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Hydrophyte communities in the Tam Giang - Cau Hai lagoon

Cao Van Luong[1,2,*], Dam Duc Tien[1], Nguyen Thi Nga[1]

[1]*Institute of Marine Environment and Resources, VAST, Vietnam*
[2]*Graduate University of Science and Technology, VAST, Vietnam*
[*]E-mail: luongcv@imer.vast.vn

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Abstract
The Tam Giang - Cau Hai lagoon in Thua Thien-Hue province is the largest lagoon in South East Asia and also one of the places having the largest area of seagrass in Vietnam. The study results from 2009 to 2017 showed that 6 seagrasses species were identified (*Halodule uninervis* is a newly recorded species, however, *Halophila minor* is not recorded) and there were 8 freshwater grass species (with the exception of *Potamogeton maackianus*), with a total area of 2,840 ha. In particular, the area of seagrass has been recovering significantly from 1,000 hectares in 2009 to 2,037 hectares in 2017.

Keywords: Seagrass, Tam Giang - Cau Hai, lagoon, Thua Thien-Hue, Vietnam.

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INTRODUCTION

Seagrass ecosystem is one of three important marine ecosystems (mangroves, seagrasses, corals). Seagrass ecosystem has the function of regulating the environment, supplying, producing and information. The role of seagrasses is very important, their participation in the sea and ocean nutrition cycle is estimated at about 3.8 trillion USD and the average value is 212,000 USD/1 ha/year [1]. In addition to the ecological value of the environment, seagrass is also used directly in many national economic sectors (paper, chemicals, explosives, soundproofing, medicine, food, fertilizer, animal feed,...).

Tam Giang - Cau Hai (TG - CH) lagoon is one of the places having well-developed seagrass beds, with the largest seagrass distribution area in Vietnam [2, 3]. The total economic value of every 1.000 hectares of seagrass here is worth about 2.4 million USD. However, assessments in 2010 showed that the quality of seagrass beds (area, coverage and biomass) was reduced by 40–50% compared to the 1990s, leading to the reduction of resources of biological species at an alarming level [3]. In order to protect, rehabilitate and sustainably develop seagrass resources in the Tam Giang - Cau Hai lagoon, an appropriate management, protection and exploitation plan is required.

In the framework of state project entitled "Assessing the degradation of coastal ecosystems in Vietnam and proposing sustainable management solutions" coded KC09.26/06–10, the project entitled "Researching scientific and legal bases for assessing and claiming compensation for damage caused by oil pollution in Vietnam's waters" coded DTDL.2009G/10, the state project entitled "Research on solutions to recover ecosystems of coastal lagoons and lakes in the central region" coded KC.08.25/11–15 and most recently, the project entitled "Investigation into overall status and fluctuations of biodiversity in Vietnam's coastal ecosystems" under Component 1 - Task No. 8 - Project 47, chaired by the Institute of Marine Environment and Resources, the current situation and fluctuation trend of seagrass community in Tam Giang - Cau Hai lagoons from 2009 to 2017 were investigated and assessed in detail.

MATERIALS AND METHODS

Data collection

The surveys were conducted in two seasons of the year, the dry season from March to May, the rainy season from September to November and continuously from 2009 to 2017. A total of 600 samples (450 quantitative samples and 150 qualitative samples), which included samples of seagrass and freshwater plants, were collected by 10 surveys of projects by the Institute of Marine Resources and Environment (Vietnam Academy of Science and Technology).

Study site

Fifteen (15) monitoring stations are spread evenly throughout the lagoon area where seagrass is distributed (table 1 and figure 1).

Table 1. Survey stations and coordinates in Tam Giang - Cau Hai

No	Stations	Latitude	Longitude
1	O Lau 1	16°38'40"N	107°26'43"E
2	O Lau 2	16°38'29"N	107°28'29"E
3	O Lau 3	16°37'19"N	107°30'46"E
4	O Lau 4	16°36'12"N	107°30'34"E
5	O Lau 5	16°36'11"N	107°31'37"E
6	Con Te	16°33'38"N	107°37'08"E
7	Dam Sam 1	16°32'53"N	107°39'10"E
8	Dam Sam 2	16°32'56"N	107°39'38"E
9	Tam Giang 4	16°32'17"N	107°40'29"E
10	Tam Giang 5	16°31'28"N	107°39'41"E
11	Cau Hai 1	16°17'36"N	107°54'49"E
12	Cau Hai 2	16°19'48"N	107°54'24"E
13	Cau Hai 3	16°20'53"N	107°51'39"E
14	Cau Hai 4	16°16'54"N	107°53'39"E
15	Cau Hai 5	16°17'33"N	107°51'43"E

Study methods

The seagrass resources survey was conducted using the method described in the document "Seagrass research methods" [5], assessing the status of seagrass beds in accordance with the document "Survey manual for tropical marine resources" [6]. At each research station, 3 quadrats of 0.5 × 0.5 m were randomly placed to take quantitative samples, and qualitative samples were collected on the entire route along the

perpendicular to the shore. Scuba diving equipment was used to observe and collect samples (both qualitatively and quantitatively) on the perpendicular section to the shore in different depth zones. Underground cameras were used to take pictures, then the photos were processed with graphics software.

