The Effect of Shore Height on the Distribution of Upper Intertidal Seagrass in the Andaman Sea, Thailand

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ABSTRACT

Shore height is one of the physical factors in marine ecology affecting marine organisms in the upper intertidal area. This study aimed to investigate the effect of shore height on the distribution of three dominant seagrass species in the upper intertidal area of the Andaman Sea in the provinces of Krabi and Trang, southern Thailand. Shore height data were collected from 155 stations in 2021 and 273 stations in 2022, using a theodolite (AP-8 Nikon) and a surveyors' rod. The measured height from the field was calculated relative to the height of water predicted above the lowest low water on a specific date and time, thus shore height is presented as the height above lowest low water (cm H_LLW). The total aboveground biomass of the three dominant seagrass species, namely, *Enhalus acoroides*, *Thalassia hemprichii* and *Halophila ovalis*, was observed through a modified Rapid Visual Estimation Technique. At different shore heights (0–100, 100–180, and above 180 cm H_LLW), the coverage of total seagrasses was highly significant ($F = 9.08$, $p = 0.002$); the biomass was also highly significant ($F = 18.72$, $p<0.001$). The highest total biomass (10.56±6.66 g dw·m^{-2} with 55.00±24.05% coverage) was found at 100–120 cm H_LLW. The shore height affected the presence of seagrass, with distinct shallow thresholds observed for *E. acoroides*, *T. hemprichii* and *H. ovalis* of 200, 200 and 220 cm H_LLW, respectively. The findings from this study hold significant implications for guiding decision-making processes related to seagrass restoration and transplantation efforts.

Keywords: Lowest low water, Seagrass distribution, Shallow threshold, Shore height, Upper intertidal area

INTRODUCTION

Seagrasses, submerged marine plants distributed along coastal areas, build up the most productive marine ecosystem. Their biological structure increases biodiversity both in the water column and underground (Bell *et al*., 1984; Orth *et al*., 1984; Hemminga and Duarte, 2000; Beck *et al*., 2001). Their leaves retard currents and encourage the settlement of sediments, while their root and rhizome system inhibits sediment resuspension and promotes carbon accumulation (Phillips and Durako, 2000; Green and Short, 2003). The seagrass plant itself plays a role as a blue carbon exporter (Kanmarangkool *et al*., 2022). It is estimated that seagrasses store 20% of oceanic blue carbon even though their coverage area is only 0.2% of the ocean surface (Short *et al*., 2016). Stankovic *et al*. (2021) estimated that storage of organic carbon within Southeast Asia seagrass

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ecosystems amounted to 121.95±76.11 $Mg \cdot ha^{-1}$. Seagrasses also provide shelter and nursing ground to many commercial marine species, including large herbivores such as sea turtles and dugongs. Although the importance of seagrass beds is well known, they are impacted by human activities such as fisheries, eutrophication, sedimentation, and shoreline development (Orth *et al*., 2006; Waycott *et al*., 2009).

Among six global seagrass bioregions, the tropical Indo-Pacific region has the largest and highest diversity, with 24 tropical seagrass species predominantly on reef flats, mostly less than 10 m deep, and commonly grazed by dugongs (Short *et al*., 2007). In this intertidal area, water depth is the key factor related to periodical cycles of air exposure, rehydration during low tide, water temperature and light requirement which affect seagrass photosynthetic efficiency, growth rate, and reproductive success of seagrasses (Bach *et al*., 1998; McKenzie and Campbell, 2004; Campbell *et al*., 2007; Collier and Waycott, 2009).

Intertidal seagrass optimum depth has been recorded in many areas. However, the measurement of water depth in seagrass studies was different according to methods and tidal datums, resulting in seagrass data that are incomparable or unintegrated. These include the level of mean low tide (MLT) (Bach *et al*., 1998), depth measured by using depth gauge board (Halim *et al*., 2020), depth at maximum tide level (MTL) (Xu *et al*., 2011), depth during high tide (Ogawa and Nanba, 2002; Bité *et al*., 2007; Tongkok *et al*., 2012; Vichkovitten *et al*., 2016), depth during low tide (Vichkovitten, 1998), shore height above lowest low water (Tongkok *et al*., 2017), and height above chart datum (Huong *et al*., 2003). Depth during high tide is frequently used for intertidal seagrass studies because seagrasses become exposed during low tide when the water depth can be measured. The depth may be reported as zero meters or above low tide, but oftentimes it is neglected in studies. In addition, the water depth is varied not only by measurement methods but also equipment, time and tide cycle. Determining the depth in the seagrass area is important for seagrass transplantation and restoration because the zone with optimum depth for seagrass restoration is limited (Aoki *et al*., 2020).

