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Comparison of physical-chemical conditions for seaweed cultivation in the Spermonde Archipelago, Indonesia

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Abstract. Seaweed cultivation is one of the alternative livelihoods that could support the economy of the small island communities. However, the good growth of seaweed is intrinsically linked to the physical-chemical conditions of the seaweed cultivation area. Therefore, the objectives of this study were to assess and compare the physical-chemical conditions of seaweed farming areas and their relationship with seaweed growth in the Spermonde Archipelago, one of the major seaweed cultivation areas in South Sulawesi, Indonesia. The physical-chemical parameters measured in the field or through laboratory analysis included temperature, salinity, pH, dissolved oxygen (DO), phosphate (PO_4), nitrate (NO_3), and carbon dioxide (CO_2). Data were collected from June to September 2019 from the waters around the islands of Balang Caddi (BC), Polewali (Pw), and Laiya (Ly), and in the coastal areas of Bonto Pannu (BP) and Punaga (Pg) villages. Data on seaweed growth was collected from seaweed (*Kappaphycus alvarezii*) farming trials using different culture methods (longlines, polyethylene nets, and baskets) at two sites (BC and Ly Islands) starting in June with further monthly planting from July to September. The physical-chemical parameters were similar for all sites and in general, met the acceptance criteria for *K. alvarezii* growth; however, seaweed growth was affected by the cultivation method applied. The growth of seaweed cultivated with the longline method was constrained by the presence of epiphytes attached to the thallus. However, with the polyethylene net and basket methods, the epiphytes were much reduced, resulting in improved growth and bright green seaweed thalli.

Key Words: Eucheumatoid algae, water quality, seaweed growth, cultivation method, Spermonde Archipelago.

Introduction. Seaweed is a mariculture commodity that has important economic value and contributes to increasing the producing country's foreign exchange (Aslan et al 2015; Widyastuti 2010). Indonesia is one of the primary seaweed producers in the world, besides China, the Philippines, South Korea, North Korea, and Japan (FAO 2016; Waters et al 2019). In 2017, the Indonesian Ministry of Maritime Affairs and Fisheries (KKP 2017) reported that seaweed production had increased by 17.37% per year during the period 2011-2015. Furthermore, from 2013 to 2016, Indonesian seaweed production increased from 9,298,474 tons to 11,631,586 tons (KKP 2018). Indonesia is the principal producer country for the seaweed *Kappaphycus alvarezii* (formerly known as *Eucheuma cottonii*), accounting for around 63.37% of total world production (WWF Indonesia 2014).

Seaweed farming has become widespread in many coastal and small island areas across Indonesia. One of the major seaweed farming areas is in the Spermonde Archipelago in South Sulawesi Province. Yulisti et al (2012) reported seaweed farming around the islands of the Spermonde Archipelago and the nearby small island and coastal waters in the Pangkep Regency and Takalar Regency. Seaweed farming has become one of the most popular alternative livelihoods for the coastal fishing communities, especially when fishing is not possible due to big waves and strong winds (WWF Indonesia 2014; Malik et al 2017). In addition, fishermen are attracted to this commodity due to accessible farming technology, relatively short cultivation cycles, a readily available market, competitive prices, and the potential to make a significant contribution to their livelihoods (Waters et al 2019). KKP (2019) reports that seaweed production in Pangkep Regency increased from 280 thousand tons in 2017 to 304 thousand tons in 2018.

However, the success of seaweed farming is intrinsically linked to factors such as the water quality and other environmental conditions (physical and chemical parameters) of each seaweed farming area; seaweed seed quality; methods used; nutrient availability; and the initial planting density or seed weight (Hasan et al 2015; Agustina et al 2017). Seaweed growth is influenced by water quality parameters such as visibility, temperature, salinity, pH, nitrate concentration and phosphate concentration (Rusliani 2016). Although aquatic productivity is determined by physical, chemical, and biological water conditions (Nursidi et al 2017), the use of superior seaweed seeds is expected to provide good yields and high production. However, seed availability is often an obstacle, especially when the prime planting seasons arrive (Muarif et al 2017). Furthermore, seawater nutrient content will be reflected in the high or low productivity, as primary productivity is highly dependent on the ability of plants living in these waters to synthesize organic and inorganic materials through photosynthesis (Sakshaug et al 1997; Najafpour 2012).

