Aquaculture feasibility and suitability of the coastal areas of Karampuang Island, West Sulawesi, Indonesia

[1]Mega L. Syamsuddin, [2]Hammami U. Faiz, [1]Mochamad R. Ismail, [1]Syawaludin A. Harahap, [1]Yuniarti MS, [1]Yudi N. Ihsan, [1,3]Fadli Syamsudin, [1]Qurnia W. Sari, [4]Christopher M. Aura

[1] Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jatinangor, Sumedang, Indonesia; [2] Marine Science Study Program, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jatinangor, Sumedang, Indonesia; [3] National Research and Innovation Agency (BRIN), Jakarta, Indonesia; [4] Kenya Marine and Fisheries Research Institute, Kisumu, Kenya. Corresponding author: M. L. Syamsuddin, mega.syamsuddin@unpad.ac.id

Abstract. The potential of Indonesia's coastal and marine areas is mainly based on both capture and aquaculture resources. This necessitates the need for development of aquaculture suitable areas for improved utilization of the coastal space. The aquaculture suitability of the coastal area of Karampuang Island is related particularly to the cultivation of sea cucumbers, seaweed, and floating net cages for fish farming. Thus, this research aimed to develop a unified suitability mapping approach for coastal aquaculture activities and to optimize the profitability of the coastal areas. The method involved the use of environmental data for the suitability matrix data application. The study recorded highly suitable areas for sea cucumber cultivation in the northern and southeastern parts of Karampuang Island, while the potentially suitable areas for seaweed cultivation were found to be located in the southwestern and southeastern parts. The areas suitable for floating net cages for fish farming were in the northern and western parts of the Island. The results of this study can be used to expand blue economy activities and maximize the utilization of coastal space for aquaculture production.
Key Words: floating net cages, aquaculture suitability, seaweed, sea cucumbers, fish farming.

Introduction. Currently, the use of natural resources is increasingly experiencing constraints. Increased demand for freshwater sources, population growth, and extended industrial discharge have significant implications for coastal ecosystems and estuaries. Additionally, coastal littoral zones bear the brunt of the synergistic effects of multiple anthropogenic activities due to their proximity to land (Alber 2002; Flemer & Champ 2006). Therefore, there is an increasing need for water resources management to mitigate human impacts on these ecosystems. Thus, the proper management of coastal and marine resources is essential for development and is expected to be a leading sector in the national, regional, and international development (Suparno et al 2022). If managed properly, the potential of coastal and marine resources can make a significant contribution to the blue economic growth of Indonesia. These areas have unique resources that include renewable and nonrenewable resources, and environmental services (Umar & Dewata 2020; Puspita et al 2023).

The potentiality of Indonesia's coastal and marine areas for both captures and aquaculture fisheries cannot be underestimated. Currently, many areas of Indonesia's sea have experienced overfishing (Sari & Muslimah 2020). This could be due to the assumption that coastal and marine areas are common property and of open access, which triggers competition in the use of such resources, leading to conflicts in the use of the coastal space (Muawanah et al 2012).

Several studies have created site suitability maps for various aquaculture cultivations using methods such as multicriteria evaluation (Aura et al 2017, 2021). Aquaculture, especially the marine aquaculture sector, due to its enormous development potential, can optimize the use of the coastal space and supplement the production of fish and fish products. The land area that might be developed for cultivation activities is approximately 158,125 ha, but only 1,390 ha has been developed (Salim 2016). This represents a significant blue economic opportunity for Indonesia to increase the production of its aquaculture. Marine aquaculture is one of the fishery activities that aims to increase the production of marine organisms that have important economic value by manipulating the growth rate, mortality, and reproduction of aquatic organisms. Seaweed cultivation has been the focus of research for over a decade with the intention of creating knowledge to support the development of the marine economy (Stanley et al 2019). Aquaculture activities in the area also provide solutions for fisheries businesses to provide fishery products continuously and can reduce the level of exploitation of the various types of marine biota that can be cultivated (Hasim & Kasim 2017). However, the magnitude of the potential of marine aquaculture has not been supported by accurate information and data, making the development of marine aquaculture businesses suboptimal and its planning more difficult. One of the critical issues is the carrying capacity of the coastal environment (Haghshenas et al 2021), and in particular the water quality parameters that are not appropriate for marine aquaculture activities and for some biota to be cultivated (Verma et al 2022).