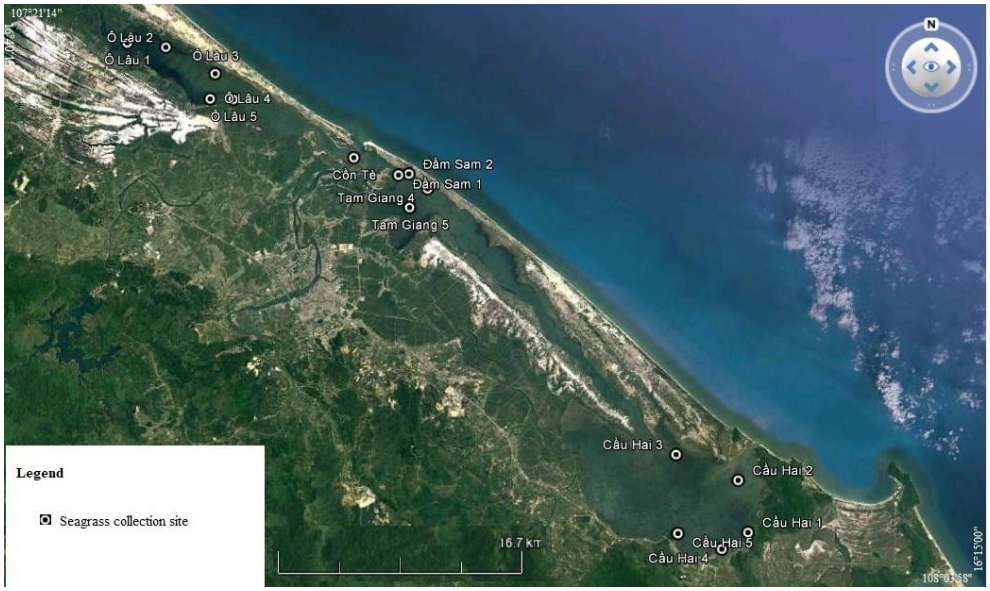

Figure 1. Seagrass collection sites in the Tam Giang - Cau Hai lagoon

Locations of stations are determined by satellite positioning (GPS) devices. The area of seagrass was calculated according to large scale maps and remote sensing images.

Seagrass was classified based on documents of Nguyen Van Tien et al., (2002) [2], Den Hartog (1970) [7], Phillips and Menez (1988) [8].

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; *b*1 + *b*2 + *b*3+ … + *bn*: Biomass of seagrass in each quadrat 1, 2, 3 (g.fresh/m^2); *n*: Total number of quadrat.

The Microsoft Excel software with ANOVA statistical analysis tool and SPSS 20 statistical software has been used for data processing.

RESULTS AND DISCUSSION

Species composition

Six (6) species of seagrasses belonging to 4 genera and 4 families were identified (Hydrocharitaceae, Cymodoceaceae, Zosteraceae and Ruppiaceae) (table 2, figure 2). *Zostera japonica* is the dominant species, which is typical of temperate and subtropical areas. In Vietnam, *Zostera japonica* has a limited distribution in coastal areas from the Gulf of Tonkin (Quang Ninh province) to South Central coast (Binh Dinh province). This result has contributed to raising the total number of seagrass species identified in Tam Giang - Cau Hai from 6 to 7 species, this may be because the historic flood in November 1999 damaged the Hoa Duan embankment [9] which destroyed the entire ecosystem here.

