# Annual Productivity of Seagrass at Khung Kraben Lagoon, Chanthaburi Province, Thailand

Sakchai Kanmarangkool, Napakhwan Whanpetch*, Tanuspong Pokavanich and Shettapong Meksumpun

## ABSTRACT

Khung Kraben Lagoon (KKL) is a coastal lagoon situated in the eastern part of Thailand. There are two major species of seagrasses in KKL, *Enhalus acoroides* (Ea) and *Halodule pinifolia* (Hp), which have a combined total areal coverage of 335 ha. These two species can be found either separately or mixed in three zones: Ea zone, Hp zone, and Mixed zone (both species). This study aims to investigate the productivity and carbon sequestration of these species. Surveys indicated that *H. pinifolia* (42.97 %) had higher carbon sequestration than *E. acoroides* (35.23 %). A high percentage of nitrogen is in aboveground parts of these plants (Hp: 2.29 % and Ea: 2.02 %). *E. acoroides* in the Ea zone had the highest mean organic carbon production of 0.0886 Mg C·ha$^{-1}$. The monsoon period has direct effect on total organic carbon (TOC) production. The Southwest monsoon (SWM) period reduces production of seagrass while the Northeast monsoon (NEM) period promotes higher seagrass production. TOC production was significantly highest in April (0.2092 Mg C·ha$^{-1}$) during the monsoon transition (between NEM and SWM) in the Hp zone, as revealed by cluster analysis. In terms of litter decomposition, *E. acoroides* has a half-life of 4.31 weeks and a turnover period of 6.21 weeks, while *H. pinifolia* has a half-life of 7.37 weeks and a turnover period of 10.64 weeks. KKL is a net exporter of organic carbon to the outer sea (0.3042 Gg C·year$^{-1}$). These findings provide useful information for planning sustainable management to conserve seagrass meadows like the one in KKL.

**Keywords:** Decomposition of seagrass litter, Productivity, Seagrass, Total organic carbon

## INTRODUCTION

Seagrasses are flowering plants that are fully adapted to marine conditions, and provide shelter and substrates for numerous benthic organisms in the marine environment. They are commonly found in tidal and estuary zones in tropical and subtropical regions (Hemminga and Duarte, 2000). Seagrasses are autotrophic plants that absorb, convert, and store $CO_2$ in the form of organic carbon (Duarte and Cebrian, 1996). Seagrass meadows are estimated to store carbon in living biomass at the rate of 7.29±1.52 Mg C·ha$^{-1}$ (Fourqurean *et al*., 2012). These meadows represent a globally significant carbon pool (i.e., blue carbon) by supporting high production of organic matter in the sediment for long-term storage. Because of their ability to absorb and store carbon, increasing the distribution of seagrasses can play a significant role in climate change mitigation (Laffoley and Grimsditch, 2009). The organic carbon that accumulates in seagrass meadows is derived not only from seagrass production but from the trapping of other particles, as the seagrass canopies facilitate sedimentation and reduce resuspension. The carbon burial and seagrass production rate is between 41 and 66 g C·m$^{-2}$·year$^{-1}$ (Kennedy *et al*., 2010).

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Southeast Asia is an important area for seagrass in the Indo-Pacific biogeographic region (Short *et al*., 2007). Khung Kraben Lagoon (KKL) in Chanthaburi Province is a small coastal lagoon in the eastern part of Thailand. The lagoon is dominated by strong tidal currents and seasonal wind-driven circulation, including a strong interconnection with the outer sea (Pokavanich and Phattananuruch, 2022). However, there is limited freshwater runoff that flows into KKL, although small canals from shrimp farms around the lagoon sometimes release effluent water into KKL and affect the seagrass. Therefore, the dynamics of seagrass communities in KKL are of interest.

