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The status of seagrass communities in the Truong Sa archipelago

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Abstract
Seagrasses in Truong Sa archipelago have not been intensively studied and understood, even in some obviously progressive works recently published. It is essential to carry out much more researches to fill up understanding gaps of seagrasses in the area. In 2019, within the framework of the project coded KC09.29/16–20, two surveys were conducted for three selected islands (Truong Sa Lon, Thuyen Chai and Song Tu Tay) in the area, focusing on marine ecosystems including seagrass beds. Survey results in the selected islands show eight seagrass species (one new record), the estimated total distribution area of 1,190 ha, the total reserve of biomass reaching 7,417.2 tons.dry, equivalent to 11,432.8 tons.CO_2.

Keywords: Seagrass, distribution, Truong Sa archipelago, Vietnam.

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INTRODUCTION

The Truong Sa archipelago composed of islands, hundreds of reefs, banks and shoals scattered from 6°12'N to 12°00'N and from 111°30'E to 117°20'E are considered to have the greatest marine biodiversity on the planet [1] with two typical ecosystems: Coral reefs and seagrass beds. Before World War II, from some surveys in the Truong Sa archipelago by De Lanessan of French scientists, seagrass and some others were published in the annual reports of the Indochina Oceanographic Institute (1933–1937). Until 1975, there was almost no remarkable work except Dawydoff's summation of Indochina bottoms (1952) and the report of the NAGA (1961) [2]. After 1975, the surveys in the Truong Sa archipelago were recognized (April 1981) and conducted by Vietnamese - Russian scientists on the islands of Sinh Ton and Truong Sa by the Kallisto and Berril vessels. The study of seagrass in general and in the , the surveys in the Truong Sa archipelago were recognized (April 1981) was only started in the 1990s of the previous century [3]. In the early 2000s, recognizing the great role and significance of seagrass ecosystems, scientists around the world as well as in Vietnam paid more attention to seagrass study [4, 5]. In 1994–1996, the project entitled "Integrated assessment of marine biological resources of Truong Sa archipelago" surveyed seaweeds in Truong Sa Lon, Nam Yet, Son Ca, Song Tu Tay and Thuyen Chai islands but no seagrasses were recorded [5]. During 2002–2003, in the framework of the project "Assessment of biological resources and environmental status of the Truong Sa archipelago" within the East Sea and Islands Program, the surveys were conducted on 4 islands (Da Nam, Toc Tan, Sinh Ton and Da Tay) and mainly focused on assessing the status of coral reefs. Thereby, based on environmental factors favorable for seagrass growth such as transparency, salinity, substrate characteristics, flow,... in the Truong Sa archipelago, the seagrass ecosystem is assumed to be present there. Then, seagrasses were found in tidal flats around Nam Yet, Son Ca, and Thuyen Chai islands with significant growth of two species *Thalassia hemprichii* and *Halophila ovalis* [1, 7]. Another work of UNEP/GEF Project recorded 7 species, belonging to two families in the Truong Sa archipelago. Among these, there were two dominant species including *Thalassia hemprichii* and *Halophila ovalis* with a high frequency of occurrence based on analyses of more than 20 seagrass specimens from the field surveys in 1995 (conducted at Nam Yet and Son Ca islands), in 1996 (Thuyen Chai island, Menzies and Scarborough shoals) and in 1999 (Thuyen Chai and Phan Vinh islands) [8].

Most recently, within the framework of the national project coded KC09.29/16–20, entitled "Scientific basis and comprehensive solution for sustainable development of Truong Sa (Truong Sa archipelago) district, Vietnam", the seagrass ecosystem was surveyed as the most important subject in the three selected islands of Truong Sa Lon island (Truong Sa archipelago), Thuyen Chai island (Barque Canada Reef) and Song Tu Tay island (Southwest Cay). Survey results allow updating data on the seagrass composition, distribution, and the change of seagrass area and coverage in these islands.