Table 2. Composition of seagrass and freshwater plants

No	Taxon	Name in Vietnamese	Code	Distribution				
				OL	TG	DS	HT_TT	CH
Seagrasses								
Hydrocharitaceae								
1	*Halophila beccarii* Asch.	Cỏ nàn	H.b		+		+	+
2	*Halophila ovalis* Hooker	Cỏ xoan	H.o		+	+	+	+
Zosteraceae								
3	*Zostera japonica* Ash.	Cỏ Lươn nhật	Z.j		+	+	+	+
Ruppiaceae								
4	*Ruppia maritima* Lin.	Cỏ kim biển	R.m	+	+	+	+	+
Cymodoceaceae								
5	*Halodule pinifolia* (Miki) den Hartog	Cỏ hẹ tròn	H.p		+	+	+	+
6	*Halodule uninervis* (Forsk.) Asch.	Cỏ hẹ ba răng	H.u			+		+
Freshwater plants								
Lentibulariaceae								
7	*Utricularia aurea* Lour.	Rong li	U.a	+				
Ceratophylaceae								
8	*Ceratophyllum demersum* L.	Rong đuôi chó	C.d	+				+
Haloragaceae								
9	*Valisneria spiralis* Graebn.	Rong mái chèo	V.s	+				
10	*Blyxa aubertii* Rich.	Rong lá hẹ	B.a	+				
11	*Myriophyllum spicatum* L.	Rong xương cá	M.s	+				
Potamogetonaceae								
12	*Potamogeton malaianus* Miq.	Cỏ nhãn tử Mã lai	P.m	+				
Najadaceae								
13	*Najas indica* (W.) Cham	Rong từ	N.i	+			+	+
14	*Hydrylla verticillata* Royle	Rong đen lá vòng	H.v	+	+		+	+
	Total			9	6	5	7	9

Notes: OL: O Lau lagoon; TG: Tam Giang lagoon; DS: Dam Sam lagoon; HT_TT: Ha Trung - Thuy Tu lagoon; CH: Cau Hai lagoon.

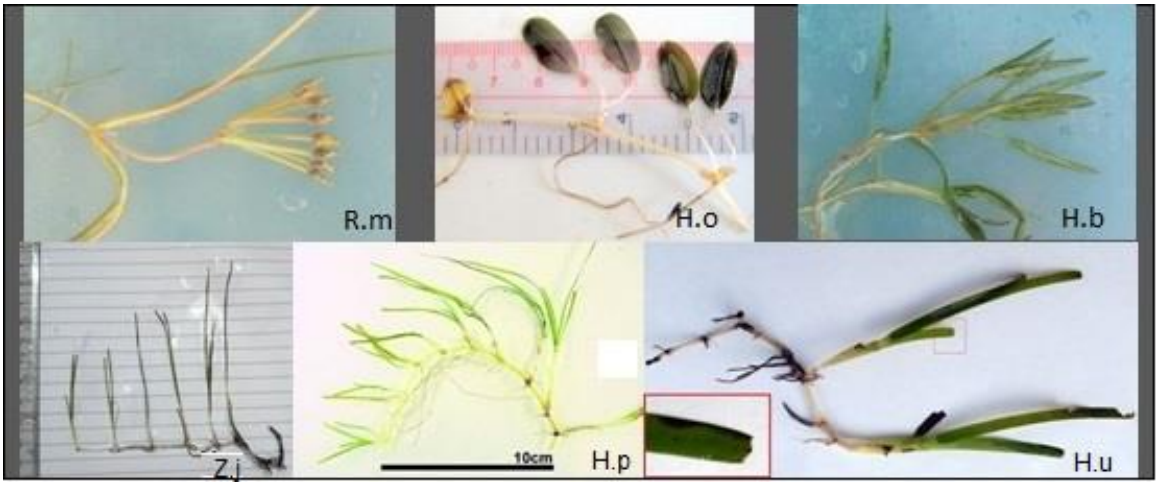

Figure 2. Morphology of seagrasses in Tam Giang - Cau Hai lagoon (see code in table 2)

Especially, *Halophila beccarii* is a species in the "Red List" of IUCN-2010 [10], which is in danger of degradation and extinction (*Vulnerable B2ab(iii)c(ii,iii) ver 3.1*) in the world, but appears a lot in the Tam Giang - Cau Hai lagoon. This species is a food source for marine invertebrates and some species of shrimp and fish, and is a habitat for juvenile

horseshoe crabs. *Halophila beccarii* is commonly found in the world's oceans and is scattered in Southern China, Southeast Asia, India and Madagascar, in coastal mangroves and lagoons, and estuaries on mudflats.

In addition, based on the results of morphological analysis, 8/9 species of freshwater plants were identified in 5 families (table 2, figure 3). Although there is no distribution of *Potamogeton maackianus*, which can be missed during the investigation, the Tam Giang - Cau Hai lagoon is still the region with the greatest diversity of freshwater plant in Vietnam [4].