We hypothesize that the existence and distribution of seagrass in upper intertidal areas are restricted by shore height, which affects other environmental factors such as desiccation, light intensity and high water temperature during low tide. The shore height is specific to each location and it is unchanged by tide. In addition, shore height measurement in this study can provide insight into seagrass distribution above low tide. In this study, we use the lowest low water (LLW), which is one of the reference points for measuring depths or heights in marine environments. We examined shore heights above LLW together with the presence of three dominant seagrass species, *Enhalus acoroides*, *Thalassia hemprichii* and *Halophila ovalis*, at the Andaman Sea intertidal seagrass beds in Trang and Krabi provinces, Thailand. The shore height above lowest low water can be precisely measured, compared and calculated with measurement done anywhere with specified chart datum. This study aims to investigate the effect of shore height above lowest low water to the distribution and abundance of upper intertidal seagrasses. We provide information on intertidal seagrass zonation at different shore heights which is useful for decision making on seagrass restoration and transplantation in the future.

MATERIALS AND METHODS

Study site

The study sites are located along the Andaman Sea coast: Laem Yong Lum, Haad Chao Mai National Park in Trang Province (N 07°23'58.7" E 99°20'47.6" to N 07°21'55.0" E 99°21'08.7") and Ao Ta Len in Krabi Province (N 08°11'50.9" E 98°44'50.8" to N 08°08'24.7" E 98°44'20.4"), Thailand (Figure 1). The seagrass bed at Haad Chao Mai National Park is one of the most undisturbed seagrass beds under the monitoring of the National Park, Wildlife and Plant Conservation Department. It is also the largest seagrass bed, covering an area of 18 km^2 and containing nine seagrass species (Nakaoka and Supanwanid, 2000; Supanwanid and Lewmanomont, 2003). At Ao Ta Len, the seagrasses cover 6 km^2, with eight seagrass species (Marine and Coastal Resources Research and Development Institute, 2006). Both seagrass beds are very important as a feeding ground for dugong (*Dugong dugon*). The tidal regime is regular semidiurnal, leading to a periodicity in low tide at early morning and late afternoon during spring tide.

The study stations were set by transects, which were perpendicular from the coastline, parallel to each other, and separated by 200 m. Along transect lines, the stations were set with an interval of 50 m and positioned by using a handheld GPS (GPSMAP64xGARMIN). The length of each transect and number of stations depended on the depth profile at the transect location. The study area covered 1.79 km^2 at Krabi and 1.67 km^2 at Trang. We collected specimens and data from 155 stations in 2021 and 273 stations in 2022.

Sampling techniques and data analysis

At each station, shore height was measured by using a theodolite (AP-8 Nikon) and a surveyors' rod (Leliaert and Coppejans, 2004). A theodolite was set up between two transect lines. The measured height from the field was calculated relative to the height of water predicted above the lowest low water on a specific date and time. These relative measurements were transformed to shore height above the lowest low water (H_LLW: cm) relating to Tide Tables: Thai Waters A.D. 2022, which varied from 0 to 240 cm. The lowest low water is the average height of the lowest tide recorded at a tide station for an 18.6-year recording period of tidal cycles (Hydrographic Department, Royal Thai Navy, 2022).

The abundance of seagrass species was determined in the study areas. The total aboveground biomass of these species was observed by modifying the Rapid Visual Estimation Technique (Mellors, 1991). Seagrass species, aboveground biomass, and percent coverage were also recorded. The three dominant seagrass species were selected as those with the highest total percentage of abundance for data analysis.

