RESEARCH ARTICLE
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# Changes in seagrass communities along the runoff gradient of the Trang river, Thailand

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**ABSTRACT**: Seagrasses are widely distributed from coastal estuaries through to deep waters. We examined the spatial pattern in seagrass species composition, biomass, and their relationships with various physical factors: salinity, mean sea level, light extinction coefficient, temperature, grain size (gravel, coarse sand, fine sand, clay), and soil organic matter between dry and rainy seasons along the gradient of Trang river mouth around Talibong Island, Trang province. Ten species were found in an area of 61 $km^2$ in the dry season, whereas only eight species were found in 24 $km^2$ in the rainy season. *Halophila decipiens* Ostenfeld was the dominant species covering 29 $km^2$ in the dry season. *Enhalus acoroides* (Linnaeus f. Royle) and *H. ovalis* (R. Brown) J.D. Hooker extended over a large area. Density, area covered, and biomass decreased in the rainy season for most species. A clear seasonal variation was observed both in physical and chemical parameters as well as seagrass species composition, biomass, and reproduction. Water depth and light intensity were the limiting factors that influenced species composition, biomass, and reproduction.

**KEYWORDS**: salinity, sedimentation, siltation, species composition, biomass, reproduction

## INTRODUCTION

Seagrasses are often associated with estuarine habitats, affected by freshwater runoff[1]. These water runoffs carry sediments from terrestrial to coastal areas, resulting in increased siltation[2,3]. A heavy sedimentation load has a negative effect on seagrasses. For example, experimental burial in *Zostera noltii* resulted in a decreased shoot density[4].

Thailand and Southeast Asia are biodiversity hotspots of seagrasses[5]. Seagrasses often occur near river mouths with increasing of flooding events and intense coastal developments in the region[2]. In the Philippines and Thailand, seagrass species richness and community leaf biomass are lower in sediments with high silt and clay contents[6,7], *Enhalus acoroides* being the only species remaining in heavily silted sediments[7]. The principal cause of siltation in estuary habitats is runoff from seasonal rains[8,9]. Increasing river flows result in higher sediment loads which reduce light available for seagrasses. This is becoming a critical problem in the tropical regions, where coastal developments are intense[2]. Also, climate change may increase flooding and runoffs[10].

In estuaries, seasonal trends in the seagrass biomass are often driven by light availability[6,11]. Seasonal runoffs also result in differing saline regimes, and some species can tolerate changes in salinity. Salinity is an important factor affecting the osmosis pressure in cells, and most seagrasses are adapted to live in constant saline regimes. Thus decreased salinity generally has negative impacts on most seagrasses species, causing biomass declines in the rainy season[12,13].

The aim of this study is to assess the vulnerability of seagrass community health related to environment along a gradient in the Trang river mouth.

## MATERIALS AND METHODS

### Sampling site and environmental factors

Talibong island in Trang province is the largest seagrass bed in Thailand designated as the first Ramsar site in the country. This site is the largest site for dugong population in Thai waters. Nine species were reported around the island (*Enhalus acoroides*, *Halophila beccarii*, *H. ovalis*, *Thalassia hemprichii*, *Cymodocea serrulata*, *C. rotundata*, *Halodule pinifolia*, *H. uninervis*, and *Syringodium isoetifolium*); *E. acoroides*, *C. serrulata*, *C. rotundata*, and *H. ovalis* were often at shallow areas (depth of +0.3 to −1.9 m), while only *H. ovalis* was dominant in deep areas (depth of −0.7 to −2.4 m)[11]. Ten line transects, with a total length of 18 km, were laid out to cover the study area covering a total area around 259 km$^2$ (18 km × 14.4 km). Light intensity was measured with an Underwater Quantum Sensor (LI-192, LI-COR, Lincoln, NE, USA) as $\mu$mol m$^{-2}$ s$^{-1}$. The light extinction coefficient $K_{\mathrm{d}}$ was calculated as the difference between the irradiance above the water and irradiance at the level of the seagrass canopy, or sediment surface if seagrass was absent, following this Beer-Lambert equation:

$$K_{\mathrm{d}} = \left(\ln \frac{I_z}{I_0}\right)\frac{1}{z},$$

where $I_0$ and $I_z$ are light intensity at depths of 0 and $z$, respectively.