MATERIALS AND METHODS

Sample collection

The two surveys were conducted in July and October 2019. A total of 140 seagrass samples (105 quantitative samples and 35 qualitative samples) were collected by the scientists from the Institute of Marine Environment and Resources, Vietnam Academy of Science and Technology.

Study site

Thirty-six (36) monitoring stations were set throughout the island areas for recording seagrass distribution (table 1).

Study methods

Survey and assessment of seagrass beds

Methods for surveying seagrass resources and assessing the status of seagrass beds were employed [9, 10]. Locations of the stations were coordinated by satellite positioning (GPS) devices (table 1). At each station, three quadrats of 0.5 × 0.5 m were randomly placed to take quantitative samples and qualitative samples were collected along entire perpendicular transects to the shore (fig. 1).

Table 1. Locations of survey stations

No.	Stations	Latitude	Longitude	No.	Stations	Latitude	Longitude
1	TS1.1	8°39’15”N	111°55’49”E	19	ThC3.1	8°09’41”N	113°17’40”E
2	TS1.2	8°39’10”N	111°55’43”E	20	ThC3.2	8°09’31”N	113°18’07”E
3	TS1.3	8°39’06”N	111°55’38”E	21	ThC3.3	8°09’24”N	113°18’55”E
4	TS2.1	8°39’07”N	111°55’03”E	22	ThC4.1	8°04’32”N	113°13’41”E
5	TS2.2	8°39’03”N	111°55’07”E	23	ThC4.2	8°04’47”N	113°13’53”E
6	TS2.3	8°39’01”N	111°55’11”E	24	ThC4.3	8°05’04”N	113°14’17”E
7	TS3.1	8°38’48”N	111°55’25”E	25	STT1.1	11°26’01”N	114°20’08”E
8	TS3.2	8°38’44”N	111°55’22”E	26	STT1.2	11°26’04”N	114°20’08”E
9	TS3.3	8°38’41”N	111°55’20”E	27	STT1.3	11°26’08”N	114°20’07”E
10	TS4.1	8°38’24”N	111°55’05”E	28	STT2.1	11°26’03”N	114°19’50”E
11	TS4.2	8°38’20”N	111°55’01”E	29	STT2.2	11°25’58”N	114°19’43”E
12	TS4.3	8°38’23”N	111°54’55”E	30	STT2.3	11°25’48”N	114°19’34”E
13	ThC1.1	8°15’39”N	113°21’02”E	31	STT3.1	11°25’49”N	114°20’06”E
14	ThC1.2	8°15’56”N	113°21’16”E	32	STT3.2	11°25’40”N	114°20’01”E
15	ThC1.3	8°16’09”N	113°21’33”E	33	STT3.3	11°25’32”N	114°19’54”E
16	ThC2.1	8°09’10”N	113°16’60”E	34	STT4.1	11°25’35”N	114°19’40”E
17	ThC2.2	8°08’57”N	113°17’24”E	35	STT4.2	11°25’33”N	114°19’36”E
18	ThC2.3	8°08’39”N	113°17’52”E	36	STT4.3	11°25’29”N	114°19’33”E

Notes: TS is Truong Sa Lon island, ThC is Thuyen Chai island, STT is Song Tu Tay island.

