Shading effect of seaweed farming on the growth and health of the corals *Porites cylindrica* and *Acropora formosa*

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Abstract. The objective of this study was to analyze the effect of shading from seaweed farming on coral growth and health. The study applied an *in-situ* experimental approach, placing 3 replicate seaweed farming plots with an area of 40x30 m^2 (floating longline system; 30 m lines with 0.5 m spacing) in a coral reef area, with a control area of approximately 50 m from the plots. Seaweed seedlings (±100 g) were attached 0.2 m apart. In each plot and the control area, colonies of two branching corals, *Porites cylindrica* and *Acropora formosa* (10 of each species) were tagged on a principal branch. The growth of the selected branches was measured every 2 weeks during a 6-week observation period. As an indicator of coral health, colony color was recorded using a standard coral health index monitoring chart. The t-test was used to analyze the effect of shade on coral growth and coral health, comparing coral colonies shaded by seaweed cultivation with unshaded corals (natural conditions). There was no significant difference in the growth and health level of the 2 coral species between colonies living in the seaweed farming area and in natural conditions (control). These results indicate that the shading effect of seaweed does not significantly affect the growth of the two coral species commonly found in the study area.
Key Words: branching corals, coral growth, health index, shading, West Sulawesi.

Introduction. Although seaweed farming is still a relatively recent industry in the global aquaculture field, it has presented rapid growth in the global production over the past 50 years, tripling between 1997 and 2012, from 7 million tons to 24 million tons (FAO 2014). Seaweed is predicted to play an important role in fulfilling the global need for food. Seaweed farming not only provides resources in the form of human food and animal feed, but also raw material that can be processed to produce environmentally friendly energy, antioxidants, products with probiotic or prebiotic properties, while providing environmental and economic services (Radulovich et al 2015; Dring et al 2007).

The world seaweed industry is estimated to be worth 5.5-6 billion USD per year, out of which 5 billion USD are for consumption, and the rest for hydrocolloid and other derivative products. The global seaweed industry uses 7.5-8 million tons of wet seaweed per year, more than 90% from aquaculture and mariculture, while the other small part was obtained from the wild (FAO 2010, 2012). It is estimated that 90% of total world seaweed was supplied from Indonesia and the Philippines (Valderrama et al 2015). Total wet seaweed production from Indonesia continued increasing, from 5.17 million tons in 2011 to 9.99 million tons in 2013, with an average increase of 34% (Salim & Ernawati 2015). From 2000 to 2010, seaweed production was still dominated by 5 major producing countries with a total contribution of 99.9% in 2000. This slightly decreased to 99.6% in 2010. The 5 countries that produce the most seaweed in 2000 were the Philippines, Indonesia, Republic of Tanzania, Kiribati and Fiji, with a total contribution of 71.9%, 20.9%, 5.4%, 1.2% and 0.6%, respectively (ITC 2015). Interestingly, in 2010, Indonesia became the largest seaweed producing country with a total contribution of 60.5%, followed by the

Philippines, Malaysia, Tanzania, and China. These 4 countries contributed with 30.9%, 3.7%, 2.3% and 1.1% of the total seaweed production, respectively (Salim & Ernawati 2015).

In Indonesia, an archipelagic nation with 17504 islands and 99093 km of coastline, there is great potential for the development of seaweed as a commodity. To achieve production targets, the Indonesian government has sought to develop a seaweed farming program with the collaboration of relevant agencies and ministries. Seaweed farming has been promoted across Indonesia, from Nangroe Aceh Darussalam to West Papua, attaining a current effective seaweed cultivation area of approximately 384733 ha. To reach some proposed targets, assuming productivity remains at current levels, a cultivation area of around 769452 ha is needed.

Currently, seaweed cultivation is developing rapidly and intensively in some coastal areas, with a non-negligible number of fishermen shifting from fishing to seaweed farming. Seaweed cultivation technology has developed and undergone many changes and modifications to suit different regions and the capacity of seaweed farmers. Currently, floating line systems are the dominant seaweed cultivation technology (Blankenhorn 2007). Under this technological system, seaweed farmers can utilize coastal waters to a depth of around 12 m, a zone in which corals and coral reefs are often present. Using the floating line seaweed cultivation system on coral reefs is thought to have an effect on marine biota living below the lines, especially on the hard (scleractinian) corals forming the basis of the reef ecosystem. In particular, shading effects are thought to reduce the intensity of sunlight penetration to the water column. This shading could affect the photosynthesis of the symbiotic zooxanthellae within the corals, and therefore it could reduce coral growth rates. Schutter et al (2012) considers that light is one of the most important abiotic factors influencing the (skeletal) growth of scleractinian corals. Light stimulates coral growth by the process of light-enhanced calcification, which is mediated by zooxanthellar photosynthesis. Levy et al (2003) note that light was the most effective factor in eliciting full tentacle contraction in stony corals (*Favia favus* and *Plerogyra sinuosa*). Zooxanthellae densities in tentacles were significantly higher in stony corals, which continuously expanded the tentacles.

In natural conditions, the most common shading effect on coral reefs is the turbidity caused by the presence of suspended or dissolved particles in the water column. A study by Roger (1979) found that shading on San Cristohal reef, northwest of Puerto Rico, over an area of 20 m^2 for 5 weeks changed the structure and function of the community by reducing net primary productivity and respiration, causing bleaching and death in some hard coral species, all due to sediment turbidity. Shading significantly reduced the coral growth rate of *Acropora cervicornis*. Ten months later, after the shading ceased, there were no new corals growing on the dead coral skeletons that were quickly overgrown by algae. Although coral reefs can adapt to temporary increases in turbidity, a sustained reduction in light penetration, for example after dredging, will greatly change the function and structure of the community by reducing photosynthesis. Bessell-Browne (2017) studied the effects of water quality degradation due to dredging or natural resuspension on coral reefs with different suspended sediment concentrations, for a period of 28 days. *Acropora millepora*, *Montipora capricornis* and *Porites* spp. exhibited a loss of chlorophyll-a and a change in color (bleaching) after a week in low light conditions.

