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Geospatial Assessment of Water Suitability for Rabbitfish (*Siganus* sp.) Cultivation in Moyohilir Waters, West Nusa Tenggara

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Abstract

Rabbitfish (Siganus sp.) is an economically valuable fishery commodity widely consumed in eastern Indonesia, with increasing demand for animal protein. Indonesia's rabbitfish production rose steadily from 13.6 million tons in 2011 to 22.6 million tons in 2016 but declined after 2017, reaching 21.8 million tons in 2021. Most of this production came from capture fisheries, with only a small portion from the aquaculture sector. To address the declining production, sustainable farming development is essential to improve the stability of rabbitfish supply. The waters of Moyohilir, Sumbawa Regency, exhibit strong potential for rabbitfish cultivation. However, a comprehensive site suitability assessment is essential before initiating aquaculture activities. This study utilized Geographic Information Systems (GIS) to analyze spatial suitability for floating net cage systems. Primary water quality data, namely temperature, salinity, pH, dissolved oxygen, brightness, nitrate, phosphate, and seabed type, were collected from 40 purposively selected sampling points. Secondary data on current speed and water depth were obtained from 2023 bathymetric and wind speed datasets. All parameters were analyzed geospatially using ArcGIS version 10.8. The results revealed three suitability classes: Less Suitable (39.98%; 479.86 ha), Moderately Suitable (48.38%; 595.4 ha), and Suitable (12.64%; 155.57 ha). Based on this assessment, 10% of the Moderately Suitable and Suitable areas, equivalent to 75.1 ha, are recommended for cultivation. This area has the potential to produce up to 117.55 tons of rabbitfish per cycle, supported by 830 floating net cage units, assuming a 60% survival rate.

Keywords: *West Nusa Tenggara, Moyohilir Waters, Water Suitability, Rabbitfish, Geospatial*

Introduction

The Rabbitfish (*Siganus* sp.) is a fishery commodity with significant economic value. This species serves as a consumable fish in communities, particularly those in the eastern part of Indonesia, including the West Nusa Tenggara region (Mahrus and Syukur, 2020). The rising community demand for animal protein sources like rabbitfish has spurred efforts to meet it. From 2011 to 2016, Indonesia's rabbitfish production increased steadily, rising from 13.6 million tons in 2011 to 22.6 million tons in 2016 (MMAF, 2021). However, production declined from 2017 onward, reaching 21.8 million tons in 2021, with productivity peaking at 23 million tons in 2017 before decreasing in subsequent years. Given the decline in national rabbitfish production, comprehensive measures are needed to enhance the stability of rabbitfish production, one of which is through the development of sustainable rabbitfish farming activities.

The Moyohilir Waters, located within Saleh Bay in the Moyohilir District, Sumbawa Regency, hold great potential for rabbitfish cultivation as a source of income for the local community. The fisheries sector in Saleh Bay, including aquaculture activities, is a primary source of income for the local community (Darmawan *et al*., 2022). Historically, the production output of rabbitfish in West Nusa Tenggara experienced a decline from 2019 to 2020, followed by a gradual increase in 2021. The production figures were: 1.15 million tons (2019), 907 thousand tons (2020), and 946 thousand tons (2021). Most of this production came from capture fisheries, with only a small portion from the aquaculture sector (MMAF, 2021). A feasibility analysis is necessary to determine suitable locations for rabbitfish cultivation in the Moyohilir waters, with the aim of enhancing aquaculture productivity in the region. Previous studies on aquaculture site selection have generally focused on broader marine areas or relied on limited

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environmental parameters. However, integrated spatial analysis that combines hydrodynamic modeling and environmental suitability for rabbitfish (*Siganus* sp.) cultivation in this specific region remains limited. Therefore, this study aims to identify optimal cultivation zones by applying a comprehensive multi-criteria approach, thereby providing a more accurate and location-specific recommendation for sustainable rabbitfish aquaculture development in Moyohilir.

Selection of locations for rabbitfish cultivation requires consideration of several parameters as indicators of water suitability. These include temperature, salinity, current speed, depth, brightness, nitrate, phosphate, seabed type, dissolved oxygen (DO), and pH. Rabbitfish (*Siganus* sp.) generally prefer warm, stable coastal waters with sea surface temperatures between 28–29°C, moderate salinity levels, dissolved oxygen concentrations above 7 mg.L^{-1} and slightly alkaline pH. Nutrient availability (nitrate and phosphate) and appropriate depth and brightness also influence their feeding and growth (Table 1). These complex parameters need to be processed into easily understandable data through geospatial analysis via mapping (Rofizar *et al*., 2017). Therefore, the role of GIS in evaluating the suitability of waters for rabbitfish cultivation in the Moyohilir Waters needs to be carried out to assist in identifying locations with optimal suitability levels. Furthermore, GIS can help identify the extent of waters recommended for development as aquaculture sites and the most appropriate cultivation systems to be implemented based on the suitability level of the waters.

