, 2017; Fagerberg et al., 2012). Additionally, its stolons grew rapidly when buried in sand and exhibited a high tolerance of low light conditions (Park et al., 2022). Therefore, the

sandy-mud substrate type can generally be considered a suitable environment for sea grapes (Nguyen et al., 2015; Park et al., 2022; Williams et al., 1985; Windarto et al., 2021).

Coverage and Ecological indices of seaweed

In December 2022, the present study recorded only rare thallus seaweed at all sampling sites. Therefore, seaweed coverage was not measured during this period. This was consistent with Le (2000)'s evaluation, which indicated that seaweed begins growing in January, flourishes in February and March, and gradually declines by June. Hence, seaweed coverage was surveyed in March and May of 2023 at five transects in the Tu Thien intertidal zone. The coverage values ranged from 103.36 to 343.19 in March and decreased from 113.19 to 0 in May (Fig. 6). Chlorophyta demonstrated dramatically higher coverage than Rhodophyta and Ochrophyta (Phaeophyceae) in the study area (p -value < 0.05) in March. The coverage of *Ulva reticulata* ranged from 10% to 80% in March, with peak coverage observed at most sites within the middle intertidal flat (Fig. 7A). Notably, *Ulva reticulata* accounted for over 60% of the total coverage during the March survey (Fig. 7B); however, this species was absent in May. Statistical analyses revealed significant differences in average seaweed coverage between two sampling periods (p -value < 0.05), with higher value recorded in March and a subsequent decline in May. The Simpson index indicated a strong dominance of a single seaweed species in March, with values ranging 0.7 - 0.9 in most study sites, except for of sites V where values ranged



FIGURE 5. Some common seaweeds of Tu Thien seaweed field, (a) *Ulva intestinalis*, (b) *Ulva reticulata*, (c) *Valonia fastigiata*, (d) *Monostroma nitidum*, (e) *Boergesenia forbesii*, (f) *Hydroclathrus tenuis*, (g) *Sargassum ilicifolium*, (h) *Hormophysa* sp., (i) *Padina boryana*, (j) *Turbinaria ornata*, (k) *Gelidiella acerosa*, (l) *Gracilaria eucheumatoides*, (m) *Amphiroa fragilissima*, (n) *Gracilaria salicornia*, (o) *Asparagopsis taxiformis*, (p) *Amansia glomerata*, (q) *Hypnea cervicornis*, (r) *Gracilaria arcuata* [Photo credit, Luat M. Dang; Yen T. K. Nguyen; Trinh B. T. Le]. Scale bar (A) represents for the species a, b, d, e, f, g, i, j, n & r (cm); Scale bar (B) represents for the species c, h, k, l, m, o, p & q (cm).

from 0.3 to 0.7. Based on these analyses, *Ulva reticulata* was identified as a dominant species, resulting in high Simpson index values.

According to Le (2000), the seaweed growing season in the intertidal zone of Ninh Thuan province typically occurs from January to April annually. Our

