Spatial multi-criteria approach for determining the cultivation location of seaweed *Eucheuma cottonii* in Takalar Regency, South Sulawesi, Indonesia

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Abstract. The success of seaweed cultivation activities is determined by various factors. One of the determining factors is the location of seaweed cultivation. Seaweed cultivation in Takalar District is an important source of income for coastal communities. The purpose of this study was to analyze the suitable areas for conducting cultivation of seaweed *Eucheuma cottonii* in Takalar Regency. This study used quantitative description methods and survey techniques through field observations and laboratory tests. The collected data were physical and environmental parameters of waters which were distributed in several stations in Takalar Regency. These data included sea surface temperature, water clarity, dissolved oxygen (DO), water salinity, pH, nitrate (NO_3), phosphate (PO_4), and chlorophyll *a* (Chl *a*), total suspended solid (TSS) and current velocity. The data collected were then analyzed with a spatial multi-criteria approach in GIS to determine the best area for seaweed cultivation. This study covered approximately 13 222 ha of waters in Takalar Regency. The results of this study indicated that there were suitable and less suitable areas for the cultivation of seaweed *E. cottonii* in Takalar Regency. This study showed that the spatial multi-criteria approach in GIS could be effectively used for determining the suitable areas for seaweed cultivation activities, especially in complex waters such as Takalar Regency waters.

Key Words: spatial multi-criteria analysis, seaweed cultivation, water quality, *Eucheuma cottonii*, Takalar.

Introduction. Seaweed is a commodity that has great potential to be developed. Seaweed products can be used in various industries, such as the pharmaceutical industry (ointments and medicines) and the food industry (agar, alginate, and carrageenan). KKP (2017) reported that seaweed had become a leading commodity of marine aquaculture during the period 2011-2015 and its production had increased to 17.37 percent annually.

Seaweed production in Indonesia can still be improved. The increase in seaweed production in Indonesia is limited by several factors, such as weak cultivation technology (seeds, cultivation methods, harvest age, and post-harvest handling), government regulations (spatial and resource management), and climate change (Campbell & Hotchkiss 2017). One consequence of weak cultivation technology is that seaweed is susceptible to disease, such as ice-ice disease which causes low carrageenan content of seaweed (Carte 1996). These things simultaneously inhibit the increase in seaweed production in Indonesia. The solution that can be done to increase seaweed production is by selecting the suitable cultivation location, knowing the optimal area of cultivated land, and better utilization of seaweed cultivation technology (Rorrer et al 1998; Peira 2002).

Indonesian wet seaweed production in 2001 was 212 478 tons and in 2004 was 410 570 tons. The low seaweed production is due to the potential utilization of the sea which is not yet optimal. Indonesian seaweed production in 2015 amounted to 10 112 107 tons (KKP 2017). Indonesia has vast territorial waters so that seaweed farming activities still have the potential to be developed. According to the KKP (2017), from the total potential area that can be utilized for marine cultivation in Indonesia (12 123 383 ha), only around 2.32% (281 472 ha) had been utilized. This shows the magnitude of the potential development of seaweed cultivation in Indonesia.

One of the seaweed producing areas in Indonesia is South Sulawesi Province, which is the highest seaweed producing province in Indonesia in 2015. The province of South Sulawesi is the largest producer of *Eucheuma cottonii* and *Gracilaria* seaweed in Indonesia. Production of *E. cottonii* seaweed is nine times greater than *Gracilaria* (KKP 2017).

Takalar Regency is one of the areas in South Sulawesi Province that has a long coastline, which is around 74 km, so it has great potential for the development of seaweed farming activities. Rahadiati et al (2018) conducted a mapping of the existing area of seaweed cultivation in Takalar District by using Landsat 8 OLI and reported that the existing area of seaweed cultivation in Takalar Regency reached 2,451 hectares. Seaweed production in Takalar Regency increases every year. According to Dinas Kelautan dan Perikanan Provinsi Sulawesi Selatan (2017), seaweed production in Takalar reached 923 832 tons. This production can still be improved.

Takalar Regency has great potential for developing seaweed cultivation activities. One of the important information needed for the development of seaweed farming activities in Takalar District is information about potential areas of development. This information is very important, but research on potential development areas in Takalar District is still lacking.

The location of seaweed cultivation can be done by taking into account various environmental factors in waters (Chua 1992), especially the influence of the physical, chemical and biological conditions of the aquatic environment on the quality of seaweed. Research on the selection of suitable locations for seaweed activities had been carried out previously by several researchers (Hasnawi et al 2013; Akbar & Nasution 2015; Mustafa et al 2017). These studies used physical, chemical and biological parameters to assess the suitability of cultivation sites and reported that the environmental approach could provide detailed information about potential locations for the development of seaweed cultivation in various regions of Indonesia. Studies on environmental parameters need to be carried out in order to facilitate the selection of locations which can further increase the production and quality of seaweed.

Determination of location and arrangement of space for seaweed farming activities need to be improved to build suitable coastal areas for seaweed cultivation (namely *E. cottonii*). The study related to land suitability analysis for seaweed cultivation needs to be done by considering the biophysical and chemical aspects of the water, all of which are integrated into the concept of land suitability for the development of seaweed cultivation areas. This study aimed to analyze the suitable areas for seaweed cultivation (*E. cottonii*) in Takalar District with a spatial multi criteria approach combined with geographic information systems (GIS). It is hoped that this research can provide information on the optimal potential of seaweed cultivation that can be achieved based on suitable land allocation and can produce a zoning policy formulation for the development of an area based on seaweed cultivation on the coast of Takalar Regency

Material and Method. This research was conducted in the area of Takalar Regency, South Sulawesi Province. There are several sub-districts in Takalar District which are located on the coast and the people carry out seaweed farming activities, such as Sanrobone, Mappakasunggu, and Mangarabombang Districts. The sampling locations were spread over 15 points in the waters of Takalar Regency. Water samples were taken at several points which were scattered in Takalar waters about 4 to 6 km from the coastline. The distance between water sampling points in a line of 3 sampling points was about 1.5-2.5 km. The distance between a line of 3 sampling points was was about 4.5-8 km. Sampling with these distribution patterns was expected to represent the condition of the waters in Takalar Regency (Figure 1).

Field research for primary and secondary data collection was carried out from July to August 2018. The method used for water quality sampling was the ground check survey method designed based on GIS (Geographic Information System). Determination of the location of the observation was carried out by purposive sampling technique.

Water sampling was carried out at a depth of about 1 m below the sea level. According to Hutagalung (1997), the water sampling point for coastal areas with a depth of less than 5 m can be done at one meter below the sea level. Determination of sampling points for estuary or seawater at a certain depth was based on differences in temperature and salinity (Hadi 2005). Water quality sampling was carried out at 08.00-17.00 Central Indonesian Time.

