Influence of seaweed farming on the growth of the seagrass *Enhalus acoroides*

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**Abstract.** The goal of this research was to analyse the influence of seaweed farming on the growth of the seagrass *Enhalus acoroides*, as well as the relationship between seagrass growth and environmental parameters. The research was carried out at Karampuang Island, Mamuju District, Sulawesi Barat Province, Indonesia, from August to November 2017. Data were collected from three plots (frames) in seagrass areas with seaweed farming (treatment plots) and 3 plots (frames) in seagrass areas without seaweed farming (control plots). The growth of *E. acoroides* was measured through sampling 10 plants (3 leaves per plant) in each plot. The selected leaves were marked and the new growth measured at fortnightly intervals using a ruler with a precision of 1 mm. Average growth rates were calculated, and the Student t-test was applied to the difference in average growth rates. The absolute growth and growth rates of *E. acoroides* did not differ significantly between the treatment and control plots. Highest and lowest growth rates were recorded during the fourth and sixth fortnightly observations, respectively. Principal Component Analysis (PCA) showed clear temporal differentiation of *E. acoroides* leaf growth based on measurement timing, but did not differentiate between (separate) the treatment and control plots. The highest growth rates were associated with elevated levels of nitrate (NO₃) and total organic carbon (TOC) in the water column, with relatively low seawater temperatures.

1. **Introduction**

Seaweed communities are highly productive, providing food and habitat for many marine organisms [1][2]. Despite the many factors which can affect seagrass growth, seagrass productivity is primarily controlled by the light radiation penetrating the water column, water temperature, and nutrient availability [3]. The rising intensity of human activity in coastal areas tend to result in environmental pressures with impacts on seagrass ecosystems including physical and functional changes to the coastline, pollution, over fishing, eutrophication, and impacts from aquaculture.

Seaweed farming is one of the many human activities which can have a negative effect on coastal ecosystems. Seaweed farming is relatively new compared to many other types of farming which has expanded rapidly over the past 50 years, with global production tripling from 1997 to 2012, rising from around 7 to 24 million metric tons [4].
There are well-documented cases of negative impacts from seaweed farming on the marine environment. Positive impacts from seaweed farming include the possibility of increasing the available fisheries resources, while negative impacts include the risk of conflict in coastal areas as fishers lose access to spatially limited coastal resources (fishing grounds), and there can be spatial conflict between seaweed farms and the shallow-water ecosystems. Research by Blankenhorn in 2007 in Puntondo village, Takalar District [5] revealed that seaweed farming does exert a shading effect. Although the impact on leaf/plant density of small seagrasses such as *Cymodocea* spp. and *Thalassia hemprichii* was considered small, it is important to gain better understand of the effects of such shading due to seaweed farming on seagrass growth. The goal of this research was to evaluate the influence of seaweed farming on the growth of the seagrass *Enhalus acoroides* as well as the physical environment (water quality). This research contributes to the scientific basis for coastal management, especially in seaweed farming areas.

2. Method

2.1. Research site and timeframe

This research was conducted from August to November 2017. Field research to measure seagrass growth was carried out at three sites in the seagrass beds along the eastern coast of Karampuang Island, Mamuju District, East Sulawesi Province, Indonesia (Figure 1).
2.2. Research procedures
To evaluate the effect of seaweed farming on seagrass ecosystems, three seaweed farming units (experimental replicates) were placed parallel to the coastline with a gap of around 100m between the units. Each unit consisted of a modified floating long-line system comprising 60 lines, 30m long and 50 cm apart. Seaweed seeds of around 100 g were attached at a planting density of 100/line. A similar seagrass area at a distance of around 100 m from the units was selected as a control, where no seaweed farming took place.

The effect of seaweed farming on the seagrass ecosystem was evaluated through measuring the growth of the seagrass *Enhalus acoroides* beneath each of the 3 seaweed farming units and in the control plot (3 stations) at fortnightly intervals. At each station, 10 plants were selected, and the new growth was measured for 3 leaves from each of these plants using a ruler with a 1mm scale. The method used to measure the new growth involved a marking technique [6] illustrated in Figure 2.

From these measurements, the growth was calculated using the following formula:

\[ GA = L_t - L_0 \]

where:

- \( GA \) = absolute growth in length at time \( t \)
- \( L_t \) = shoot length (cm) at time \( t \)
- \( L_0 \) = initial shoot length (cm)

Water quality was measured every 2 weeks for 36 days. Water quality parameters measured were temperature (°C), pH, salinity (ppt), dissolved oxygen (O2) (ppm), carbon dioxide concentration (CO2) (ppm),and dissolved organic matter (DOM) (mg/l). Water samples (250ml) were collected, placed in a coolbox and taken to the laboratory for analysis of nitrate (NO3) and phosphate (PO4) concentrations (ppm). In addition, light intensity, current speed and current direction were recorded at each site.