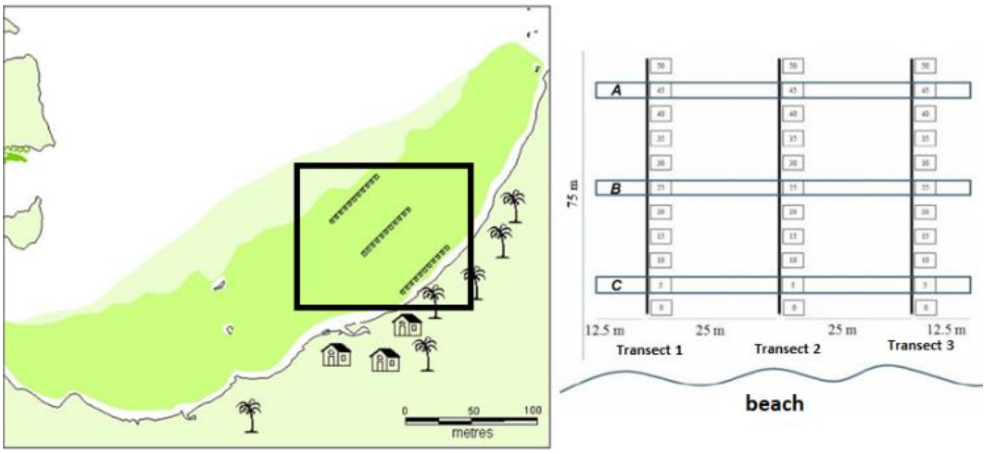

Figure 1. Sampling designs [*Source:* SeagrassWatch]

SCUBA diving equipment was used for observing and collecting samples (both qualitative and quantitative) on the perpendicular transects to the shore in different depth zones. Underwater cameras and graphics software were utilized for taking and processing pictures.

Seagrass was classified based on the documents of Nguyen Van Tien et al., (2002) [3]; Den Hartog (1970) [11], Phillips and Menez (1988) [12].

Quantitative research method followed Short et al., (2001) [13] and Nguyen Van Tien et al., (2008) [9]. The coverage (*C*) of each species in each quadrat is calculated as follows:

$$C = \sum (Mi \times fi) \Big/ \sum f$$

Where: Mi: midpoint percentage of class *i*; *f*: frequency, number of sectors with the same class of dominance (*i*).

The biomass (b) is calculated as follows:

$$b = \frac{b1 + b2 + b3 + ... + bn}{n}$$

Where: b: Average biomass of seagrass; $b1$+ $b2$ + $b3$ +…+ bn: Biomass of seagrass in each quadrat 1, 2, 3 (g fresh/m^2); n: Number of quadrat.

Rapid assessment of organic carbon reserves (mC_{org}) is conducted by the formula in IPCC (2006) [14]:

$$mC_{org} = b \times 0.42 \times S \text{ (grams or tons)}$$

Where: b: Biomass (dry g/m^2 or dry ton/ha); 0.42: The conversion coefficient for the organic carbon content from biomass; S is the existing distribution area = total distribution area × coverage (m^2, ha).

The amount of carbon dioxide (mCO_2) is calculated by the formula:

$$mCO_2 = mC_{org} \times 3.67 \text{ (grams or tons)}$$

Where: 3.67 is the coefficient between atomic carbon (C = 12 g/mol) and carbon dioxide (CO_2 = 44 g/mol).

The Microsoft Excel software with ANOVA statistical analysis tool and SPSS20 statistical software has been used for data processing.

The seagrass bed area in hectare was calculated based on large scale maps of 1/5,000 updated with data extracted from remote sensing images of very high spatial solution [13].

Methods of remote sensing

Image acquisition

The status of the seagrass area was estimated from 2018 to 2020 using Sentinel-2 imagery (table 2) acquired from the European Space Agency [15]. The images were obtained in the same period of the day. A total of 3 scenes were Sentinel-2 L2A images of cloud free Sentinel-2 imagery acquired. The images were geometrically corrected from image source, satellite image with coordinates WGS84/UTM zone 49.