Although research has shown negative effects of shade on hard corals due to sediment re-suspension in turbid waters, there is a lack of data on the effects of shade due to seaweed cultivation on the hard corals living underneath the seaweed. The influence of shade by the presence of seaweed cultivation on stony corals did not receive much attention. The study performed by Mulyani et al (2018) treats the effect of space and depth seaweed culture on the growth of *Acropora muricata*. Therefore, the objective of this study was to determine the effect of shading from seaweed farming on the growth and health status of hard corals. The specific aim was to analyze the effect of shade due to the installation of floating long-line seaweed cultivation units on the growth and health of the scleractinian corals *Porites cylindrica* and *Acropora formosa*.

Material and Method. This research was conducted from May to October 2017 in the coastal waters of Karampuang Island, Mamuju District, Mamuju Regency, West Sulawesi Province, Indonesia. The waters around the island of Karampuang were chosen because the deeper water area offshore is protected by a coral reef around the island. This formation has resulted in a protected lagoon, which makes seaweed cultivation physically possible (Figure 1).

The seaweed cultivation media was installed in a coral reef area with a water depth of 3-5 m. 3 replicate units were set up 50 m apart. The floating longline system used was a modification of the floating line (long line) system commonly used and developed in West Sulawesi. Rectangular seaweed cultivation frames (30x40 m) were made from polyethylene (PE) rope, 9-10 mm in diameter. These main rope frames were held in place using PE anchor ropes (Ø 9-10 mm) and sandbags as anchors. Each anchor was comprised of 4-6 plastic sacks filled with 75 kg of sand. Polystyrene or plastic floats were attached to the surface end of the anchor ropes to provide buoyancy and to keep the frames in place, despite wave action and currents. Within each frame, 80 seaweed planting lines (30 m in length) were placed 0.5 m apart. Seaweed seedlings (≈100 g each) were attached 0.2 m apart, resulting in 150 seeds per line and 12000 seedlings (≈1.2 tons) per unit.

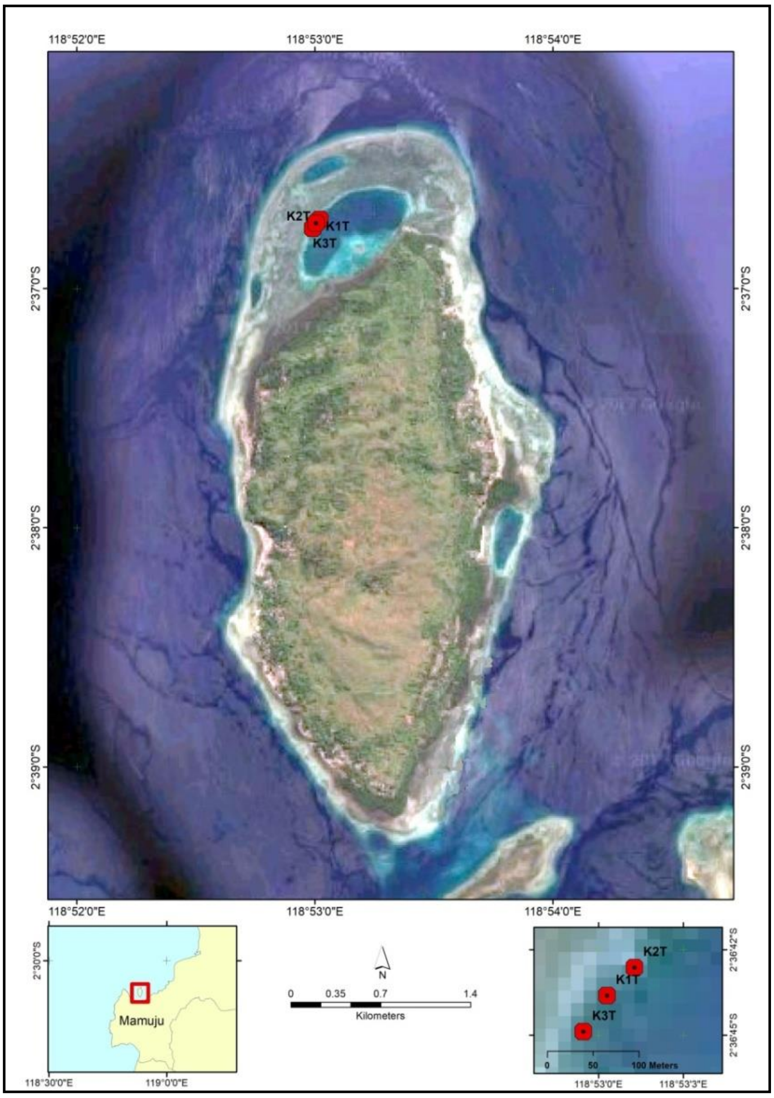

Figure 1. Map of the study site, showing the placement of the seaweed farming units (red dots) over the coral reef surrounding Karampuang Island in Mamuju District, West Sulawesi Province. K1T - replicate 1; K2T - replicate 2; K3T - replicate 3; the 3 controls were close to each seaweed farming plot replicate, seawards.

The effect of seaweed cultivation on coral reef ecosystems was assessed through observing the growth and coral health index (CHI) of two branching scleractinian coral species found at the study site: *P. cylindrica* and *A. formosa*. In each replicate plot, 10 shaded colonies (growing under the seaweed frames) were selected for each species. A further 10 control colonies growing on the surrounding reef without shade (controls) were selected from 3 control areas, each situated 50 m away from one of the seaweed cultivation units. The selected colonies (10x3 replicates x2 treatments = 60 corals per species) were tagged on a principal branch. Coral growth was estimated by measuring the length and diameter of a primary branch of each colony (Figure 2) at fortnightly intervals using calipers.