A Hydrolab multiparameter water quality probe (MS5, Hach Environmental, Loveland, CO, USA) was deployed to measure salinity, temperature, and water depth. Thus water depth was measured at different times in each station and re-calculated with mean sea level (MSL) as the standardized depth. Salinity was classified to mixohaline (0.5–30 psu) and euhaline (30–40 psu) associated with river discharge. Sediments were collected using sediment cores 4.5 cm diameter, 25 cm for analysis of grain size and organic matter. The sediments were dried at 60 °C for 48 h; 20 g of sediment was sieved on a sieve shaker to classify the grain size following Wentworth[14]. Sediment grain size was classified as coarse sand (250 µm), fine sand (63–250 µm), and mud (63 µm). Sediment (5 g) was combusted in a furnace at 550 °C for 4 h to measure the organic matter content (OM). The OM was calculated from the weight loss of the dry sediment on ignition[15].

## Plants measurement

Seagrasses were observed at 77 sites distributed in a grid in the studied seagrass bed (Fig. 1). At each permanent station, five replications of 0.25 m$^2$ quadrats were haphazardly placed by scuba divers in the dry season (February in 2014) and the rainy season (November in 2014). In each quadrat, the total species percentage cover, the percentage cover and the number of shoots and reproductive structure were examined for each seagrass species. The plants were collected and in the laboratory, they were separated to above-ground parts (leaf and leaf sheath) and below-ground parts (rhizome and root) before drying at 60 °C for 48 h to determine dry weight.

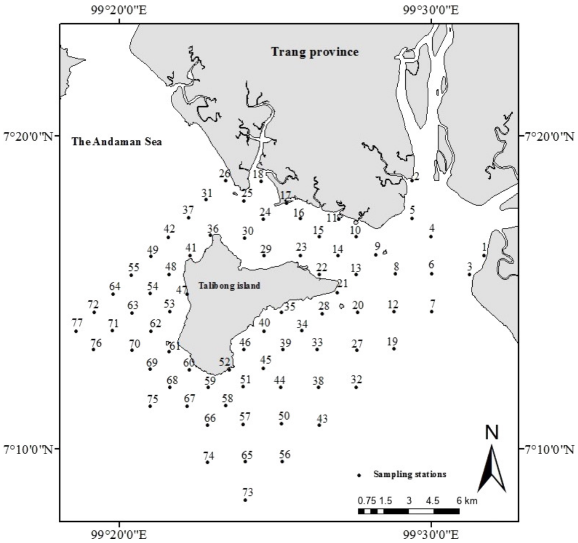

**Fig. 1** Map of study area around Talibong island. Circles indicate sampling stations.

## Data analyses

Data from 77 permanent stations were interpolated using IDW algorithm to generate contours of all species and separately for each species in the study area of 215.85 km$^2$. One-way ANOVA was used to test the differences in physical and chemical parameters between seasons. The seagrass parameters (percentage cover, density, above-ground biomass, below-ground biomass, fruiting, and flowering) did not meet the assumption of ANOVA, thus a Kruskal-Wallis test was used to test the differences in those seagrass parameters between species, salinity gradients, and seasons. Canonical correspondence analysis (CCA) was conducted to determine the multivariate correlations between the seagrass distribution and the physical and chemical parameters, using PC-ORD 5.0. Monte Carlo tests with 999 permutations were used in this analysis, and the joint plot only variables with values 0.05. The relationships between physical and chemical parameters and seagrass percentage cover, density, above-ground biomass, below-ground biomass, flowering, and fruiting were tested using stepwise multiple regressions, using SPPS 13.0.

## RESULTS

### Environmental factors

The average light intensity, $K_{\mathrm{d}}$, salinity, coarse sand, and silt differed between dry and rainy season, whereas there were no significant differences in water depth, gravel, fine sand, and OM between