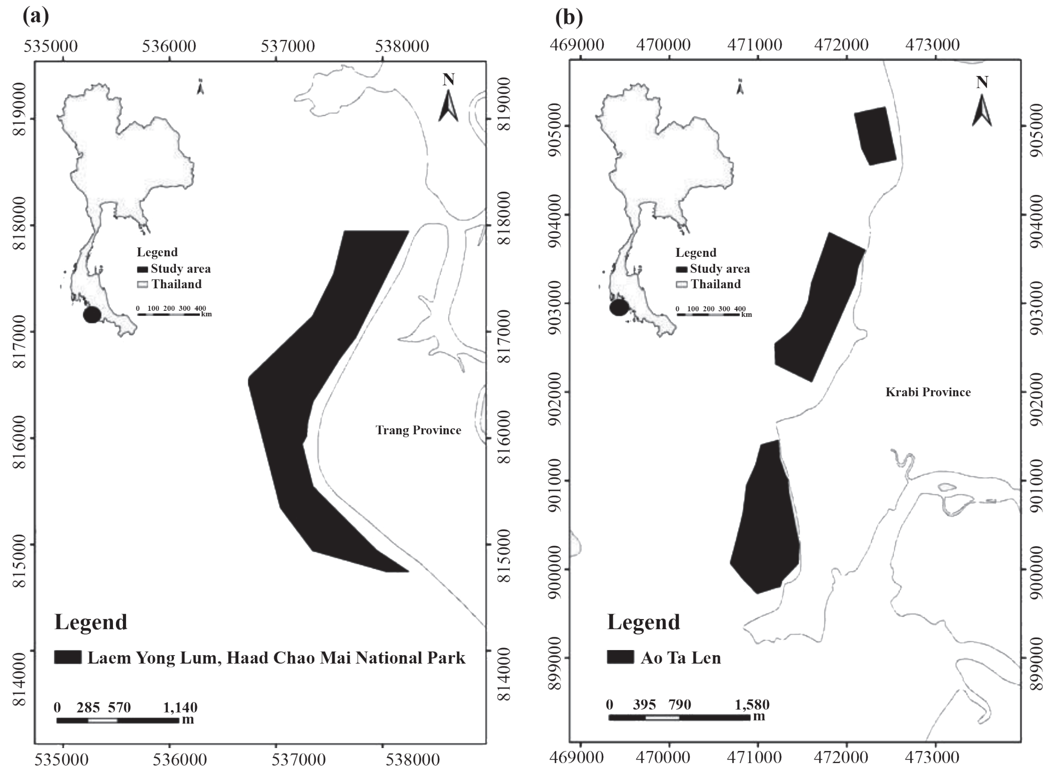

Figure 1. Intertidal seagrass study areas in Trang (a) and Krabi (b) provinces, Thailand.

We used R program for data analysis (R Development Core Team, 2020). The ggplot was used for statistical histogram and graphical analysis. The variance among H_LLW, species coverage and aboveground biomass were analyzed by ANOVA function. Tukey's HSD post hoc test was used to test multiple comparisons between aboveground biomass and H_LLW. Multiple correlations among H_LLW, percentage coverage and biomass were tested by principal component analysis (PCA).

RESULTS AND DISCUSSION

Six seagrass species, namely, *Enhalus acoroides*, *Thalassia hemprichii*, *Halophila ovalis*, Cymodocea rotundata, *C. serrulata* and *Halodule uninervis*, were found in the study sites. Three species (*E. acoroides*, *T. hemprichii* and *H. ovalis*) were considered dominant based on their percentage of abundance (Table 1). In the area above lowest low water, seagrasses were distributed both in monospecific meadows and mixed with other seagrass species in a larger area. The distribution of seagrass was different according to H_LLW. At high tide, the stations with high H_LLW were in shallow water, while stations with low H_LLW were in deeper water. Seagrass presence frequency showed a normal distribution ($W = 0.98$, p-value $= 0.13$) over the range of H_LLW. Seagrasses were generally distributed at 100–180 cm H_LLW, mostly at 120–140 cm H_LLW, and unable to become established above 220 cm H_LLW (Figure 2). The shore height at 220 cm H_LLW was the shallowest threshold for seagrasses in this area.

In terms of abundance of total seagrasses, different H_LLW (0–100, 100–180 and above 180 cm H_LLW) showed highly significant differences in coverage ($F = 9.08$, $p = 0.002$), and very highly significant difference in biomass ($F = 18.72$, $p<0.001$). For this reason, seagrass abundance was intensively analyzed for the zone between 100 and 180 cm H_LLW. The highest total biomass was found at 100–120 cm H_LLW (10.56±6.66 g $dw \cdot m^{-2}$ with 55.00±24.05% coverage), and was significantly different ($F = 2.69$, $p = 0.04$) from the biomass at 140–160 cm H_LLW (Figure 3 and Table 2). Nonetheless, there were no differences in total coverage among depth groups ($F = 0.18$, $p = 0.90$). The principal component analysis (PCA) coincidentally showed no correlation among total coverage, total biomass and H_LLW (Figure 4), indicating that the three seagrass species, which were different in shape and size, could independently vary their total coverage and total biomass.