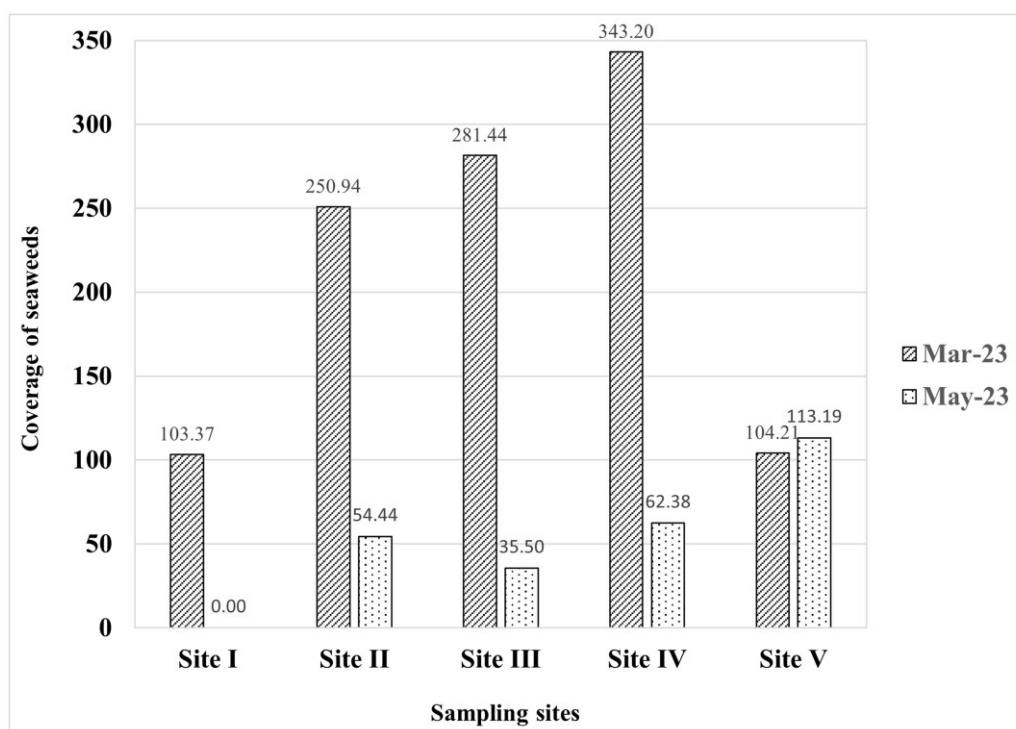


FIGURE 6. The bar chart depicts the coverage of seaweeds in March and May 2023.

study, conducted from December to May, showed fluctuations in similarity of species composition between surveys as indicated by the Sorensen index (Fig. 8). The similarity of species composition between surveys ranged from 32.35 to 67.57. The Sorensen index was highest between March and May 2023 surveys, reaching 67.57, followed by the index between December 2022 and March 2023 surveys, at 59.38 and lowest at 32.35, between December 2022 and May 2023. These variations might be attributed to the March-May period representing the seaweed blooming phase, followed by a decline. Additionally, December marked the beginning of regeneration of seaweed. This result was also consistent with Le (2000)'s explanation.

A potential explanation for the reduction in seaweed species diversity and coverage may be attributed to the blooming of the dominant species, *Ulva reticulata*, which formed dense mats during low tide and green tide during high across most of the intertidal rocky shore. These massive macroalgae mats exhibit the ability to dominate coastal ecosystems. Such domination can alter and restrict light penetration, nutrient availability, and organism's motility, consequently leading to the decreased biological diversity in the area (Guidone and Thornber, 2013; Ok-Hwan, 2006; Park et al., 2023; Thomsen and McGlathery, 2006). These changes appear to be predominantly influenced by human activities. Field observation along the coast of Tu Thien Village revealed numerous aquaculture ponds discharging

effluents into the seashore. This discharge has been identified as a factor contributing to substantial nutrient enrichment in the zonation (Gautier, 2002; Hernández-Ayón et al., 2004) and potentially acts as a major contributor to local eutrophication, facilitating periodic blooms of *Ulva* (Blomme et al., 2023, Sun et al., 2022). Moreover, strong coastal upwelling along the eastern coast of Ninh Thuan province provides additional significant nutrient input to coastal waters (Bui et al., 2022; Camacho-Ibar et al., 2003). Additional anthropogenic pressures on intertidal biodiversity include over-exploitation and tourist activities, resulting in habitat destruction through trampling of coral reefs and seaweed (Msangameno, 2015). Hence, these anthropogenic activities contribute to localized changes in the species composition and potential species decline within this zonation (Airoldi, 1998; Coelho et al., 2000; Chen, 2019; Msangameno, 2015).

As documented by Tran (2015), Ninh Thuan province is located in the Eastern Subtropical Subdivision. However, based on the Cheney index (2.28), the Tu Thien seaweed community was characterized as temperate (Han et al., 2023). This apparent discrepancy can be attributed to the significant influence of coastal upwelling in southern central Vietnam on Ninh Thuan coastal water (Bui and Phan, 2022; Hu and Guillemain, 2016). Furthermore, the presence of intertidal hollows provided suitable habitats for brown seaweed. The abundance of brown seaweed species consequently resulted in lower Cheney index value.