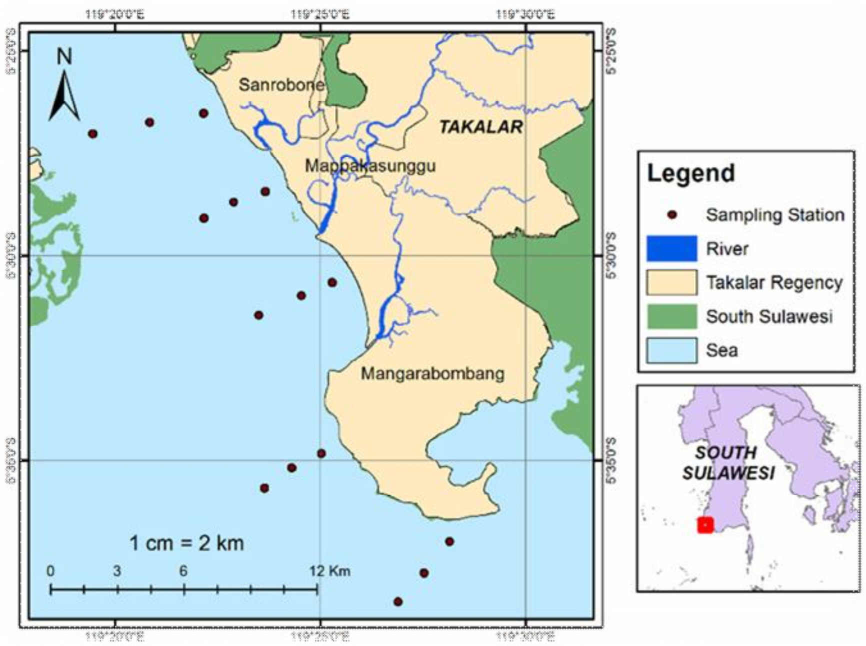

Figure 1. Location of sampling locations in the waters of Takalar Regency.

Data acquisition. Physical, chemical and biological parameters observed in the study were dissolved oxygen (DO), pH, nitrate (NO_3), phosphate (PO_4), temperature (T), chlorophyll concentration (Chl *a*), clarity, salinity, current velocity and total suspended solid (TSS). Interviews were also conducted on seaweed farmers to obtain various information about seaweed activities in Takalar Regency. The secondary data were obtained from the results of previous studies and supporting literature related to the location of the study. Data on physical, chemical and biological parameters were collected directly in the field at each station in three trips. The method of taking water samples and the method of analysis refered to APHA (1992). Each parameter analysis was repeated three times. Parameters observed/measured in detail are presented in Table 1.

Data analysis. The collected water parameter data were analyzed descriptively by comparing with the water quality standard published by KLH (2004) for aquaculture activities or by the standard criteria used by previous studies. Water quality data was shown in the form of tables and drawings.

The suitability analysis of seaweed cultivation location was carried out spatially and based on physical, chemical and biological parameters. The water quality parameters were adjusted to the requirements for feasibility in seaweed cultivation. Analysis of suitability area for seaweed cultivation and mapping of the results were carried out using ArcGIS software version 10.3. The level of suitability was determined by the scoring method and weighting on water quality parameters. Combining several water quality parameters was done by overlaying techniques. The overlay process was done by combining each layer of water quality parameters. The flow of the suitability analysis of seaweed cultivation location used in this study was shown in Figure 2.

Table 1

Observed water quality parameters in the waters of Takalar Regency

No	*Parameter*	*Tools used*	*Data collection methods*	*Unit*
1	Clarity	Secchi disk	In situ	m
2	Temperature (T)	Thermometer kit	In situ	^oC
3	Current velocity	Current meter and stopwatch	In situ	m s^{-1}
4	Salinity	Refractometer ATC 0-100%	In situ	ppt
5	Dissolved oxygen (DO)	Lutron DO Meter-5509	In situ	ppm
6	pH	ATC pH Meter	In situ	
7	Phosphate (PO_4)	Spectrophotometry	In situ and laboratory analysis	mg L^{-1}
8	Nitrate (NO_3)	Spectrophotometry	In situ and laboratory analysis	mg L^{-1}
9	Chlorophyll (Chl *a*)	Niskin bottle	In situ and laboratory analysis	mg m^{-3}
10	Total Suspended Solid (TSS)	Niskin bottle	In situ and laboratory analysis	mg L^{-1}

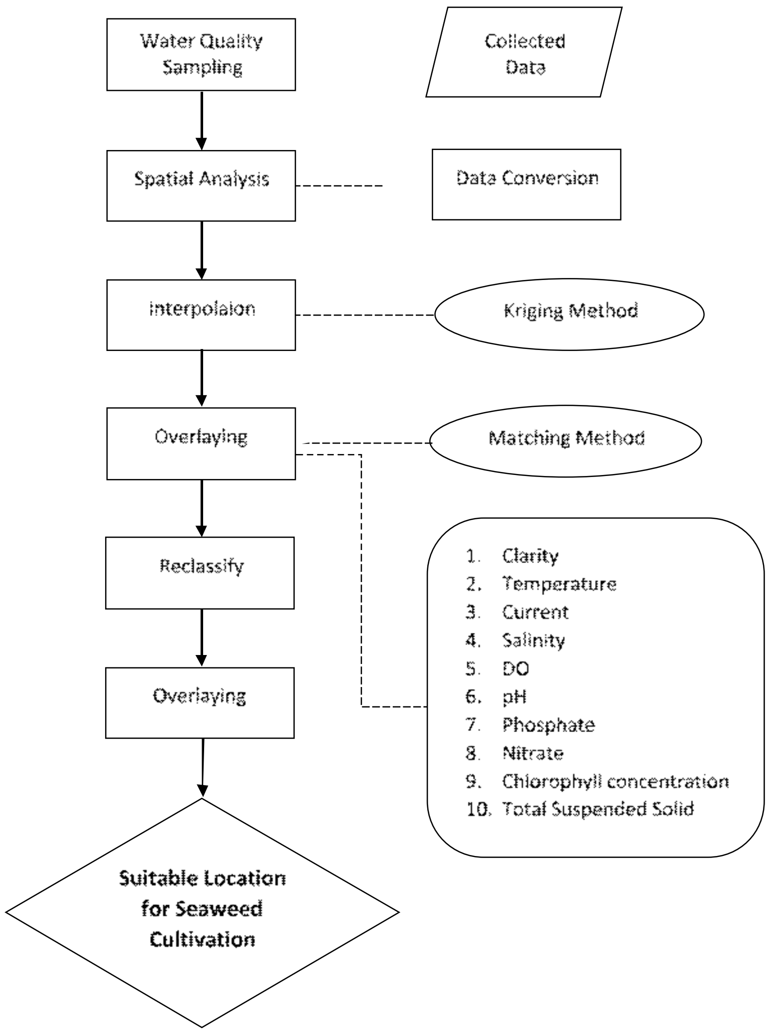

Figure 2. The flow of the suitability analysis of seaweed cultivation location used in this study.

The first step in the location suitability analysis was the preparation of a suitability matrix. This matrix was the basis for spatial analysis. This matrix was prepared through literature studies and it showed the environmental parameters that were important for seaweed cultivation. The criteria used in preparing the matrix to determine the location feasibility of seaweed cultivation were from various sources and research results (Aslan 1988; Dahuri 1998; Harrison & Hurd 2001; KLH 2004; Radiarta et al 2003; Sulistyowati 2003; Arianti et al 2007; Setiyanto et al 2008; Gazali 2013). The criteria used in preparing the suitability matrix were shown in Table 2.