Materials and Methods

This research was conducted in the Moyohilir Waters, Sumbawa Regency, NTB from September 2023 to February 2024. The data used in this study comprised primary and secondary data. Primary data included water quality parameters such as temperature, salinity, pH, dissolved oxygen, brightness, nitrate, phosphate, and seabed type. All primary data were obtained from measurements at 40 pre-designated sampling points. Secondary data encompassed bathymetric data of the waters obtained from the BATNAS (Indonesian National Bathymetric) website (https://tanahair.indonesia.go.id/demnas/#/batnas) and wind data acquired from the CDS Copernicus website (https://cds.climate.copernicus.eu/). This secondary data was used for water depth and current speed modeling.

The research method employed in this study was exploration, aimed at exploring new phenomena not yet known to the public (Mudjiyanto, 2018). This method was used to measure water quality parameters in marine waters within Moyohilir District, Sumbawa Regency, West Nusa Tenggara. Field data obtained through exploratory methods were supplemented with secondary data and subsequently analyzed descriptively (Sukiyah, 2013).

Water quality measurements were conducted at 40 sampling points from September 2023 to February 2024, covering both the transitional period and the peak of the rainy season. This time frame was chosen to capture seasonal variability, as water parameters such as temperature, salinity, dissolved oxygen, and nutrient levels are known to fluctuate significantly with seasonal changes like rainfall, runoff, and ocean currents.

The determination of sampling points was carried out using a purposive sampling approach to ensure spatial representation of diverse environmental and hydrodynamic conditions, as well as proximity to potential aquaculture areas. Coordinates were selected using Avenza Maps and recorded using GPS devices. Primary data collection was conducted using a Water Quality Checker (WQC) for sea surface temperature and pH, a DO meter for dissolved oxygen, a refractometer for salinity, a modified Secchi disk for brightness, a Ponar grab sampler for seabed type, and nitrate and phosphate test kits for nutrient levels.

Of the 40 sampling points, 70% were used to generate spatial surfaces of each water quality parameter, while the remaining 30% were allocated for accuracy testing through cross-validation. The details of the spatial interpolation methods and modeling procedures are explained in the following section.

Spatial analysis

Spatial analysis was employed to visualize the distribution of water quality data and the suitability levels of the waters in the study area through thematic maps. The spatial analysis of primary data was conducted in three stages: interpolation, reclassification, and overlay, using ArcGIS 10.8. The first stage involved interpolation using the spline interpolation method, which was chosen for its ability to produce smooth and continuous surfaces that effectively represent gradual spatial variations in water quality parameters. For current speed parameters, current modeling was first conducted using the DHI MIKE 21 software due to its proven reliability in simulating two-dimensional coastal and estuarine hydrodynamics, allowing for accurate representation of current patterns in complex marine environments. The results of the current modeling were then analyzed using the same steps as for the other parameters.

The next stage involved the reclassification or regrouping of values for each parameter based on the predetermined water suitability matrix (Table 1). The values and weights of each parameter were determined by the level of influence a parameter has on the cultivated species to be farmed and the aquaculture system to be implemented (Setiaji *et al*., 2018; Sarjito *et al*., 2022). The values for each parameter based on their suitability are as follows: 5 (Very Suitable), 4 (Suitable), 3 (Moderately Suitable), 2 (Less Suitable), and 1 (Not Suitable). Meanwhile, parameters acting as limiting factors were assigned a weight of 3, those acting as masking factors were given a weight of 2 and a weight of 1 was assigned to parameters acting as controlling factors if in optimal conditions or for parameters with a less significant level of influence.

The final stage involved overlaying all the classified water suitability parameters for rabbitfish cultivation. The overlay process was carried out using the raster calculator. The assessment of the suitability class range for rabbitfish cultivation was determined using the equal interval method. According to Ferdiansyah *et al*. (2019), the formulation of the equal interval method is as follows.

$$I = \frac{\Sigma(AxB)Max - \Sigma(AxB)Min}{K}$$

Note: I= Suitability Interval; A= Value; B= Weight; K= Number of Classes

Based on this equation, the suitability score range for aquaculture of rabbitfish is classified as follows: Not Suitable (NS) with a range of 17.0–30.5; Less Suitable (LS) with a range of 30.6–44.1; Moderately Suitable (MS) with a range of 44.2–57.7; Suitable (S) with a range of 57.8–71.3; and Highly Suitable (HS) with a range of 71.4–85.0.