To select the location and use of space for sustainable marine aquaculture activities, it is necessary to carry out suitability mapping with integrated proximity (biosphere concept) based on the scientific rules of mapping (Geodetic Science) (Haghshenas et al 2021) and on coastal ecosystems and landscapes management (Coastal Management) (Stead et al 2003). The results of the mapping are vital as reference information for planning sustainable aquaculture. Spatial mapping could also be useful for monitoring water quality change detection in space and time (Thuan 2022; Ranintyari et al 2018; Simanjorang et al 2018).

The coastal and marine resources of West Sulawesi Province have high and prospective potential for the development of marine aquaculture activities. This is in line with the government policies for the issuance of regional autonomy policies (Law Number 22, 1999). This is also because the provincial governments are now authorized to manage coastal and marine resources up to 12 miles, and it is critical to pay attention to the potential of these resources (PP 25 2000). The current study focuses on the province of West Sulawesi, which consists of 5 districts, namely, North Mamuju, Mamuju, Majene, Polewali, and Mamasa (Law Number 26, 2004). The strategic location of West Sulawesi is due to its closeness to the integrated development area of Tomini Bay, in the shipping lanes of the Makassar Strait (Gani et al 2022).

Considering some of the fundamental aforementioned reasons, regional mapping, particularly of marine aquaculture activities in West Sulawesi waters, documented by digital (images) and dynamic multi-scale data, is necessary in order to provide reliable and up-to-date data on aquaculture suitability. In this case, the database is the fundamental asset that can assist in identifying and exploring mariculture potential and can be used as a foundation for preparing a Coastal and Marine Spatial Plan and serve as a reference for a sustainable Integrated Marine Resources Management (IMRM) and Utilization Plan. A clear, certain, applicable, reliable, and accountable action plan should be based on maps (Haghshenas et al 2021).

Material and Method

Description of the study sites. Karampuang Island is located in Mamuju District, Mamuju Regency, West Sulawesi Province, Indonesia, with a wide area of 6.37 km^2. The water quality of Karampuang Island was analyzed by taking water samples from eight georeferenced point stations around the island (Figure 1).