The depth limitation and distribution were different among seagrass species (Figures 5, 6 and Table 2). For *E. acoroides*, the shallow threshold was at 200 cm H_LLW. Its distribution and reproduction in the shallow areas were limited by the height of shore, which allowed desiccation and high light intensity during low tide. Likewise, Dagapioso and Uy (2011) reported that *E. acoroides* seed germination was lower in shallower areas with a longer desiccation period during low tide. The coverage of *E. acoroides* showed vertical distribution based on tidal change, especially in terms of depth and desiccation period at spring tide (Ogawa and Nanba, 2002). The results of our study demonstrated that coverage was greater when shore height was

Table 1. Abundance of seagrass species in two study sites in the Andaman Sea, Thailand.

Location	Percentage of abundance					
	EA	HO	TH	CR	CS	HU
Ao Ta Len, Krabi	26.58	18.99	30.37	20.89	1.90	1.27
Laem Yong Lum, Trang	38.73	43.35	13.87	4.05	-	-
Total	32.93	31.72	21.76	12.08	0.91	0.60

Note: EA = *Enhalus acoroides*; HO = *Halophila ovalis*; TH = *Thalassia hemprichii*; CR = *Cymodecea rotundata*; CS = *Cymodecea serrulata*; HU = *Halodule uninervis*

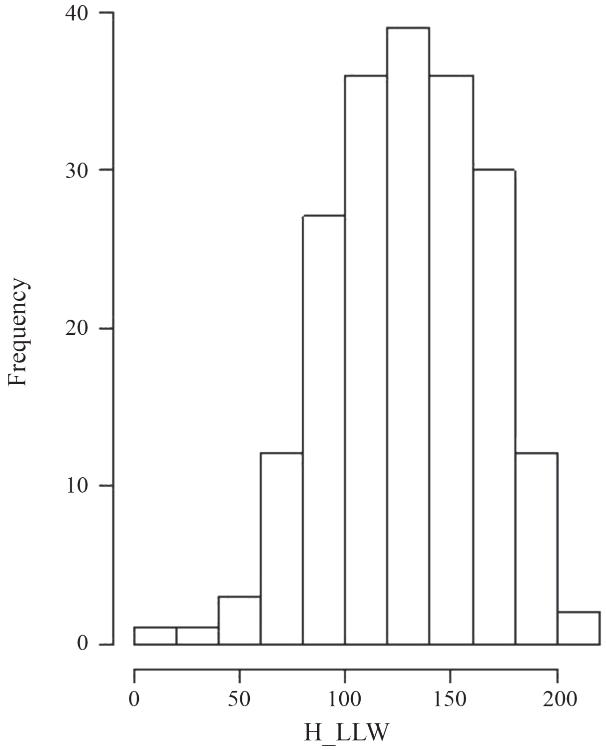

Figure 2. Frequency distribution of seagrass presence at different heights above lowest low water (H_LLW: cm).