The parameters used to evaluate growth are growth in length after 2 weeks, 4 weeks and 6 weeks. The formula used was:

$$GA = Lt - Lo$$

Where: GA - absolute growth in length at time t (in cm); Lt - branch length (cm) at time t; Lo - branch length (cm) at the start of the experiment (day 0); t - time (2 weeks, 4 weeks, 6 weeks).

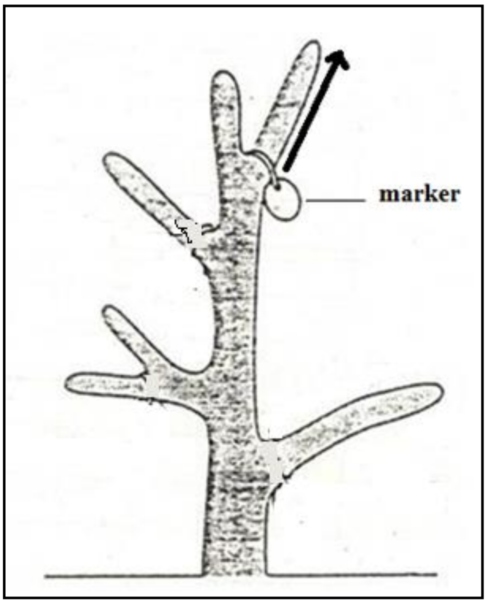

Figure 2. Measurement of the primary branch of tagged corals and tagging method (English et al 1997).

Coral colony health was evaluated using the CHI based on coral colony color brightness (Siebeck et al 2006). The CHI value of each coral colony was assessed by placing the Coral Health Chart (Figure 3) next to the colony underwater (*in-situ*) and selecting the chart color that most closely matched the color of the coral (Siebeck et al 2008). Each Coral Health Chart code consists of a letter and a number (e.g. E4). The CHI range is from 1 to 6 (Figure 3), while the letters (B, C, D, E) represent the hue range of the coral.

Measurements of physical and chemical seawater parameters were conducted both inside and outside the cultivation area. Measurements were conducted every 2 weeks during the cultivation period. Water quality parameters measured *in situ* were the pH, salinity (‰), dissolved oxygen (ppm), and light intensity (lux). In order to measure nitrate, phosphate and dissolved organic matter (DOM) concentrations (ppm), water samples were collected from the surface layer in 600 mL containers and placed in a cooler for transporting to the laboratory, where the analyses were carried out (2 days after sampling). Results were presented as mean values ± standard error (SE).

The effect of shade from seaweed cultivation was evaluated by comparing the growth and health of the corals *P. cylindrica* and *A. formosa* in the control areas and the treatment areas (under the seaweed aquaculture units), using the t-test and through principle components analysis (PCA) implemented in the statistics software Minitab 14.0.

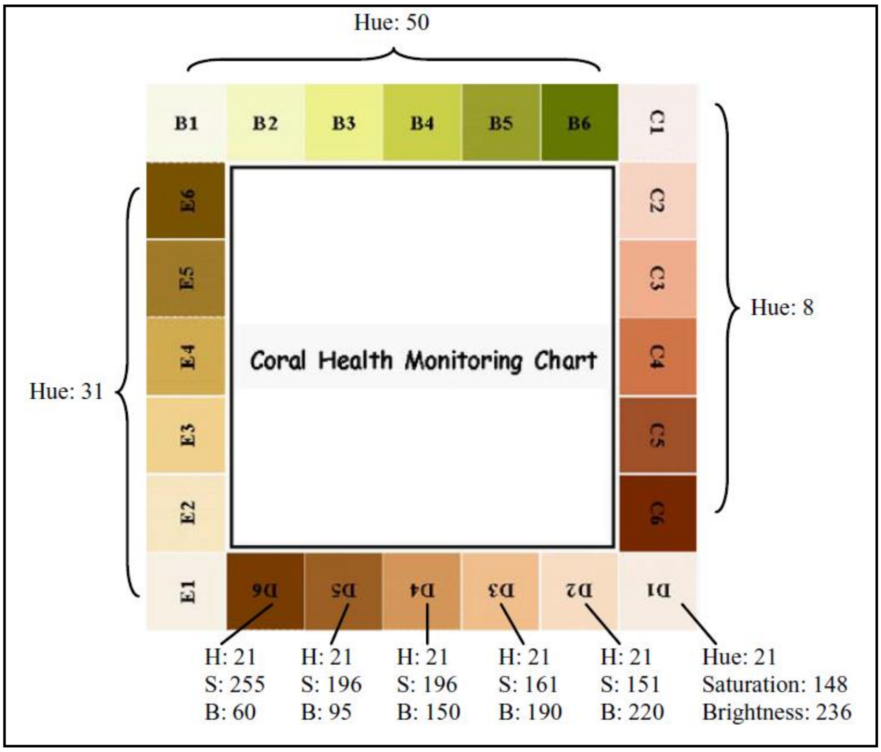

Figure 3. Coral health index monitoring chart based on coral color brightness (Siebeck et al 2006).

Results and Discussion

Growth of corals P. cylindrica and A. formosa. During the 6 weeks of observation, there were changes in the branch length of the 2 types of coral observed. The fortnightly changes in branch length are presented in Figure 4 and show that both types of coral had positive growth during each 2-week period.