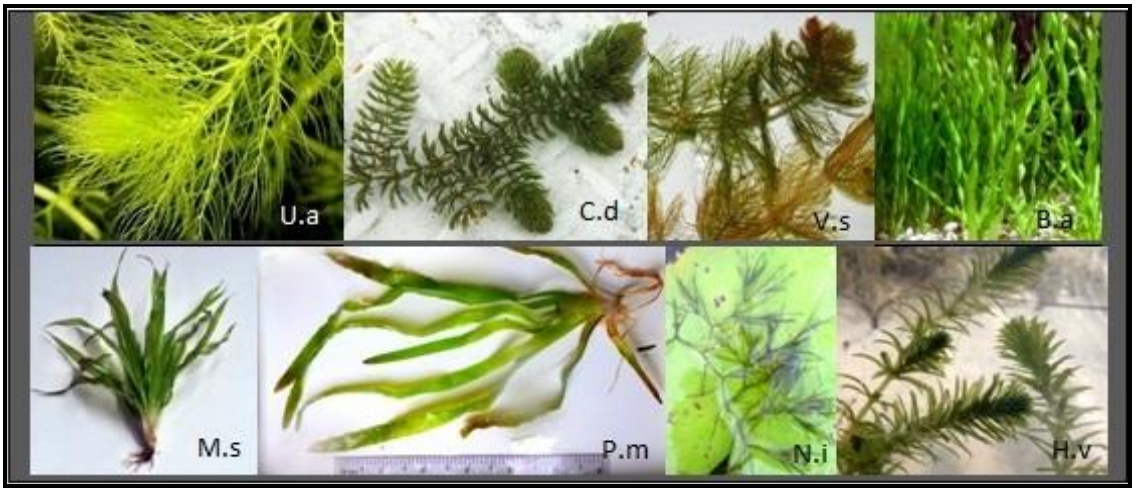

Figure 3. Morphology of freshwater plants in Tam Giang - Cau Hai lagoon (see code in table 2)

Area and distribution

The trend of area decline was very strong in 1996–2010, in 1996 the area of seagrass beds was 2,200 ha [1], in 2003 was 1,200 ha [4], and remained at 1,000 ha in 2010 [3] . Currently, the area of seagrass distribution has increased significantly, about 2.037 ha (figure 4), perhaps due to the efforts of the project "*For Integrated Management of Lagoon Activities (IMOLA) Project of Thua Thien-Hue province (FAO, GCP/VIE/029/ITA)*" [4] to improve people's livelihoods by strengthening sustainable management of aquatic resources with the participation of the community in accordance with the socio-economic and production requirements of the local population. At the same time, the Decision No. 1142/QD-UBND dated June 6, 2011 of the People's Committee of Thua Thien-Hue province approved "*Plan for clearance and reorganization of stake traps in Tam Giang - Cau Hai lagoon, Phu Vang district*" [11], accordingly, implementing the zoning of stake trap fishing planning in the lagoon, reducing 45% of stake traps in the whole lagoon area of Phu Vang district, reducing the pressure of exploiting stake trap fishing to gradually restore the ecological environment and aquatic resources, opening the waterways and migrations of aquatic species in the Tam Giang - Cau Hai lagoon area. It belongs to Thuan An town and 8 communes: Phu Thuan, Phu Hai, Phu Dien, Vinh Xuan, Vinh Ha, Vinh Phu, Phu Da and Phu Xuan.

Some seagrass beds with large area are Tam Giang 5 (Con Dai) with 1,450 ha; Cau Hai 2 (Con Lay - Vinh Hien): 105 ha; Cau Hai 3 - Cau Hai 4 (Vinh Giang - Ba Con): 224 ha, Con Co: 130 ha, Cau Hai 5 and Cau Hai 1 (Loc Binh - Le Thien): 78 ha; Dam Sam and Tam Giang 5 (Con Son - Hop Chau): 60 ha; Con Te - Quang Thanh: 70 ha,... Freshwater plants are concentrated in O Lau 1, O Lau 2 and Cau Hai 4 with a total area of 803 ha (table 3). If the total area of freshwater plants and seagrass is calculated, the distribution area of seagrass in Tam Giang - Cau Hai lagoon is over 2,840 ha. These are important habitats and breeding grounds for aquatic and marine species in this lagoon.