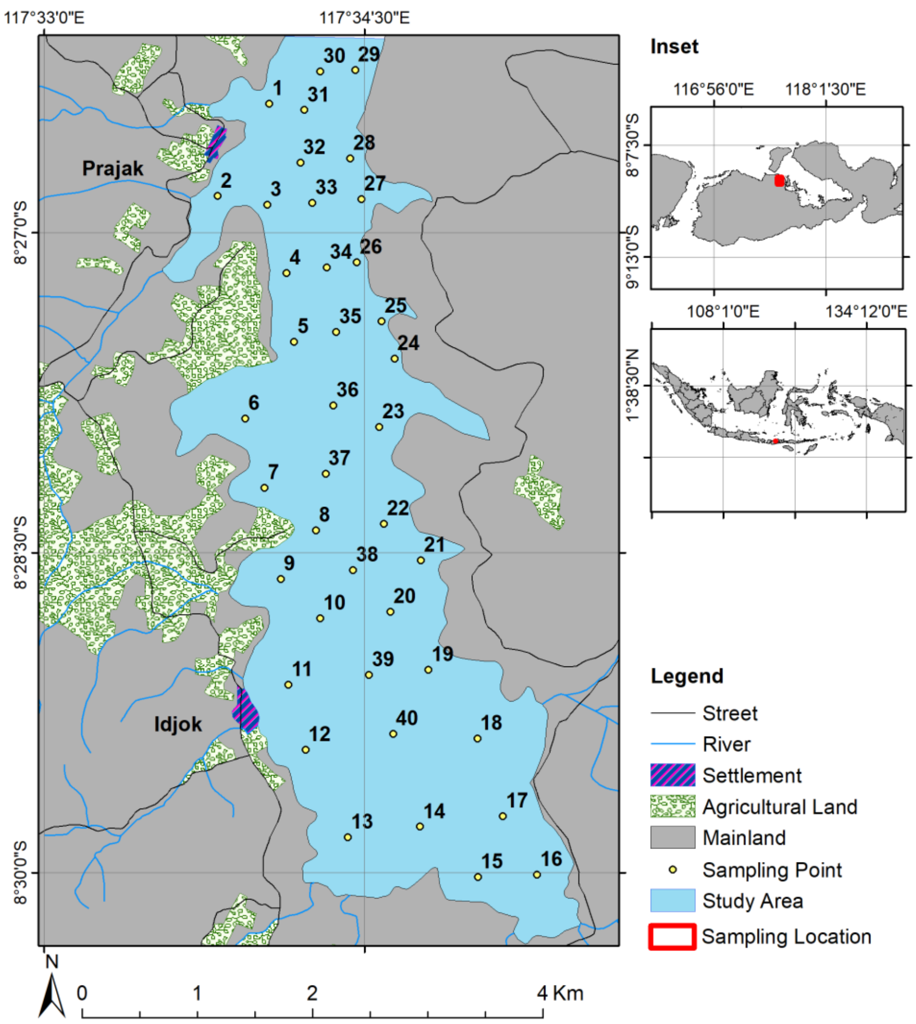

Figure 1. Research Location

Table 1. Waters Suitability Matrix for Rabbitfish Cultivation

Parameters	Range	Value (A)	Weight (B)	Score (AxB)	Source
Temperature (°C)	28–29	5	1	5	Modification of Syaifullah (2015); Cabanilla-Legaspi *et al*. (2021); Salampessy and Irawati (2021); Fahrezi *et al*. (2022); Jaya *et al.* (2022).
	27; 30	4		4	
	25–26; 31–32	3		3	
	23–24; 33–34	2		2	
	<23; >34	1		1	
Salinity (ppt)	33–34	5	1	5	Modification of Rauf *et al.* (2017); Cabanilla-Legaspi *et al*. (2021); Salampessy and Irawati (2021); Jaya *et al*. (2022); Rasheeq *et al*. (2023).
	28–32; 35–36	4		4	
	22–27; 37	3		3	
	17–21	2		2	
	<17; >37	1		1	
Dissolved Oxygen (DO) (mg.L^{-1})	>7	5	2	10	Modification of Latuconsina *et al*. (2020); Madyawan *et al*. (2020); Jaya *et al*. (2022); Rasheeq *et al*. (2023).
	6–7	4		8	
	4–5	3		6	
	2–3	2		4	
	<2	1		2	
pH	7.7–8.3	5	1	5	Modification of Ernawati and Dewi (2016); Cabanilla-Legaspi *et al*. (2021); Salampessy and Irawati (2021); Jaya *et al*. (2022).
	7.2–7.6; 8.4–8.5	4		4	
	6.5–7	3		3	
	8.6–9	2		2	
	<6.5; >9	1		1	
Depth (m)	11-15	5	3	15	Modification of Hidayat *et al*. (2018); Ngabito and Auliyah (2018); Isdianto, *et al*. (2020); Prakasa and Perbani (2021); Kamaludin *et al*. (2022).
	8-10	4		12	
	6-7	3		9	
	16-20	2		6	
	<6; >20	1		3	
Brightness (m)	7–10	5	1	5	Modification of Koniyo and Lamadi (2017); Hamuna *et al*. (2018); Rasheeq *et al*. (2023).
	11–12	4		4	
	5–6	3		3	
	3–4	2		2	
	<3; >12	1		1	
Current Speed (m.s^{-1})	0.6–0.7	5	3	15	Modification of Rauf *et al*. (2018); Kurniawan *et al*. (2021); Jaya *et al*. (2022).
	0.5–0.59	4		12	
	0.71–0.8	3		8	
	>0.8	2		6	
	<0.5	1		3	
Nitrate (mg.L^{-1})	0.008–0.01	5	2	10	Modification of MoMEF Decree No. 51 (2004); Putri *et al*. (2019); Putri *et al*. (2021).
	0.02–0.04	4		8	
	0.05–0.07	3		6	
	0.08–0.09	2		4	
	<0.008; >0.09	1		2	
Phosphate (mg.L^{-1})	0.010–0.015	5	2	10	Modification of MoMEF Decree No. 51 (2004); Putri *et al.* (2021); Hendrayana *et al*. (2022).
	0.016–0.029	4		8	
	0.003–0.009	3		6	
	0.03–0.09	2		4	
	<0.003; >0.9	1		2	
Seabed Type	Coral Sand	5	1	5	Modification of Prasetyo *et al*. (2018); Hidayat (2021); Lahope *et al*. (2022)
	Coral Rubble	4		4	
	Sand	3		3	
	Muddy Sand	2		2	
	Mud	1		1	

Data analysis

The data analysis used in this study was descriptive analysis, where data from spatial analysis was clearly explained in the form of descriptions. In this study, the collected data was processed and visualized in the form of thematic maps for each parameter and integrated into a water suitability map, as well as graphs showing the area of water suitability. The maps and graphs will be described descriptively with supporting literature, and an analysis of the potential production of rabbitfish using the floating net cage system will be conducted based on the literature.