There are four species of seagrasses present in KKL: *Enhalus acoroides* (Ea), *Halodule pinifolia* (Hp), *Halophila minor* (Hm), and *Halophila decipiens* (Hd). Among these, the first two species are abundant (Aryuthaka *et al*., 1992). These seagrasses are found densely at high mean sea levels, as monospecific seagrass meadows and extensive mixed meadows. KKL is a demonstration area for sustainable development projects to address deforestation problems in Thailand, known as Khung Kraben Bay Royal Development Study Center in "The Royal Project," a non-profit organization founded by His Majesty, King Bhumibol Adulyadej. The area is also utilized for fishery activities, including harvest of fin fishes, lamp shells, ark clams, blue swimming crabs, and shrimps.

The objective of this study is to investigate the productivity, coverage and carbon sequestration of *Enhalus acoroides* and *Halodule pinifolia* in KKL for their sustainable utilization and annual blue carbon production.

## MATERIALS AND METHODS

*Study site*

Khung Kraben Lagoon is a shallow leaky coastal lagoon. It has an average depth of 0.8 m within the lagoon's interior and around 5 m at the mouth. Water movement within the lagoon is controlled by tides and seasonal monsoonal winds. Strong tidal currents flow in and out of the lagoon and replace most of the water within the lagoon in a very short time (residence time of 2-5 days) (Pokavanich and Phattanuruch, 2022).

Water is well-mixed by two gyre circulations splitting the lagoon in two areas, i.e., the northwest gyre (NWG) and the southeast gyre (SEG). In the southwest monsoon (SWM) period, the circulation is stronger than in the northeast monsoon (NEM) period; during SWM, NWG is counterclockwise and SEG flows clockwise. The circulations are reversed during the NEM period. During the monsoon transition periods water circulation is weak. Water temperature and salinity of the lagoon reach their highest values during the transition from NEM to SWM in April and May. Water temperature reaches its lowest point during NEM, while salinity is lowest during SWM.

Due to the lagoon's shallowness, during low tides up to 70 % of the lagoon is dry, especially during the middle of the year when mean sea level of the outer sea is at its annual lows (Pokavanich and Phattanuruch, 2022). Tidal phase shifts create tidal flats, which result in the drying up of seagrass habitat in the daytime, from May to August. During this period, seagrasses experience extremely high temperature and salinity. In other periods of the year, the tidal flats are covered with water in the daytime. These seasonal variations affect the sea bottom and influence the environment and marine life of the seagrass ecosystem in KKL and other adjacent coastal areas (Aryuthaka *et al*., 1992; Satumanatpan *et al*., 2011).

*Field observation*

Intensive field surveys were carried out in the KKL. One hundred and fifty-seven sampling stations were selected for mapping seagrass distribution and coverage of seagrass from January to December, 2017. Seagrass habitat in KKL consists of three zones, namely an *Enhalus acoroides* zone (Ea) in the east, a *Halodule pinifolia* zone (Ha) in the northeast, and a mixed zone (*E. acoroides* and *H. pinifolia*) in the northwest of the bay, as shown in Figure 1. This bay is affected by two monsoons, NEM from mid-October to mid-February, and SWM from mid-May to mid-October.

*Seagrass growth and biomass production*

The growth rate and biomass production of *Enhalus acoroides* and *Halodule pinifolia* were observed in the three seagrass zones within KKL. The samples were collected with five replications (10 plants per replication) for Ea seagrass in two zones (Ea and Mixed zone) and five replications (one 50×50 cm quadrat per replication) for Hp seagrass in two zones (Hp and Mixed zone).

The growth rate of seagrasses was investigated using Plastochrone Interval (Short and Coles, 2001a), by marking the leaves of Ea and rhizomes of Hp in selected plants. These samples were collected after two weeks, and dried at 60 °C until they reached a constant weight. The daily growth rate of sampled plants was calculated from the increase of Ea leaf mass ($g \cdot day^{-1}$), and increase of whole shoots and rhizomes of Hp ($g \cdot day^{-1}$). The growth rate ($g \cdot m^{-2} \cdot day^{-1}$) of seagrasses within each sampling replicate was calculated from the increase in biomass of aboveground portions of seagrass (i.e., shoots and leaves) multiplied by that species' coverage area. Biomass production ($g \cdot m^{-2}$) was then calculated for each month of the study.