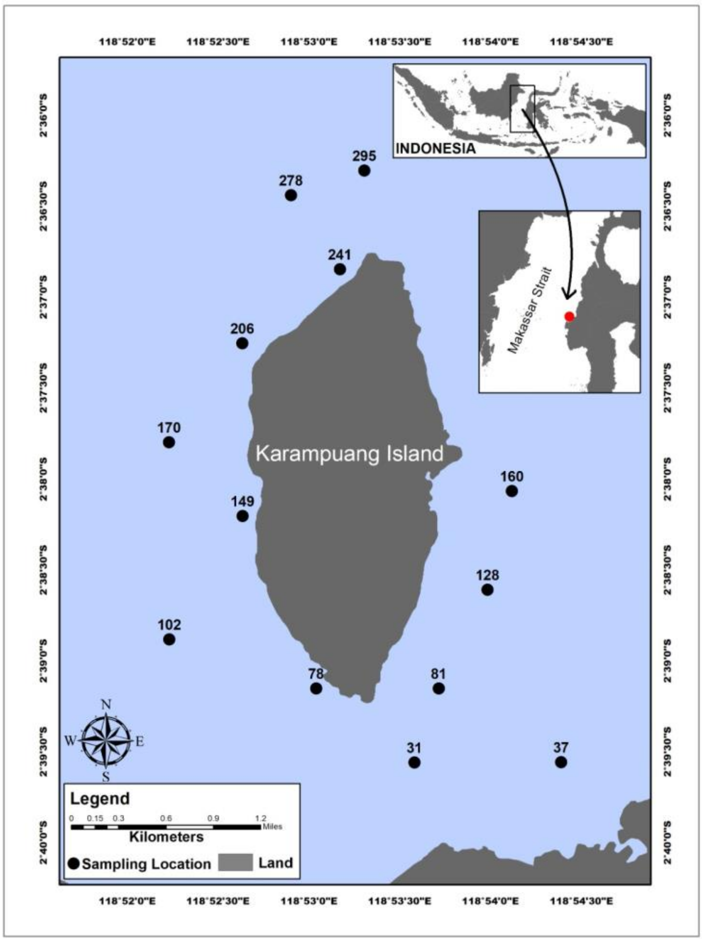

Figure 1. Map of study area and sampling locations in the Karampuang Island Waters, West Sulawesi, Indonesia. The black dot shows a georeferenced point station.

Field survey. The data in this study were obtained from a field survey of selected water quality parameters, including temperature, salinity, pH, dissolved oxygen (DO), nitrates, phosphates, ammonia, biological oxygen demand (BOD), current velocity, sea depth, and water brightness. In situ sampling was conducted from 18th of March to 22nd of March, 2022. Prior to the field survey, it was necessary to acquire imagery and digital spatial data as baseline information for suitability mapping. The study activities involved mapping the suitability of aquaculture locations in the selected study areas with the support of satellite and other digital spatial data. Furthermore, ground-truth and sea-truth surveys were conducted to provide justification for geometric correction and analysis of digital thematic maps by using global positioning system (GPS). This activity included an analysis of various primary data, such as geostatistical plots of field data distribution, and determination of the aquatic environment's condition score based on quality standards for marine aquaculture activities. Geostatistical potential maps were generated by conducting ground truth procedures using GPS and by collecting and measuring field data parameters (Aura et al 2021).

Data analysis. The selected water quality parameters were spatially analyzed using a geographic information system (GIS). The GIS produced a thematic map indicating the suitability of coastal space for the cultivation of seaweed, sea cucumbers, and floating net cages. The suitability of water areas for marine aquaculture activities was analyzed on a spatial basis using satellite imagery and digital maps. The analysis of spatial data processing included image transformation, overlays, clips, intersects, buffers, unions, and mergers (spatial analysis operators). In this study, spatial analysis was carried out as a preliminary process to prepare data for determining the ecological potential and environmental conditions (Suparno et al 2022). Afterward, the suitability of allocating marine aquaculture activities was analyzed based on the criteria and matrices of parameters of marine aquaculture activities and commodities. In this case, each parameter had a degree of importance represented by a weight value, and its status was assessed based on the score of that parameter. The equations used for such analysis are as follows (Cornelia et al 2005):

$$K_y = \sum_{i,j=1}^{n} \frac{(S_{ij} \, x \, B_i)}{(S_{ijmax} \, x \, B_i)} x \; 100\%$$

Where:
K_y- degree of land suitability;
S_{ij}- J-th class of the i-th parameter score;
B_i- weight of the i-th parameter;
S_{ijmax}- maximum class of the i-th parameter score.

Conformity class categories:
Highly compliant (K_1): $K_y \geq 75\%$
Corresponding (K_2): $50\% \leq K_y < 75\%$
Conditionally appropriate (K_3): $25\% \leq K_y < 50\%$
Non-conforming (N): $K_y < 25\%$

Suitability matrix. This study utilized measurements and studies of environmental biophysical factors and water quality that are closely related to the sustainability of aquaculture activities (Andi et al 2014; Aura et al 2016; Riyanto et al 2020; Szuster & Albasri 2010). These factors were compiled in the form of a matrix of the suitability criteria of aquatic space for marine aquaculture activities. Furthermore, a spatial approach was applied to analyze these factors using the degree of land suitability. Matrices of parameters of water conditions related to the suitability of cultivation sites for various fishery commodities are presented in Tables 1, 2, and 3.