**Table 1** Summary of statistical analysis for one-way ANOVA testing effects of seasons on all variables.

| Variables | Transf.* | Dry season | | Rainy season | | *F*-values |
|---|---|---|---|---|---|---|
| | | Min–Max | Mean ± SE | Min–Max | Mean ± SE | |
| light intensity ($\mu$mol m$^{-2}$ s$^{-1}$) | $\sqrt{x}$ | 0–1706.8 | 567 ± 52 | 0–718.20 | 110 ± 18 | 83.44‡ |
| $K_d$ (m) | $\sqrt{x}$ | 0.13–14.73 | 6.02 ± 0.58 | 0.10–6.53 | 1.37 ± 0.20 | 71.13‡ |
| MSL (m) | $\sqrt{x}$ | 0.13–17.50 | 6.64 ± 0.53 | 0.22–14.56 | 6.21 ± 0.57 | 0.48§ |
| temperature (°C) | $\sqrt{x}$ | 27.44–32.98 | 29.03 ± 0.11 | 28.79–30.77 | 30.06 ± 0.07 | 49.76‡ |
| salinity (ppt) | $1/x$ | 30.35–33.60 | 32.91 ± 0.07 | 21.72–32.40 | 30.30 ± 0.33 | 234.15‡ |
| gravel (%) | $\log x$ | 0.55–44.29 | 10.6 ± 1.5 | 0.16–50.73 | 9.3 ± 1.4 | 0.23§ |
| coarse sand (%) | $\log x$ | 1.88–67.00 | 20.1 ± 1.8 | 0.21–43.48 | 11.0 ± 1.3 | 20.78‡ |
| fine sand (%) | $\log x$ | 10.60–95.29 | 66.1 ± 2.8 | 10.12–98.03 | 72.8 ± 2.4 | 3.06§ |
| silt (%) | $\log x$ | 0.93–11.74 | 3.19 ± 0.21 | 0.35–25.66 | 6.82 ± 0.85 | 4.57† |
| organic matter (%) | $\log x$ | 0.88–16.62 | 4.29 ± 0.39 | 0.80–24.80 | 5.21 ± 0.55 | 2.28§ |

* Transformation; † $p < 0.01$; ‡ $p < 0.001$; § no significant difference.

seasons (Table 1). Water were mixohaline (stations 3, 4, 5, 6, 7, 8, 12, 13, 14, 15, 19, and 27) and euhaline (the rest of the stations) associated with river discharge.

Seasonal changes in light intensity and $K_d$ depended on the combination of river discharge and water depth. Near the river mouth, light intensity near the sea bottom was less than 100 $\mu$mol m$^{-2}$ s$^{-1}$ in the dry season, reaching 0 $\mu$mol m$^{-2}$ s$^{-1}$ only at station 3, where it was directly exposed to the river discharges (Fig. 2a). However, in the rainy season light levels were near 0 $\mu$mol m$^{-2}$ s$^{-1}$ at stations 3, 4, 6, 8, and 19 (Fig. 2b). Water depth ranged 0.13–17.50 m below mean sea level in the dry season, and 0.22–14.56 m below mean sea level in the rainy season; the tidal range was 1–3.5 m (Fig. 2c). The lowest water depth was at station 18 (0.13 m) located at the upper intertidal zone, while the deepest water depth was at station 77 (17.50 m) located at the north west of the island. The changes of the water depth might be a result from the sediment movement at the sea bottom, which was clearly observed in many stations during the rainy season (Fig. 2d). Salinity was also influ-