Table 2

Suitability matrix for cultivation location of seaweed *Euchema cottonii*

No	*Parameter**	*Unit*	*Suitability*	*Range*	*Weight (A)**	*Score (B)*	*Total (A x B)*
1	Clarity	m	S1	< 3	12	30	360
			S2	3-5		20	240
			N	> 5		10	120
2	(T)	^oC	S1	24-30	12	30	360
			S2	20-24		20	240
			N	< 20 & > 30		10	120
3	Current velocity	$m\ s^{-1}$	S1	0.2-0.3	10	30	300
			S2	0.1-0.2 & 0.3-04		20	200
			N	< 0.1 & > 0.4		10	100
4	Salinity	ppt	S1	30-32	6	30	180
			S2	22-30 & 32-34		20	120
			N	< 22 & > 34		10	60
5	DO	ppm	S1	> 6	12	30	360
			S2	4-6		20	240
			N	< 4		10	120
6	pH		S1	6.5-8.5	12	30	360
			S2	4-6.5 & 8.5-9.5		20	240
			N	< 4 & > 9.5		10	120
7	PO_4	$mg\ L^{-1}$	S1	0.2-0.5	15	30	450
			S2	0.1-0.2 & 0.5-1		20	300
			N	< 0.1 & > 1		10	150
8	NO_3	$mg\ L^{-1}$	S1	0.9-3.2	8	30	240
			S2	0.1-0.8 & 3.3-3.4		20	160
			N	< 0.1 & > 3.4		10	80
9	Chl *a*	$mg\ m^{-3}$	S1	3.5-10	4	30	120
			S2	0.2-3.4		20	80
			N	< 0.2		10	40
10	TSS	$mg\ L^{-1}$	S1	< 10	9	30	270
			S2	10-40		20	180
			N	> 40		10	90

* Criteria used to prepare the suitability matrix to determine suaitable seaweed location were modified following some information from results of other researchers/agencies (Aslan 1988; Dahuri 1998; Harrison & Hurd 2001; KLH 2004; Radiarta et al 2003; Sulistyowati 2003; Arianti et al 2007; Setiyanto et al 2008; Gazali 2013);
** Value based on references/taking into account dominant variable.

The parameters in this study were categorized into three categories (classes), namely highly suitable category (S1) given a class score 30, suitable category (S2) given a class score 20, and less suitable category (N) given a class score 10. Each parameter was given a weight according to the level of the dominant influence. Furthermore, to conclude the level of suitability of the waters, the final value of all parameters at the station was accumulated. The total score from the multiplication of parameter values with its weight was then used to determine the suitability class of seaweed cultivation based on the characteristics of water quality with the following calculations (Prahasta 2002):

$$Y = \sum a_i . x_n$$

where: Y = final value;

a_i = weighting factor;

x_n = value of suitability level.

Class interval values are determined based on Rauf (2007) using the following formula:

$$I = \frac{(\sum[a_i . x_n]) \quad (\sum[a_i . x_n])_{min}}{k}$$

where: I = suitability class interval;

a_i = weighting factor;

x_n = value of suitability level;

k = desired number of waters suitability classes.

Results and Discussion. Talakar Regency had the potential for high seaweed cultivation. Seaweed in Takalar Regency was cultivated in groups and individually in three different locations, namely in the coastal areas of Mangarabombang District, Mappakasunggu District, and Sanrobone District. The success of seaweed cultivation was greatly influenced by environmental conditions, especially the influence of current velocity and salinity. Seaweed cultivation could be carried out throughout the year, but there were several seasons that have a high productivity for seaweed cultivation. These seasons started from the west season to the first transition season (January - May).

The area of seaweed cultivation per farmer varied depending on location, season and capital. Most farmers had 100-500 stretches of rope. Seaweed cultivation in Takalar was carried out by the long-line method. Some farmers had joined in the seaweed cultivation group. One group consisted of 10 to 15 farmers with adjacent cultivation location. The size of one unit of seaweed cultivation location depended on the number of stretches. In general, the size of one unit was 50 x 50 m or 50 x 100 m, with a rope length of about 25-50 m and a distance between ropes was 1 m. Planting seaweed seedlings was done by tying in the stretch ropes, with distance between seedlings was 10-20 cm.

Spatial distribution profile of water quality parameters. Measurements of water quality parameters were carried out to determine water quality as well as a basis for determining the suitability of *E. cottonii* seaweed aquaculture in Takalar Regency. Water quality sampling was done in August 2018 at several locations, namely Mangarabombang, Mappakasunggu and Sanrobone. Seawater quality data was taken at 15 water station points in Takalar Regency, so that it could represent the spatial profile of water quality parameters. Water quality parameter data was shown in Table 3.

Table 3

Range of water quality parameters in Takalar Regency waters

No	*Parameter*	*Unit*	*Value*	*Standard*	*Reference*
1	Clarity	m	5.91±2.67	> 3	Sulistyowati (2003)
2	Temperature	^oC	26.76±0.31	24-30	Glenn & Doty (1981)
3	Current velocity	m s^{-1}	0.24±0.12	0.04-0.06	Hurd et a (2014)
4	Salinity	ppt	34.20±0.40	25-35	Yong et al (2014)
5	DO	ppm	7.38±0.24	> 5	PHILMINAQ (2006)
6	pH	-	8.23±0.27	7.8-8.4	Prema (2013)
7	PO_4	mg L^{-1}	1.00±0.12	0.2-0.5	Harrison & Hurd (2001)
8	NO_3	mg L^{-1}	0.13±0.13	0.9-3.2	Parenrengi et al 2011)
9	Chl *a*	mg m^{-3}	0.83±0.66	Not blooming	KLH (1998)
10	TSS	mg L^{-1}	3.07±2.08	< 10	PHILMINAQ (2006)

Sea surface temperature. The results of the measurements of sea surface temperature in August 2018 in the waters of Takalar Regency showed that the lowest temperature reached 25.70°C and the highest reached 27.24°C, with an average of 26.76°C (Figure 3). Based on the spatial distribution profile of sea surface temperature, there was a similar distribution pattern, where temperature was relatively lower around the coast. There was no difference in temperature in the waters of Takalar Regency and it generally had a uniformly distributed temperature. The low temperature found near the coast was influenced by the presence of rivers that affected the sea surface temperature in this area. The river provided fresh water input to the ocean waters, which affects the sea surface temperature.