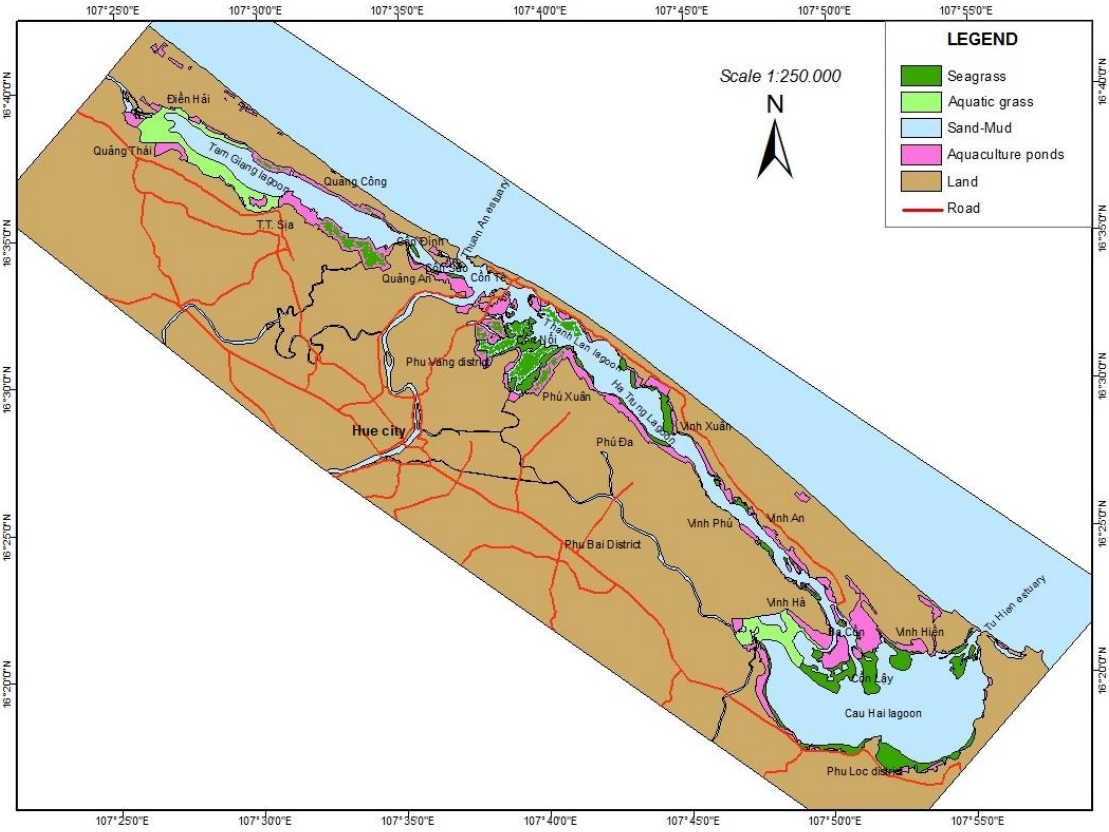

Figure 4. Map of seagrass distribution in Tam Giang - Cau Hai lagoon

Table 3. The area of some typical seagrass beds in Tam Giang - Cau Hai lagoon

No	Sites	Area (ha)	Species
1	O Lau 1	803	*Utricularia aurea, Ceratophyllum demersum, Valisneria spiralis, Blyxa aubertii, Myriophyllum spicatum, Potamogeton malaianus, Najas indica, Hydrylla verticillata,Ruppia maritima*
2	O Lau 2		
3	O Lau 3		
4	O Lau 4	50	*Zostera japonica, Halodule pinifolia, Valisneria spiralis, Ruppia maritima*
5	O Lau 5		
6	Con Te	70	*Zostera japonica, Halophila beccarii*
7	Dam Sam 1	60	*Zostera japonica, Halodule pinifolia, Halodule uninervis, Ruppia maritima, Hydrylla verticillata*
8	Dam Sam 2		
9	Tam Giang 4		
10	Tam Giang 5	1,450	*Zostera japonica, Ruppia maritima*
11	Cau Hai 5	78	*Zostera japonica, Halodule pinifolia, Halodule uninervis,*
12	Cau Hai 1		
13	Cau Hai 2	105	*Zostera japonica, Halodule pinifolia, Halodule uninervis, Halophila ovalis*
14	Cau Hai 3	224	*Zostera japonica, Halodule pinifolia, Halodule uninervis, Halophila ovalis, Halophila beccarii, Ceratophyllum demersum, Najas indica, Hydrylla verticillata*
15	Cau Hai 4		

The spatial distribution characteristics of seagrass and freshwater plants in Tam Giang - Cau Hai lagoon are presented in table 2. In Tam Giang lagoon, 6 species has been identified (including 1 species of freshwater plant group), in Cau Hai: 5 species of seagrass, in Ha Trung - Thuy Tu: 7 species (there are 2 species of freshwater plants). The two areas with the most diverse species are O Lau and Cau Hai lagoon with 9 species, but different in

composition. O Lau has 8 species of freshwater plants, whereas in Cau Hai lagoon there are 6 species of seagrass.

The bottom topography of the central region of Tam Giang lagoon and Thuy Tu is like a basin without seagrass. Seagrasses are mostly distributed along the edge of the lagoon or on the floating dunes (figure 5), with a depth of 0.5–2.5 m; seagrass is also distributed at the sand dune inside Tu Hien estuary - the deepest area, with 3 species of *Zostera japonica*, *Halodule pinifolia* and *Halophila ovalis*.