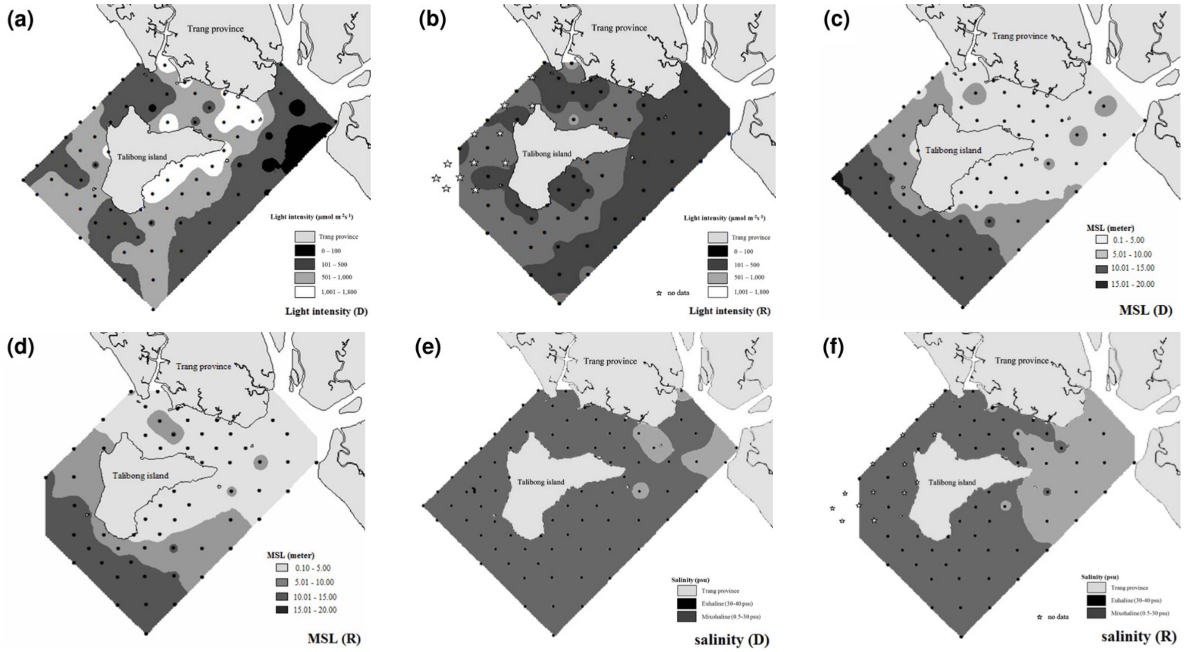

**Fig. 2** Spatial distribution of physical factors: (a,b) light intensity, (c,d) MSL, and (e,f) salinity, along Trang river mouth. (D) = Dry season, (R) = Rainy season.

**Table 2** Summary statistic for Kruskal-Wallis tests of all seagrass variables testing the effects of seagrass different species, seasons, and their interactions.

| Variables | SS | G | SP | SS × G | SS × SP | G × SP | SS × G × SP |
|---|---|---|---|---|---|---|---|
| Coverage | $26.11^{\ddagger}$ | $33.11^{\ddagger}$ | $39.39^{\ddagger}$ | $27.30^{\ddagger}$ | $95.76^{\ddagger}$ | $85.69^{\ddagger}$ | $224.05^{\ddagger}$ |
| Density | $44.74^{\ddagger}$ | $33.82^{\ddagger}$ | $29.24^{\ddagger}$ | $99.83^{\ddagger}$ | $177.17^{\ddagger}$ | $76.77^{\ddagger}$ | $243.12^{\ddagger}$ |
| Above-ground biomass | $13.05^{\ddagger}$ | $32.37^{\ddagger}$ | $88.48^{\ddagger}$ | $53.89^{\ddagger}$ | $112.04^{\ddagger}$ | $137.80^{\ddagger}$ | $246.47^{\ddagger}$ |
| Below-ground biomass | $11.47^{\ddagger}$ | $35.61^{\ddagger}$ | $80.87^{\ddagger}$ | $54.46^{\ddagger}$ | $113.85^{\ddagger}$ | $132.90^{\ddagger}$ | $224.68^{\ddagger}$ |
| Flowering | $30.60^{\ddagger}$ | $10.45^{\ddagger}$ | $34.68^{\dagger}$ | $46.78^{\ddagger}$ | $101.40^{\ddagger}$ | $42.29^{\ddagger}$ | $263.50^{\ddagger}$ |
| Fruiting | $8.76^{\dagger}$ | NS | $26.62^{\ddagger}$ | $13.39^{\ddagger}$ | $62.43^{\ddagger}$ | $29.49^{\dagger}$ | $229.03^{\ddagger}$ |

SS = seasons, G = gradients, SP = species; $^{\dagger}p < 0.01$; $^{\ddagger}p < 0.001$; NS = no significant difference.

enced by the river discharge; water near the river mouth became brackish in the rainy season due to increased freshwater runoff (Fig. 2e,f).

## Seagrass distribution

There were significant differences in cover, density, above-ground biomass, below-ground biomass, and reproduction in different species affected by gradients and seasons ($p < 0.001$; Table 2). Highest values of cover, density, aboveground biomass, belowground biomass, flowering, and fruiting densities were for *C. rotundata* in the mixohaline zone in the dry season (48 ± 12%), *Halophila beccarii* at euhaline in the rainy season (280 ± 16 leaf pair/$m^2$), *C. rotundata* and *E. acoroides* at euhaline in the rainy season (2.69 g DW/$m^2$), *E. acoroides* at euhaline in the dry season (6.45 ± 0.92 g DW/$m^2$), *H. decipiens* at euhaline in the rainy season (18.7 ± 7.3 flowers/$m^2$), and *H. decipiens* at euhaline in the rainy season (22.33 ± 0.33 fruits/$m^2$), respectively. Generally, coverage, density, above-ground biomass, below-ground biomass, and flowering were higher in euhaline (11 ± 1%, 16.5 ± 2.8 shoots/$m^2$, 0.44 ± 0.05 g DW/$m^2$, 1.07 ± 0.16 g DW/$m^2$, and 0.96 ± 0.23 flowers/$m^2$) than mixohaline zone (4.3 ± 1.9%, 4.0 ± 1.7 shoots/$m^2$, 0.22 ± 0.91 g DW/$m^2$, 0.20 ± 0.81 g DW/$m^2$, and flowers and fruits were absent).