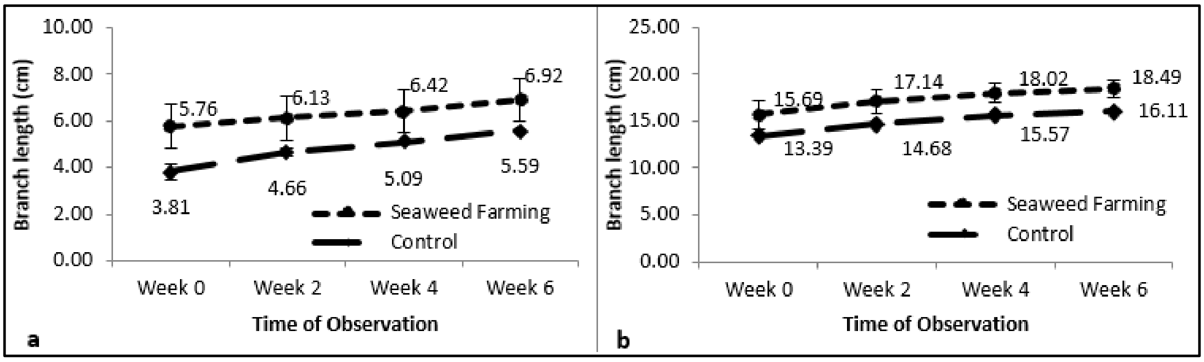

Figure 4. Fortnightly changes in the branch length of two corals in the reefs around Karampuang Island over a 6-week period of observation; a - *Porites cylindrica*; b - *Acropora formosa*.

The growth of *P. cylindrica* tended to be stronger in the control areas than in the cultivated areas, while the opposite trend was observed for *A. formosa* (Figure 5). However, the results of the t-test (at α=0.05) did not show any significant differences between the growth of coral colonies growing under the seaweed cultivation plots and those growing in the control areas (natural conditions) over the 6 week observation period, for either *P. cylindrica* or *A. formosa*.

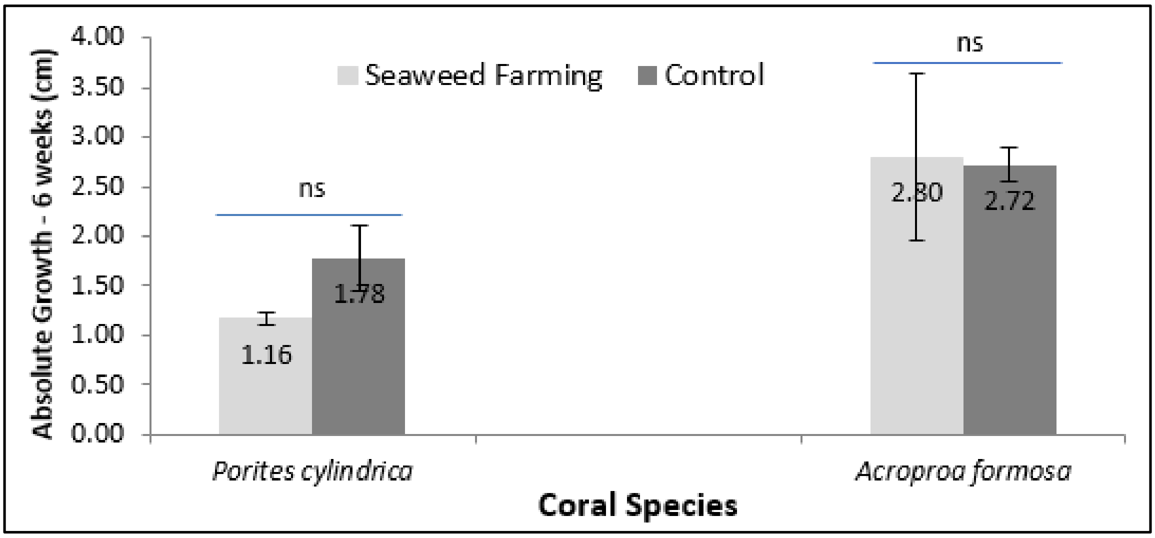

Figure 5. Absolute growth (increase in branch length) of the corals *Porites cylindrica* and *Acropora formosa* growing in the seaweed farming areas and in the control areas over the 6-week study period. Whiskers show standard error (SE); ns - not significant.

Similar trends were observed during each 2-week period, with no significant differences (P>0.05) in absolute growth between the control areas (natural reef conditions) and treatment areas (seaweed farming) for either species of coral (Figure 6).

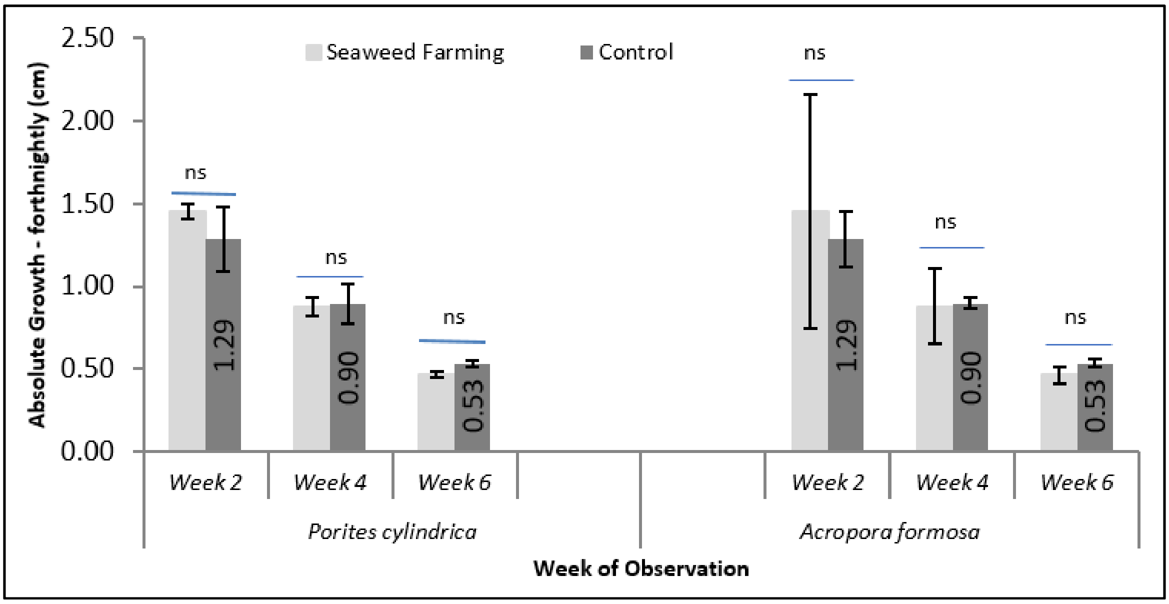

Figure 6. Fortnightly growth of the corals *Porites cylindrica* and *Acropora formosa* in the seaweed farming area and in the control area (surrounding reef) over the 6-week study period. Whiskers show standard error (SE); ns - not significant.