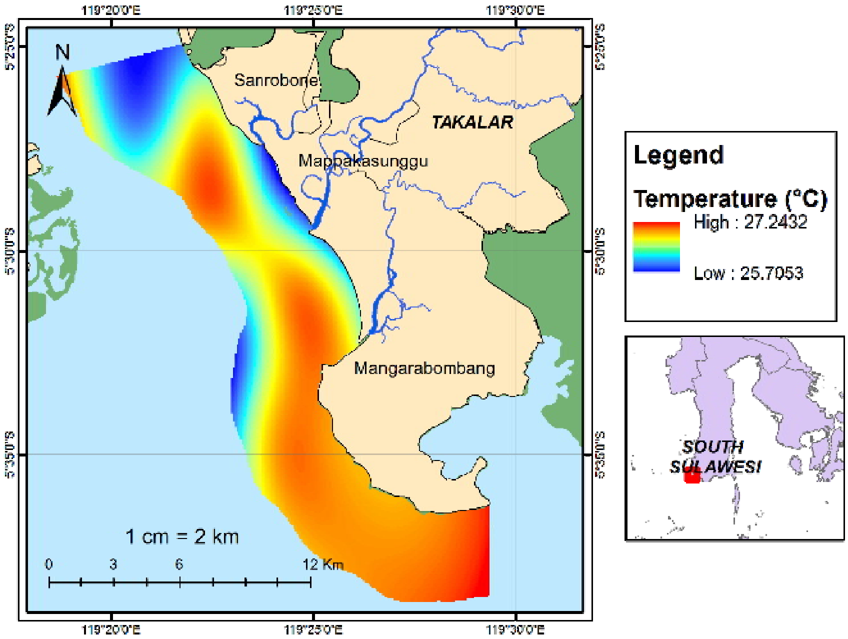

Figure 3. Spatial distribution profile of seawater temperature in the waters of Takalar Regency.

Seawater temperature was one of the parameters that determined the success of *E. cottonii* seaweed cultivation. Kawabe & Kawabe (1997) also emphasized that the most important factors for photosynthesis for algae are solar radiation and seawater temperature if compared to nutrient factors in the waters. The temperature of seawater could affect the photosynthesis rate and growth rate. Optimal photosynthesis rates are at a temperature range of 23-30°C (Glenn & Doty 1981; Mairh et al 1995; Ding et al 2013; Redmond et al 2014) and photosynthesis would decrease in the range of temperatures below 20°C and above 35°C (Glenn & Doty 1981; Mairh et al 1995). Based on the measurement results, the average water temperature in August 2018 in Takalar Regency was 26.76°C. This showed that these waters could maximize the photosynthetic rate of seaweed.

Chlorophyll a concentration. The results of chlorophyll *a* measurements showed that chlorophyll concentrations were relatively higher in the coastal area (3.1062 mg m^{-3}) and lower in the central part (0.1 mg m^{-3} of Takalar Regency waters. The average chlorophyll concentration in Takalar Regency waters was 0.83 mg m^{-3}. The spatial distribution profile of chlorophyll concentration was shown in Figure 4. As a biological parameter, chlorophyll is often used as an indicator of stability and fertility as well as water quality. Therefore, chlorophyll has an important role in the food chain in aquatic ecosystems. The relationship between the concentrations of chlorophyll to the growth of seaweed is the concentration of chlorophyll as an indicator of water fertility. Aquatic fertility indicated the presence of nutrients contained in the waters, namely nitrate and phosphate. By knowing the fertility of a waters it will affect the growth of seaweed optimally. According to Msuya & Neori (2008), high nutrient content in a water can support optimal seaweed growth.

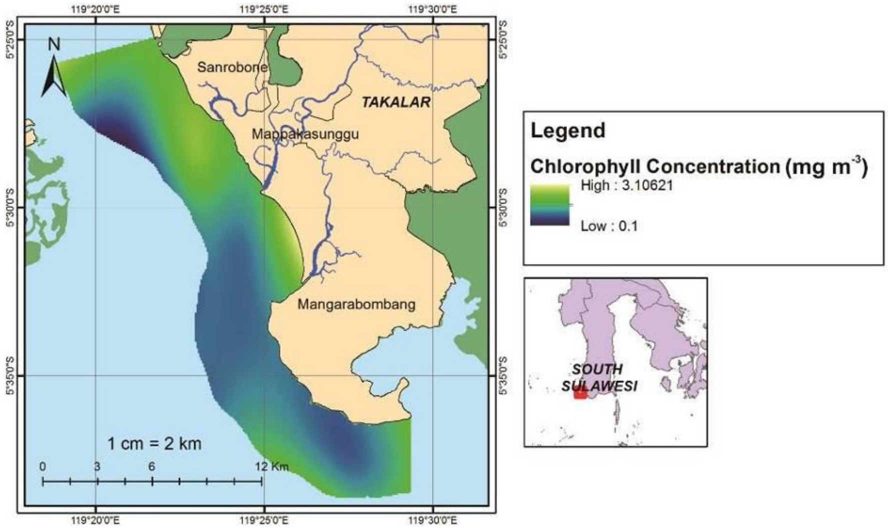

Figure 4. Spatial distribution profile of chlorophyll concentration in the waters of Takalar Regency.

Phosphate (PO_4) concentration*.* Based on the results of phosphate analysis in Takalar District waters, the spatial distribution pattern of phosphate tended to have the same concentration in Takalar waters. The phosphate concentration in the waters of Takalar Regency in August 2018 ranged from 0.49 to 1.83 mg L^{-1}, with an average of 1 mg L^{-1}. High phosphate concentration was in the southern part of Takalar Regency waters. This was probably due to industrial waste around Mallasoro Bay (Figure 5).

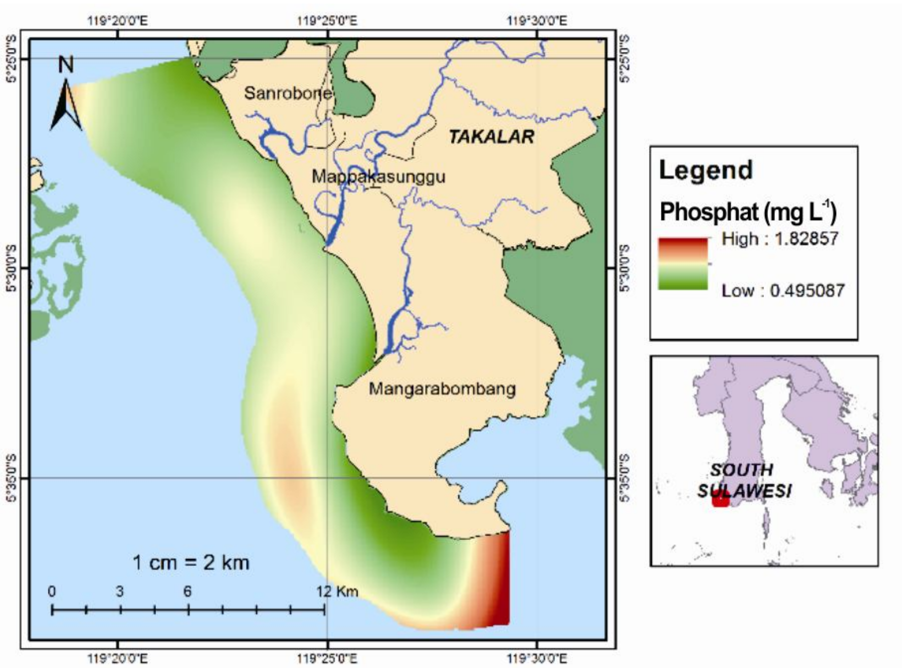

Figure 5. Spatial distribution profile of phosphate (PO_4) in the waters of Takalar Regency.