Ten seagrass species covered an area of 61.37 $km^2$ around the island in the dry season (Fig. 3a). In the rainy season, eight species covered only 24.04 $km^2$; *Halophila major* and *Halodule*

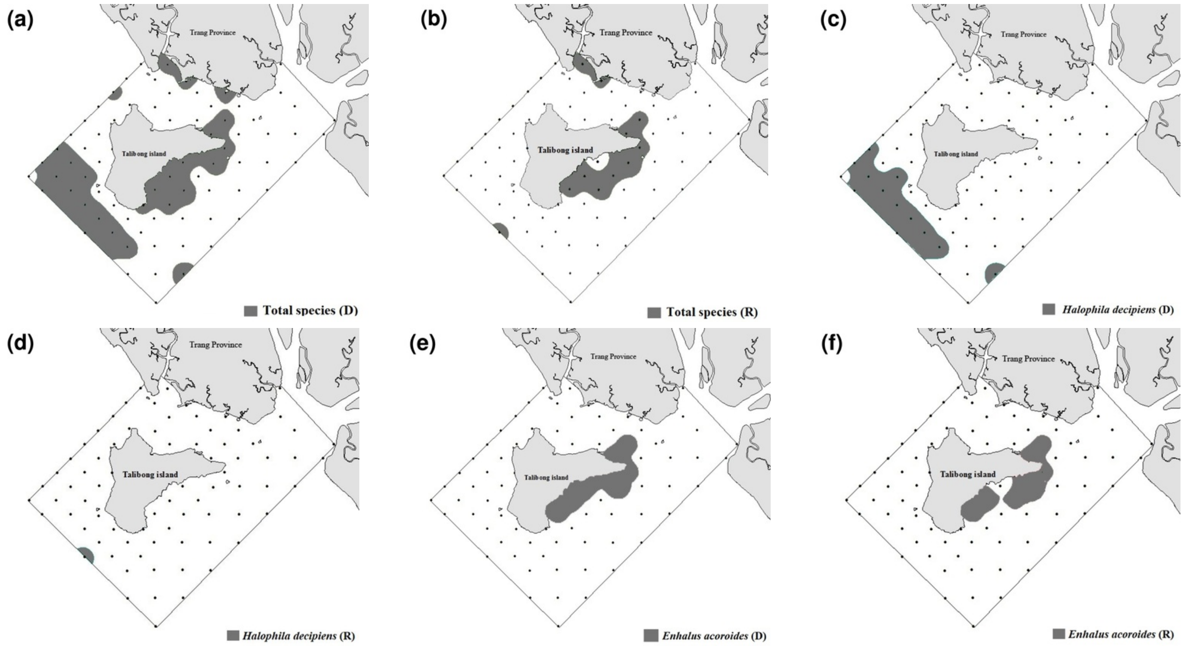

**Fig. 3** Distribution of the ten seagrass species from 77 sampling stations along Trang river mouth: (a,b) total seagrass species; (c,d) *H. decipiens*; (e,f) *E. acoroides*; (g,h) *H. ovalis*; (i,j) *C. rotundata*; (k,l) *C. serrulata*; (m,n) *T. hemprichii*; (o,p) *H. beccarii*; (q) *H. major*; (r) *H. pinifolia*. (D) = Dry season, (R) = Rainy season.