Health of the corals P. cylindrica and A. formosa. The CHI did not differ significantly (P>0.05) between coral colonies growing in the treatment (seaweed farming) areas and control areas (natural reef conditions) for either *P. cylindrica* or *A. formosa,* for any of the fortnightly observations (at 0, 2, 4 and 6 weeks). The CHI values for both coral species were typically 6 during the initial measurement, and decreased slightly during the following weeks, in both treatment and control areas (Figure 7).

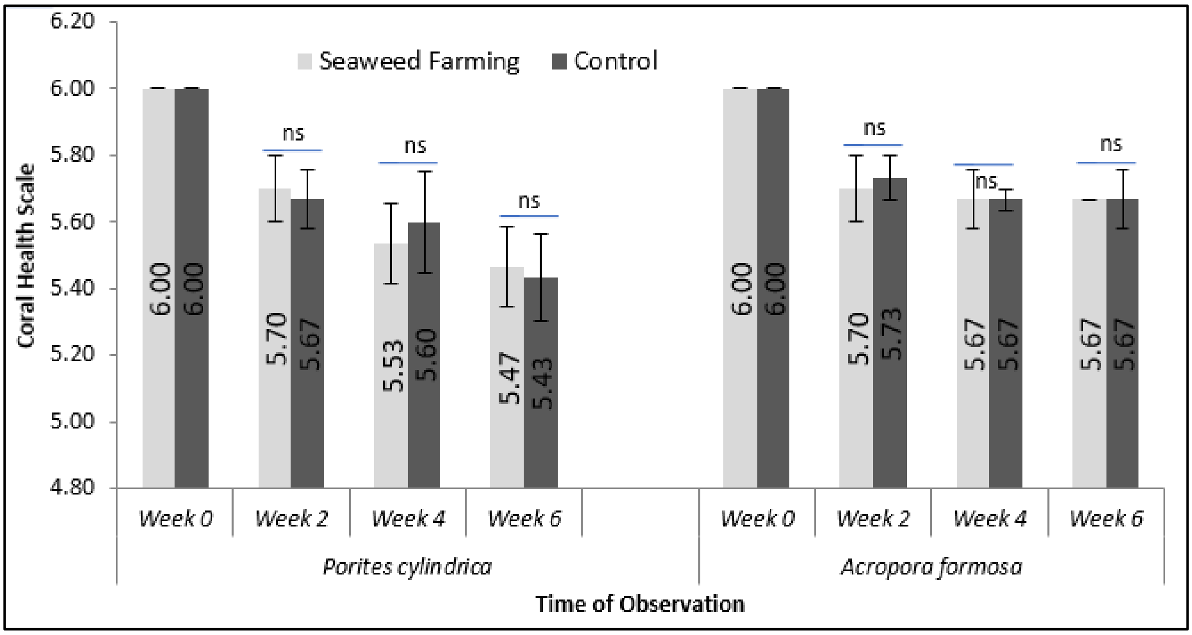

Figure 7. Coral health index values recorded for *Porites cylindrica* and *Acropora formosa* in the treatment (seaweed farming) areas and control (natural reef) areas every 2 weeks during the 6 week study period. Whiskers show standard error (SE); ns - not significant.

Correlation of coral growth and health with environmental factors. The environmental key parameters measured during the study remained within the range considered suitable for scleractinian corals. At the beginning of the study, dissolved oxygen (DO) and phosphate concentrations were significantly higher in the treatment (seaweed farming) areas compared to the control areas, while other environmental parameters measured did not differ significantly. In the second week, environmental conditions were also relatively similar, except for higher temperature and pH values in the control areas (without seaweed cultivation). In the fourth week, temperature and salinity were significantly higher in areas without cultivation (control). In the sixth (final) week, only DO values were significantly different, being higher in the areas without cultivation (control) (Table 1).

The PCA analysis results (Figure 8) show high values for *A. formosa* growth and CHI in the third treatment replicate (SF3) at the end of the second week. Conditions at this experimental unit were characterized by relatively high values for DO, pH, PO_4 and temperature. The growth of *P. cylindrica* was highest in all treatment replicates in the sixth week, and was associated with high salinity and low DOM.

Shading effect of seaweed farming on the growth of the corals P. cylindrica and A. formosa. The tendency of both *P. cylindrica* and *A. formosa* coral branches to increase in length under both treatments (cultivation and control areas) over 6 weeks of observation (Figure 4) indicates that the environmental conditions remained suitable for coral growth. However, in addition to the effects of shading, the parameters measured may have affected the growth rates, in particular DO, pH, PO_4, and water temperature (Table 1; Figure 8).

The pH value can affect coral growth because growth is related to the availability of carbonate ions for the formation of coral skeleton. According to Mollicaa et al (2017), low water pH (ocean acidification) is considered an important threat to coral reef ecosystems, because it can reduce the availability of carbonate ions for skeleton formation in corals and other calcifying organisms. Low pH can not only reduce the calcification rate but also reduce the density of coral skeletons. The effects of low light and lowered pH appear to be additive, rather than interactive (Vogel et al 2015), and thus any effect from shading could appear to be magnified under lowered pH and vice-versa. In this experiment, both pH and coral growth declined over the study period. While the reasons for the decline in pH are not known, this positive correlation could represent a causative relationship; it is also possible that both trends might have been caused by one or more other (confounding) factors.