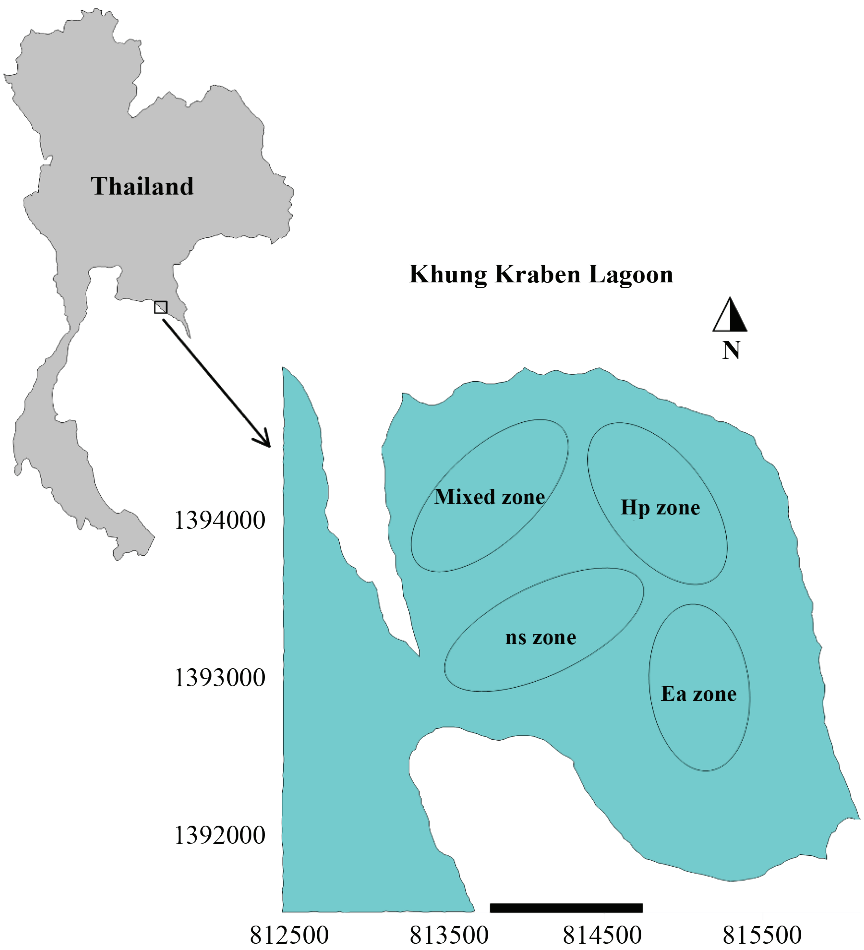


Figure 1. The location of *Enhalus acoroides* zone (Ea zone), *Halodule pinifolia* zone (Hp zone), Mixed zone (both species) and no seagrass (NS zone) in Khung Kraben Lagoon (KKL), Chanthaburi Province, Thailand.

*Stable isotope analysis*

Samples were prepared from leaves, rhizomes and roots of Ea, and from aboveground and belowground parts of Hp. The samples were treated with 2 N HCl to remove $CaCO_3$, centrifuged twice for 5 min at 3,500 rpm and 4 °C, then vacuum-dried for 48 h. The samples were analyzed with an elemental analyzer (Flash Elemental Analyzer 1112 Series, Thermo Electron) and continuous-flow isotopic ratio (Delta Plus, Thermo Electron). All isotopic ratios were reported in delta notation (in ‰). The percentage of carbon content was calculated as total organic carbon (TOC).

*Biomass of seagrass litter*

The wrack and leaf litter of seagrass were collected from the living seagrass meadow by suction device with 0.5 mm sieve. Samples were separated after drying at 60 °C until reaching constant weight. Then 1 g of subsample was combusted at 450 °C for 2 h to identify the percentage of ash content (ash free dry weight [AFDW]) (Short and Coles, 2001b).