Table 2. Dates and detailed information of the image acquisition

Name of satellite scene	Name of images	Date of acquisition	Time of acquisition (UTC + 07:00)	Spatial resolution of the used images
Sentinel-2 L2A	S2A_MSIL1C_20200327T024541_N0209_R132_T49PGK_20200327T062212	27 March 2020	09:45:41	10 m
Sentinel-2 L2A	S2A_MSIL1C_20200127T024951_N0208_R132_T49PGK_20200127T062019	27 January 2020	09:49:51	10 m
Sentinel-2 L2A	S2B_MSIL1C_20181118T025009_N0207_R132_T49PGK_20181118T053500	18 November 2018	09:50:09	10 m

Image analysis

All the images followed the same workflow (fig. 2). Atmospheric correction, resampling, subset,... used the SNAP 7.0 with band 2. Deglint used Sen2Coral plugin for SNAP 7.0 with bands 2, 3, 4, 5 and band 8. Depth invariant indices used DepthInvariant Indices Processor [16]. Sen2Coral Toolbox was used for coral reef monitoring, Great Barrier Reef version 1.1.

The Semi-Automatic Classification plugin [17] was used for QGIS [18] in QGIS software to select the sample according to the survey data to classify the substrate.

Image processing involved machine learning supervised classification, support vector machine, in which six categories were used (seagrass, seagrass/coral, seagrass/lagoon, coral reef, sand, rubber/dead coral/algae). The classification was performed in combination of the Green, Yellow, Blue, Red, Light Yellow, Dark Blue obtained after water column correction. Ground truthing data for classification were selected on this survey data of the seagrass distribution. Another set of data was created using the same publications for accuracy assessment [1, 3, 6–8].

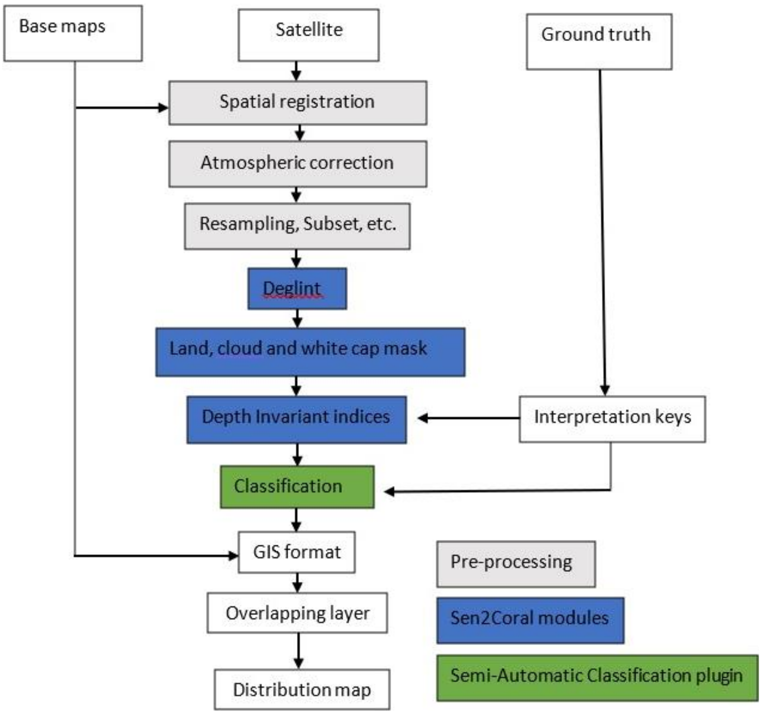

Figure 2. Workflow of the image processing and analysis

Ground truth

For the ground truth: we work from inflatables in teams of two people. Each team takes an image and goes to the preselected site and other representative places chosen from the images. Ground truth is done by diving, snorkeling or looking through the water with a viewer. Occasionally, a control point is obtained by getting the GPS of a prominent point on an island, emerged rock or prominent submerged point on sand. All of the sites visited in the field have their GPS position recorded and stored in the GPS and an assessment made of the category type of the substratum. Categories were described above and recorded as field notes. Unusual or representative examples of the seagrass are collected for identification, and later preparation as herbarium material. Particular emphasis was placed in finding and positioning the deeper edge of seagrass meadows. All site descriptions are entered into an Excel spreadsheet containing the downloaded GPS position. Each site is given a unique number and later identified from the description on the spreadsheet.