2.3. Data analysis
The data were tabulated and the fortnightly growth averages were calculated for the seaweed farming/shaded treatments (combined) and the (unshaded) control. The t-student test was applied to evaluate the significance level of the difference between the averages and the results displayed graphically as histograms.

3. Results

3.1. Seagrass growth
The fortnightly *E. acoroides* leaf growth in seaweed farming (shaded) and control (unshaded) plots is shown in Figure 3. The student t-test did not indicate a significant difference in the means (\( p>0.05 \))
either overall or for any fortnightly period. However the growth recorded in all plots varied significantly over time, with the highest growth between week 2 and 4 (10-12.4 cm new growth) and the lowest growth between week 4 and 6 (3.1–3.6 cm). Average growth over the 45 day study period was higher (19.89 cm) in the seaweed farming plots than the control (16.91 cm), however the standard errors resulting from variation between plants and leaves were greater than the difference in means.

![Figure 3. Growth of *Enhalus acoroides* during each 2 week period in the seaweed farming and control areas (whiskers show the standard error). Differences were not significant (at $\alpha = 0.95$)](image)

### 3.2. Environmental parameters (water quality)

The water quality data aggregated for the treatment (seaweed farming) stations and for the control station are presented in Table 1. Most environmental parameters (salinity, pH, NO3, PO4) were not significantly different ($p > 0.05$) between the plots with and without seaweed farming. Temperature differed significantly in weeks 4 and 6 (but not week 2) with a range of in the seaweed farming plots (30.11-30.43°C) lower than that in the control plots (30.79-30.95°C). Dissolved Oxygen (DO) was significantly higher (5.76 ppm) in the seaweed farming plots than the control plot (5.47) ppm in week 2. The average ranges in both plots for other parameters were: salinity 30.11–32.47 ppt; pH 7.45–8.29; nitrate (NO3) concentration 0.025–0.056 ppm; phosphate (PO4) concentration 0.003 – 0.018 ppm; DOM 39.05–51.34 mg/l.

| Parameter | Week 2 | | | Week 4 | | | Week 6 | | |
|-----------|-------|---|---|-------|---|---|-------|---|---|
|           | SF    | C | p  | SF    | C | p  | SF    | C | p  |
| Temperature| 30.43 | 30.93 | ±0.14 | 0.495 | ±0.17 | ±0.15 | 0.033* | ±0.10 | ±0.10 | 0.010* | 30.97 |
| Salinity  | 32.30 | 32.47 | ±0.19 | 0.754 | 30.11 | ±0.53 | 30.80 | ±0.19 | 0.287 | 30.95 | ±0.11 | ±0.06 | 0.895 |
| pH        | 8.29  | 8.24 | ±0.04 | 0.262 | 7.58 | ±0.03 | 7.54 | ±0.01 | 0.357 | 7.52 | ±0.01 | ±0.05 | 0.238 |
| DO        | 5.76  | 5.47 | ±0.09 | 0.037* | 4.74 | ±0.06 | 4.53 | ±0.09 | 0.118 | 4.93 | ±0.07 | ±0.19 | 0.555 |
| NO3       | ±0.01 | 0.011 | 0.018 | 0.007 | ±0.01 | 0.027 | 0.003 | 0.114 | 0.03 | ±0.003 | ±0.003 | 0.003 | 0.101 |
| PO4       | ±0.000 | ±0.003 | ±0.003 | ±0.003 | ±0.003 | ±0.003 | ±0.003 | ±0.000 | ±0.000 | ±0.003 | ±0.374 | 39.05 |
| DOM       | 46.73 | 43.99 | ±1.84 | 0.292 | 51.34 | ±3.63 | 46.59 | ±2.86 | 0.362 | 40.95 | ±1.53 | ±0.71 | 0.321 |
3.3. The relationship between growth and environmental factors

The results of the Principle Components Analysis (PCA) in Figure 4 separate the *E. acoroides* growth data points into 3 groups which are separated along axes related to environmental parameters. The first group, with low seagrass growth correlated with elevated temperatures and relatively low nitrate and DOM concentrations, corresponds to the final fortnight (week 6: SF6 and C6). The second group with moderate growth represents the first fortnight (week 2, SF2 and C2), while the third group, with the highest growth in the middle fortnight (week 4: SF4 and C4) was associated with relatively lower temperatures and higher nitrate and BOT concentrations.

![Figure 4. Principle components analysis (PCA): spatial repartition along Component 1 and 2 (left), and spread (contribution) of the parameters relative to Component 1 and 2 (right). SF = seaweed farming; C = control; numbers indicate the week in which data were recorded.](image)

4. Discussion

Seagrass leaf growth in the seaweed farming area was not significantly different from the control plot. This could be due to the influence of environmental factors and the physical characteristics of the seagrass *Enhalus acoroides*. Most seagrass species can survive under light-limited conditions through physiological or leaf form adaptations [7]. *Enhalus acoroides* has some morphological characteristics which differ from other seagrasses found in Indonesian waters, in particular it has the largest rhizome.