Result and Discussion

Waters suitability analysis based on water quality parameters

The water quality measurements in Moyohilir waters are presented in a thematic map shown in Figure 2. These results have been classified according to the suitability matrix for rabbitfish cultivation, based on parameters including temperature, salinity, pH, dissolved oxygen (DO), depth, brightness, nitrate, phosphate, and seabed type. Additionally, two current distribution maps display current velocity data: one representing seasonal variations and another for the entire year 2023 (Figure 3).

Temperature measurements at 40 sample points ranged from 27.5–28.3°C. The temperature values obtained from measurements are classified into two suitability classes: the temperature range of 27.5–27.9°C falls into suitability class 4 (Suitable), while the range of 28.0–28.3°C falls into suitability class 5 (Highly Suitable). As for the role of temperature in the cultivation of rabbitfish, it controls biochemical reactions in the water and directly affects biochemical parameters such as dissolved oxygen (DO) and salinity. Higher water temperatures lead to lower DO levels and salinity, and vice versa (Hamuna *et al*., 2018).

Regarding salinity distribution, values ranging from 30 to 35 ppt are classified into two suitability classes: suitability class 4 (Suitable) and suitability class 5 (Highly Suitable) (Figure 2b). Salinity values between 30 and 32 ppt, recorded at 16 sampling points, fall under class 4, while values between 33 and 34 ppt, observed at 24 points, fall under class 5. These salinity levels are considered normal, as the regional average salinity from 2019 to 2023 fluctuated within the same range (Marine Data Copernicus, 2024). In marine organisms, salinity directly affects osmoregulation and nutrient absorption from food (Faozan *et al*., 2019). As a marine species, rabbitfish require adequate salinity for effective osmoregulation. One of the key factors influencing salinity changes is temperature: higher temperatures lower salinity, and vice versa (Fajarwaty *et al*., 2022).

The pH values measured at 40 sampling points in the Moyohilir waters ranged from 7.5 to 8.0 and were also divided into two suitability classes: class 4 (Suitable) and class 5 (Highly Suitable) (Figure 2c). A pH of 7.5, recorded only at point 17, is categorized as class 4. The range of 7.9 to 8.0, observed at 39 points, falls into class 5. These pH levels are considered neutral to alkaline. For reference, the current average global surface seawater pH is approximately ±8.04 (Global Ocean Acidification, 2022). pH variability in aquatic environments can result from fluctuations in dissolved oxygen and carbon dioxide, as well as from organic matter decomposition at the seabed (Rukminasari *et al*., 2014).