The harvested weight of seaweed can also be negatively influenced by a range of predatory pests (grazers) that feed on the seaweed, while seaweeds can also be attacked by diseases and epiphytes that inhibit seaweed growth (Neish 2008; Hurtado et al 2019). In particular, "ice-ice" is a disease that often occurs in tropical Indo-Pacific farmed seaweeds (Ward et al 2019). The name comes from the symptomatic bleaching, as affected thalli become bright white and easily break off; furthermore, the thallus may be further degraded through infection with opportunistic bacteria. It has been proposed that this disease may not only enable secondary infection but in fact, could be caused by infection with pathogenic bacteria (Riyaz et al 2019). Ice-ice is frequently associated with extreme environmental changes in parameters such as current strength, temperature, salinity, and pH; it is thought that these changes can weaken the seaweed and thus the bacteria can more easily attack the thalli (Poncomulyo et al 2006; Haryasakti 2017).

These challenges need to be mitigated in order to realise the potential for increasing and optimising seaweed production in the Spermonde Archipelago, Indonesia. Therefore, the objectives of this study were to assess and compare the physical-chemical conditions of seaweed farming areas and to examine their relationship with seaweed growth in this region.

Materials and Methods

Description of the study sites. This research was conducted in the Spermonde Archipelago, with a focus on the waters around the small islands of Balang Caddi (BC), Polewali (Pw), and Laiya (Ly), and in the coastal areas of Bonto Pannu village (BP), and Punaga village (Pg) (Figure 1). Four sampling sites were selected (BC, Pw, Ly, and BP) due to the presence of seaweed farming which had been conducted with poor management of the cultivation areas, resulting in suboptimal production. The fifth area, Pg village (Pg1 and Pg2 sites) was chosen as a comparison as it has been well cultivated with much higher production. BC, Pw, and Ly Islands and the BP village coastal area are within Pangkep Regency. The islands of BC, Pw and Ly are the closest islands to the Sulawesi Island mainland of this regency, while Pg village is situated in the coastal area of Takalar Regency.