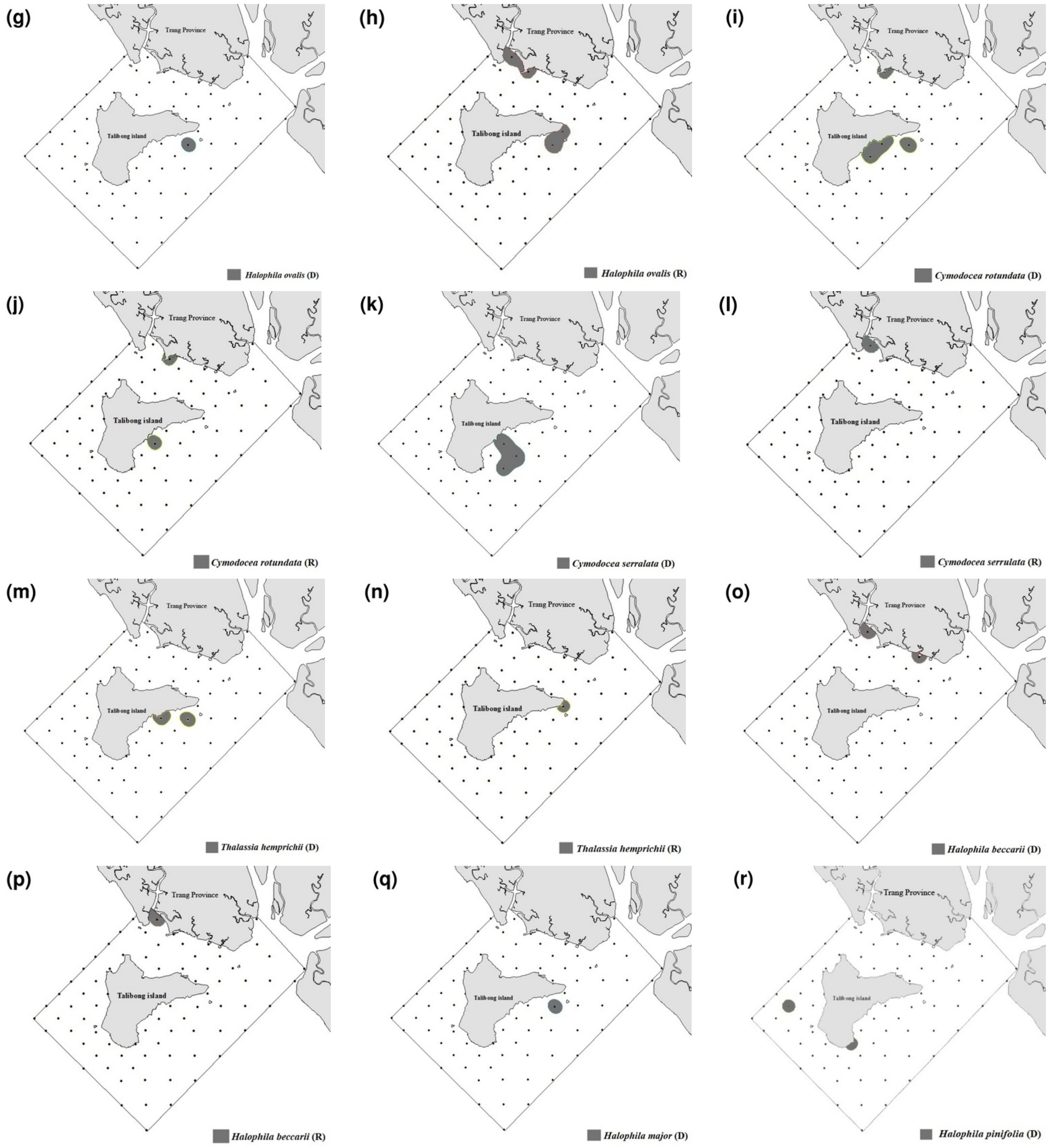

**Fig. 3** (Continued).

*pinifolia* were absent in the rainy season (Fig. 3b). *H. decipiens* was the most widely distributed species, covering 28.55 km$^2$ in the dry season (Fig. 3c); but only 0.88 km$^2$ in the rainy season (Fig. 3d). As expected, *E. acoroides* was not influenced by season, covered 15.87 km$^2$ in both seasons (Fig. 3e,f). *H. ovalis* covered 12.60 km$^2$ in the dry (Fig. 3g) and only 6.96 km$^2$ in the rainy season (Fig. 3h). In addition, *C. rotundata*, *C. serrulata*, *T. hemprichii*, *H. beccarii*, *Halodule uninervis*, *H. major*, and *H. pinifolia* were observed in this study (Fig. 3i–r), but they were less abundant and varied between seasons.