The mean growth of the corals observed over the six week period of this study (Figure 5) can be expressed in cm per month. For *P. cylindrica*, this translates to 1.07 cm per month in the seaweed farming areas and 1.41 cm per month in the control (natural reef) areas, whereas for *A. formosa* it translates to 1.87 cm per month in the seaweed farming areas and 1.81 cm per month in the control (natural reef) areas. As a comparison, for corals transplanted onto MARSS spider reef rehabilitation modules, Rani et al (2017) obtained a growth of 0.12-0.18 cm per month, while fragments transplanted onto natural substrate grew by 0.1-0.24 cm per month. Apart from the difference in *P. cylindrica* substrate between the study of Rani et al (2017) and this study, the translocated fragments on "spiders" and on the natural substrate (dead coral rock) had recently undergone fragmentation. These fragments may well have been allocating a substantial proportion of their energy resources to healing and adaptation rather than to growth, a trade-off which can occur under certain circumstances and may be beneficial to survival (Denis et al 2013). Although Seebauer (2001) considers *P. cylindrica* as a tolerant, long-living and fast-growing species, the fragmentation process could affect these characteristics, especially short-term growth.

The growth rate of *A. formosa* has been reported from studies in several different areas and environmental conditions (Table 2). The data indicates that the growth rates in both seaweed farming and control reef areas were above average for this species.

The t-test showed no significant difference between the treatment and control areas in the growth rates of *P. cylindrica* and *A. formosa* ($P>0.05$). Combined with the high growth rates observed under the seaweed farming units and in the control reef areas around Karampuang Island, it would seem that shading from the seaweed farming units did not affect the growth of either species.

Environmental conditions, including light penetration, can affect coral productivity (Hennige et al 2010), with effects on growth. *A. formosa* is reported as requiring higher light intensity for photosynthesis (170-600 PAR, ideal 340 PAR) compared to *P. cylindrica* (150-250 PAR, ideal 200 PAR) (PAR: $\mu E\ m^2$ sec) (http://www.arcadia-aquatic.com). The light intensity (lux) penetrating to the corals differed between the 2 treatments (Figure 9). However, the difference was not statistically significant ($P>0.05$). Using the empirical lux-PAR transformation of Desmond et al (2015), the light intensity in the seaweed farming and control plots was around 500-600 PAR, at the higher end of the reported range for *A. formosa* and above that for *P. cylindrica*, indicating that some level of shading might be beneficial. Throughout the study period, light intensity remained within a range considered optimal for photosynthesis by zooxanthellae (*Symbiodinium* sp.) living in the coral gastrodermis (Weis 2008; Osinga et al 2012). The lack of significant difference in either growth or CHI between the shaded and non-shaded corals indicates that the range of light intensity remained within the tolerance limits of both coral species observed at the study site.

Table 1

Recorded values of physical and chemical seawater parameters (mean ± SE) over the 6 week study period in the seaweed farming (SF) and control (C) areas

Parameter	*Week 0*			*Week 2*			*Week 4*			*Week 6*		
	SF	*C*	*P*	*SF*	*C*	*P*	*SF*	*C*	*P*	*SF*	*C*	*P*
Temperature (°C)	30.09±0.27	30.4&±0.27	0.375	30.67±0.05	30.98±0.07	0.020*	29.77±0.10	30.43±0.07	0.006*	30.16±0.032	30.33±0.072	0.099
Salinity (‰)	30.83±0.20	30.94±0.14	0.679	31.72±0.15	31.79±0.08	0.709	30.56±0.09	30.92±0.07	0.036*	33.27±0.024	33.09±0.137	0.305
pH	8.32±001	8.24±0.13	0.63	7.93±0.01	7.86±0.02	0.031*	7.48±0.008	7.31±0.06	0.093	7.48±0.009	7.37±0.04	0.097
DO (ppm)	5.58±006	5.03±0.05	0.001*	5.76±0.29	5.36±0.20	0.315	4.2±0.07	4.35±0.13	0.377	4.18±0.01	4.37±0.054	0.021*
NO3 (ppm)	0.03±003	0.03±0.006	0.748	0.02±0.005	0.02±0.005	0.988	0.03±0.006	0.03±0.005	0.717	0.03±0.009	0.02±0.005	0.768
PO4 (ppm)	0.05±0.002	0.04±0.001	0.034*	0.01±0.002	0.01±0.001	0.430	0.01±0.0003	0.01±0.001	0.423	0.01±0.002	0.01±0.001	1,000
DOM (ppm)	34.51±2.47	33.1±2.60	0.714	42.72±1.02	39.54±0.98	0.088	47.88±2.71	41.63±2.52	0.166	40.15±1.131	35.50±1.281	0.053

Note: DO - dissolved oxygen; DOM - dissolved organic matter; * - shows significant differences for P<0.05.