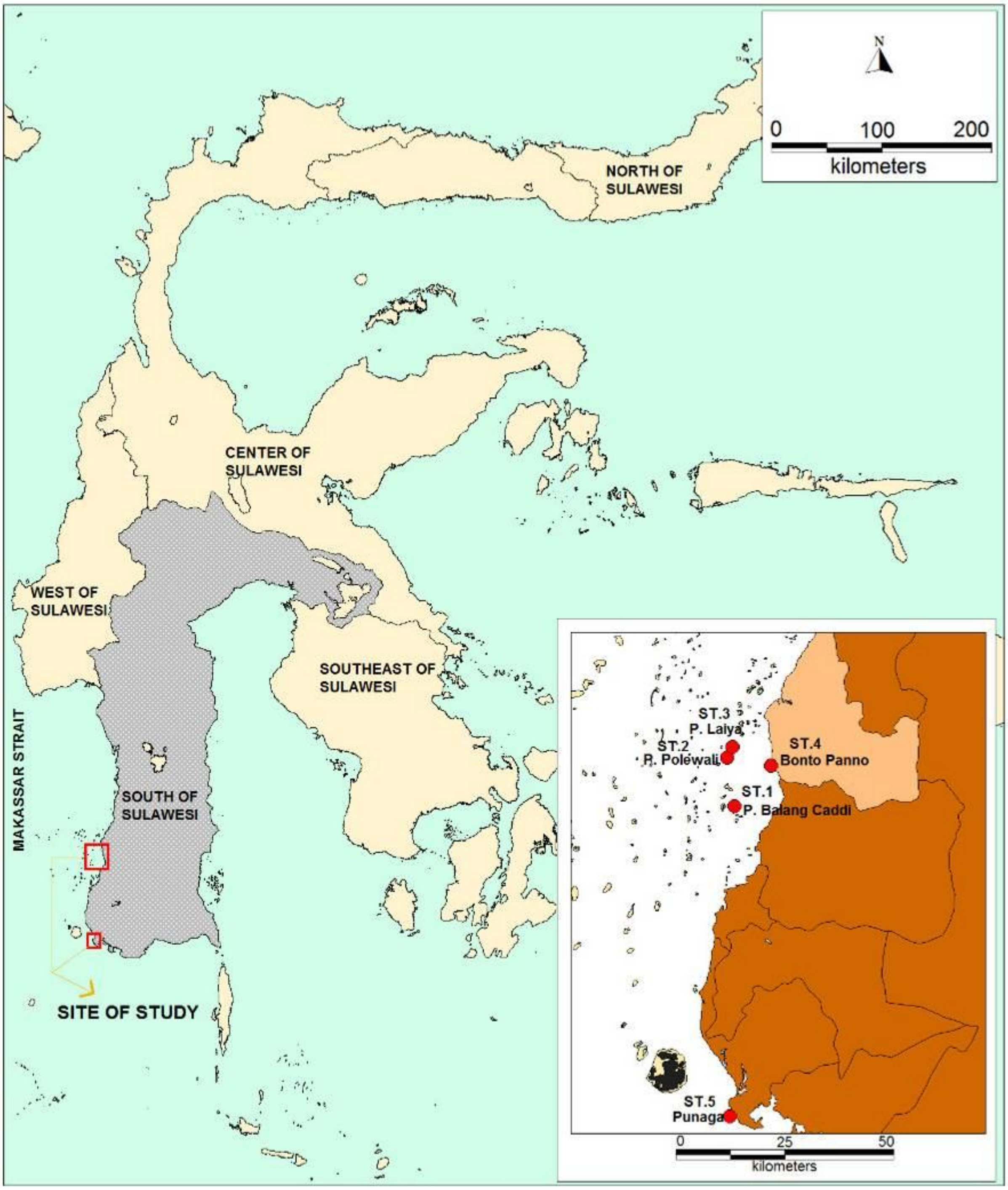

Figure 1. Map of Sulawesi showing the two study areas (red rectangles) and five study sites (insert): Balang Caddi, Polewali, and Laiya Islands, and coastal areas of Bonto Pannu and Punaga.

Data collection. Data on physical-chemical waters conditions of seaweed farming areas (temperature, salinity, pH, dissolved oxygen (DO), phosphate (PO_4), nitrate (NO_3), and carbon dioxide (CO_2)) were collected from June to September 2019. Most parameters were measured directly *in situ* at each site, while phosphate and nitrate concentrations were also measured in the laboratory (Table 1). Measurements were taken primarily in the morning (from 07.00 to 12.00) and all measurements were repeated three times (3 replicates). The suitability of the sites based on seawater parameters was evaluated based on the standards in Table 2.

Seaweed growth data was collected through seaweed (*K. alvarezii*) farming trials using three different planting methods: longline, polyethylene net, and basket methods

(Figure 2). The cultivation trials were conducted at two sites (BC and Ly islands) and started in June. The trials continued every month from July to September. Growth data were collected by measuring the growth of seaweed thalli.

Figure 2. The three methods used in the seaweed growth trials.

Table 1

Seawater physical and chemical parameters measured and methods/equipment used

No.	*Parameter*	*Materials*	*Methods*
1	Temperature (^{o}C)	Digital thermometer (CE TP101 China)	*In situ*
2	Salinity (ppt)	Hand refractometer (Atago Master-S/Mill M Cat No 2493 Japan)	*In situ*
3	pH	pH meter (Hanna Instrument HI 8424 Romania)	*In situ*
4	Dissolved oxygen (DO) (mg L^{-1})	Monotaro Disposal Pipette Dropper PE 25-35microl Japan	*In situ* (titration)
5	Phosphate (PO_4) (mg L^{-1})	Spectrophotometer (Hach DR 2800 type LPG 422.99.00012 USA)	*In situ* and laboratory analysis(spectrophotometry)
6	Nitrate (NO_3) (mg L^{-1})	Spectrophotometer (Hach DR 2800 type LPG 422.99.00012 USA)	*In situ* and laboratory analysis (spectrophotometry)
7	CO_2 (gram)	Monotaro Disposal Pipette Dropper PE 25-35microl Japan	*In situ* (Titration)

Table 2

Suitability classification of water quality parameters for eucheumatoid seaweed farming

Suitability classification	*Parameter*					
	Temp. (^{o}C)	*Salinity (ppt)*	*pH*	*PO_4 (mg L^{-1})*	*NO_3 (mg L^{-1})*	*DO (mg L^{-1})*
Suitable	28-30	28-32	7-8.5	0.051-1	0.1-0.7	> 6
Moderately suitable	26-27; 30-33	25-27; 33-35	6.5-7; 8.5-9.5	0.021-0.05	0.01-< 0.1	4-6
Non suitable	< 26; > 33	< 25; > 35	< 6.5; > 8.5	< 0.021; > 1	< 0.01	< 4

Source: Waluyo et al (2016).