*Seagrass decomposition*

Litter analysis was carried out in situ according to Short and Coles (2001b) using 10×10 cm net bags with mesh size of 1 mm. The litter of seagrasses or the living whole plant was cut into 1 cm pieces and weighed to collect 10 g per bag for Ea litter and 5 g per bag for Hp litter. These bags were placed on the sea bottom within all study sites. Litter bags were randomly collected from the field after 2, 4, 8, 12, 16 and 20 weeks. The seagrass decomposition was calculated from the litter bags' organic mass weight loss to determine the detritus processing rate. The exponential equation for seagrass decomposition is

$$W_t = W_0 e^{(-Kt)}$$

where Wt is the weight of seagrass litter remaining from the initial weight ($W_0$) after time t, and K is the decay constant. Exponential regression is used to generate the decay constant, which is negative.

*Cluster analysis*

Data were analyzed monthly based on TOC values for growth and biomass production, litter decomposition rate, and seagrass coverage area using K-means cluster analysis (RStudio, 2022).

## RESULTS AND DISCUSSION

*Seagrass surveys*

Surveys showed that the KKL seagrass meadow consisted of approximately 92 ha of Ea, 127 ha of Hp and 116 ha where the two species co-occurred (mixed zone).

*Seagrass growth and biomass production*

The result shows that the TOC production of Ea seagrass was triple that of Hp seagrass ($p<0.05$, t-test) (Table 1). The TOC of Ea seagrass in the Ea zone was highest (mean = 0.0886±0.0085 Mg C·ha$^{-1}$, median = 0.0680 Mg C·ha$^{-1}$) among all samples in KKL, but this was less than the mean TOC for aboveground biomass in seagrasses based on a global data set (0.755±0.128 Mg C·ha$^{-1}$) (Fourqurean *et al*., 2012). Our results indicated that the TOC values of both Ea and Hp seagrasses in the Mixed zone were lower than in the Ea and Hp zones. This could be due to competitive interactions between the seagrass species in the Mixed zone that did not occur in the single-species zones (Agustin *et al*., 2021).

Monthly values for TOC production, seagrass biomass productivity and litter decomposition rate are shown in Figure 2. The year-round monitoring of areal coverage showed that Hp was the dominant seagrass species in April with the highest growth rate. Results also showed that KKL exported the TOC of seagrass to the outer sea at a rate of up to 0.3042 Gg C·year$^{-1}$. However, at the beginning of the SWM period, the seagrass was stressed by low water level, causing prolonged drying until TOC reached its lowest value. At low tides, 60 % of the maximum wet area is dry in the SWM period (Pokavanich and Phattananuruch, 2022). During the NEM period, from mid-October until mid-February, the seagrass grows well, corresponding to an increase in coverage and persistence of seagrass in all areas of KKL.

*Stable isotope analysis*

In this study, the mean values of $\delta^{13}C$ were significantly different among the sampled parts of Ea (-9.19 to -10.86 ‰) and of Hp (-11.94 to -13.96 ‰) (t-test) (Table 2). Both seagrasses had high values of $\delta^{13}C$, from approximately -9 to -13 ‰, which were higher than other producers in KKL: -14 to -18 ‰ for macroalgae, -21 ‰ for phytoplankton, -28 to -29 ‰ for mangroves leaves, and -12 to -29 ‰ for herbivores (Thimdee *et al.*, 2004). The high $\delta^{13}C$ values found for these seagrass species indicate their importance as primary producers in KKL. Figure 3 shows the relationship between the $\delta^{13}C$ and $\delta^{15}N$ values of both Ea and Hp. The results clearly show that leaves of seagrasses in the study area use a different nitrogen source than the roots and rhizomes. The mean $\delta^{15}N$ values

Table 1. Total Organic Carbon (TOC) production (Mg C·ha$^{-1}$) in Ea, Hp, and Mixed zones.