Table 1
Matrix parameters of water conditions for the aquaculture suitability of seaweed

Parameters	*Weight*	*Suitability level*			*Source*
		Very appropriate (Score 3)	*Quite appropriate (Score 2)*	*Non-conforming (Score 1)*	
Substrate	2	Sandy corals	Sand – Muddy sand	Mud	Agustina et al (2017); Ferdiansyah et al (2019)
Wave (m)	2	0.2–0.3	>0.1 - <0.2 or >0.3 - <0.4	< 0.1 or > 0.4	
Current (m s^{-1})	2	0.25–0.40	>0.10 - <0.25 or >0.40 - <0.60	<0.10 or >0.60	
Brightness	2	>5	>1.5 - <5	<1.5	
Depth (m)	2	4–6	>3 - <4 or >6 - <10	<2 or >10	
Temperature (°C)	1	26–32	>22 - <24 or >32 - <36	<22 or >36	
Salinity (%)	1	28–34	>25 - <28 or >33 - <37	<25 or >37	
pH	1	7.5–8.5	>6 - <7 or >8.5 - <9	<5 or >9	
Nitrate (mg L^{-1})	1	0.04–0.1	>0.01 - <0.04 or >0.1 - <0.5	<0.01 or >0.5	
Phosphate (mg L^{-1})	1	0.1–0.2	>0.01 - <0.1 or >0.2 - <1	<0.01 or >1	

Table 2
Matrix parameters of water conditions for the aquaculture suitability location of sea cucumber

Parameters	*Weight*	*Suitability level*			*Source*
		Very appropriate (Score 3)	*Quite appropriate (Score 2)*	*Not appropriate (Score 1)*	
Depth (m)	1	<15	15 – 20	>20	Sulardiono et al (2017)
Current speed at tide (cm $^{-1}$)	1	0.003–0.005	>0.005-10	<0.003 or >10	
Temperature (°C)	2	28 - <32	23 - <27	<23 or >34	
Salinity (%)	2	26–33	19 - <28 or 34–36	<28 or >34	
pH	2	7.9–8.4	6.5–7.9	<6.5 or >8.5	
DO (mg L^{-1})	3	>9	4–9	<4	

Table 3
Matrix parameters of water conditions for the aquaculture suitability of floating net cages

Parameters	*Weight*	*Suitability level*			*Source*
		Very appropriate (Score 3)	*Quite appropriate (Score 2)*	*Not appropriate (Score 1)*	
Depth (m)	1	10 - 25	4 - <10	<4 and >25	Affan et al (2011); Purnawan et al (2015)
Brightness (m)	1	>5	3 - 5	< 3	
Temperature (°C)	3	28 - 32	26 - <28	< 26 or > 30	
Current velocity (m s^{-1})	1	0 – 0.3	>0.3 – 1	>1	
DO (mg L^{-1})	3	>6	3 – 6	<3	
Ammonia (mg L^{-1})	3	0 – 0.02	>0.02 – 0.5	>0.5	
pH	2	7.5 – 8.0	7.0 - <7.5 or >8.0 – 8.5	<7.0 or >8.5	
BOD_5 (mg L^{-1})	1	<3	3 – 5	>5	

Results. The results of the physical and chemical parameters contributions based on the observations are shown in Table 4. Based on our findings, the temperature value at the observation site ranged from 29.1 to 32.3°C. Point (station) 170 had the highest temperature value (32.3°C) and the lowest temperature value at point 31 (29.1°C). The spatial distribution of temperatures can be seen in Figure 2, where the western part of the Karampuang Island tends to be warmer than other areas.

The salinity value in the coastal area ranged between 30 and 34 ppt. The highest salinity value was found at station points 160, 31, and 78 (i.e., 34 ppt), and the lowest value was found at point 295, which had a salinity of 30 ppt. The salinity of the waters of Karampuang varied seasonally, with higher salinity levels observed during the dry season and lower salinity levels observed during the wet season. This was likely due to the influx and dilution effect of freshwater from the surrounding rivers and streams during the wet season.