For the differential GPS: For the scale of mapping, it is essential that GPS is used. In some areas there may be no control, so these have to be found and positioned. Differential correction data for the area of operation are broadcast via communication satellite, which is an ideal medium for remote sites. The derived positions are real-time corrected for the effects of selective availability. Ground truth sites are logged as spot waypoints. The positions are taken only when the quality of the GPS signal is satisfactory. Control points are logged to a computer for 10 minutes and the coordinates are averaged.

Seagrass distribution was mapped in GIS platform with base maps of the three islands and surveyed data as follows:

The positions of ground truth sites are regularly downloaded from the GPS to a computer and the field notes are entered into a spreadsheet. Positions are recorded as eastings and northings as distinct from latitude and longitude because eastings and northings can be measured on a map and grid size remains the same regardless of the global position. At the completion of the field trip, the ground truth sites, distinguished by their categories, are placed on new images and the underwater features are traced on these, assisted by the knowledge gained from each ground truth site. Once tracings are made and each traced polygon is complete, they are digitized and stored in ArcInfo, a geographic information (GIS) package. Some corrections and alterations may be necessary in case polygons are not complete or incorrectly labeled.

RESULTS AND DISCUSSION

The species composition

Eight species of seagrasses were recorded, belonging to 6 genera (Halophila, Thalassia, Cymodocea, Halodule, Syringodium and Thalassodendron), 2 families (Hydrocharitaceae and Cymodoceaceae), order Hydrocharitales, class Monocotyledoneae and phylum Angiospermae (table 3). Among these species, *Syringodium isoetifolium* (Asch.) Dandy is a new record in seagrass communities of the Spratly Islands when compared with the past records [1, 7]. The highest species number (8 species) was found in the composition of seagrasses in Thuyen Chai Island, dominated by *Thalassodendron ciliatum* (Forsk) den Hartog and *Cymodocea rotundata* Asch. & Sch. Meanwhile, in Truong Sa Lon and Song Tu Tay islands, there was only *Halophila ovalis* (R. Br.) Hooker f. with negligible distribution area, 12 m deeper.

Table 3. The seagrasses composition in the Truong Sa archipelago

No.	Taxon	Name in Vietnamese	Distribution							
			TS	ThC	STT	PV*	NY*	SC*	AL*	SBR*
	Hydrocharitaceae									
1	*Halophila ovalis* (R. Br.) Hooker f.	cỏ xoan	+	++	+	+	+	+		
2	*Halophila minor* (Zoll.) Hartog	cỏ xoan nhỏ		+		+				
3	*Thalassia hemprichii* (Ehrenb. ex Solms) Asch.	cỏ vích		+			+	+		
	Cymodoceaceae									
4	*Cymodocea serrulate* (R.Br.) Asch. et Mag.	cỏ kiệu răng cưa		+						+
5	*Cymodocea rotundata* Asch. & Sch.	cỏ kiệu tròn		+++		+				
6	*Halodule uninervis* (Forsk.) Asch.	cỏ hẹ ba răng		+		+				
7	*Syringodium isoetifolium* (Asch.) Dandy	cỏ lăn biển		++						
8	*Thalassodendron ciliatum* (Forssk.) Hartog	cỏ đốt tre		+++					+	
	The total number of species		1	8	1	4	2	2	1	1

Notes: TS: Truong Sa Lon island, ThC: Thuyen Chai island, STT: Song Tu Tay island, PV: Phan Vinh island, NY: Nam Yet island, SC: Son Ca island, AL: Menzies Reef, SBR: Scarborough; +, ++, +++: Mean few, numerous, very numerous; *: Nguyen Van Tien (2013) [7]; Do Cong Thung et al., (2014) [1].