| | n | Range | Median | Mean±95 % CI |
|---|---|---|---|---|
| Total Ea seagrass | 407 | 0.0113-0.8309 | 0.0623 | 0.0788±0.0061$^{a}$ |
| Ea zone | 262 | 0.0167-0.8309 | 0.0680 | 0.0886±0.0085$^{a}$ |
| Ea in Mixed zone | 145 | 0.0113-0.1774 | 0.0525 | 0.0612±0.0064$^{b}$ |
| Total Hp seagrass | 70 | 0.0012-0.1291 | 0.0252 | 0.0286±0.0057$^{c}$ |
| Hp zone | 35 | 0.0012-0.1291 | 0.0266 | 0.0334±0.0101$^{c}$ |
| Hp in Mixed zone | 35 | 0.0052-0.0687 | 0.0199 | 0.0239±0.0057$^{c}$ |

**Note:** * Means±SD in the same column superscripted with different lowercase letters are significantly ($p<0.05$) different.

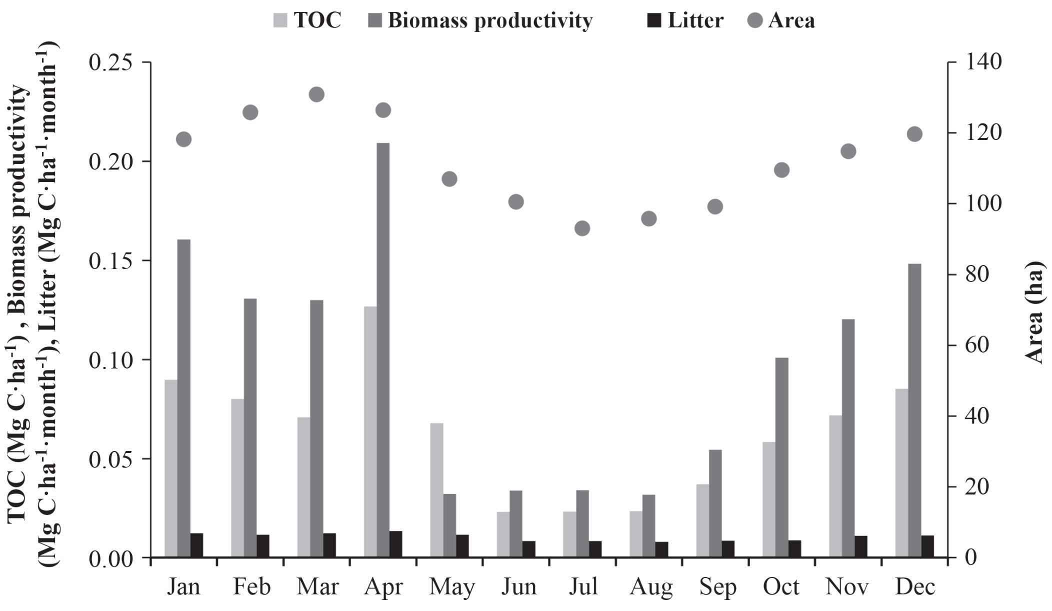


Figure 2. Relationship of monthly TOC production (Mg C·ha$^{-1}$) and seagrass area (ha) with respect to biomass productivity and litter decomposition rate (Mg C·ha$^{-1}$·month$^{-1}$).

of belowground parts of both seagrass species were less than the aboveground parts, as shown in Table 2. In addition, the carbon content in Ea seagrass was significantly less than in Hp seagrass. The nitrogen content analysis showed significantly different nitrogen accumulation between aboveground and belowground parts of these two seagrass species. Both the aboveground nitrogen content and C:N ratios were higher than belowground values for both seagrasses.