DO measurements at the 40 sampling points indicate DO concentrations ranging from 6.8 to 7.3 $mg.L^{-1}$. These values are divided into two suitability classes: 6.8–7.0 $mg.L^{-1}$ is classified as class 4 (Suitable) and was observed at 13 points, while 7.1–7.3 $mg.L^{-1}$ falls into class 5 (Highly Suitable), found at 27 points (Figure 2d). The relative stability of DO levels in the region is attributed to its location in a bay, where oxygen diffusion from the open sea occurs regularly. This is further enhanced by tidal fluctuations, which increase DO levels near the coast and at the surface (Madyawan *et al*., 2020). Dissolved oxygen is a critical controlling factor, influencing other biochemical parameters such as pH and CO_2, as it affects the release of hydrogen ions and carbonates (Rukminasari *et al*., 2014). Aquatic organisms, including rabbitfish, depend on DO for respiration and metabolic activities.

The water depth values obtained from the analysis of bathymetric data at 40 sampling points, with a range of 3–39 m, are classified into five suitability classes: suitability class 1 (Not Suitable) at 21 points, suitability class 2 (Less Suitable) at 2 points, suitability class 3 (Moderately Suitable) at 5 points, suitability class 4 (Suitable) at 2 points, and suitability class 5 (Highly Suitable) at 10 points (Figure 2e). These variations reflect the water depth levels, which are influenced by the topographic contours of the seabed (Sirajudin and Putri, 2022). Water depth levels significantly impact the design of cultivation containers to be used. Rabbitfish are commonly cultured in floating net cages, making water depth a crucial factor to consider.

Water clarity measurements across the 40 sampling points range from 3.0 to 7.7 m (Figure 2f).

These are grouped into three suitability classes: class 2 (Less Suitable) at 8 points, class 3 (Moderately Suitable) at 22 points, and class 5 (Highly Suitable) at 10 points. Water clarity is affected by turbidity, which indicates the presence of suspended sediment and pollutants. Lower turbidity allows for deeper light penetration, improving photosynthetic activity (Harmilia *et al.*, 2021).