The distribution characteristics of seagrass beds

Although the basic physical parameters of water in the Truong Sa archipelago are relatively the same with the salinity of 31–34‰, seawater temperature averaging 30.6^{o}C and pH of 7.9–8.3 [1], seagrasses were not found in all islands. Updated survey results show that Thuyen Chai island had the highest number of species (8 species), followed by Phan Vinh island (4 species), the islands of Nam Yet and Son Ca with 2 species. The others such as Menzies Reef and Scarborough have one species (table 3). The highest frequency of occurrence (62.5%) belonged to *Halophila ovalis*, followed by *Thalassia hemprichii* (37.5%). The lowest frequency of occurrence (12.5%) belonged to *Syringodium isoetifolium*.

Comparison of the number of seagrass species in the Truong Sa archipelago with some islands (table 4 and figure 4) reveals that the number of seagrasses in the Truong Sa archipelago (8 species) is only smaller than that in Con Dao islands (10 species) and Phu Quoc islands (9 species) [7, 19], but equal to or one to two species higher than that in other islands and regions such as Phu Quy (Vietnam), Cape Bolinao, Palawan region (Philippines) and Hai Nam islands (China) [7, 19–21].

Figure 3. Seagrass beds in Thuyen Chai island (1. *Thalassodendron ciliatum* (Forssk.) Hartog meadows; 2. Monitoring at transect ThC1; 3. *Cymodocearotundata* Asch. & Sch. meadows; 4. Biological resources in the seagrass beds)

Table 4. Comparing the number of seagrasses among some regions

No.	Species name	1	2*	3*	4*	5*	6**	7***
1	*Halophila beccarii* Ascherson							+
2	*Halophila decipiens* Ostenf.		+					
3	*Halophila ovalis* (R. Br.) Hooker f.	+	+	+	+	+	+	+
4	*Halophila minor* (Zoll.) Hartog	+	+	+	+			
5	*Thalassia hemprichii* (Ehrenb. ex Solms) Asch.	+	+	+	+	+	+	+
6	*Enhalus acoroides* (L. f.) Royle		+		+	+	+	
7	*Cymodocea serrulata* (R. Br.) Asch. et Mag.	+	+	+	+	+	+	
8	*Cymodocea rotundata* Asch. & Sch.	+	+	+	+	+	+	
9	*Halodulepi nifolia* (Miki) den Hartog		+		+	+	+	+
10	*Haloduleuni nervis* (Forsk.) Asch.	+	+	+	+	+	+	+
11	*Syringodium isoetifolium* (Asch.) Dandy	+	+	+	+	+		
12	*Thalassodendron ciliatum* (Forssk.) Hartog	+					+	
13	*Ruppia* sp.							+
14	*Zostera japonica* Asch. & Graebn							+
	Total	8	10	7	9	8	8	7

Notes: 1. Truong Sa archipelago, 2. Con Dao islands, 3. Phu Quy island, 4. Phu Quoc islands, 5. Bolinao island (Philippine); 6. Palawan region (Philippines), 7. Hainan islands (China); *: Cao Van Luong et al., (2012) [19], Nguyen Van Tien, (2013) [7]; **: Menez et al., (1983) [20]; ***: Zhijian Jiang et al., (2017) [21].

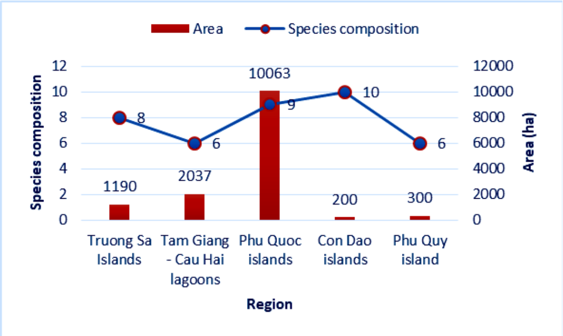

Figure 4. Acreage and species composition of some seagrass beds in Vietnam [4, 7, 19]

Bottom sediments of places with seagrass growing are sands and dead corals with the rate of 80% sands and 20% dead corals [1] and the depth from 0.5 m to 2 m (except for Song Tu Tay island with seagrass found at 12–30 m deep).