*Decomposition of seagrass*

The decay rate experiments for the two seagrass species showed that Ea decomposed faster than Hp, with a litter half-life of 4.31 weeks and a turnover period of 6.21 weeks. The exponential equation for Ea seagrass decomposition is shown in equation 1.

$$y = 130.73\ e^{-0.161x};\ r^2 = 0.9812 \qquad (1)$$

Table 2. Mean values of nitrogen and carbon content, isotopic values, and C:N ratio in parts of *Enhalus acoroides* (Ea) and *Halodule pinifolia* (Hp).

| | **$\delta^{13}$C (‰)** | **$\delta^{15}$N (‰)** | **% C** | **% N** | **C:N** |
|---|---|---|---|---|---|
| Ea Leaf | 4-10.86±0.61 | 5.26±0.83 | 35.23±2.95$^{c}$ | 2.01±0.03$^{b}$ | 20.41$^{d}$ |
| Ea Rhizome | -9.66±0.53 | 2.86±0.95 | 38.11±0.75$^{b}$ | 0.74±0.06$^{d}$ | 60.75$^{a}$ |
| Ea Root | -9.19±0.32 | 2.76±2.14 | 28.92±1.13$^{d}$ | 0.90±0.06$^{c}$ | 37.64$^{c}$ |
| Hp Aboveground | -13.96±1.20 | 4.40±0.48 | 42.97±1.26$^{a}$ | 2.29±0.15$^{a}$ | 21.90$^{d}$ |
| Hp Belowground | -11.94±0.50 | 3.13±0.93 | 39.36±1.46$^{b}$ | 0.87±0.07$^{c}$ | 52.76$^{b}$ |

**Note:** Values with different superscript letters in the same column are significantly different ($p<0.05$).

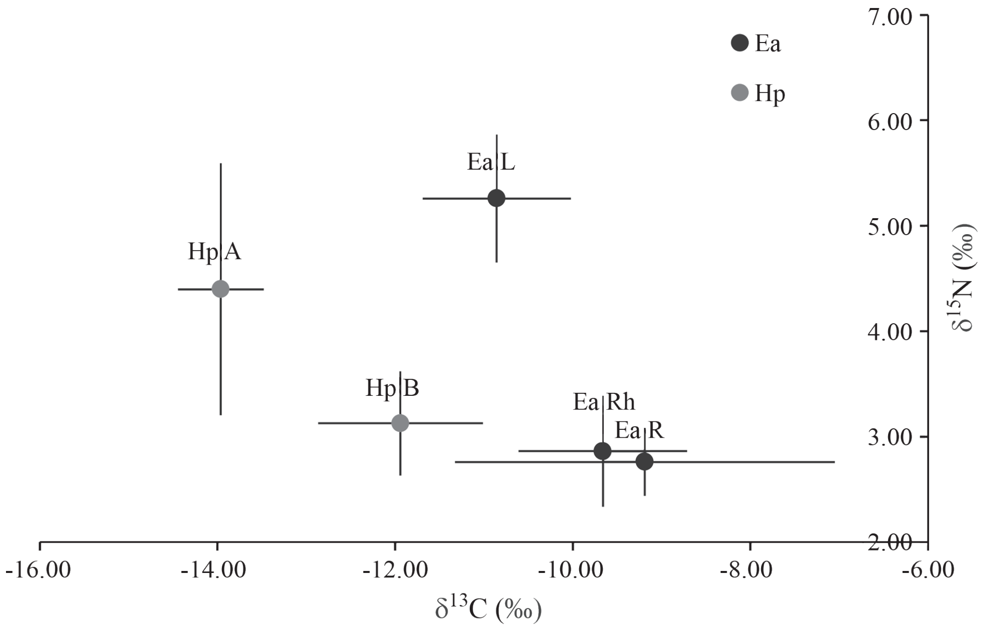


Figure 3. $\delta^{13}$C and $\delta^{15}$N values from parts of *Enhalus acoroides* (Ea) and *Halodule pinifolia* (Hp) plants. A = aboveground; B = belowground; L = leaf; Rh = rhizome; R = root.

Hp seagrass decomposed more slowly, with a litter half-life of 7.37 weeks and a turnover period of 10.64 weeks. The exponential equation for Hp seagrass decomposition is shown in equation 2.

$$y = 96.464\ e^{-0.094x};\ r^2 = 0.9612 \qquad (2)$$

The KKL has short flushing times of between 3 and 10 days, in which 90 % of the lagoon's water is replaced by water from the outer sea. The shortest flushing time occurred in the SWM period, whereas the longest flushing time occurred in Transition 1 (Pokavanich and Phattananuruch, 2022). This means that the high amount of TOC observed in April (Figure 3) was accumulated in the bay over a long time during Transition 1, and material was flushed out to the sea in the shortest time in the SWM period.