The average of phosphate concentration in the waters of Takalar Regency was 1 mg L^{-1}. Based on the suitability criteria for seaweed cultivation, the phosphate concentration in the waters of Takalar Regency in August 2018 was is suitable category (S1). Phosphate concentration in a water will affect the growth of seaweed. Phosphate deficiency will have more impact on aquatic plants including seaweed compared to lack of nitrate in the waters. Phosphate is a form of phosphorus that can be utilized by plants and is an important element for higher plants and algae, so that phosphate concentration can affect the level of fertility and productivity of water. Phosphate in waters can be sourced from industry, domestic waste, agricultural activities, rock phosphate mining, and deforestation. Based on AMWQ (2008), the standard safe limit for the life of organisms in the sea and for human health to phosphate concentration is 15 µg L^{-1} (0.015 mg L^{-1}).

Nitrate (NO_3) concentration. Based on the results of the analysis, the concentration of nitrate in the waters of Takalar Regency in August 2018 showed a tendency for the same nitrate concentration in all waters, except for the higher in southern part (Figure 6). Nitrate concentration in Takalar waters ranged from 0.01 to 0.56 mg L^{-1}, with an average nitrate concentration of 0.13 mg L^{-1}. Nitrate concentration in the waters of Takalar Regency was still in a good range for marine biota. Parenrengi et al (2011) reported that nitrate concentrations suitable for seaweed growth ranged from 0.9 to 3.2 mg L^{-1}.

Seaweed as a chlorophyll plant requires nutrients as raw material for photosynthesis. Nitrate is the main form of nitrogen in the waters and is the main nutrient needed for plant growth and algae. Nitrates are very easy to dissolve in water and are stable. The main sources of enrichment of nitrate nutrients in waters are derived from runoff, erosion, leaching of fertile agricultural land and residential waste. The element of nitrate in waters is very important because nitrate shows the level of fertility of waters. The higher the nitrate concentration, the higher the fertility level of the waters. However, if nitrate is too high, it can create algae as competitors in obtaining nutrients and affecting the growth of seaweed. Teichberg et al (2010) reported that seaweed growth had a positive correlation with increasing concentrations of dissolved inorganic nitrogen.

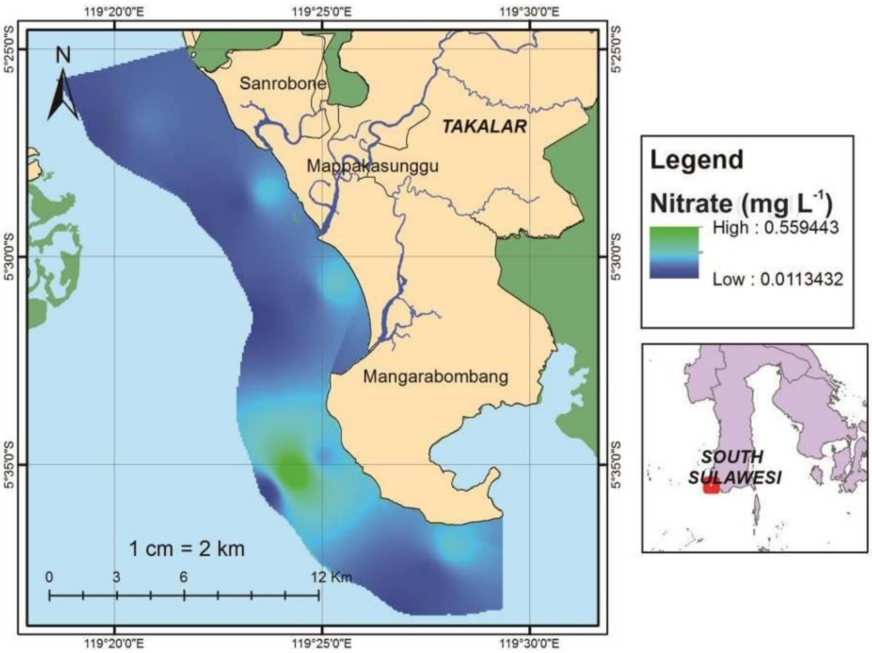

Figure 6. Spatial distribution profile of nitrate concentration in the waters of Takalar Regency.

Clarity. Based on the results of the analysis, the clarity of the waters in Takalar Regency ranged from 2.15 to 10.48 m, with an average clarity of 5.91 m. The clarity level of water in Takalar Regency was lower in the north when compared to the southern part (Figure 7). This was probably due to the existence of a river that carries run off from the land in the north. The run off affected the clarity of the waters around the mouth of the river.

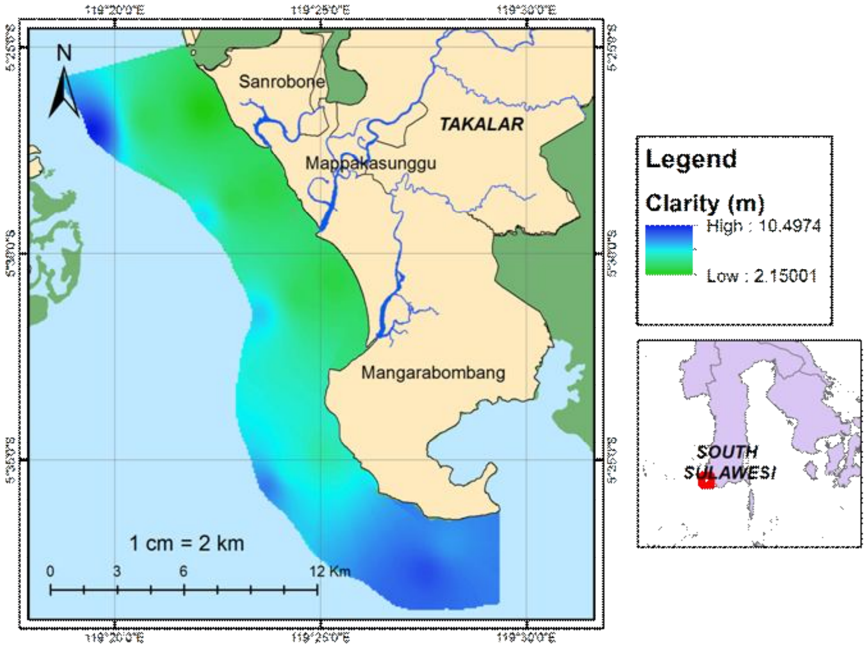

Figure 7. Spatial distribution profile of clarity in the waters of Takalar Regency.

The average clarity of the waters in Takalar Regency was 5.91 m. This showed that Takalar waters could support the growth of seaweed optimally. Clarity of waters that was suitable for seaweed cultivation locations is more than 3 m (Sulistyowati 2003). The clarity level of waters could affect the growth of seaweed. The higher the level of brightness, the more effective the photosynthesis process will be for the addition of the mass of cells forming seaweed talus (Hayashi et al 2007).