The acreage and coverage

A total of 1,180 hectares of seagrass bed area were estimated with average coverage of 32.5% for the three selected islands (table 5). Mixed populations (from 2 species or more) were often observed in the inner side of coral reefs and semi-submersible reefs around Thuyen Chai island. The highest coverage (90% on average) of dominating *Thalassodendron ciliatum* was in Northeast and Southwest Thuyen Chai island (fig. 5) with seagrass beds up to 1.2 km wide. In Truong Sa Lon and Song Tu Tay islands, only *Halophila ovalis* was sporadically distributed with negligible area.

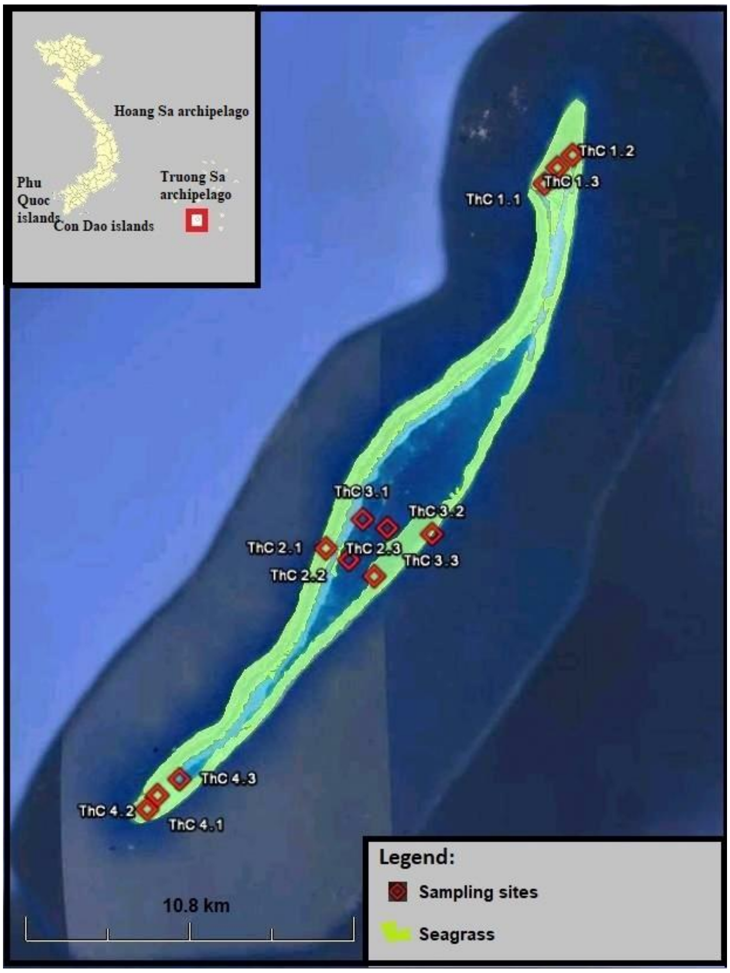

Figure 5. Seagrass sites in Thuyen Chai island

Thus, new estimation of seagrass bed area in Thuyen Chai island (1,180 ha) is higher than that (350 ha) from Nguyen Van Tien (2013) [7]. Combining this estimation with seagrass bed area in Nam Yet island (10 ha) [1], the total area estimation for seagrass beds in the Truong Sa archipelago would be 1,190 hectares, ranked third among regions with the largest seagrass area in Vietnam (fig. 3), after Phu Quoc islands (10,063 ha) and Tam Giang - Cau Hai lagoons (2,063 ha) [4, 19].

Biomass and reserves

Seagrass reserves and biomass of Thuyen Chai island were estimated based on the quantitative and qualitative researches in this study. Combining with data from other researches in Nam Yet and Son Ca islands [1, 7], a summary of the basic results of seagrass reserves in the Truong Sa archipelago is shown in table 5, figure 6.