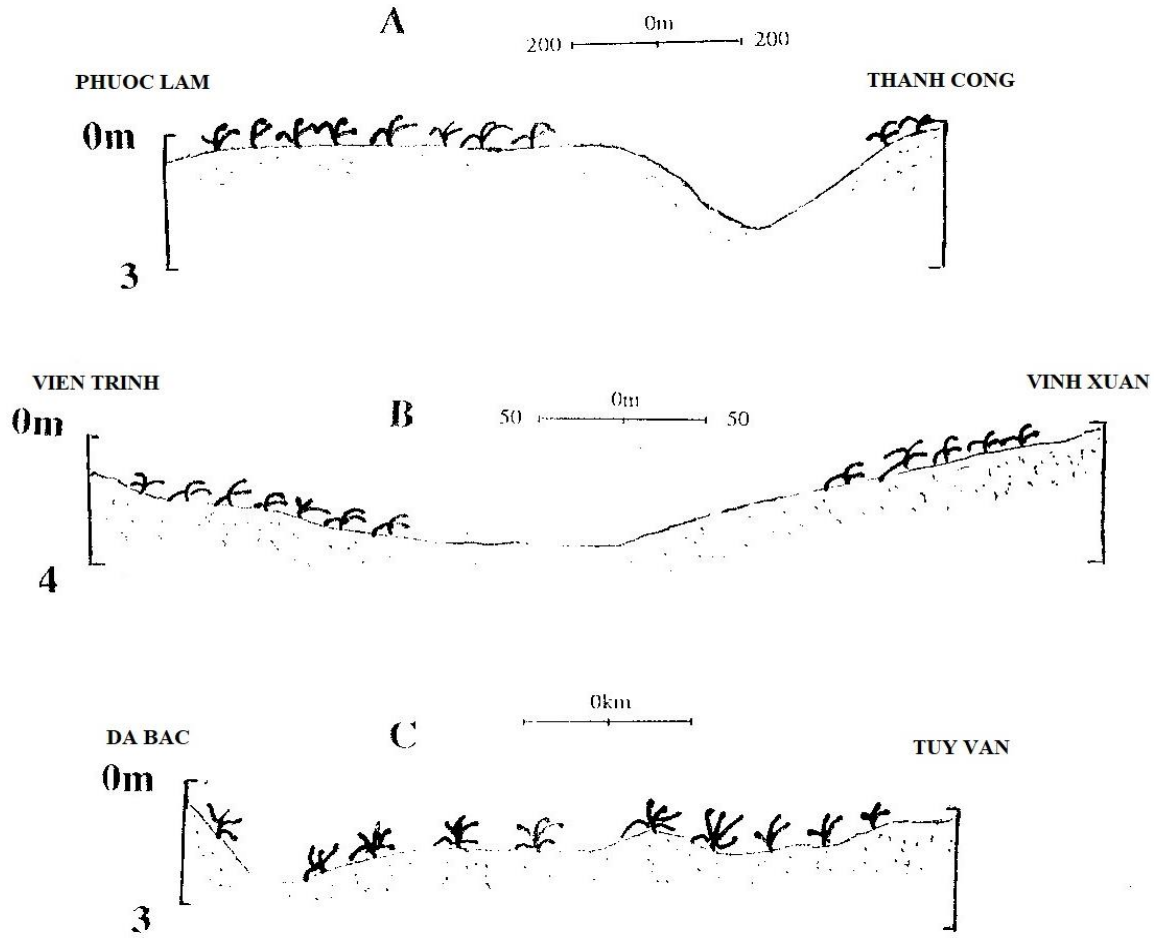

Figure 5. Distribution of seagrasses on the bottom in Tam Giang - Cau Hai lagoon [2], A: Quang Loi transect (Tam Giang); B: Vinh Xuan transect (Thuy Tu); C: Cau Hai transect

The coverage and shoot density

The highest density of shoots and coverage belonged to *Zostera japonica* with 9,905 ± 550 shoots/m^2, followed by *Halodule pinifolia* with 6,010 ± 722 shoots/m^2 and the lowest belonged to *Ruppia maritima* with 325 ± 17 shoots/m^2 (table 4).

A comparison of shoot density from 2009 to 2017 showed that there is a different variation among different species. In 2009, the shoot density of *Zostera japonica* reached 8,550 shoots/m^2, but in 2016 it was 9,905 ± 550 shoots/m^2 (an increase of 1.15 times). Similarly, the shoot density of *Ruppia maritima* increased from 200 shoots/m^2 to 325 ± 17 shoots/m^2. However, in the remaining species, there was a slight decrease in density, in *Halodule pinifolia* from 8,734 shoots/m^2 to 6,010 ± 722 shoots/m^2, in *Halophila ovalis* from 5,359 shoots/m^2 to 3,407 ± 843 shoots/m^2 and in *Halophila beccarii* from 5,850 shoots/m^2 and 5,725 ± 434 shoots/m^2 [4].