Total Suspended Solid (TSS) concentration. Based on the results of measurements of TSS, the waters in Takalar Regency tended to be higher near the coast. The TSS in the waters of Takalar Regency in August 2018 ranged between 0 and 10 mg L^{-1} (Figure 8). Based on the land suitability criteria for *E. cottonii* seaweed cultivation, the waters of Takalar Regency with an average TSS of 3.07 categorized into the highly suitable category. Adipu et al (2013) reported that TSS which was highly suitable for *E. cottonii* seaweed growth was less than 10 mg L^{-1}.

TSS is something that is held by a filter, while those passing through filters are classified as dissolved solids, which are usually 0.45 µm (APHA 1998). The level of turbidity of waters can affect the level of penetration of light entering the water column and as an ingredient for photosynthesis for algae. Some of the factors that influence TSS concentration are high current velocity, soil erosion, freshwater input from land through rivers (run off), domestic and industrial waste and so on (PHILMINAQ 2006). High TSS concentrations have several negative effects, such as reducing the amount of light that can penetrate into the water column, thus slowing down the process of photosynthesis. Sastrawijaya (2000) states that TSS concentration in waters generally consists of phytoplankton, zooplankton, human activity waste, sludge and industrial waste.

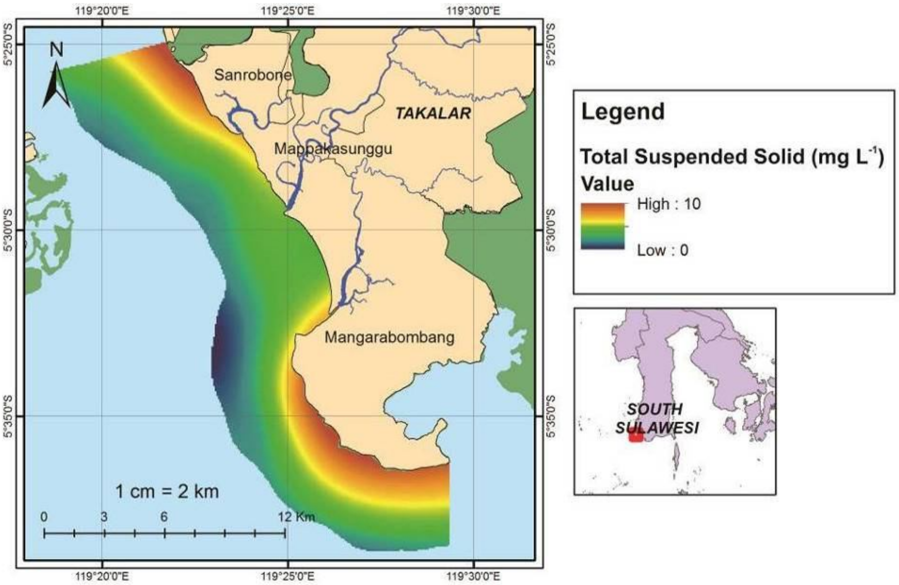

Figure 8. Spatial distribution profile of total suspended solid in the waters of Takalar Regency.

pH of sea water. The results of pH measurements of seawater in the waters of Takalar Regency in August 2018 showed a pattern of pH concentration which tended to be the same in all waters. The waters of the southern part of Takalar Regency had a slightly higher pH than the northern part. This was probably due to the presence of freshwater input from the river in the northern part of the waters. The waters of Takalar Regency had pH ranging from 7.83 to 8.69, with an average of 8.23 (Figure 9). Based on this, it could be concluded that the waters of Takalar Regency was suitable for seaweed cultivation. Prema (2013) reported that waters with a pH between 7.8 and 8.4 are still in a good category for marine biota.

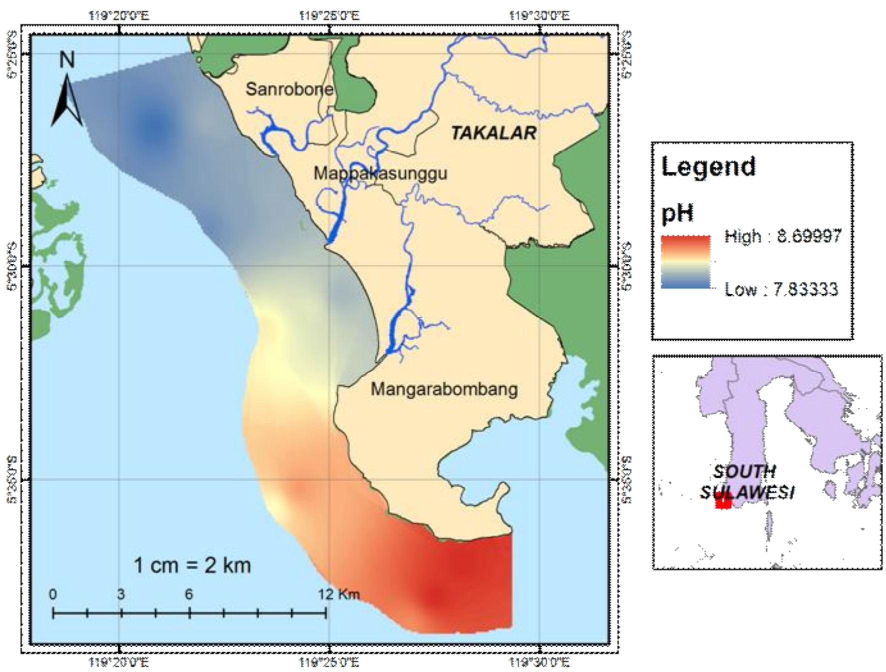

Figure 9. Spatial distribution profile of pH in the waters of Takalar Regency.

The pH concentration of a water can affect the growth of seaweed. Luzio & Thompson (1990) reported that the optimum pH condition for the growth of *E. cottonii* was in slightly more alkaline water conditions (pH ranged from 7.5 to 8.0). Furthermore Tee et al (2015) reported that the growth of *Kappaphycus alvarezii* was influenced by the pH condition of waters.

Salinity. The results of measurements of salinity in the waters of Takalar Regency indicated that the average salinity was equal to 34.20 ppt. The spatial distribution pattern of salinity in the northern part of the waters starting from Sanrobone Districts to Mappakasunggu Districts which is equal to 34.0 ppt tended to be lower compared to the southern parts of waters which reached 34.99 ppt. This showed that the salinity in the coastal part of the waters tended to be lower compared to the middle part of the waters. According to Gazali (2013), salinity averages 33.69-34.53 ppt was suitable for the growth of seaweed *E. cottonii*. The spatial distribution of seawater salinity in the waters of Takalar Regency was presented in Figure 10.

Salinity is a very important factor in supporting the growth of *E. cottonii*. This is because the salinity of seawater greatly determines the quality of seaweed, growth and the aging process of the seaweed thallus. Naturally, the *E. cottonii* seaweed will grow well under high salinity conditions. Salinity of sea water greatly affects the carrageenan content and growth of *E. cottonii*. Ding et al (2013) and Yong et al (2014) stated that the highest growth rate of *E. cottonii* was at salinity of 25-30 ppt. The highest carrageenan content of *E. cottonii* was at 25 ppt salinity (Hayashi et al 2011).