Seagrass biomass in Thuyen Chai island ranged from 15.2 ± 2.3 g dry/m^2 (*Halophila minor*) to 2,300.8 ± 180.3 g dry/m^2 (*Thalassodendron ciliatum*), averaging 612,5 ± 284,9 g dry/m^2 (fig. 6). The total biomass reserve of seagrass communities in the Truong Sa archipelago was estimated at 7,417.2 tons.dry (table 4).

Table 5. Summary of biomass characteristics

Location	Species	Biomass (g.dry/m^2)	Coverage (%)	Acreage (ha)	Reserves (tons.dry)	References
Thuyen Chai	*Halophila ovalis*	36.6 ± 6.7	10	1,180	7227.9	This study
	Halophila minor	15.2 ± 2.3	5			
	Thalassia hemprichii	1,206.6 ± 17.6	65			
	Cymodocea serrulata	831.3 ± 15.3	15			
	Cymodocea rotundata	356.6 ± 34.7	35			
	Halodule uninervis	94.05 ± 17.8	25			
	Syringodium isoetifolium	179.1 ± 30.5	15			
	Thalassodendron ciliatum	2,300.8 ± 180.3	90			
Nam Yet	*Halophila ovalis*	16.5	27.5	10	18.2	[1, 7]
	Thalassia hemprichii	348	55			
Son Ca	*Halophila ovalis*	15	15	-	-	
	Thalassia hemprichii	313	45			
Total				1,190	7,417.2	

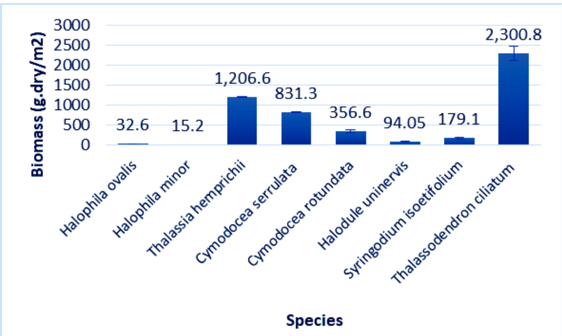

Figure 6. Biomass distribution of seagrasses in Thuyen Chai island

Additionally, the organic carbon stocks of seagrass beds of the Truong Sa archipelago were quickly assessed. The default coefficient of 0.42 by the Intergovernmental Panel on Climate Change [14] was employed to convert reserves biomass of seagrass (7,417.2 tons) to organic carbon stocks output 3,115.2 tons.C_{org}, equivalent to 11,432.8 tons.CO_2 absorbed (based on instantaneous measurements).

CONCLUSIONS AND RECOMMENDATION

Eight species with dominating *Thalassodendronciliatum* (Forssk.) Hartog, belonging to 5 genera, 2 families, order Hydrocharitales, class Monocotyledoneae, phylum Angiospermae were recorded in the Truong Sa archipelago. Among these species, *Syringodium isoetifolium* (Asch.) Dandy is a newly recorded species in Thuyen Chai island. The total distribution area of seagrass beds was estimated at 1,190 ha, mainly concentrated in Thuyen Chai island (1,180 ha), with the average coverage of 32.5%. The total reserve of biomass reached 7,417.2 tons.dry, equivalent to 11,432.8 tons.CO_2.

It is believed that seagrass composition in the Truong Sa archipelago will certainly be recorded more sufficiently once surveys are carried out in other submerged islands and shoals. Considering the important role of seagrass ecosystem, it is strongly recommended to continue and expand research scope, for studying composition, distribution area and functions of the ecosystems (especially an assessment of their functions as nursery habitat) in the Truong Sa archipelago. It helps the regulatory agencies have scientific basis in making appropriate policies for the exploitation and conservation of seagrass resources in the Truong Sa archipelago.

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