Table 4. The coverage and shoot density of seagrasses in Tam Giang - Cau Hai lagoon

Species	Cover (%)		Density (shoots/m^2)	
	2009	*2016–2017*	*2009*	*2016–2017*
Zostera japonica	5–100	90	3,000–14,100	9.905 ± 550
Halodule pinifolia	5–90	75	5,600–11,867	6,010 ± 722
Halodule uninervis	-	25	-	1,200 ± 125
Halophila ovalis	20–50	45	2,050–8,667	3,407 ± 843
Halophila beccarii	50–75	90	3,550–8,150	5,725 ± 434
Ruppia maritima	5–10	25	200	325 ± 17

Quantity characteristics of some typical species

Zostera japonica

In the rainy season, the average length of *Zostera japonica* varies from 8.18 cm at O Lau 3 to 20.50 cm at Tam Giang 5, the average length for the whole study area is 14.14 cm. The amount of biomass varied from 123.8 g.fresh/m^2 at O Lau 4 to 1,113.8 g.fresh/m^2 in Tam Giang 5, the average biomass was 804.4 ± 54.7 g.fresh/m^2.

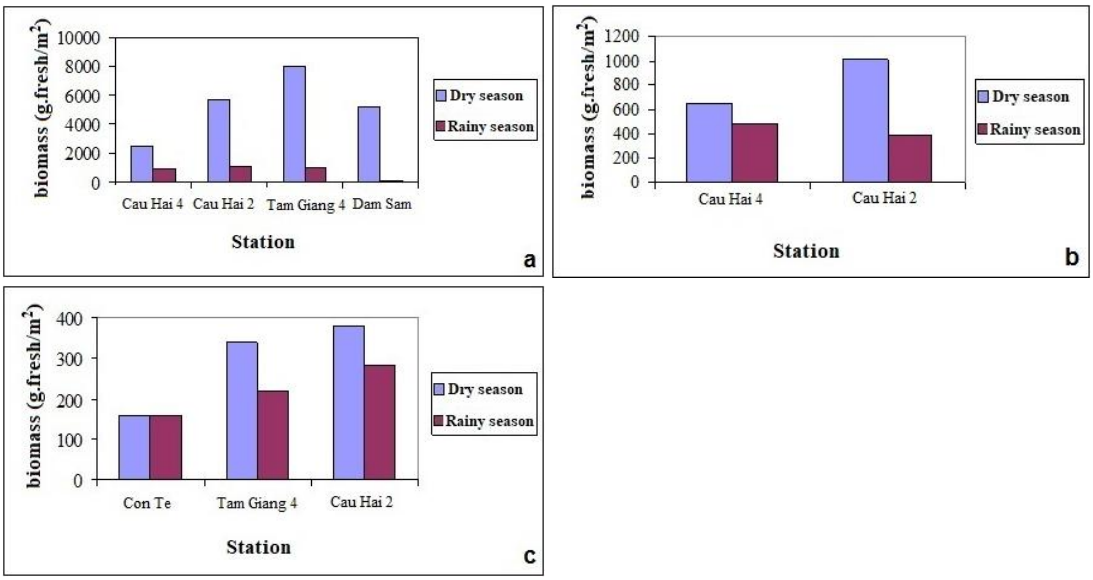

Figure 6. Seasonal change in seagrass biomass in Tam Giang - Cau Hai lagoon: (a) *Zostera japonica*, (b) *Halodule pinifolia*, (c) *Halophila ovalis*

In the dry season, the average length of *Zostera japonica* varies from 19.53 cm at Cau Hai 4 to 36.70 cm at Tam Giang 5, the average length of the whole study area is 27.29 cm. Similarly, biomass varied from 2,466.4 g.fresh/m^2 at Cau Hai 4 to 8,041.5 g.fresh/m^2 at Tam Giang 5; the average was 5,355.4 ± 326.5 g.fresh/m^2 (figure 6a).

Halodule pinifolia

During the rainy season, the average length of *Halodule pinifolia* reaches the lowest value (8.10 cm) at Cau Hai 2 and the highest value (12.88 cm) at Cau Hai 4, the average length for the whole study area in 2009 was 10.49 cm. The amount of biomass varied from 387.5 g.fresh/m^2 at Cau Hai 2 to 475.0 g.fresh/m^2 at Cau Hai 4; the average biomass was 431.3 ± 25.8 g.fresh/m^2.