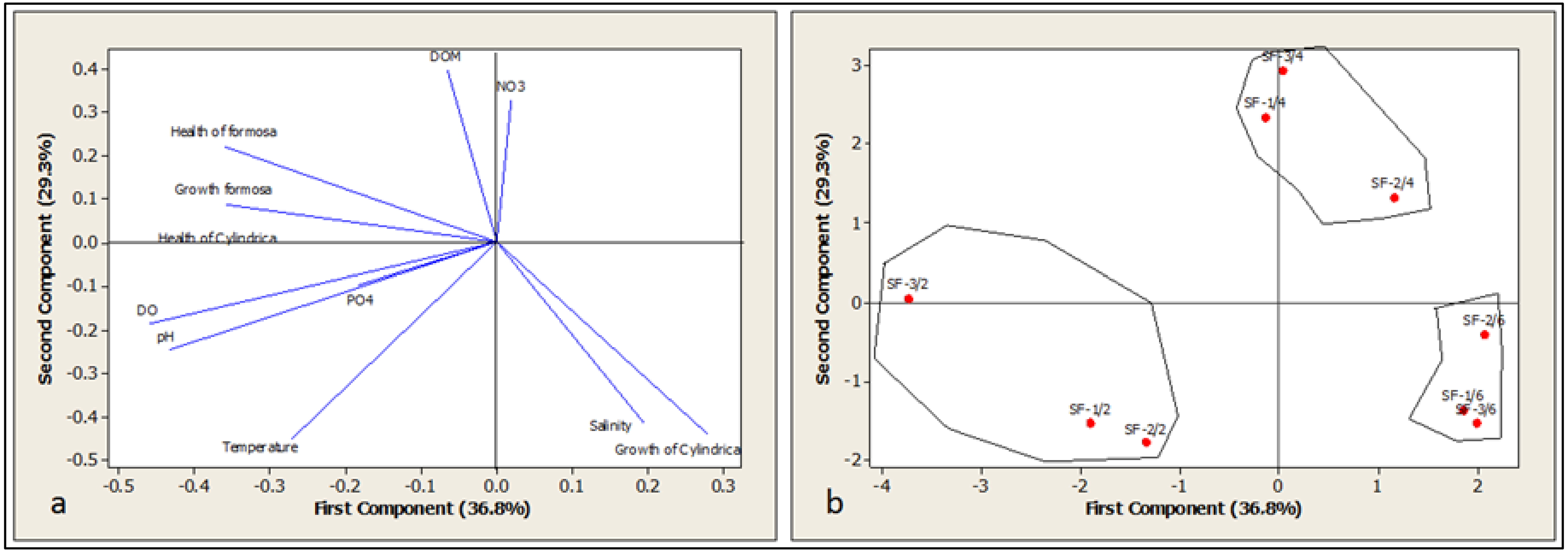

Figure 8. Distribution along the two principal component analysis axes (Axis 1 - first Principal Component Analysis (PCA) component and Axis 2 - second principal component analysis component) of: a - environmental variables, coral growth, and coral health; b - the 2, 4 and 6 week seaweed farming (treatment) plots.

Table 2
Comparison of mean growth rates of *Acropora formosa* from this study and other studies

Region	*Growth rate (cm per month)*	*Environment/remarks*	*Reference*
Indonesia, West Sulawesi, Karampuang Island	1.87 1.81	under seaweed farming units natural reef (control)	Current study
Malaysia, Tioman Island, Pangkor Island	0.65 0.39	natural reef (6 month period)	Xin et al (2013)
Malaysia	0.59-1.20 0.55-0.72	natural reef (control) transplantation site	Xin et al (2016)
Sri Lanka	0.89 0.96	west monsoon period east monsoon period	Jinendradasa & Ekaratne (2000)
Andaman Sea	0.67	fringing reef	Charuchinda & Hylleberg (1984)

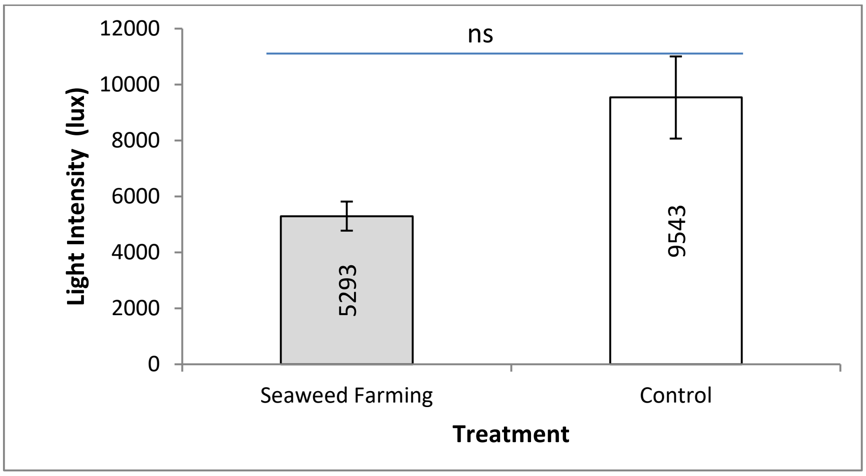

Figure 9. Average light intensity (lux) reaching the substrate under the seaweed farming units (treatment) and in the natural reef (control) areas around Pulau Karampuang. Whiskers show standard error (SE); ns - not significant.

Effect of seaweed shading on the health of the corals P. cylindrica and A. formosa. The CHI values of *P. cylindrica and A. formosa* growing in the seaweed farming plots did not differ significantly (P>0.05) from those in the control area (Figure 7). The range of CHI values remained in the healthy range (codes E4-E6) for both *P. cylindrica* and *A. formosa* with a mode of code E6. These results show that the density of zooxanthellae and chlorophyll content in the coral colonies remained fairly constant throughout the study. According to Siebeck et al (2006), a change of two or more classes in the Coral Health Chart (Figure 3) indicates a significant change in symbiont density and chlorophyll content. If this change is in a negative direction, the corals can be considered to be experiencing bleaching.

Over the 6-week study period, of the 60 *P. cylindrica* colonies and 60 *A. formosa* colonies sampled in the seaweed farming plots, two colonies of each species dropped from code E6 to code E4 (3.33%). Thus, they can be considered to have undergone mild bleaching. However, the remaining colonies (96.67%) stayed in the highest class, HCI 6 (code E6). Likely reasons for this lack of effect are the seaweed farming method used and the environmental conditions. The distance between planting lines (50 cm) was wide enough to enable good light penetration to the substrate below (Figure 9). Furthermore, the study area was quite shallow, mostly 3-4 m at low tide, and horizontal visibility was typically over 20 m throughout the study period. This combination of shallow depth and high visibility enabled a high proportion of sunlight to penetrate to the substrate where the corals were growing. Fitzgerald (2010) found that symbiotic zooxanthellae in hard corals cannot use the full range of light spectra and light intensity penetrating the water column. However, the light spectrum reaching the substrate at water depths found at the study site was within the range that can be effectively utilized by symbiotic zooxanthellae in corals.