Results and Discussion

Physical and chemical conditions of seaweed farming sites

Temperature. On average, the temperature in Pangkep Regency waters (close to 30^oC) was significantly higher than the average temperature in Pg2 (27.7^oC) and Pg 1 (28.25^oC). The mean temperature was similar in BC, Pw, Ly and BP sites (Figure 3). The lower temperatures observed in the Pg1 and Pg2 sites are thought to be due to the influence from the Flores Sea because of the position of this site at the boundary between the Makassar Strait and the Flores Sea.

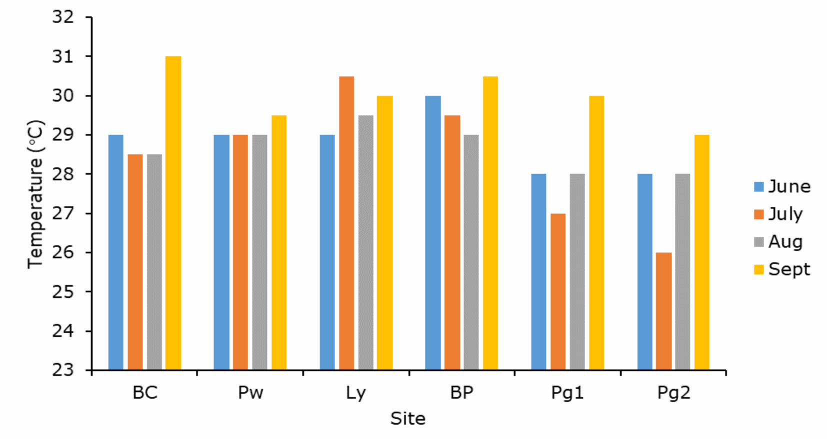

Figure 3. Temperature measured at each site. BC: Balang Caddi Island; Pw: Polewali Island; Ly: Laiya Island; BP: Bonto Pannu; Pg1: Punaga 1; and Pg2: Punaga 2.

Salinity. During the period from June to August salinity was fairly stable at around 35 ppt in the BC, Pw, Ly, and BP sites. This relatively high value was associated with low rainfall. However, water salinity declined in September. The salinity at the Pg1 and Pg2 sites ranged from 34 to 36 ppt. The higher temperatures from July to August were likely the cause of the high salinity, reaching 36 ppt during these months (Figure 4).

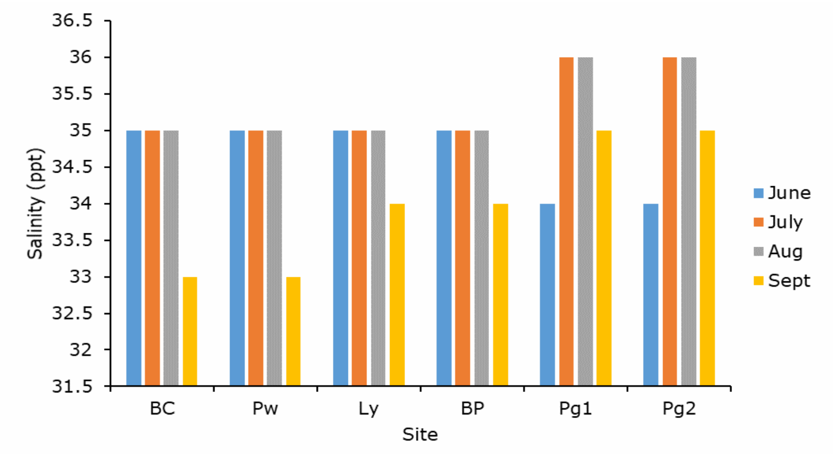

Figure 4. Salinity measured at each site. BC: Balang Caddi Island; Pw: Polewali Island; Ly: Laiya Island; BP: Bonto Pannu; Pg1: Punaga 1; and Pg2: Punaga 2.

pH. The pH at the Pangkep Regency sites ranged from 7.01 to 7.91, with the lowest values at the BP site in July and the highest at the Ly Island site in September. At the Pg 1 and Pg2 sites, pH was in the range of 7.2-7.9. In general, pH tended to decrease from June to July and then increase until September. The pH did not differ much between the Pangkep Regency sites and the Pg 1 and Pg 2 sites (Figure 5) and remained within the range considered suitable for seaweed cultivation throughout the study period.