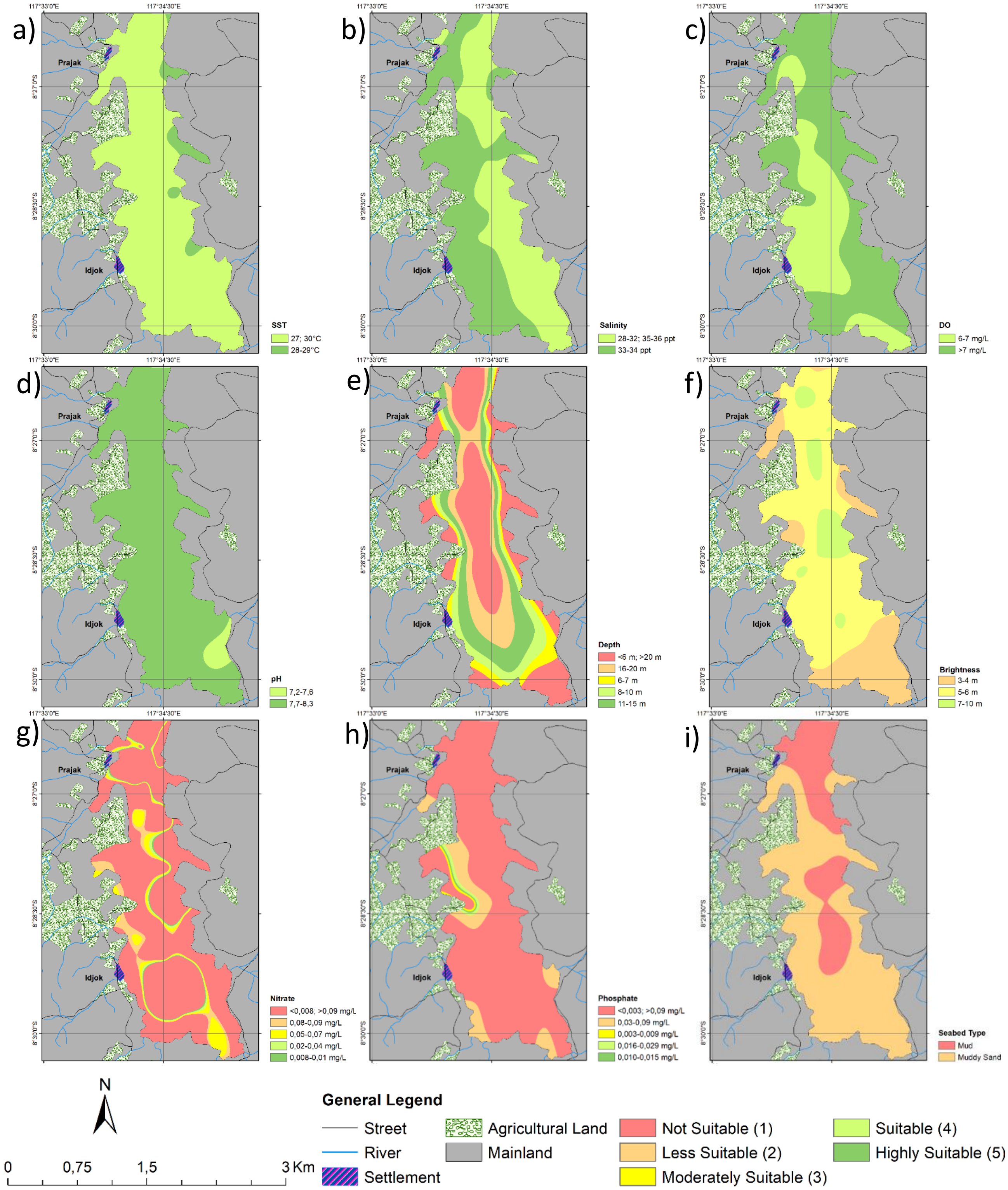

Figure 2. Distribution of Physical and Chemical Parameters: a) SST (Sea Surface Temperature); b) Salinity; c) DO (Dissolved Oxygen); d) pH; e) Depth; f) Brightness; g) Nitrate; h) Phosphate; i) Seabed Type

Nitrate concentrations at the 40 sampling locations ranged from 0 to 2 mg.L^{-1}, with all values falling into suitability class 1 (Not Suitable) (Figure 2g). The maximum concentration of 2 mg.L^{-1} was found at 2 points; 1 mg.L^{-1} was recorded at 4 points and 0 mg.L^{-1} at 34 points. Despite this classification, localized areas within the region may have nitrate levels suitable for rabbitfish cultivation. Extremely low nitrate concentrations, as observed at 34 points, restrict phytoplankton growth due to the lack of essential nutrients such as nitrates and phosphates. These nutrients are key indicators of water fertility (Hendrayana *et al*., 2022). Conversely, elevated nitrate levels, seen at the remaining 6 points, may also be harmful. Concentrations above 0.9 mg.L^{-1} can trigger algal blooms, leading to oxygen competition between phytoplankton and culture organisms (Putri *et al*., 2021).

Phosphate concentrations measured at the 40 points ranged from 0 to 0.2 mg.L^{-1}, also falling under suitability class 1 (Not Suitable) (Figure 2h). A phosphate concentration of 0 mg.L^{-1} was found at 3 points, while 0.1 mg.L^{-1} was recorded at 36 points, and 0.2 mg.L^{-1} at a single point. Like nitrates, phosphate is a vital nutrient influencing water fertility and the success of rabbitfish cultivation.

Seabed types identified at the 40 sampling points include muddy sand and mud substrates, which fall into suitability class 2 (Less Suitable) and class 1 (Not Suitable), respectively (Figure 2i). Mud substrates are not recommended for rabbitfish culture in floating net cages, especially if water depth and current velocity are suboptimal. This is due to the potential release of harmful gases such as ammonia, hydrogen sulfide, methane, and phosphine during upwelling events, which pose a threat to aquatic life (Hidayat, 2021).

According to the hydrodynamic model, water current velocity shows temporal variation, with values ranging from 0.41–1.99 m.s^{-1} in January, 0.33–1.71 m.s^{-1} in April, 0.26–1.26 m.s^{-1} in July, and 0.25–1.17 m.s^{-1} in October (Figure 3a–d). The annual integrated current velocity in 2023 ranged from 0.32 to 1.53 m.s^{-1} (Figure 3e). Current velocities in the central and peripheral bay areas are generally less suitable for rabbitfish culture using floating net cages. Currents play an essential role in seawater recirculation and influence the construction and stability of floating cages, as well as the distribution and fluctuation of key water quality parameters including dissolved oxygen, temperature, pH, suspended solids, and salinity (Yunus *et al*., 2019).

Furthermore, water current velocity is crucial for the sustainability of cultivation systems and containers. It plays a significant role in reducing fouling organisms in marine cultivation containers, such as floating net cages (Haris *et al*., 2019). By minimizing fouling on the cages, the risk of structural damage is reduced, thereby extending their lifespan. However, excessively high current velocities can also have adverse effects on the durability of floating net cages and the well-being of the cultured organisms.

In the case of Moyohilir, the current velocity that previously described, generally falls within a favorable range for aquaculture development. This condition supports fish growth and cage stability, although periods of higher flow may require attention to structural reinforcement and site management.