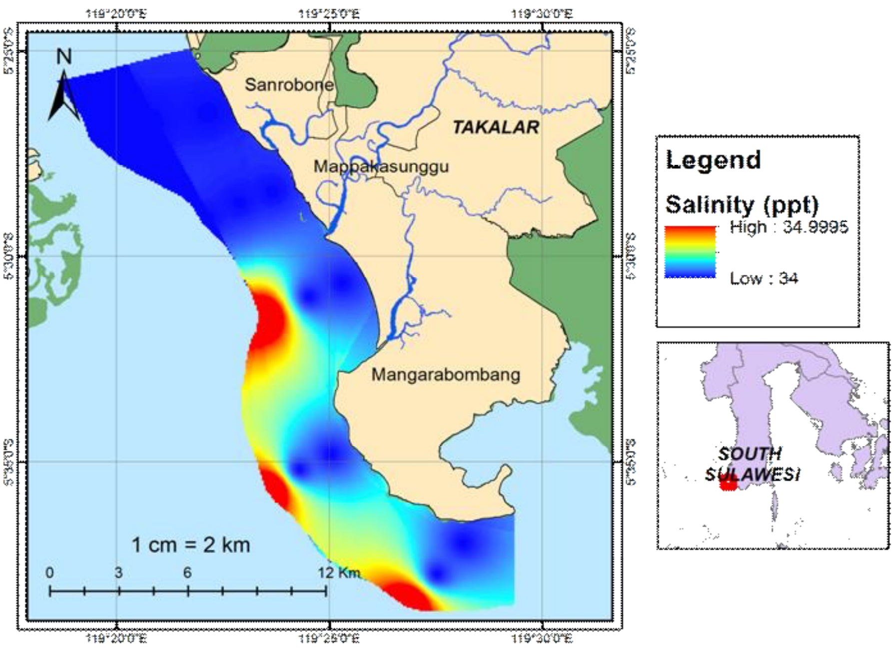

Figure 10. Spatial distribution profile of salinity in the waters of Takalar Regency.

Dissolved oxygen (DO). DO is an oceanographic parameter that is important for aquatic ecosystems. The life of organisms in the waters is dependent on the ability of water to maintain the minimum oxygen concentration needed for life. According to Radiarta et al (2004), one of the factors that influence the respiration process of seaweed in the waters is DO. Based on the results of the study, DO in Takalar Regency waters ranged from 7 to 8.62 ppm (Figure 11). The suitable DO for seaweed cultivation is more than 5 ppm (Radiarta et al 2004; KLH 2004). This indicated that the waters of Takalar Regency were suitable for seaweed farming activities. According to Rahadiati et al (2017), the waters of Takalar Regency had a suitable DO to support the seaweed farming activities.

Based on the results of DO measurements in the waters of Takalar Regency, there was no significant difference between the northern waters and the southern waters with an average of 7.38 ppm. However, it tended to be higher on the coastal part of the waters, reaching 8.6225 ppm (Figure 11). The magnitude of the change in DO content in the sea is strongly influenced by changes in temperature, where the higher the temperature the DO concentration decreases. Oxygen plays an important role as an indicator of water quality, because DO plays a role in the process of oxidation and reduction of organic and inorganic materials. KLH (2004) reported that DO is important for the survival of marine life in a water.

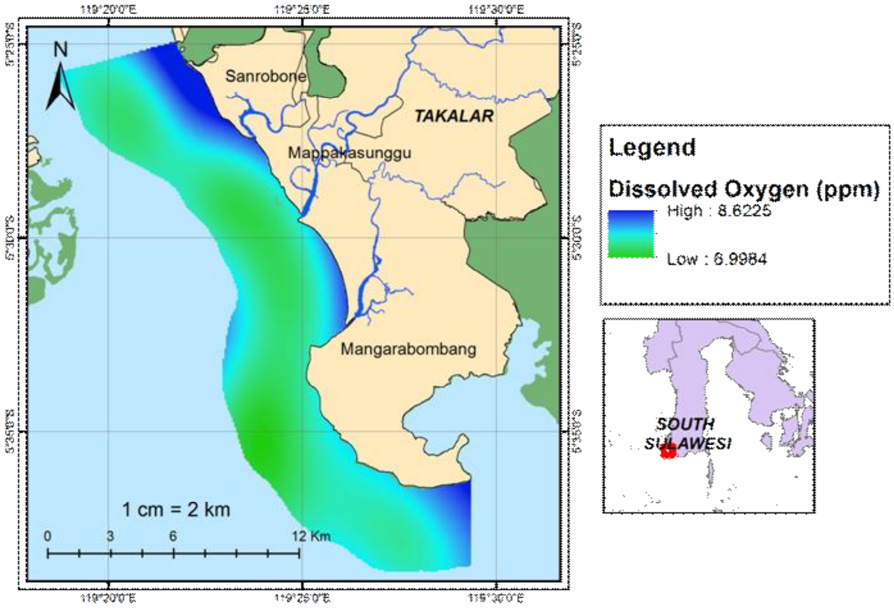

Figure 11. Spatial distribution profile of dissolved oxygen in the waters of Takalar Regency.

Current velocity. The results of the current velocity analysis showed that Takalar Regency waters had an average current velocity of 0.24 m s^{-1}. The current velocity in the waters of Takalar Regency was generally higher in the southern part, which was 0.49 m s^{-1}. This was probably due to the fact that in the southern part of the waters of Takalar Regency was directly adjacent to the open water, namely the Flores Sea. The current velocity in the north was lower at 0.03 m s^{-1}. The profile of current velocity distribution in the waters of Takalar Regency was presented in Figure 12.

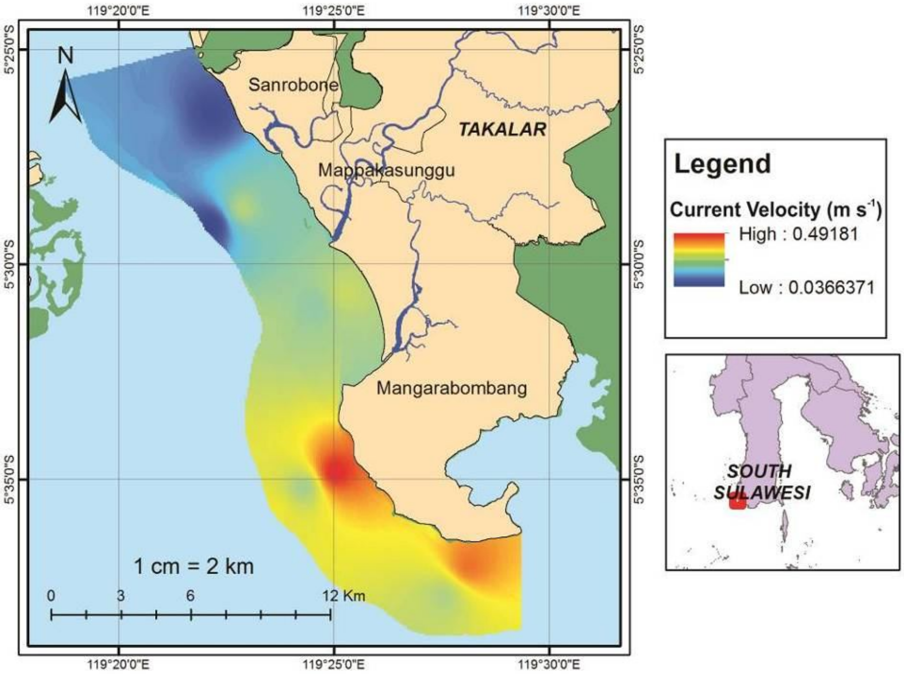

Figure 12. Spatial distribution profile of current velocityin the waters of Takalar Regency.