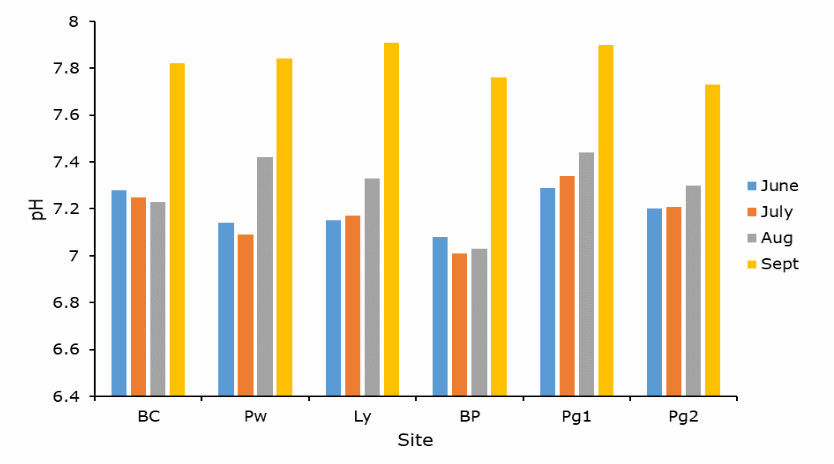

Figure 5. pH measured at each site. BC: Balang Caddi Island; Pw: Polewali Island; Ly: Laiya Island; BP: Bonto Pannu; Pg1: Punaga 1; and Pg2: Punaga 2.

Dissolved oxygen (DO). DO concentrations fluctuated over the four-month study period but remained within the range considered suitable for seaweed culture (Figure 6). In the Pangkep Regency sites, DO ranged from 5.19 to 8.82 mg L^{-1}, with the lowest values at the BP site in September and the highest at the Pw site in August. At the Pg1 and Pg2 sites in Takalar Regency, DO ranged from 6.17 to 8.9 mg L^{-1}, and was highest at the Pg1 and Pg2 sites in July.

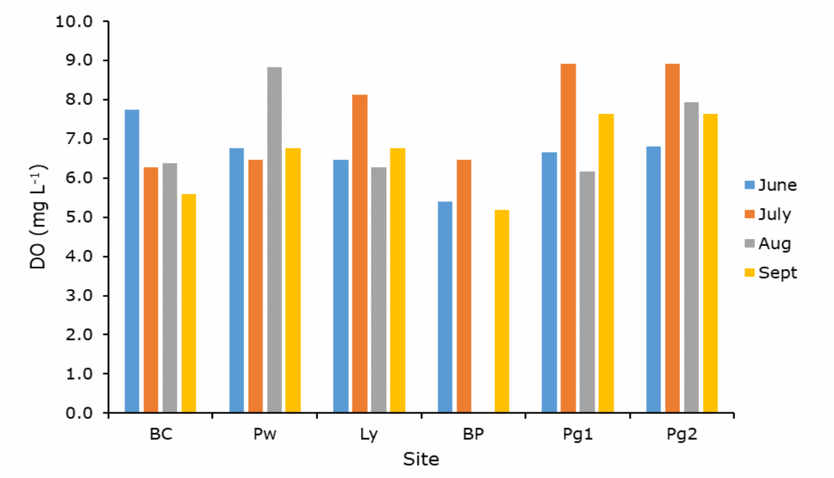

Figure 6. Dissolved oxygen (DO) at each site. BC: Balang Caddi Island; Pw: Polewali Island; Ly: Laiya Island; BP: Bonto Pannu; Pg1: Punaga 1; and Pg2: Punaga 2.

Phosphate (PO_4). The phosphate concentration changed significantly during the study period, declining from June to August, then remaining fairly stable from August to September (Figure 7). At the Pangkep Regency sites, phosphate levels in June were in the range of 0.091-0.124 mg L^{-1}, indicating a highly eutrophic condition, with the lowest concentration at the BC site and the highest at the Ly site. In July the level decreased to 0.079 to 0.092 mg L^{-1}, classified as eutrophic water. At the Pg1 and Pg2 sites, phosphate content was somewhat lower, ranging from 0.049 to 0.055 mg L^{-1} in June and 0.033 to 0.039 mg L^{-1} in July, classified as eutrophic water conditions. In August to September, the phosphate levels decreased, with the lowest level reached in Pangkep Regency being 0.011 mg L^{-1} at the BP site, while at the Pg1 and Pg2 sites the lowest level was 0.01 mg L^{-1}. The decrease in phosphate levels may have been due to low rainfall, reducing the flow of rivers carrying phosphate from the land.