Based on the analysis of integrated suitability parameters for rabbitfish cultivation in the Moyohilir waters, Sumbawa, the final suitability scores range from 35 to 71. These scores are categorized into three suitability levels: Less Suitable (LS), Moderately Suitable (MS), and Suitable (S) (Figure 4). The percentage of suitable water area in the region, relative to the total area, is as follows: 38.98% (479.86 ha) falls under the LS class, 48.38% (595.4 ha) under the MS class, and 12.64% (155.57 ha) under the S class.

The predominance of the LS and MS classes is primarily influenced by three limiting factors: water depth, nutrient availability (nitrate and phosphate), and water clarity. Bathymetric analysis revealed that more than half of the sampling points (21 out of 40) fall under class 1 (Not Suitable) for depth, which is critical for floating net cage systems commonly used in rabbitfish aquaculture. Additionally, all nitrate and phosphate concentrations across the sampling locations were categorized as class 1, indicating either deficiency or excess that may hinder phytoplankton productivity or trigger algal blooms, respectively. Water clarity was also mostly moderate, with only 10 points classified as highly suitable. In contrast, salinity did not appear to be a limiting factor, as all values ranged from 30 to 34 ppt—consistent with the normal regional range from 2019 to 2023.

To improve the overall suitability of the area, it is recommended to prioritize site selection in deeper zones with better light penetration and to consider the application of integrated multi-trophic aquaculture (IMTA) systems that enhance nutrient cycling. Moreover, efforts to manage nutrient inputs, either through supplementation of artificial feeds in low-nutrient areas or mitigation in high-nutrient zones may help balance productivity and ecological safety.

Seasonal effects also play a significant role in suitability dynamics. During the rainy season (December–February), increased freshwater runoff tends to reduce clarity and alter nutrient levels, which can affect the temporal classification of suitability zones. Thus, adaptive seasonal planning and regular monitoring are essential for sustainable aquaculture development in Moyohilir.

Cultivation development potential analysis

According to the analysis of water suitability levels, approximately 61.02% (75.1 ha) of the Moyohilir water area can be developed for rabbitfish cultivation using the floating net cages system. Within this recommended area, 48.38% are classified as Moderately Suitable, while 12.64% are classified as Suitable. The total ideal area for floating net cage installation is approximately 75.1 ha. This recommendation is based on the guideline that the optimal use of water for floating net cage cultivation should not exceed 10% of the recommended water area (Suryono *et al.*, 2017; Sarjito *et al.*, 2022). Consequently, the potential for developing small-scale rabbitfish cultivation includes 830 floating net cages measuring 2 x 2 x 3 m (Visca, 2017), with a projected production capacity of 117.55 tons per cycle, with a low stocking density of 15 to 20 fish.m^{-3} and an assumed survival rate of 60% (Syah *et al.,* 2020).