In the dry season, the average length of *Halodule pinifolia* changes from 9.86 cm at Cau Hai 4 to 17.26 cm at Cau Hai 2, the average length for the whole study area is 13.56 cm. The amount of biomass varied from 650.0 g.fresh/m^2 at Cau Hai 4 to 1,012.5 g.fresh/m^2 at

Cau Hai 2, the average biomass was 831.3 ± 155.3 g.fresh/m^2 (figure 6b).

Halophila ovalis

This species is only distributed in areas with high salinity such as the vicinity of Thuan An estuary (Con Te, Tam Giang 5), Tu Hien estuary (Cau Hai 2) and even in the area of Truong Ha bridge (Vinh Xuan). In the rainy season, the average length varies from 2.96 cm at Cau Hai 2 to 3.59 cm at Tam Giang 5; the average length of the whole study area is 3.17 cm. The biomass varied from 160.0 g.fresh/m^2 at Con Te to 280.0 g.fresh/m^2 at Cau Hai 2, the average of the whole study area was 220.0 ± 25.1 g.fresh/m^2.

During the dry season, the length of *Halophila ovalis* varies from 3.69 cm at Cau Hai 2 to 3.93 cm at Tam Giang 5; average length of the whole study area is 3.79 cm. The biomass varied from 1,600 g.fresh/m^2 at Con Te to 380.0 g.fresh/m^2 in Cau Hai 2. The average weight of the whole study area was 293.3 ± 44.9 g.fresh/m^2 (figure 6c).

The seasonal effects on seagrass biomass and correlation

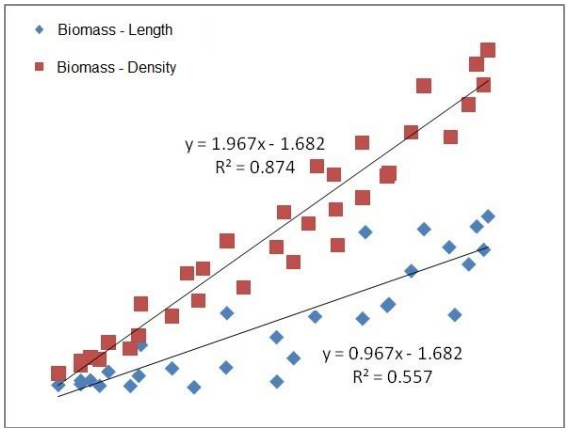

Figure 7. The correlation of biomass of *Zostera japonica*

To see the seasonal effects on seagrass biomass, we analyzed the correlation between shoot density, length and biomass of *Zostera japonica* with 120 quantitative samples. Applying linear equations ($y = ax + b$, with $p < 0.05$) gives positive correlation results (figure 7) and also shows that shoot density is a factor that has a stronger influence on biomass than the length. At the same time, the results of analyzing the above/below ground biomass showed that seagrass in dry season developed better than in rainy season with an average of 1.32 (i.e. 1 kg of rhizome would have 1.32 kg of leaf), during the rainy season this ratio is 0.91 (i.e. 1 kg of rhizome would have 0.91 kg of leaf).

The result is consistent with the general ecological characteristics of tropical seagrass, which means that seagrasses usually grow well in the dry season with the low rainfall, high and stable salinity, few or no storms. At the same time, seagrasses often suffer from a decrease in standing density (shoots) in the rainy season due to high turbidity, decreased and unstable salinity. This result is consistent with the results of the study on *Zostera japonica* in Cua Dai (Quang Nam) [12, 13] and the study on seagrass in the Philippines by Terrados et al., (1998) [14].

CONCLUSION

A total of 6 species of seagrass were identified (*Halodule uninervis* is recorded for the first time in Tam Giang - Cau Hai lagoon, but *Halophila minor* is absent) and 8 species of freshwater plants were also recorded (*Potamogeton maackianus* is absent).

The total distribution area of seagrass and freshwater plants is over 2,840 ha. In particular, seagrass area has been recovering significantly compared to the previous study, from 1,000 ha in 2009 to 2,037 ha in 2017.

Most seagrasses are distributed on the edge of the lagoon or on the islets with a depth of 0.5–2.5 m. The biomass, coverage, shoot density and observation frequency showed that the *Zostera japonica* was the dominant species (the biomass of 5,355.4 ± 326.5 g.fresh/m^2, the shoot density of 9,905 ± 550 shoots/m^2 and the coverage of 90%).

The analytical results showed that the season significantly affects the growth of seagrasses, most of which have a very high biomass in the dry season, and a decrease in the standing shoot density in the rainy season.

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