Table 4

Average values of physical and chemical environmental parameters in Karampuang Island waters

Location (point)	*Temperature (°C)*	*Salinity (ppt)*	*pH*	*DO (mg L^{-1})*	*Nitrate (ppm)*	*Phospate (ppm)*	*Ammonia (ppm)*	BOD (ppm)
160	31.1±0.05	34	9.48	39.7	1.420	0.074	0.103	5.16
37	29.5±0.05	32	7.74	29.7	0.953	0.105	0.095	5.03
31	29.1±0.05	34	7.60	29.5	0.476	0.053	0.088	4.61
170	32.3±0.05	32	7.95	12.0	1.750	0.090	0.644	6.40
241	39.9±0.05	32	8.39	30.0	1.030	0.047	0.097	4.52
295	29.7±0.05	30	7.30	59.5	0.907	0.051	0.080	4.50
209	32.0±0.05	33	6.43	60.0	0.816	0.048	0.03	4.44
78	30.0±0.05	34	8.13	92.2	0.801	0.066	0.093	4.70

The pH value ranged from 6.43 to 9.48. The highest pH value was found at point 160 (i.e., 9.48), and the lowest value was found at point 209 (i.e., 6.43). Spatially, the distribution of pH value was relatively even, although there was one location that had the highest pH values in the south part of Karampuang Island waters. The DO value in the Karampuang Island waters varied from 12 mg L^{-1} to 92.2 mg L^{-1}. The station that had the highest value was at point 78 (92.2 mg L^{-1}), and the lowest value was at point 170 (12 mg L^{-1}).

Nitrate concentrations were found between 0.746 and 1.42 ppm. The station with the highest value of nitrate was found at point 160 (1.42 ppm), and the lowest value was at point 31 (0.746 ppm). On the spatial scale, the highest values were found in the western and eastern parts of Karampuang Island waters. Phosphate values occurred in the range of 0.047 and 0.105 ppm. The highest value of pH was found at point 37 (0.105 ppm), and the lowest value was found at point 241 (0.047 ppm). In general, the distribution of relative phosphate was low in the Karampuang Island waters, except in the southeast and western parts.

Ammonia values occurred in the range of 0.047 to 0.105 ppm. The highest value of ammonia was found at point 170 (0.644 ppm), and the lowest value was found at point 209 (0.03 ppm). Spatially, the distribution of ammonia was relatively low, and there was only one location that had a high ammonia value in the western part of Karampuang Island. The biological oxygen demand (BOD) concentrations were between 0.047 and 0.105 ppm. The station with the highest BOD value was located at point 170 (6.4 ppm), and the lowest value was at point 209 (4.44 ppm). Generally, the distribution of BOD values was relatively low, and high BOD values were found only in the western part of Karampuang Island waters. The current velocity value was also relatively low, with a range of 0.05 to 0.1 m s^{-1}, lower in the eastern part than that in the western part of the island (Figure 2).

The bathymetric map showed that coastal area of Karampuang Island have slopes and cliffs with depths reaching approximately 200 m below sea level (Figure 3a). The seawater transparency on Karampuang Island was relatively high since the location has a depth that ranges from 100-200 m below sea level (Figure 3b).

The interpolation pattern reveals the categories of suitability locations on the thematic map. The suitability location criteria were determined based on the results of scoring calculations that were adjusted to the class categories.

Figure 2. The ocean current velocity distribution in the coastal area of Karampuang Island.