The high CHI of *P. cylindrica* and *A. formosa* at the study site was most likely related to water quality. Several parameters can have a significant influence on coral health, one of which is temperature. Water temperature was monitored at 15 recording stations in the seaweed farming area and 15 stations in the control area. The temperature range in the seaweed farming area over the 6-week period was from 29.28 to 32.62°C (mean 30.17±0.55), and from 29.37 to 31.72°C (mean 30.55±0.52) in the control area. The range of temperatures that can be tolerated by corals appears to vary between species and between geographical locations for a given species (Clausen & Roth 1975; Kleypas et al 1999; Anderson et al 2017). Guan et al (2015) give the mean global annual temperature range for corals in tropical regions as 21.7-29.9°C, while Reynolds & Marsico (1993) give a weekly tolerance limit of 18.1-31.5°C. The water temperature at the study site was above the range cited by Guan et al (2015), but within the tolerance range given by Reynolds & Marsico (1993). Annual growth rates of 3 branching coral species (*Acropora muricata, Pocillopora damicornis* and *Isopora palifera*) at 3 distinct locations (Lizard Island, Davies/Trunk Reef, and Heron Island) along Australia's Great Barrier Reef (GBR) were highest at Lizard Island and declined with increasing latitude, corresponding with differences in temperature (Anderson et al 2017).

The salinity at the study site ranged from 29.34 to 34.85‰ (mean 31.60±1.23‰) in the seaweed farming area, whereas in the control area the range was from 29.59 to 33.91‰ (mean 31.69±1.10‰). These ranges and the fortnightly measurements are within the ranges reported as suitable for tropical corals such as the two species studied, for example 28.7-40.4‰ Guan et al (2015); 30-39 (annual) and 23.3-41.8‰ (monthly) (Levitus et al 1994).

The similarity in nitrate concentration is also a factor that may have contributed to the similarity in CHI of the *P. cylindrica* and *A. formosa* in the seaweed farming plots and the control area. High levels of nitrate can result in the proliferation of macroalgae, which can outcompete corals, reducing the ecological functions in the coral reef (Wiedenmann et al 2013). The mean nitrate concentration range during this study (0.027±0.02 ppm) is lower than the 0.032 ppm reported by Levitus et al (1993) and the 0.073 ppm reported by Guan et al (2015), indicating that eutrophication is not a problem in the study area.

Influence of environmental factors on coral growth and coral health. At the start of the research and in week 6, DO was significantly higher ($P<0.05$) in the seaweed farming area compared to the control area. One explanation for this difference could be the position of the two areas, because the seaweed farming units were slightly more exposed to wave and current action, as the control areas were in a more protected area of the lagoonal back reef. Water movement can increase the amount of oxygen diffusing into the seawater (Patterson et al 1991). However, in both seaweed farming and control areas, the DO levels varied with a similar pattern, being lower in week 4 and 6 compared to the start of the study and week 2. Phosphate concentration was significantly higher in the control area compared to the seaweed farming plots at the beginning of the study period. This could be related to the absorption and use of phosphate by the seaweed.

There were significant ($P<0.05$) differences in at least one measurement period in several parameters, including temperature, pH, and salinity. The PCA indicated that the parameters influencing coral growth and health were primarily DO, pH, phosphate, temperature and DOM. Growth of *A. formosa* and CHI were particularly high in the third replicate seaweed farming plot (SF3) in week 2, associated with high DO, pH, PO4 concentration and sea temperature.

The elevated temperature and PO_4 concentration could have positively influenced the rate of photosynthesis by the symbiotic zooxanthellae, resulting in accelerated calcification. Elevated temperature and PO_4 could also increase the mitotic index of the zooxanthellae, increasing the coral health index due to a higher density of zooxanthellae in the coral polyp gastrodermis. The mean temperature in both the seaweed farming plots (30.17°C) and control area (30.53°C) appeared to be within the optimal range for these corals, even though research by Hasanah et al (2018) on the effect of temperature (treatments: 28°C, 30°C, 32°C, and 34°C) on the density of zooxanthellae in the corals *Isopora palifera* and *Acropora hyacinthus* observed a reduction in the density of zooxanthellae in all treatments after 48 hours.

Changes in the oxygen saturation of seawater are also known to influence coral calcification rates (Rinkevich & Loya 1984; Al-Horani et al 2007; Wijgerde et al 2012), possibly because oxygen is an important substrate for ATP synthesis (Babcock & Wikstroem 1992), which in turn is required for the energy-driven process of calcification (Ip et al 1991; Zoccola et al 2004).

Calcification would also be positively influenced by the greater availability of carbonate ions at higher pH. According to Marubini et al (2003), biogenic calcification is influenced by the availability of carbonate ions. Low carbonate ion treatments resulted in significant reductions in calcification and the formation of weaker crystalline structures in the distal regions of the coral *A. verweyi*; calcification was reduced by 13-18% in the corals *Acropora verweyi, Galaxea fascicularis, Pavona cactus and Turbinaria reniformi*.

Conclusions. Seaweed farming units with a 20 cm seed spacing and 50 cm distance between lines did not significantly affect the growth or health index of the scleractinian corals *P. cylindrica* and *A. formosa*. Higher average values of DO, pH, temperature and salinity with lower levels of DOM were associated with faster growth and higher coral health index values.

Acknowledgements. We are grateful to M. Aidil, S. Kel., Muh. Takbir Dg. Sijaya, S. Kel., and Rara Adesuara, S. Kel., for their participation and assistance during the field trips.

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Received: 10 October 2019. Accepted: 12 January 2019. Published online: 30 June 2020.
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How to cite this article:
Parakkasi P., Syamsuddin R., Najamuddin, Haris A., Rani C., 2020 Shading effect of seaweed farming on the growth and health of the corals *Porites cylindrica* and *Acropora formosa.* AACL Bioflux 13(3):1650-1664.