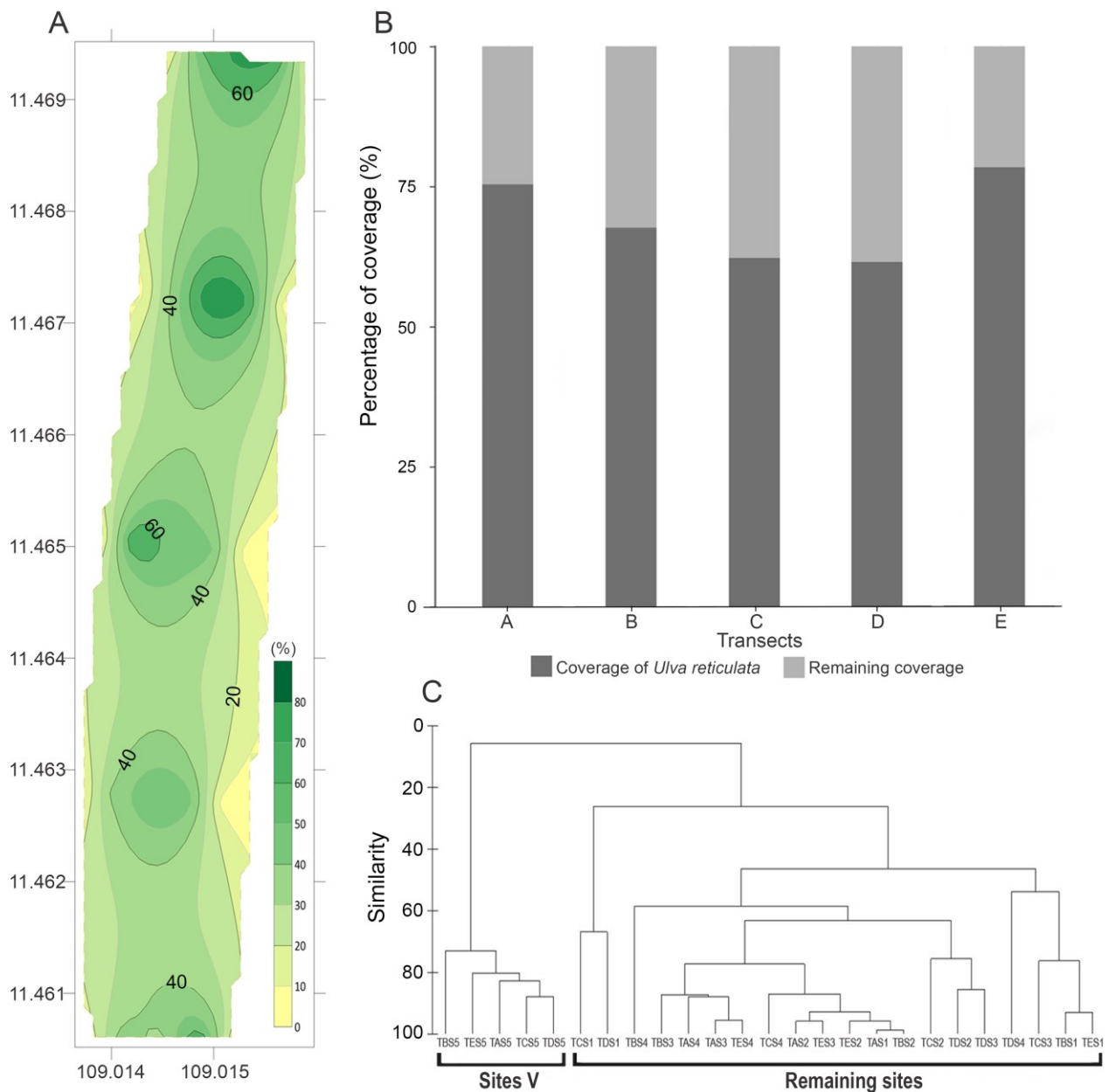


FIGURE 7. Coverage of *Ulva reticulata* in March includes: **(A)** a contour diagram showing the percentage (%) of *Ulva reticulata* coverage in the study area, with the color bar indicating the extent of coverage; **(B)** a bar chart depicting the percentage coverage (%) of seaweeds; and **(C)** a cluster analysis (Bray–Curtis qualitative index) of sites sampled within the study area.