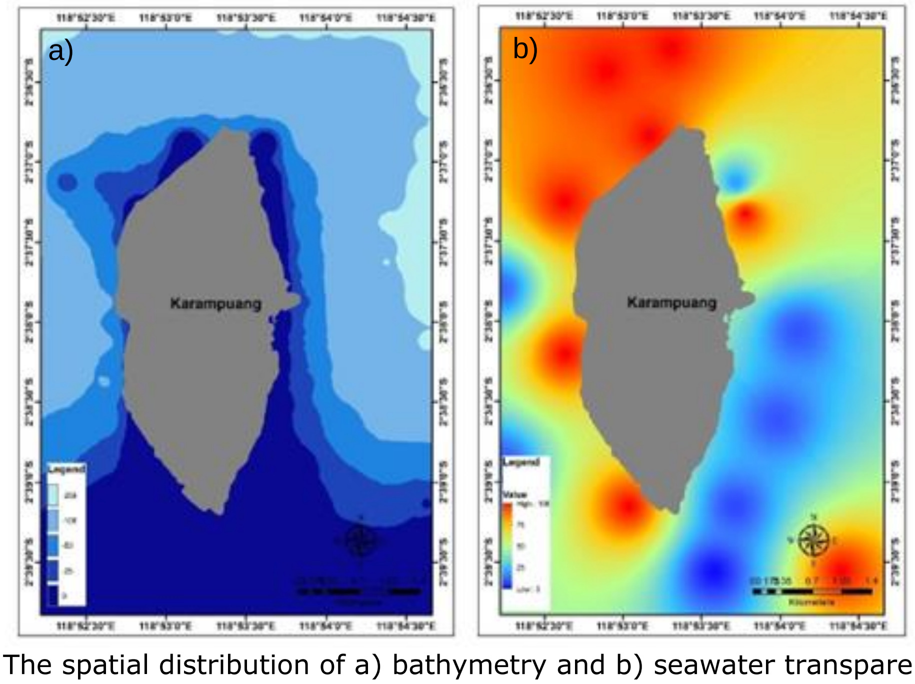

Figure 3. The spatial distribution of a) bathymetry and b) seawater transparency in the coastal area of Karampuang Island.

Aquaculture suitability of sea cucumber. The coastal area of Karampuang Island was assessed for its suitability as a location for sea cucumber cultivation. The results showed that the northern and southeastern waters were highly suitable, while the western and eastern parts of the island were moderately suitable for this purpose. Physical and chemical oceanographic parameters were also evaluated, DO being a significant parameter. The observed DO levels in the waters surrounding Karampuang Island ranged from 12 to 92.2 mg L^{-1}, which falls within the optimal range for sea cucumber cultivation. Sitoresmi & Pursetyo (2020) suggested that water temperature should be within the range of 27 and 30°C, DO>5 mg L^{-1}, pH within the range of 7.5 to 8.6, and salinity between 30 and 34 ppt, for an optimal sea cucumber cultivation (Figure 4).

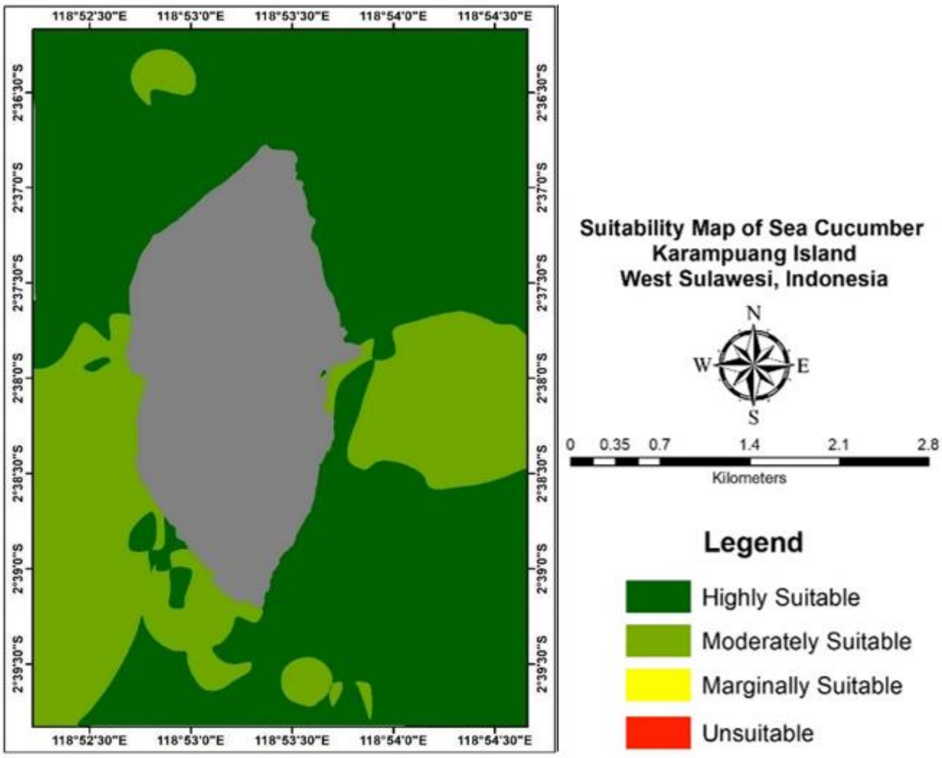

Figure 4. Suitability map of sea cucumber aquaculture in the coastal area of Karampuang Island.