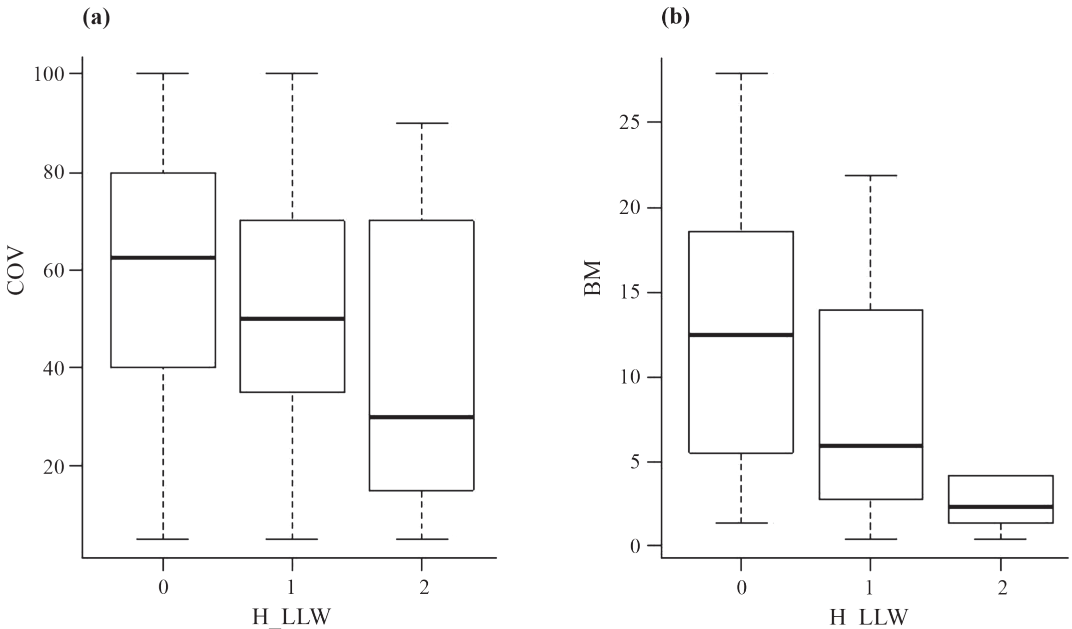

Figure 3. Boxplot showing median value of coverage (COV) (%) (a) and biomass (BM) (g DW·m^{-2}) (b) of seagrass, where 0 = 0–100 cm H_LLW; 1 = 100–180 cm H_LLW; 2 = >180 cm H_LLW.

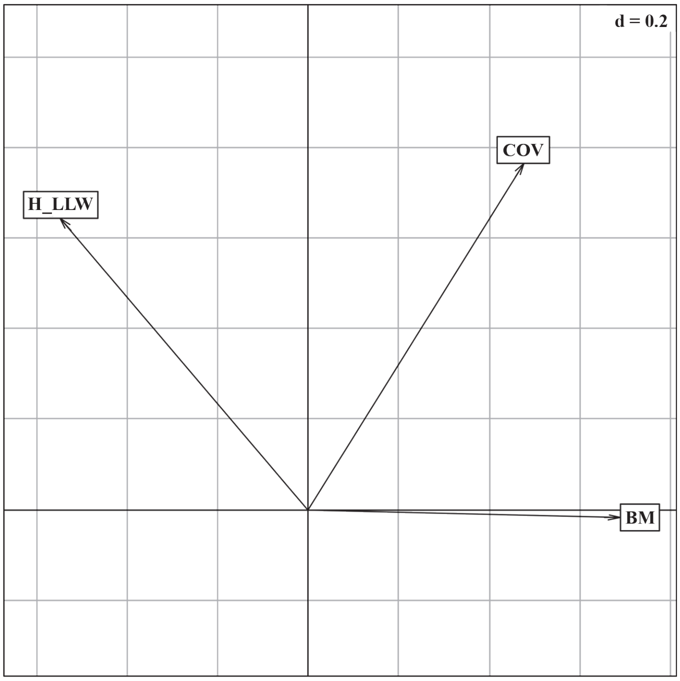

Figure 4. Principal component analysis (PCA) of total coverage of seagrass (COV), total biomass (BM) and shore height (H_LLW).