## Relationship between environmental factors and species distribution

There was a significant relationship between species distribution and physical and chemical parameters ($p < 0.01$; the explained variance of Axis 1 =

**Table 3** Partial correlation coefficients of the effects of environmental parameters on coverage, density, above-ground biomass, and below-ground biomass of significant seagrass species.

| Variable | Species | Constant | Depth | Temp. | Sal. | df | *F* | $R^2$ | *p*-value |
|---|---|---|---|---|---|---|---|---|---|
| Coverage | *E. acoroides* | 1.10 | 6.92 | NS | NS | 38 | 6.71 | 0.15 | $< 0.05$ |
| | *H. ovalis* | −7.04 | NS | NS | NS | 21 | 5.37 | 0.21 | $< 0.05$ |
| | *C. rotundata* | 78.19 | NS | NS | NS | 13 | 1.93 | 0.62 | $< 0.01$ |
| | *H. decipiens* | 0.36 | 4.21 | NS | NS | 42 | 4.54 | 0.10 | $< 0.05$ |
| Density | *H. decipiens* | 2.81 | 37.20 | NS | NS | 42 | 510 | 0.11 | $< 0.05$ |
| Above-ground biomass | *E. acoroides* | 1.60 | 1.97 | NS | NS | 38 | 8.41 | 0.19 | $< 0.01$ |
| | *C. rotundata* | 30.22 | 2.69 | NS | NS | 13 | 11.23 | 0.67 | $< 0.01$ |
| | *H. decipiens* | 0.12 | 0.04 | NS | NS | 42 | 5.91 | 0.13 | $< 0.05$ |
| Below-ground biomass | *E. acoroides* | −24.41 | NS | NS | 26.98 | 38 | 5.74 | 0.13 | $< 0.01$ |
| | *T. hemprichii* | −54.71 | NS | 41.41 | NS | 3 | 23.1 | 0.92 | $< 0.05$ |
| | *C. rotundata* | 10.76 | NS | NS | NS | 13 | 7.69 | 0.39 | $< 0.05$ |
| | *H. decipiens* | −0.24 | NS | 0.19 | NS | 42 | 5.61 | 0.12 | $< 0.05$ |
| Flowering | *H. decipiens* | 22.27 | NS | −13.19 | NS | 42 | 9.45 | 0.19 | $< 0.05$ |
| Fruiting | *H. decipiens* | 12.91 | −4.19 | NS | NS | 42 | 14.34 | 0.26 | $< 0.01$ |

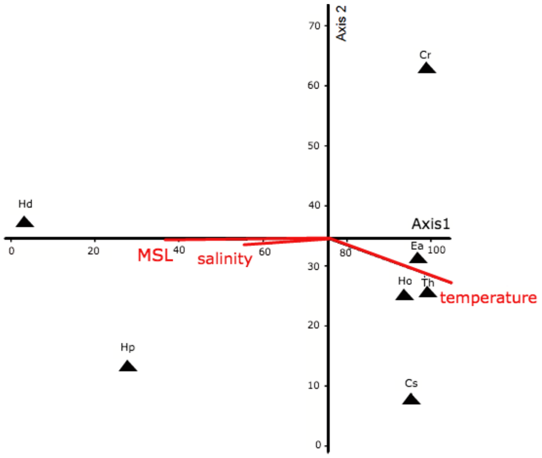

**Fig. 4** CCA biplot of analysis for the seagrass distribution versus physical parameters: species codes: Ea (*E. acoroides*); Ho (*H. ovalis*); Hp (*H. pinifolia*); Hd (*H. decipiens*); Th (*T. hemprichii*); Cr (*C. rotundata*); and Cs (*C. serrulata*). Environment parameter codes: MSL (mean sea level), salinity, and temperature.

22% and Axis 2 = 12%). Only *Halophila decipiens* was associated with increasing mean sea level (MSL) and salinity, while *E. acoroides*, *H. ovalis*, and *T. hemprichii* had a positive relation with temperature (Fig. 4).

The stepwise multiple regressions showed that there were relationships, but these varied among species between plants and physical and chemical parameters (Table 3). Percentage cover and above-ground biomass of *E. acoroides* and *Halophila decipiens*, for example, were positively correlated with water depth, while below-ground biomass of *E. acoroides* was positively correlated with salinity. Below-ground biomass of *T. hemprichii* had a positive relationship with temperature. *H. decipiens* was the only species influenced by various physical conditions, including their flowering and fruits density.

## DISCUSSION

Light intensity, MSL, and salinity showed gradients from Trang river mouth to the open sea, increasing with the distance from the river mouth. Coverage, density, biomass, and reproduction in most seagrass species were significant higher in euhaline than in mixohaline zones. Most species showed negative correlation with salinity as suggested by the CCA, but there were no clear relationships between biological parameters and salinity except the below-ground biomass of *E. acoroides*, which increased with increasing salinity. Salinity did not affect the biomass and cover of the standing seagrasses, possibly because these occurred in lower tidal or subtidal areas and were thus little exposed to waters with reduced salinity. *E. acoroides* was the exception, showing decreased below-ground biomass with reduced salinity, but, in contrast with other seagrasses, this species persisted in areas near the river mouth, including during the rainy season.