Aquaculture suitability of seaweed. The suitability category for seaweed cultivation on Karampuang Island is generally classified as moderately suitable (Figure 5). However, the area with a depth of ≤2 m is highly suitable for seaweed cultivation. The physical and chemical parameters of the waters surrounding Karampuang Island generally have very low current velocities and different water morphologies, resulting in only a narrow area being categorized as highly suitable (southwest and southeast part). The main limiting factors for seaweed cultivation is the concentration of DO and the depth (Nazaruddin et al 2015). The bathymetry of Karampuang Island’s slopes around the island show a depth of 100-200 m, while the potential for seaweed cultivation ranges from 2-10 m (Ferdiansyah et al 2019). Other factors that can influence seaweed cultivation include nutrients, clarity, water movement, and salinity (Yulianto et al 2017). The seaweed cultivation category on Karampuang Island is still suitable for cultivation, despite the relatively lower depth score, as other factors in these waters were considered optimum.

Aquaculture suitability of floating net cages. Based on the results of the aquaculture suitability map, the areas highly suitable for floating net cages are located in the northern and western parts of Karampuang Island, while the eastern and southern parts are categorized as moderately suitable (Figure 6). The physical and chemical oceanographic parameters in the waters around Karampuang Island are generally suitable for use as cultivated area. According to Hasim and Kasim (2017), the main factors in floating net cage cultivation are temperature and DO. The optimum value of temperature is 28-32°C, and DO to be ≥6 mg L^{-1} (Purnawan et al 2015; Harjoyudanto et al 2020). The water quality on Karampuang Island has an optimal value for floating net cage in fish farming, as indicated by the scoring results in the highly suitable and moderately suitable categories.

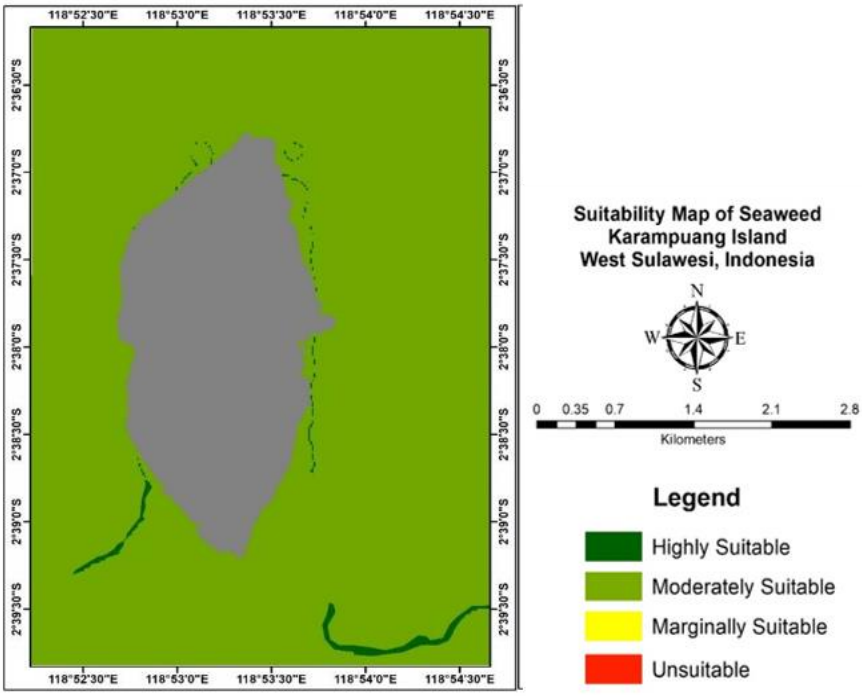

Figure 5. Suitability map of seaweed farming in the coastal area of Karampuang Island.

