ANALYSIS OF SITE SUITABILITY FOR CORAL TRANSPLANTATION IN THE WATER OF KARANG BOLONG BEACH, CILACAP

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Abstract. Coral transplantation is one of the efforts to rehabilitate coral reef ecosystems that have been damaged by human activities, environmental changes and natural disasters. The purpose of this study to analyse the suitability of coral transplantation sites in the waters of Karang Bolong Beach, Cilacap. The methods used in this study include field surveys, data collection of environmental parameters such as temperature, salinity, water brightness, pH, current speed and seabed substrate, and spatial analysis using Geographic Information Systems (GIS). The results showed that most locations in the waters of Karang Bolong Beach have quite suitable conditions for coral transplantation with environmental parameters that support coral growth. There are 1 categories of transplant site suitability obtained, namely suitable (S2) at station 1 and 2. Values included in the moderately suitable category are around 66-74% with a total area of approximately 0.5 hectares.

Keywords: Site suitability, coral transplantation, Karang Bolong Beach, Cilacap.

A. Introduction

Coral reefs are one of the most important marine ecosystems, supporting global marine biodiversity (Sobha et al., 2023).In addition to serving as a habitat for various marine species, coral reefs provide significant economic and ecological benefits to coastal communities, such as coastal protection from erosion and enhancing fish stocks (Bay et al., 2019). However, coral reef degradation due to anthropogenic activities such as industrial operations, pollution, sedimentation, climate change, and coastal development has drastically diminished the functions of these ecosystems, including in Indonesia (Ateweberhan et al., 2013).

Coral transplantation methods have been widely applied as a restoration effort to rehabilitate damaged coral reef ecosystems (Razak et al., 2022). The success of the coral transplantation process highly depends on the suitability of environmental conditions at the transplantation site, particularly physical and chemical water factors (Pelasula et al., 2023). Some important parameters to consider include temperature, salinity, water clarity, currents, pH, and site protection (Guan et al., 2015). Favorable water conditions can support healthy coral growth and reduce the risk of mortality for transplanted corals.

Karang Bolong Beach on Nusa Kambangan Island, located in the southern waters of Java, has great potential as a coral transplantation site.. However, the environmental conditions in this area face threats such as high water turbidity due to sedimentation from land, and changes in water quality due to human activities, necessitating a thorough assessment to ensure its

feasibility (Pratiwi et al., 2018). This condition became more complex after the 2006 Pangandaran tsunami disaster which impacted the Nusa Kambangan region, causing damage to coral reef structures and disrupting the balance of the marine ecosystem in the southern Java Sea (Fadilah et al., 2021). Measuring the physical and chemical parameters of the water, including temperature, salinity, clarity, and protection, is essential for determining the suitability of the site for coral reef transplantation (Pelasula et al., 2023).

The purpose of this study to analyse the suitability of coral transplantation sites in the waters of Karang Bolong Beach Cilacap. The results of this study are expected to provide guidance for selecting appropriate locations for coral reef restoration activities, as well as serve as a reference for marine ecosystem recovery efforts in in the waters around Nusa Kambangan Island, especially Karang Bolong beach.

B. Methods

The research was conducted in May 2023, using a survey method at different station locations in the waters of Karang Bolong Beach, Nusa Kambangan Island (**Figure 1**). The research locations were determined using purposive sampling with a spatial approach. The research locations were divided into two different areas: the southern and northern parts of Karang Bolong Beach.