*Cluster analysis*

The monthly k-mean values for total production of TOC, TOC production rate, litter decomposition rate, and seagrass coverage for one year of sampling were classified into three clusters, based on Ea, Hp and Mixed zones. The first cluster represents samples from the Hp zone in April. The second cluster comprises samples from the SWM period, and is dominated by the Ea zone. The last cluster has samples from the NEM period, and is dominated by the Hp zone. For the area analysis with the monthly k-mean, it was found that the different monsoonal periods (Pokavanich and Phattananuruch, 2022) affected the clustering form of different areas as shown in Figure 4. The monthly Mixed zone results were classified into two clusters, namely the SWM period and others as shown in Figure 5A. The monthly Ea zone results were classified into three clusters, namely Transition 1&2, SWM and NEM period as shown in Figure 5B. The Ea seagrass zone, which is sensitive to seasonal monsoons, showed a growth rate similar to Ea in Pali Island (Rustam *et al.*, 2013). The monthly Hp zone results were classified into three clusters: April, SWM and NEM periods. The maximum growth was found in April as shown in Figure 5c.

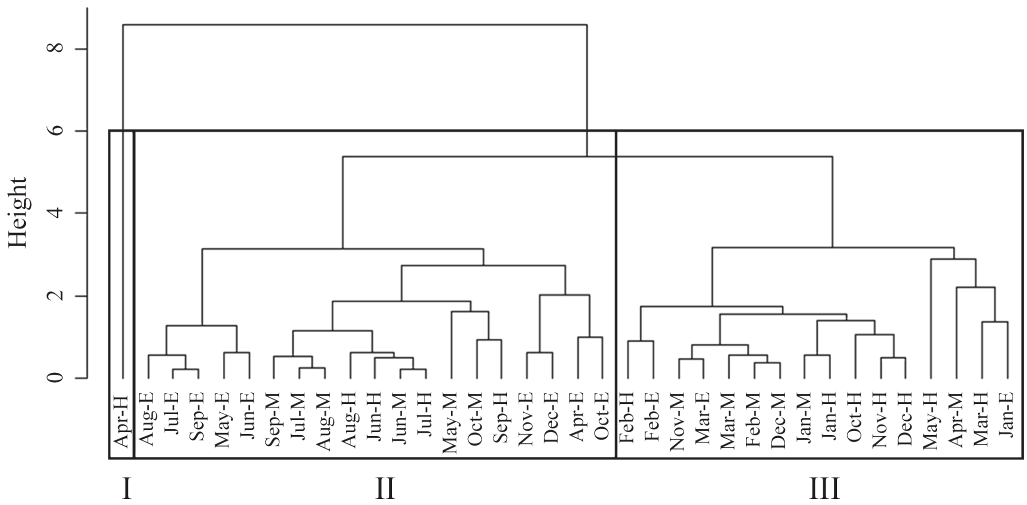


Figure 4. Cluster analysis results from monthly total organic carbon (TOC) values. Samples are labeled by month and seagrass zone (E = Ea zone; H = Hp zone and M = Mixed zone).