*H. decipiens* was the most widely distributed species, covering 28.55 $km^2$ in the dry season but only 0.88 $km^2$ in the rainy season. *H. decipiens* is a low-light species, which can grow in range 15–58 m depth in clear water[16]; here it occurred at

10–15 m depth. This species has a short life span and grows only a few months and produces seeds, which are buried in the sediment[17,18]. In our study, there were some seedlings observed in November 2014 during the transition month from rainy to dry season, however they were washed away after 2–3 days, during a short period when sand drifted and strong wave occurred. Also, large *H. decipiens* mats were often washed up on the shore during the rainy season. This species has not been previously reported or observed at our site[7,19]. The recent occurrence of *H. decipiens* might be a result from the tsunami in 2004, when the area was hit by the high waves and the sediment movements changed the macrophyte community at the site[20]. In south Florida, *H. decipiens* was also the dominant species which covered 7500 km$^2$ from 17 000 km$^2$ survey area[21]. Although *H. decipiens* beds supported fewer marine animals than intertidal seagrass beds, the productivity of depth beds is often high, which is important for epibenthic fauna[22].

There were differences in physical and chemical parameters between dry and rainy seasons. Salinity ranged 30.54–33.76 psu classified as euhaline sea in the dry season, while in the rainy season the salinity ranged 21.80–32.55 psu. Light intensity and $K_\mathrm{d}$ strongly decreased in the rainy season when underwater light intensity was less than 100 µmol m$^{-2}$ s$^{-1}$ in many stations near the river mouth. Abundance of the seagrasses at our study was much lower than at the nearby Hat Chao Mai National Park, a pristine site only 12 km away from the site. For example, the biomass of *H. ovalis*, *T. hemprichii*, and *C. rotundata* were only 223 ± 57 shoot/m$^2$, 12 shoot/m$^2$, and 72 ± 27 shoot/m$^2$ compared to 5823 ± 745 shoot/m$^2$, 1249 ± 75 shoot/m$^2$, and 1525 ± 88 shoot/m$^2$, respectively[23]. This difference in abundance most likely can be attributed to the environment at our study sites exposing the seagrasses to lower salinity, light stress, and high sedimentation. The sediment runoff did not only limit light availability but also could directly bury the small species as we often observed that *H. beccarii*, *H. uninervis*, *H. major*, and *H. pinifolia* were partially covered by the sediment; and *H. decipiens* which occurred in the deeper water was sometimes completely buried. Although larger species were not buried by the sediment, their photosynthesis might be limited by lower light intensity, which resulted in lower biomass. The largest species in the tropic, *E. acoroides*, seems to be the most tolerant species against the siltation as documented in a few studies of extensive coastal developments in the South East Asian region[7,24].

Flowering was only observed in *E. acoroides*, *H. ovalis*, and *H. decipiens*; and only *H. decipiens* developed fruits in the dry season. Generally, *E. acoroides* reproduces throughout the year, but we have found that they only reproduced during the dry season at our site. Flowering frequency at our riverine-influenced study site (0.003) was also lower than at the nearby marine site (0.1), where plants are not influenced by the salinity changes or associated with the sedimentation from the river mouth[25]. *H. ovalis* also reproduced flowers in the dry season, although in other areas it produces throughout the year[26]. A recent laboratory study, demonstrated that reproductive potential of *H. ovalis* decreased at lower salinity, dying at 3–6 psu [13]. Percentage cover and fruiting of *H. decipiens* (1.8 ± 0.7% and 0.35 ± 0.25 flowers/m$^2$) were also much lower than previously reported in Chumphon province, Gulf of Thailand (46.7 ± 6.1 and 35 ± 14 fruit/m$^2$) [17], although it was the only species for which plants developed seeds.

Global climate change, resulting in uncertain seasonal local climate, may affect the tropical seagrasses in estuarine environments. Especially, decrease in light availability with increasing fresh water runoff plays an essential role in the persistence of the seagrasses, with salinity playing a less important role. In this region, where coastal developments are intensive, such unpredicted scenario could cause a lot of sediment runoff and this could be the major cause to limit growth and reproduction of seagrasses. Increasing $CO_2$ and lower pH are also consequences of global climate changes, and these most likely do not affect the physiology of seagrasses[27], but awareness should be raised of the other consequences of global climate change as that mentioned in this study (increased terrestrial runoff).

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