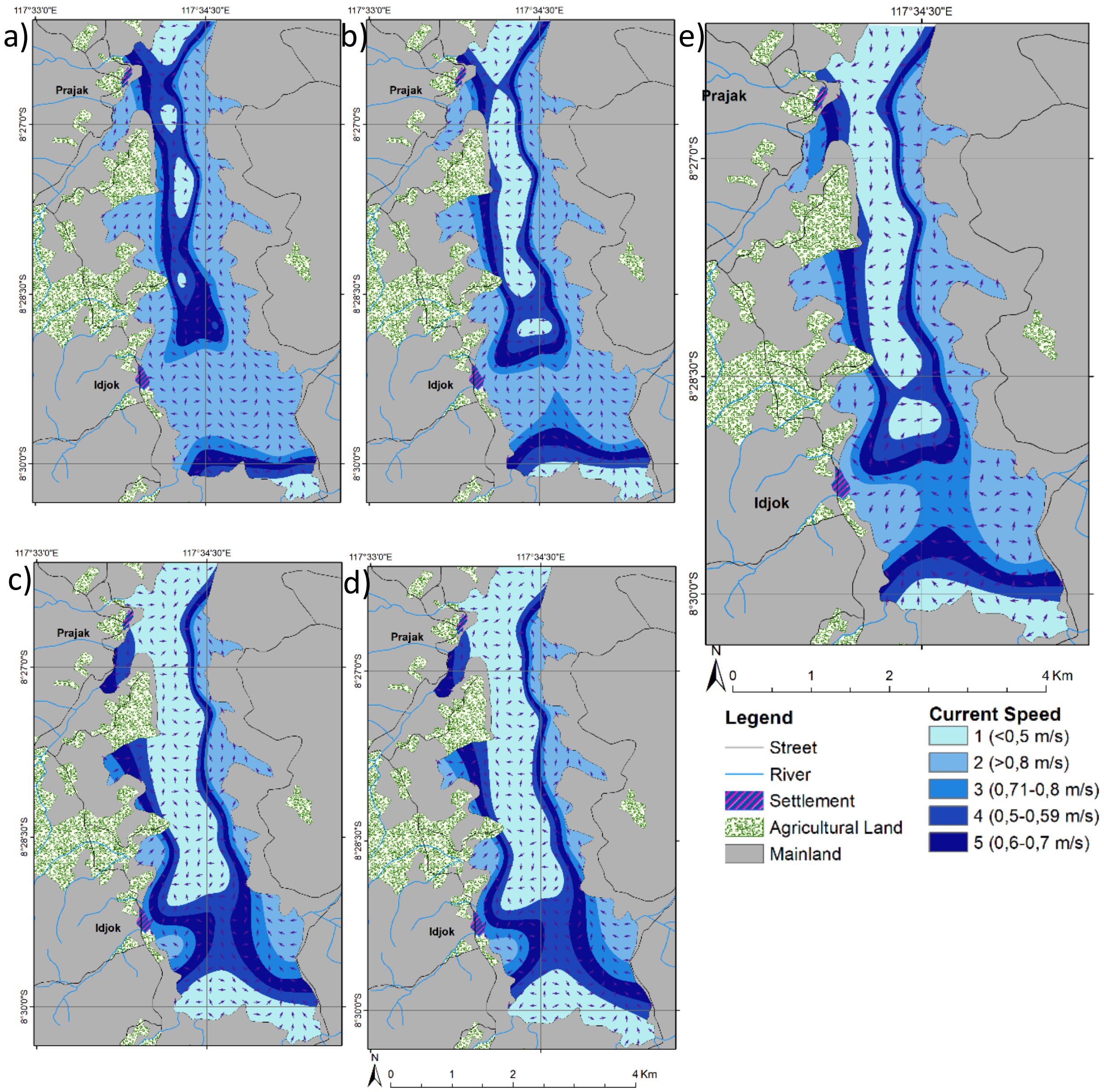

Figure 3. Simulation of Current Speed Distribution in a) January, b) April, c) July, d) October, and e) Annual Mean

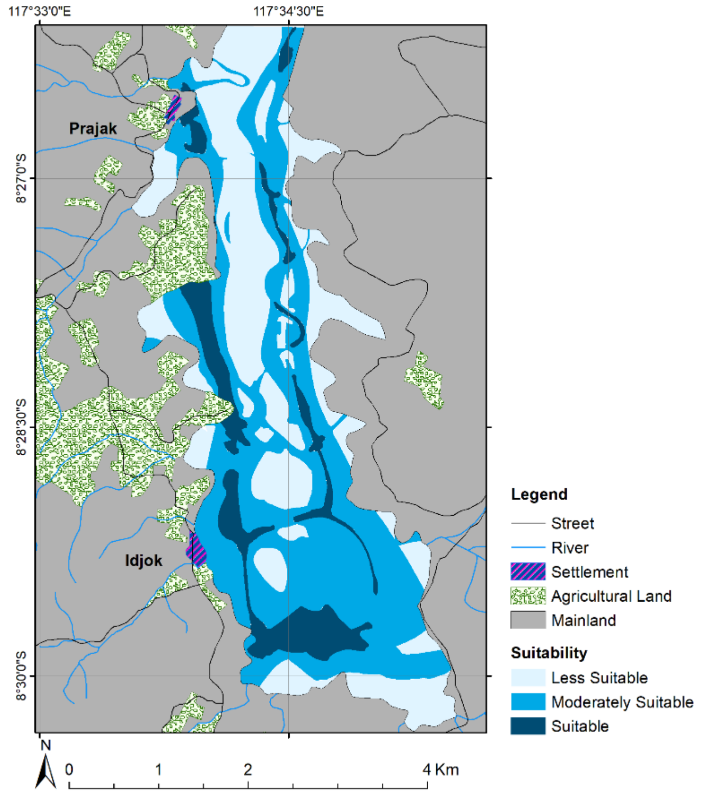

Figure 4. Map of Water Suitability Level Distribution for Rabbitfish Cultivation

Conclusion

Based on the findings of this study, the water suitability percentages for rabbitfish cultivation in the Moyohilir waters, Sumbawa Regency are as follows: 38.98% for the Less Suitable class, 48.38% for the Moderately Suitable class, and 12.64% for the Suitable class, based on the total study area. Therefore, it can be concluded that the Moyohilir waters are suitable for rabbitfish cultivation using the floating net cages system. The ideal area for cage installation is approximately 75.1 ha, with the potential of accommodating 830 floating net cage units and producing up to 117.55 tons per cycle at a 60% survival rate. It is important to note that this assessment of suitability is based solely on water quality and oceanographic parameters. The actual viable cultivation area may be less than 75.1 ha when considering additional factors such as infrastructure, accessibility, social, legality, etc.

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