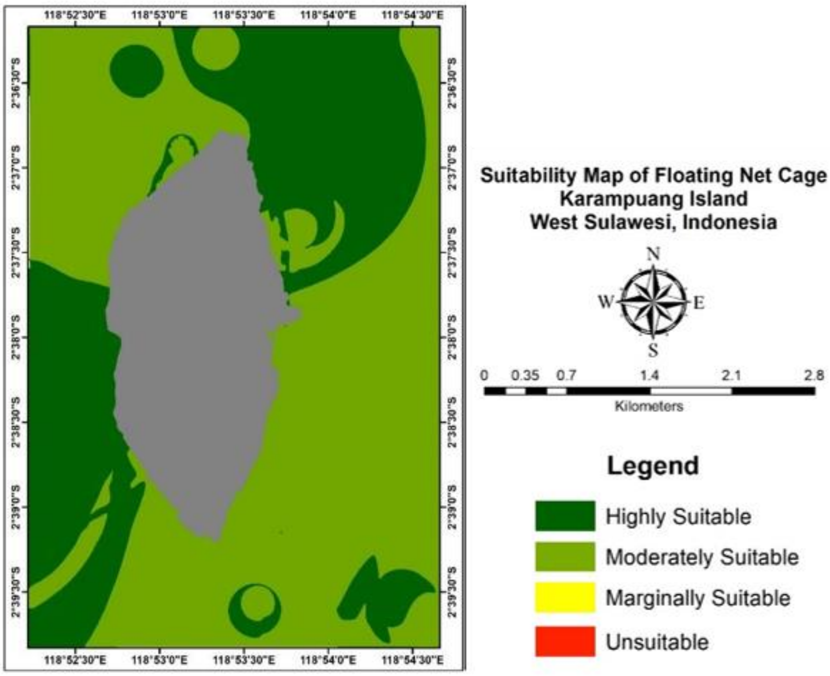

Figure 6. Suitability map of floating net cages for fish farming in the coastal area of Karampuang Island.

Conclusions. This study proposes a methodology for feasibility and aquaculture suitability determination for sea cucumbers or seaweed cultivation and for floating net cages use in fish farming, based on in situ environmental factors and spatial interpolations. The entire study area was classified into two main categories of suitability potential, namely highly and moderately suitable. The highly suitable areas for sea cucumber aquaculture were located in the northern and southeastern parts of Karampuang Island, whereas the seaweed cultivation has a high potential suitability in the southwest and southeast parts and floating net cages in the northern and western parts. The proposed approach could be incorporated into future spatial planning policies and regulations, once navigation routes and conservation zones have been mapped and included. Future studies could consider long-term in situ data representing different seasons.

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Conflict of interest. The authors declare no conflict of interest.

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Authors:
Mega Laksmini Syamsuddin, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: mega.syamsuddin@unpad.ac.id
Hammami Ulwan Faiz, Marine Science Study Program, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: hammamiuff@gmail.com
Mochamad Rudyansyah Ismail, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: m.rudyansyah@unpad.ac.id
Syawaludin A. Harahap, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: syawaludin.alisyahbana@unpad.ac.id
Yuniarti MS, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: yuniarti@unpad.ac.id
Yudi Nurul Ihsan, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: yudi.ihsan@unpad.ac.id
Fadli Syamsudin, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia; National Research and Innovation Agency (BRIN), Jalan M. H. Thamrin No. 8, 10340, Jakarta, Indonesia e-mail: fadli.syamsudin@unpad.ac.id
Qurnia Wulan Sari, Marine Science Department, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jalan Raya Bandung-Sumedang Km. 21, 45363, Jatinangor, West Java, Indonesia, e-mail: qurnia.w.sari@unpad.ac.id
Christopher Mulanda Aura, Kenya Marine and Fisheries Research Institute, P.O. Box 1881-40100, Kisumu, Kenya, e-mail: auramulanda@yahoo.com

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