Current movements are very important for the growth of seaweed. According to Arisandi (2011), surface currents greatly influence the spatial distribution of nutrients and the stability of the seaweed cultivation using the long line method. If the currrent velocity is too slow, it will disrupt the absorption of nutrients in the waters. In addition, a slow current velocity will have an impact on the increasing chances of growing epiphytes attached to seaweed, so that it can become a competitor in obtaining nutrients. Vice versa, if the flow velocity is too high, the seaweed rope will be carried away and will likely be damaged. Thus, the current velocity parameters greatly influence the suitability for seaweed cultivation by the long line method in the sea level column. Prema (2013) stated that the optimum growth of *E. cottonii* seaweed occurred during a current velocity of ± 0.2 m s^{-1}. Based on Hurd et al (1996) stated that the current velocity will affect the process of absorption of nutrients, where the maximum absorption rate at the current velocity is 0.04-0.06 m s^{-1}. The movement of surface currents is strongly influenced by the movement of wind that blows above sea level.

Location suitability for seaweed cultivation. The mapping analysis of the suitability of *E. cottonii* seaweed cultivation location was carried out by overlaying several oceanographic parameters. Before overlaying, scoring and weighting of each parameter were adjusted according to the suitability criteria in Table 1. Suitability analysis was carried out using ArGIS version 10.3.

Based on the results of the analysis, the location of *E. cottonii* seaweed cultivation in the waters of Takalar Regency with a highly suitable category (S1) was an area of 3538 hectares, the suitable category (S2) was 8736 hectares, and less suitable (N) covering an area of 1901 hectares. If assuming the highly suitable (S1) and suitable (S2) categories were combined into appropriate and suitable area for seaweed, then the corresponding total area was 12 274 hectares (Table 4).

Table 4

The results of the suitability analysis of the *Eucheuma cottonii* seaweed cultivation location in Takalar Regency

Suitability	*Area (ha)*
Highly suitable	3538
Suitable	8736
Less suitable	1901

Based on the results of the analysis of the suitability of the location of seaweed cultivation, in general, a highly suitable location for seaweed cultivation in the waters of Takalar Regency was distributed around the coast. Locations with suitable categories were almost evenly distributed in the waters of Takalar Regency. Less suitable areas were located near the Sanrobone District (Figure 13). Based on these results, it could be concluded that the potential for developing seaweed farming activities in the waters of Takalar Regency was very large. Seaweed production in the waters of Takalar Regency could still be improved. Increased seaweed activities in coastal areas could improve the welfare of the people on the coastal area.

The results of this analysis can be used as additional information to produce appropriate policies for the development of seaweed farming activities. The addition of seasonal suitability analysis can provide better information for stakeholders. Seasonal changes will affect changes in oceanographic parameters, thus affecting changes in water conditions (Rivai et al 2018). Handa et al (2013) states that in general the condition of the waters varies greatly depending on the season and changes in the ecological conditions of the waters that can affect the nutrient content in the waters. Seaweed cultivation productivity is strongly influenced by season and location (Parenrengi et al 2011). Climate change can affect the physical and chemical characteristics of waters so that it can have an impact on the emergence of ice-ice disease. This disease is the most common obstacle and is feared by seaweed farmers. Ice-ice disease can decrease seaweed production and cause a decrease in the level of seaweed carrageenan up to

40% (Trono 1993). Therefore, the planning and management of *E. cottonii* seaweed cultivation in Takalar Regency must be supported by precise and accurate data and information on oceanographic parameter fluctuations every season.

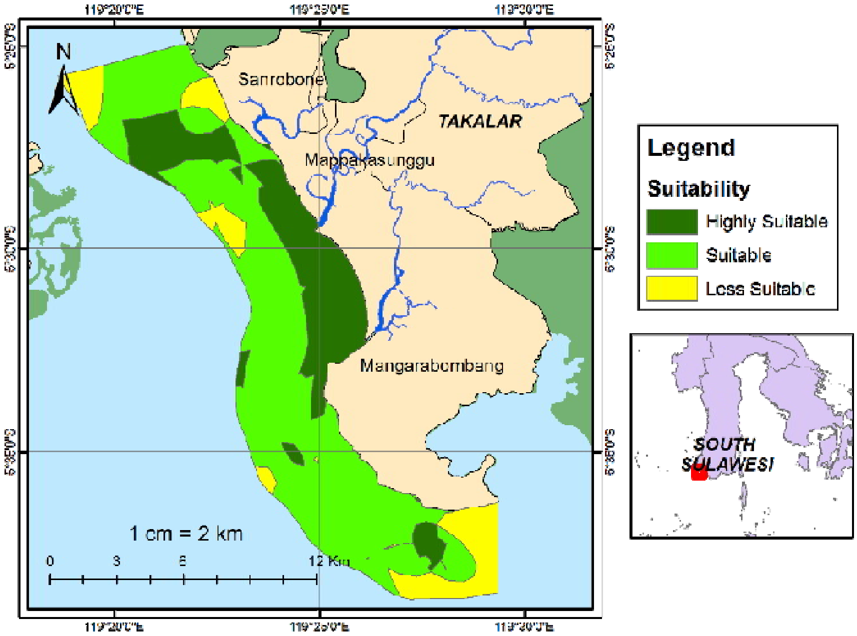

Figure 13. Map of suitability of seaweed cultivation locations in Takalar Regency.

Conclusions. There were suitable areas and less suitable areas for *Eucheuma cottonii* seaweed cultivation in Takalar Regency. In general, the waters in Takalar Regency were suitable for seaweed cultivation. The area that was suitable for seaweed cultivation in Takalar Regency was 12 274 hectares. With this area, Takalar Regency has a great potential to develop the seaweed cultivation activities. Good seaweed cultivation activities can improve the welfare of coastal communities in the Takalar Regency. This study showed that the spatial multi-criteria approach in GIS could be effectively used for the determination of suitable location for seaweed cultivation activities, especially in complex waters such as in the waters of Takalar Regency.

Acknowledgements. This research was funded by PNBP DIPA Makassar State University with SP DIPA-042.01: 2.400964/2018. Thanks to all seaweed farmers who had participated in this research. Thanks were also given to students and to the Department of Agricultural Technology Education of Makassar State University that had helped in the data collection process and had provided facilities during the research process.

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Received: 29 January 2019. Accepted: 08 May 2019. Published online: 30 August 2019.
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How to cite this article:
Jamaluddin, Syam H., Mustarin A., Rivai A. A., 2019 Spatial multi-criteria approach for determining the cultivation location of seaweed *Eucheuma cottonii* in Takalar Regency, South Sulawesi, Indonesia. AACL Bioflux 12(4):1413-1430.