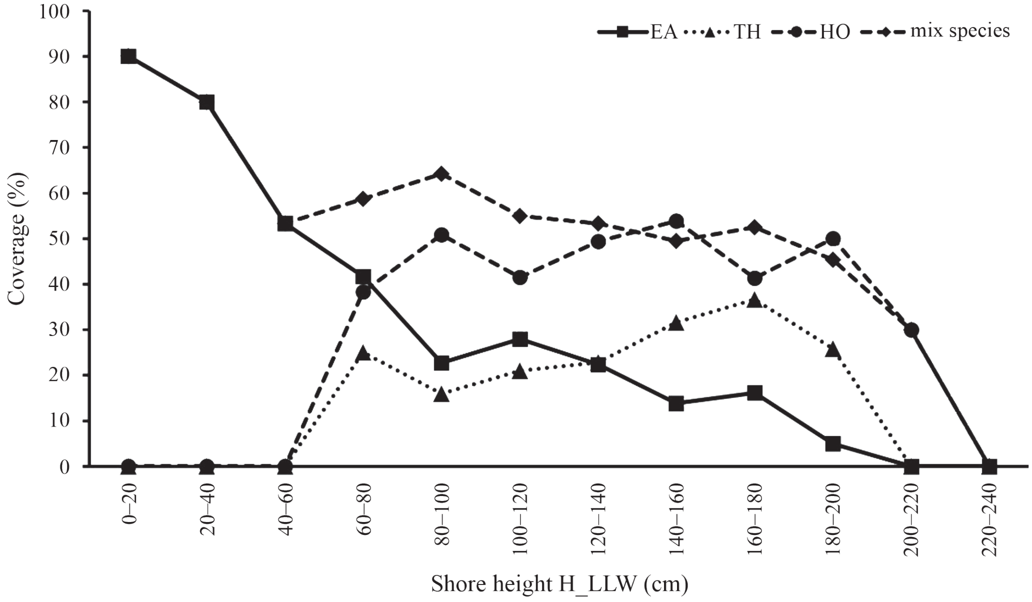

Figure 5. Mean seagrass coverage at different heights above lowest low water (H_LLW). EA = *Enhalus acoroides*; TH = *Thalassia hemprichii*; HO = *Halophila ovalis*.

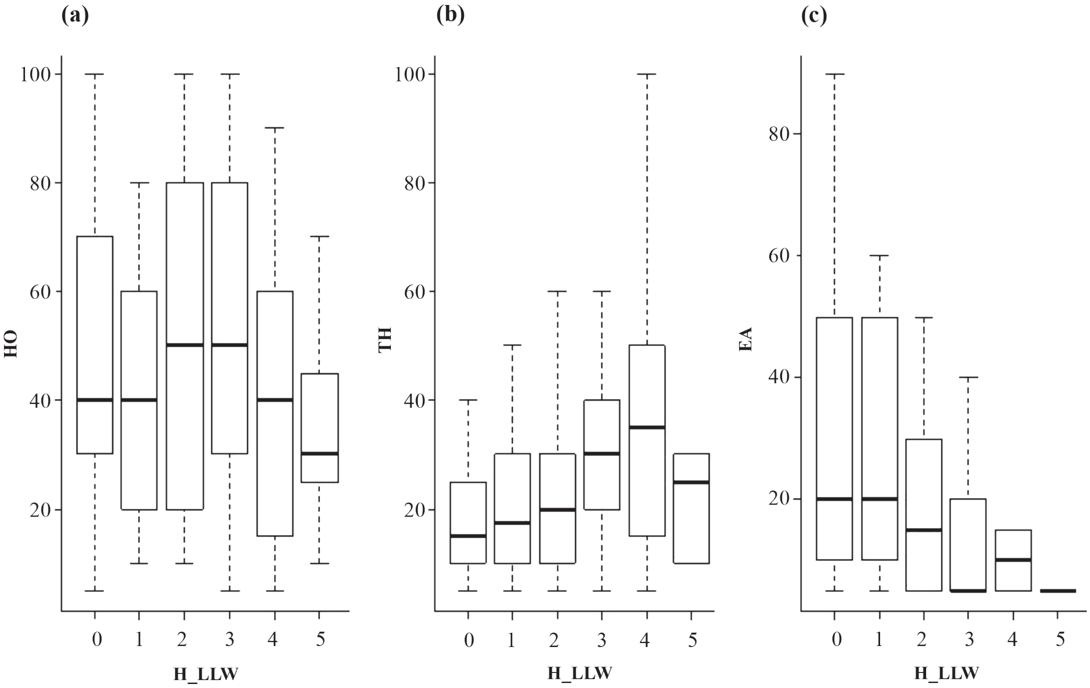

Figure 6. Boxplot showing median coverage (%) of *Halophila ovalis* (a), *Thalassia hemprichii* (b) and *Enhalus acoroides* (c). H_LLW: 0 = <100 cm; 1 = 100–120 cm; 2 = 120–140 cm; 3 = 140–160 cm; 4 = 160–180 cm; 5 = >180 cm.

Table 2. Seagrass coverage and aboveground biomass at different heights above lowest low water (H_LLW).