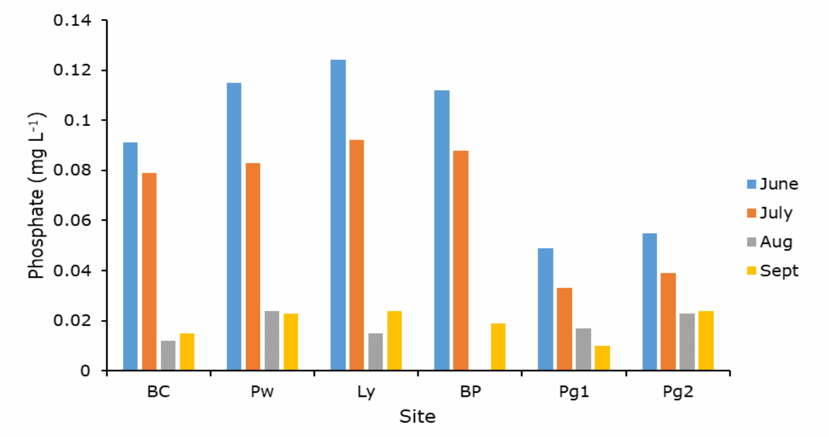

Figure 7. Phosphate (PO_4) concentrations at each site. BC: Balang Caddi Island; Pw: Polewali Island; Ly: Laiya Island; BP: Bonto Pannu; Pg1: Punaga 1; and Pg2: Punaga 2.

Nitrate (NO_3). Nitrate concentrations varied significantly over the study period (Figure 8), showing an inverse trend compared to phosphate concentrations (Figure 7) and were similar for the Pangkep and Takalar Regency sites. In June nitrate concentrations varied between sites in Pangkep Regency, with a range of 0.007-0.056 mg L^{-1} (lowest at the Ly site and highest at the Pw site), while at the Pg1 and Pg2 sites the ranges were 0.0019 to 0.022 mg L^{-1}. In July the NO_3 content at Pangkep Regency sites ranged from 0.005 to 0.033 mg L^{-1}, increasing at the Ly Island site and decreasing at the other sites, ranging from 0.0028 to 0.023 mg L^{-1} at the Pg1 and Pg2 sites. In August and September, nitrate levels increased sharply at all sites, with the lowest NO_3 levels at the Ly site in August (0.141 mg L^{-1}) and Pg1 site (also 0.141 mg L^{-1}) in September, while the highest peaks were 0.185 mg L^{-1} at the Pw site in August and 0.174 mg L^{-1} at the BC site in September.

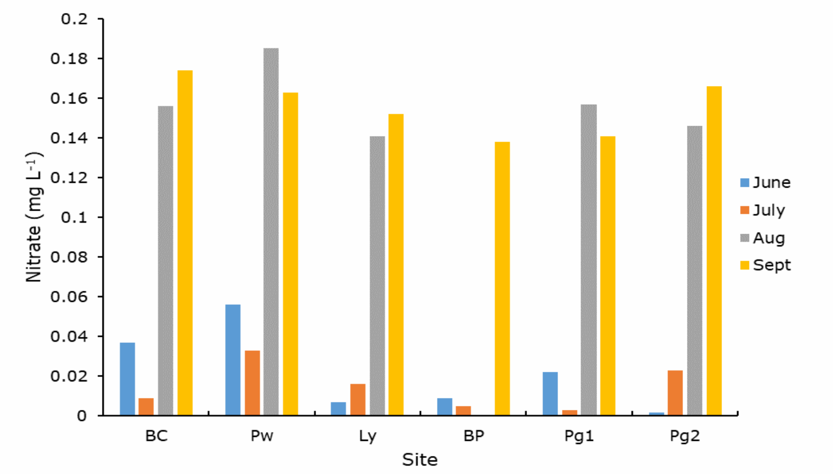

Figure 8. Nitrate (NO_3) concentrations at each site. BC: Balang Caddi Island; Pw: Polewali Island; Ly: Laiya Island; BP: Bonto Pannu; Pg1: Punaga 1; and Pg2: Punaga 2.