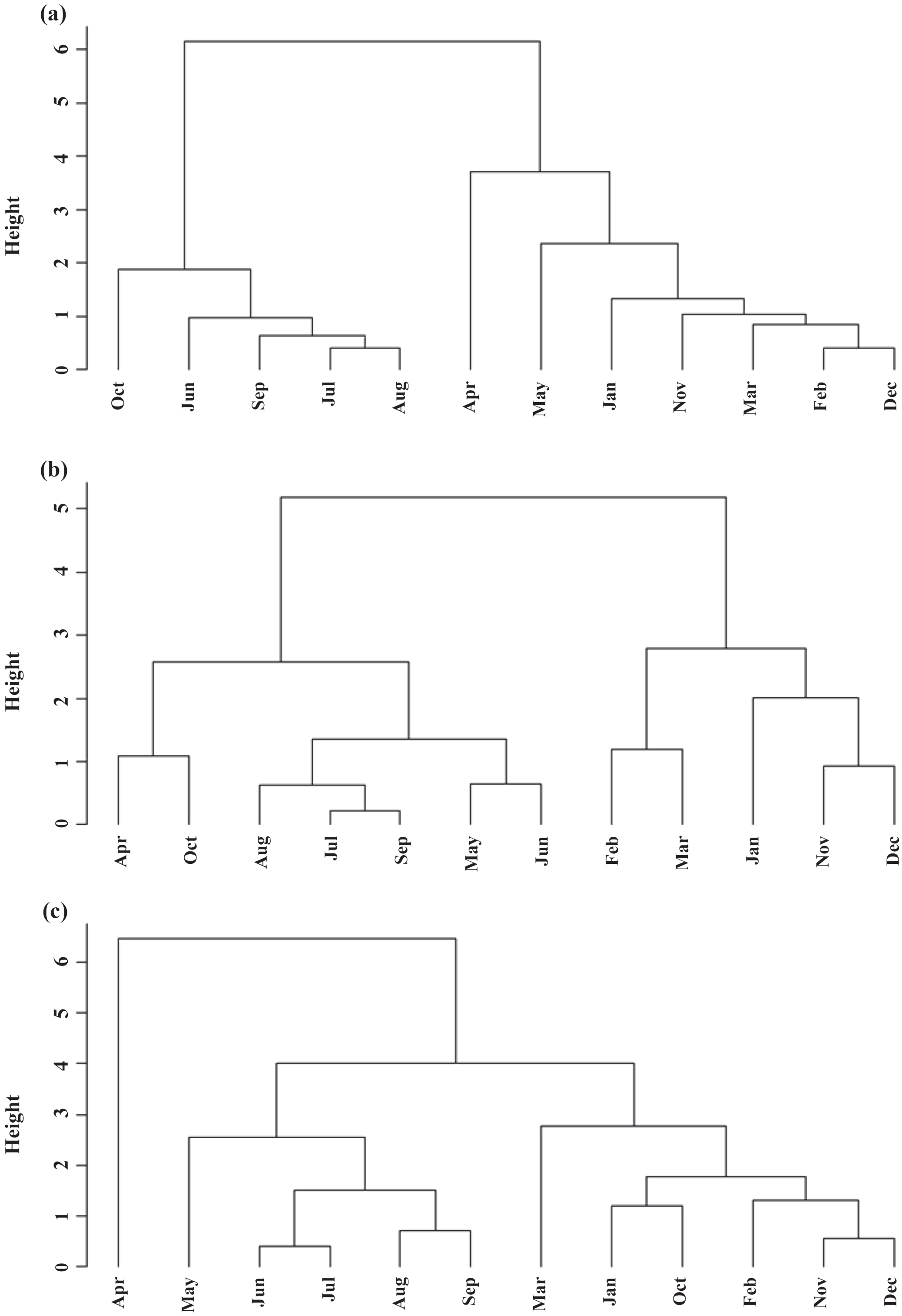


Figure 5. Cluster analysis of monthly TOC production in seagrasses [(a): Mixed zone, (b): Ea zone and (c): Hp zone].

## CONCLUSION

This study documented seagrass productivity by field investigation conducted in the KKL. The results showed that both Ea and Hp seagrasses have a high percentage of nitrogen and carbon in the aboveground parts. The isotopic values of $\delta^{13}C$ of both seagrasses are high, and similar to other primary producers in KKL. In terms of TOC of seagrass productivity, the Hp seagrass has by far the highest production in April. In the SWM period, TOC is transported into the sea at the rate of 0.3042 Gg $C{\cdot}year^{-1}$ (a Blue Carbon exporter). In the NEM period, both seagrasses are able to recover and have high rates of production due to higher water levels in the daytime, which provides a suitable environment for seagrass growth (accumulation period).

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