H_LLW (cm)	Monospecific seagrass coverage (%)			Total seagrass coverage and biomass	
	EA	TH	HO	Coverage (%)	Biomass (g dw·m^{-2})
0-20	90.00±0^{a} (1)	0 (1)	0 (1)	90.00±0^{a} (1)	90.00±0^{a} (1)
20-40	80.00±0^{a} (1)	0 (1)	0 (1)	80.00±0^{a} (1)	80.00±0^{a} (1)
40-60	53.33±30.55^{a} (3)	0 (5)	0 (5)	53.33±30.55^{a} (3)	53.33±30.55^{a} (3)
60-80	41.66±32.69^{a} (9)	25.00±21.20^{a} (10)	38.33±24.83^{a} (6)	58.75±23.26^{a} (12)	58.75±23.26^{a} (12)
80-100	22.70±19.61^{b} (24)	16.00±6.80^{a} (10)	50.88±28.29^{a} (17)	64.25±26.04^{a} (27)	64.25±26.04^{a} (27)
100-120	28.00±21.21^{b} (25)	21.00±14.6^{a} (12)	41.50±22.77^{a} (20)	55.00±24.05^{a} (36)	55.00±24.05^{a} (36)
120-140	22.38±23.16^{b} (21)	22.80±16.30^{a} (25)	49.34±28.61^{a} (23)	53.33±27.84^{a} (42)	53.33±27.84^{a} (42)
140-160	13.82±15.15^{b} (17)	31.66±17.30^{a} (9)	53.88±30.65^{a} (18)	49.44±28.37^{a} (36)	49.44±28.37^{a} (36)
160-180	16.11±20.73^{bc} (2)	36.66±27.30^{a} (12)	41.33±28.68^{a} (15)	52.50±27.25^{a} (30)	52.50±27.25^{a} (30)
180-200	5.00±0^{bc} (1)	25.83±6.55^{a} (6)	50.00±23.40^{a} (7)	45.38±4.41^{a} (13)	45.38±4.41^{a} (13)
200-220	0 (7)	0 (7)	30.00±0^{a} (1)	30.00±0^{a} (1)	30.00±0^{a} (1)
220-240	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)

Note: Values are presented as mean±SD; Different lowercase letters in the same column indicate significant ($p<0.05$) difference; Number in parentheses is the number of samples (n).

lower. At 0 to 60 cm H_LLW, *E. acoroides* grew as a monospecific bed, with 80–90% coverage and 24.59–27.84 g dw·m^{-2}. However, the abundance at lower shore height was caused more by vegetative reproduction rather than sexual reproduction, because the depth of water restricted surface hydrophobic pollination and fruit production (Tongkok *et al*., 2020). Even though the coverage by *E. acoroides* was lower at 60–200 cm H_LLW than in the deeper zone, this level became important with higher diversity of the seagrass, as *E. acoroides* was more frequently distributed and surrounded by other seagrass species. Ogawa and Nanba (2002) and Tongkok *et al*. (2012) found that the coverage of *E. acoroides* decreased when it grew in association with other seagrass species in shallow areas, but its sexual reproduction was very high. At 60–200 cm H_LLW during low tide, *E. acoroides* was exposed to air and sunlight, which caused physiological damage to its leaves. Nevertheless, Björk *et al*. (1999) indicated that its thick waxy leaf could prevent water loss and survive above sea level during low tide. Transplanting of *E. acoroides* is mostly done within intertidal areas, for example, 30 cm at low tide and 1.5 m at high tide (Thangaradjou and Kannan, 2008), 76–101 cm (Kiswara *et al*., 2010), and 50–150 cm (Ambo-Rappe *et al*., 2019). However, survival rates from these efforts were low. The depth mentioned in previous transplantation studies was not related to any chart datum, which may pose difficulty for transplantation improvement. Based on the coverage and sexual reproduction ability of *E. acoroides*, the suitable range for *E. acoroides* transplantation appears to be 60–200 cm H_LLW.