It has been found that seagrass species with large rhizomes are better able to adapt to conditions where light penetration is limited than those with small rhizomes [8]. When light availability is reduced, in general seagrass leaf growth tend to slow down [9]. However some species can exhibit an opposite trend, for example in the seagrass *Halodule pinifolia* the leaves tend to be longer [10], while *Posidonia oceanica* leaves tend to become wider [11] in order to maximise the area exposed to light, at least during early stages of shading.

Seaweed farming in seagrass ecosystems has become common place in recent years; a case study from Puntondo in Takalar District, South Sulawesi, found that heavy shading of seagrasses could reduce the productivity of smaller seagrass species, while *Enhalus acoroides* was less susceptible to the effects of shading [5]. Conversely, a study by Eklof et al. [12] found that seaweed farming had a negative effect on the biomass and density of *Enhalus acoroides*, while *Thalassia hemprichii* was not significantly affected. These findings could be related to the difference in ability to tolerate stress of specific morphologies.

Seagrass and macroalgae have a general tendency to compete for resources, particularly light and nutrients [13]. Adding nutrients to seagrass areas with seaweed farming has been shown to influence the growth of the cultivated seaweed *Eucheuma denticulatum* but not the growth of farmed *Kappaphycus alvarezii* or the seagrass density [14]. When seaweed farming is carried out continuously, the shading effect can have negative impacts on seagrass ecosystems.

Water quality is a factor which plays a role in determining seagrass growth rates. Seagrasses have specific water quality requirements to survive and to thrive. In this study, seagrass leaves sowed the
highest growth during the fortnight prior to the week 4 monitoring. It is likely that this accelerated growth was due to relatively high levels of nitrate (NO₃) and DOM as well as lower temperatures compared to the week 2 and week 6 monitoring.

According to Erftemeijer [15], *Enhalus acoroides* can tolerate seawater temperatures in the range 26.5–32.5°C; furthermore, in shallow waters this species can tolerate temperatures as high as 38°C during daytime low tides. Meanwhile, Lee *et al.* [16] found that the optimal temperature range for seagrass species is between 23–32°C, while 27°C has been reported as the optimal temperature for photosynthesis for the subtropical/tropical seagrass *Enhalus acoroides* [17].

Nitrate (NO₃) and DOM concentrations are among the environmental factors which can have a strong influence on seagrass growth. Dissolved Organic Material (DOM) is comprised of many different complex organic compounds, which are in the main undergoing decomposition processes. DOM levels in the water column can be influenced by the decomposition of dead organisms by bacteria. DOM from terrigenous sources mostly originates from phytoplankton metabolic processes and aquatic plants [18]. DOM concentrations tend to be very closely linked to nitrate (NO₃) concentrations, as high or excessive levels of nitrates can cause eutrophication. The nitrate levels of 0.025–0.056 mg/l recorded during this study (Table 1) exceed the upper level of the standard for seawater quality of 0.008 mg/l set under Ministerial Decree of the Minister for the Environment Number 51 of 2004 on Seawater Quality Standards (Kepmen LH 51/2004). Furthermore, nitrate levels in excess of 0.05 mg/l can be toxic to certain sensitive aquatic/marine organisms, while relatively high nitrate concentrations indicate that abundant nitrogen resources are available for the growth of autotrophic organisms [19].

Phosphate is another nutrient which is important for seagrass growth. The phosphate concentrations recorded at the study sites (Table 1) were below 0.015 mg/l, the maximum level set under Kepmen LH 51/2004.

Seagrasses have varying salinity tolerance ranges, however these are generally within the range of 10–40 ppt, with 35 ppt as the optimum salinity for the growth of most seagrasses [21]. *Enhalus acoroides* is a seagrass with relatively high tolerance to environmental fluctuations, and in particular an ability to with stand low salinity conditions [20].

The pH scale indicates the acidity or alkalinity of a liquid; it is a logarithmic scale based on hydrogen ion (H⁺) concentration; pH is influenced by decomposition in soils/substrate and other environmental conditions. The normal range for seawater pH is 7.8 – 8.2 [22], while the acceptable range for seawater to support marine organisms according to Kepmen LH 51/2004 is pH 7 – 8.5. Based on these ranges, the pH values recorded during this study (Table 1) are within normal limits for seawater, especially coastal waters. The DO values recorded (Table 1) are also within the acceptable range (>5ppm) according to Kepmen LH 51/2004.

In conclusion, our study found no evidence of a significant impact from seaweed farming on seagrass growth, specifically for the seagrass *Enhalus acoroides*. Seagrass growth appeared to be primarily influenced by water quality parameters, being positively correlated with nitrate (NO₃) and dissolved organic matter (DOM) and negatively correlated with seawater temperature, irrespective of the presence or absence of seaweed farming.

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