Analysis of Bray–Curtis similarity indices for seaweed coverage showed that sites V exhibited significant dissimilarity and minimal homogeneity compared to remaining sites (Fig. 7C). Coverage of seaweed increased toward the shore, reaching its peak in the middle-intertidal flat (Fig. 7A). The rocky shore in Tu Thien Village, located within the intertidal zone, is regarded as a coral rock terrace or reef platform characterized by extensive razor-sharp and jagged coral

formations, along with boulders that appear near the beach, according to coastal geomorphological classification (Kostina et al., 2016; Nguyen et al., 1988; Schellmann and Radtke, 2004; Short, 1982). Sites V, situated in the surf zone, experiences strong wave impact on the sea floor, particularly at the ledge of terrace, where waves breaking occur (Hills, 1949; Kennedy et al., 2011; Stephenson and Kirk, 2000; Retallack and Roering, 2012). *Ulva* possesses a thin,

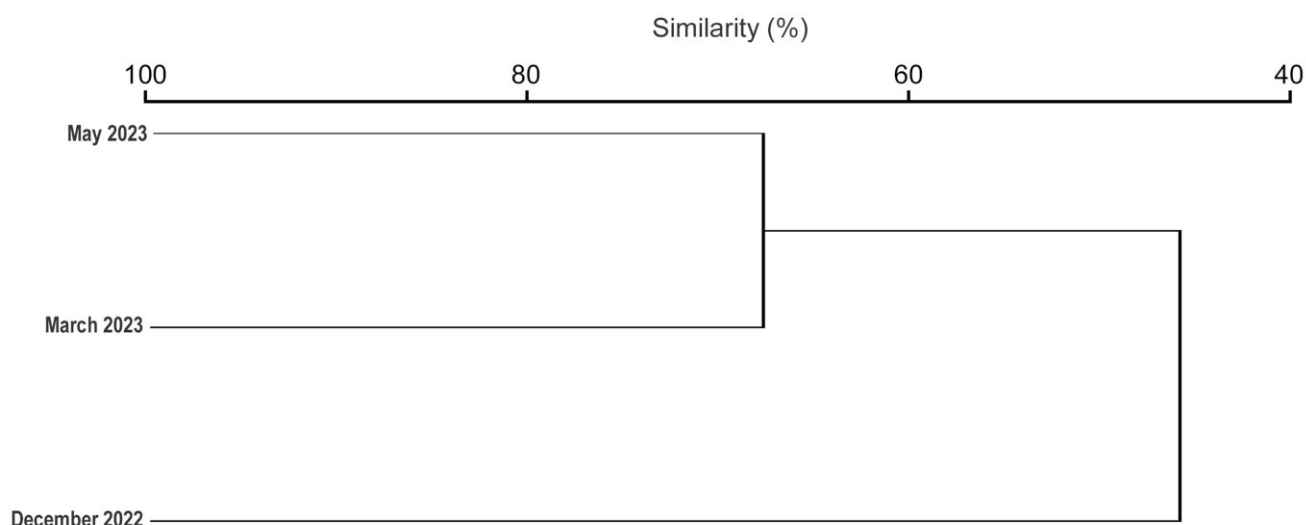


FIGURE 8. Similarity dendrogram based on Sorensen's similarity index converted to a percentage by multiplying the index by 100, presenting the tree-branches relationship between the surveyed times.

nylon-like thallus with a small holdfast part (Hiraoka, 2021), enabling attachment to various substrates or formation of floating clumps. However, these thalli are susceptible to wave damage (Littler and Littler, 1980; Saco et al., 2020) and then short-ward transport (Saco et al., 2020). Consequently, during seaweed growing season, the study area is characterized by extensive green coverage, particularly dominated by *Ulva* patches grows colonizing the bottom substrate.

CONCLUSIONS

The macroalgae of the Tu Thien seaweed field comprised 59 species from 3 phyla, 3 classes, and 34 genera. Of all the recorded families, Sargassaceae had the highest number of species, followed by Gracilariaceae. The proportion of Rhodophyta was the highest ratio of species composition. Sorensen index showed the seaweed composition in March and May was more similar than in December. In March, the diversity of seaweed species and seaweed coverage were highest. *Ulva reticulata* was the dominant species in March. Sites in the middle of the flat had the highest seaweed coverage, while sites at the margin of the flat differed from the others. This was the seaweed diversity area, including red, brown, and green algae. In particular, the strong growth of *Ulva* spp. was noteworthy in March.

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