Thalassia hemprichii was distributed between 60–200 cm H_LLW, and the highest coverage was found at 160–180 cm H_LLW (Figure 5 and Table 2). This zone of shore height was most suitable for its growth and distribution. Tongkok *et al*. (2017) found that *T. hemprichii* was distributed at 70–150 cm H_LLW, and the highest number of reproductive organs was at 150 cm H_LLW. However, coverage in those areas was not significant because of the variation caused by its natural cluster distribution, especially at 160–180 cm H_LLW (Figure 6). The cluster distribution may be related to its reproductive biology because it produces fleshy fruit with viviparous seeds. These seeds are buried in the mud and compressed by surrounding sediments, developing into seedlings with four leaves within one week in the mother patch (Tongkok *et al*., 2017). The present data revealed that the shallow threshold of *T. hemprichii* was at 200 cm H_LLW and the deep threshold was 60 cm H_LLW. The distribution of *T. hemprichii* may be restricted by the long desiccation period and high temperature during low tide (Stapel and Hemminga, 1997). The higher H_LLW and longer desiccation period affect *T. hemprichii*. It was reported that this species could only be found at 1.5–2.0 m at high water level (Abu Hena *et al*., 2001). In Papua New Guinea, Brouns (1985) reported the defoliation of *T. hemprichii* after long desiccation periods during extreme low tides.

Halophila ovalis is the only species that was found surviving above 200 cm H_LLW, although its distribution extends from 60 to 220 cm H_LLW (Figure 5 and Table 2). Huong *et al*. (2003) found *H. ovalis* at 100–140 cm H_LLW in Ha Long Bay, Vietnam. The highest coverage was found at 140–160 cm H_LLW, which was not significantly different from the other shore height zones where the species was present. Because of its small size, *H. ovalis* prefers growing in monospecific beds (Figure 6) with 100% coverage or growing with *T. hemprichii*. The shallow threshold of *H. ovalis* was at 220 cm H_LLW, which was at higher shore height (or shallower water depth) than *T. hemprichii* and *E. acoroides*. Björk *et al*. (1999) indicated that *H. ovalis* was the uppermost-growing species and very sensitive to desiccation. However, it can grow and remain in this area with seasonal variation, and is known as one of the pioneer species in tropical areas (Phillips and Meñez, 1988). Kaewsrikhaw *et al*. (2016) revealed that *H. ovalis* in upper intertidal zones had lower growth rates compared to plants in the lower intertidal zones. Because of its shape and size, it can be buried by sand and sediment during monsoon season. However, its seeds remain and accumulate underground as a seed bank, and this allows the species to recover in the appropriate season (Gu *et al*., 2022).

Table 3 shows a comparison between this study and two other studies that used the lowest low water as a reference mark. We acknowledge that the methodology for measuring shore height is more complicated than for other measurements. Still, shore height determination is important in an upper intertidal survey. It plays an important role in seagrass distribution by affecting the desiccation period and the amount of light available for photosynthesis. Among the three seagrass species, *E. acoroides* showed the highest ecosystem service (Nordlund *et al*., 2016). It is the most commonly used species for seagrass transplantation in South East Asia (Thangaradjou and Kannan, 2008; Kiswara *et al*., 2010; Vichkovitten *et al*., 2016; Irawan, 2017; Nugraha *et al*., 2020) and its tissue culture technique is in progress (Tongkok *et al*., 2023). It is transplanted mostly in the upper intertidal area during low tide for convenience. The present study indicates that the shallow threshold shore height can be used for seagrass transplantation and restoration area selection in the upper intertidal zone.

Table 3. Distribution of three seagrass species and depth related to lowest low water.

Measurement	Seagrass species			Location	Reference
	EA	TH	HO		
Shore height above lowest low water (cm)	0-200	20-200	60-200	Trang and Krabi, Andaman Sea, Thailand	This study
Shore height above lowest low water (cm)	-	70-150	-	Trang, Andaman Sea, Thailand	Tongkok *et al*. (2017)
Water depth at lowest low water (cm)	160-273	-	160-273	Bintan Is., Indonesia	Halim *et al*. (2020)

Note: EA = *Enhalus acoroides*; TH = *Thalassia hemprichii*; HO = *Halophila ovalis*

CONCLUSION

In this study, we made a significant observation regarding the influence of shore height above lowest low water on the distribution of upper intertidal seagrasses. It became evident that this factor played a crucial role in determining the extent and coverage of seagrass distribution. Notably, we discovered that the shallow thresholds of each seagrass species are at 200, 200 and 220 cm H_LLW for Enhalus acoroides, *Thalassia hemprichii* and *Halophila ovalis*, respectively. This finding holds significant implications for future consideration and decision-making pertaining to seagrass transplantation and restoration initiatives.

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