Carbon dioxide (CO_2). The concentration of CO_2 from June to September at the sites in Pangkep and Takalar Regencies was at very low levels. Therefore, the CO_2 could not be detected by the methods used.

Relationship between physico-chemical conditions and seaweed growth using different culture methods. The results of the assessment of seaweed cultivation at each site indicated that the sites were generally suitable for *K. alvarezii* cultivation. However, the growth trials demonstrated that seaweed growth varied depending on the method used (Table 3).

Table 3

Suitability classification by site and month and relationship between physico-chemical conditions and seaweed growth by culture method* at BC and Ly sites in Pangkep Regency and Pg1 and Pg2 sites in Takalar Regency

Site	*Month*	*Temperature (^oC)*	*Salinity (ppt)*	*pH*	*PO_4 (mg L^{-1})*	*NO_3 (mg L^{-1})*	*DO (mg L^{-1})*	*LL (g seed^{-1})*	*PN (g seed^{-1})*	*Bt (g seed^{-1})*	*Suitability level*
BC	June	29.0	35	7.28	0.091	0.037	7.74	+	+	-	Suitable
	July	28.5	35	7.25	0.079	0.009	6.27	120	40	-	Suitable
	August	28.5	35	7.23	0.012	0.156	6.37	20	60	+	Suitable
	September	31.0	33	7.82	0.015	0.174	5.59	20	65	70	Moderate
Ly	June	29.0	35	7.15	0.124	0.007	6.47	+	-	-	Suitable
	July	30.5	35	7.17	0.092	0.016	8.13	25	-	-	Suitable
	August	29.5	35	7.33	0.015	0.141	6.27	20	-	+	Suitable
	September	30.0	34	7.91	0.024	0.152	6.76	10	-	40	Suitable
Pg1	June	28.0	34	7.29	0.049	0.022	6.66	100	-	-	Suitable
	July	27.0	36	7.34	0.033	0.003	8.92	100	-	-	Moderate
	August	28.0	36	7.44	0.017	0.157	6.17	100	-	-	Suitable
	September	30.0	35	7.90	0.010	0.141	7.64	x	-	-	Suitable
Pg2	June	28.0	34	7.20	0.055	0.002	6.80	100	-	-	Suitable
	July	26.0	36	7.21	0.039	0.023	8.92	100	-	-	Moderate
	August	28.0	36	7.30	0.023	0.146	7.94	100	-	-	Suitable
	September	29.0	35	7.73	0.024	0.166	7.64	x	-	-	Suitable

*LL: longline method; PN: polyethylene net method; Bt: basket method. Colour codes: no colour = suitable; yellow = moderately suitable; grey = unsuitable.
(+): cultivation trial; (-): no cultivation trial; (x): crop failures

It is unclear which parameter or combination of parameters principally influenced the variability in seaweed growth; for example, the decrease in weight overtime at the BC site when using the longline method. As another example, at the Pg sites the trials produced good growth from June to August despite some environmental parameters being in the unsuitable range. Conversely, in September when the envrionmental parameters were closer to the supposedly optimal values, the growth rate was much lower. Interviews with local residents revealed that crop failures had occurred in September: from 500 kg of seedlings planted out, only 100 kg were left at harvest time.

The pH levels at each station were classified as suitable for seaweed growth based on Waluyo et al (2016), as were the DO levels, with the exception of one month in the moderately suitable category at one site (September, Ly Island). However, stable and suitable values of DO and pH were not sufficient to enable (or failed to coincide with) good growth of *K. alvarezii*. The remaining parameters varied over time not only in value but in suitability category at each site but did not show any consistent relationship with seaweed growth. It is also remarkable that the pH levels were consistently lower than the range (pH 7.83-8 57) recorded in Takalar Regency in 2016 and the pH of 8.23 ± 0.27 recorded in 2018 (Jamaluddin et al 2019). Although not outside the suitable category range, low seawater pH (below pH 8) is thought to cause stress to and potentially reduce biomass production of eucheumatoid seaweeds (Largo et al 2017). Low pH is also likely to favour the growth of pathogens such as *Vibrio* sp. (Zha et al 2017) and marine fungi (Krause et al 2013) while reducing the defences of marine plants against both grazers and pathogens (Arnold et al 2012). It is possible that relatively low pH may have been a factor promoting the epiphyte infestations observed at the island sites (longline method) and the low overall growth rates recorded during this study.

With respect to temperature and phosphate levels, conditions conducive to *K. alvarezii* growth obtained during the first two months of the study period, i.e. temperatures below 30°C and phosphate levels between 0.05 and 1 mg L^{-1}, although excessively high phosphate levels in June and temperature over 30°C in July might have adversely affected seaweed growth at Ly Island. Indeed, the longline method yielded good seaweed growth during trial 1 (June-July) except at Ly Island, the site with the highest water temperatures during this period. In August the temperature was fairly stable, but *K. alvarezii* growth was slower at the island sites, associated with low phosphate levels and an increase of nitrate levels, with growth slowing further in September, associated with rising temperatures (Table 3). The *K. alvarezii* cultivation trials on BC Island showed that, although physico-chemical conditions changed, seaweed growth remained stable when using the polyethylene net and basket methods. At the Takalar Regency (Pg) sites, the lower temperatures may have accounted for the consistently good growth of *K. alvarezii*. However, when the temperature increased the growth decreased, resulting in the above-mentioned harvest failure at Pg1 in September.

Salinity levels at all sites were quite high, mostly around 35 ppt, and classified as moderately suitable for seaweed growth based on Waluyo et al (2016). However, even when salinity peaked at 36 ppt in the Takalar Regency sites during July and August, *K. alvarezii* still grew well at the Pg1 and Pg2 sites using the longline method. At the BC site, the seaweed cultivated using the longline method grew well during June and July, but growth slowed subsequently despite stable or improved salinity levels. However, when the polyethylene net method used, there was consistently good growth of 40-65 g $seed^{-1}$ every month. The basket method was only used during one planting period, applied at two of the three island sites (BC and Ly). This one-time trial, implemented towards the end of the study period, also resulted in good growth with a rate of 40-70 g $seed^{-1}$.

The results of this study indicate that, with the probable exception of temperature, the water quality parameters outside the optimal ranges, in particular, the higher salinity levels measured during this trial, were most likely not the main factors causing variability in seaweed growth. Although the study did not cover a long enough time period and had insufficient replicates of some methods for statistical power, the results indicate that planting method may have a significant influence on seaweed health and growth, and indeed may (at least under certain circumstances) have a greater effect on yield than inter-site differences in seawater parameters (with the probable exception of temperature, as noted above).

One interesting and unexpected finding from this trial relates to the prevalence of epiphytes on the seaweed thalli. The longline trials at the two islands sites (BC and Ly) were plagued by the growth of epiphytes which became firmly attached to the thalli of *K. alvarezii* associated with a noticeable slowing in thallus growth. However, seaweed seeds from the same source, grown at the same time and in the same waters (i.e. experiencing the same physical and chemical environmental/water quality parameters), grew far better when planted using the polyethylene net and basket methods rather than the longline method (Table 3). The thalli of seaweed planted using these two methods appeared healthy with a bright green colour throughout the trial period for each method and grew three to four times faster than those on the nearby longlines. The reasons for this difference in health (and presumably therefore in growth) are not clear and warrant further research.

Conclusions. This study assessed the physico-chemical conditions of seaweed farming areas and the relationship of these parameters with the growth of the seaweed *Kappaphycus alvarezii* in the Spermonde Archipelago, Indonesia. In general, the physico-chemical conditions were similar at all sites in Pangkep Regency and Takalar Regency, and all or most parameters remained within the ranges considered suitable or moderately suitable for seaweed cultivation during the study period June-September 2019, despite pH levels below recent historical ranges. Water temperature was generally lower in the Takalar Regency sites than the Pangkep Regency sites and is thought to be one reason for faster seaweed growth at the Takalar sites using the longline method. At one Pangkep Regency site, good *K. alvarezii* growth using the longline method in June to July was associated with relatively high phosphate (PO_4) but low nitrate (NO_3) concentrations. Seaweed growth on the longlines in August and September at the Pangkep Island sites was poor, apparently constrained by the presence of epiphytes attached to the thallus, and may have been influenced by low phosphate and high nitrate levels as well as higher seawater temperatures. However, at these sites, seaweed growth was consistently good with the polyethylene net method and during the basket method trial. Seaweeds grown using these methods attracted far fewer epiphytes compared to those grown on longlines, allowing the thalli to grow and maintain a healthy bright green colour.

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