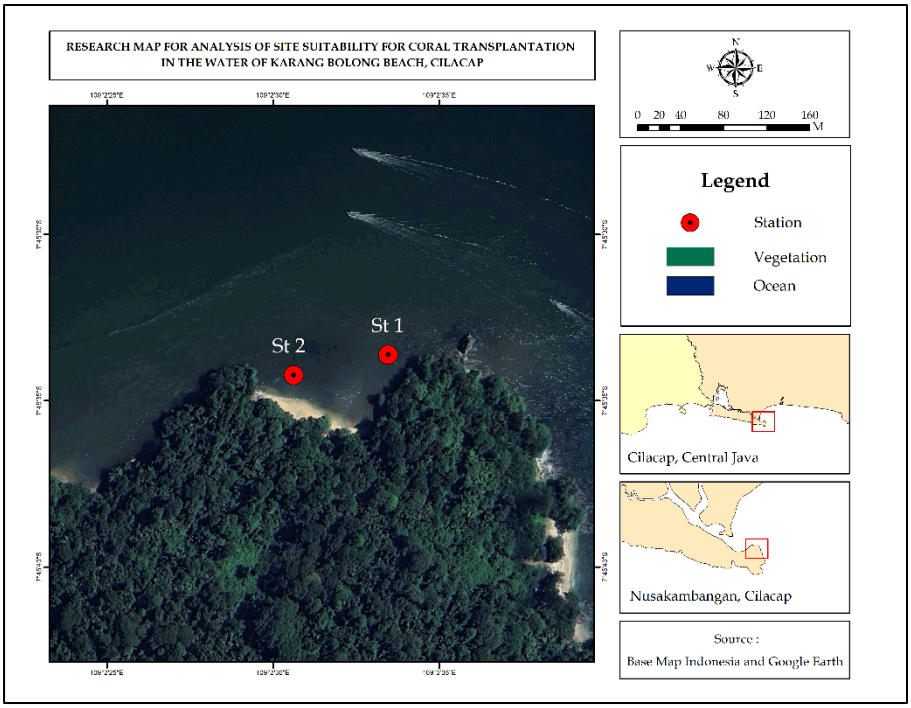


Figure 1. Research Map

Primary physical water data collection was carried out in situ during low tide with three repetitions, including temperature data using a water quality checker, depth with a weighted scaled rope, and water clarity using a Secchi disk, while current data was collected using the floating method. Similar to the physical water measurements, chemical water data collection included pH measurements with a water quality checker and salinity measurements using an Atago hand refractometer (Pelasula et al., 2023). The data obtained were then compared with the standard water quality criteria for coral transplantation (**Table 1**).

The suitability of coral transplantation sites is assessed based on several evaluation parameters, including water depth, temperature, pH, salinity, water clarity, current speed, wave action, substrate type, site protection, and distance from the source of coral larvae (**Table 2**).

Table 1. Standard water quality criteria for physical and chemical parameters for coral transplantation.

Parameters	Standard water quality	Source
Temperature (°C)	28 – 30	(Leong et al., 2020)
Salinity (ppt)	31 – 36	(Isdianto et al., 2020)
pH	7,0 – 8,5	KEPMEN LH No 51 2004
Current Velocity (m/s)	0,2 – 3,0	(Kenyon et al., 2023)
Depth (m)	2 – 7	(Nybakken, 1992)
Visibility (cm)	High	(Rouzé et al., 2021)
Substrate	Hard	(Pelasula et al., 2023)
Waves	Moderate	(Kenyon et al., 2023)
Site Protection	Protected	(Prema, 2013)

Table 2. Coral Transplantation Assessment Index

Parameters	Weight	Category 1	Score	Category 2	Score	Category 3	Score
Depth (m)	4	2 – 7	3	8 – 15	2	<2 or >15	1
Temperatur (˚C)	4	25 - 29	3	23 - 35	2	<23 or >35	1
pH	4	7 - 8	3	5 – 9	2	<5 or >9	1
Salinity (ppt)	4	31 – 36	3	30 or > 36	2	<30	1
Visibility (cm)	4	High	3	Moderate	2	Low	1
Current (m/s)	3	0,1 - < 0,3	3	0,3 – 0,4	2	<0,1	1
Waves	3	Moderate	3	Low waves	2	High waves	1
Substrate	3	Hard (rock, coral, rubble)	3	Semi Hard (Rubble and Sand)	2	Soft (Sand and Mud)	1
Site Protection	2	Protected	3	Sufficiently protected	2	Relatively open	1
Source distance	2	< 100 – 300	3	300 – 500	2	>500	1
Total Weight x Score		**99**		**66**		**33**	

The Suitability Index for Transplantation is an extension of the suitability matrix analysis, also referred to as (Coral Reef Transplant). The equation used to determine the suitability of coral rehabilitation locations for transplantation is based on the following equation and categories:

$$CRT = \sum \frac{Ni}{Nmax} \times 100\%$$

Explanation :
CRT : Coral Reef Transplant Suitability Index
Ni : Value of the i-th parameter
Nmax : Maximum value of a transplantation category (maximum value 99)

Table 3. Coral Transplant Suitability Score Categories

Number	Value	Explanation	Category
1	80 – 100 %	Highly suitable: No limiting factors were found that could impede the cultivation process or disrupt the environment.	S1
2	59 – 79 %	Suitable: There are limiting factors, but can still be managed or engineered.	S2
3	36 – 58 %	Conditionally suitable: The area has significant limiting factors that require substantial effort for management.	S3
4	16 – 36 %	Not suitable: The area has significant limiting factors and may not be feasible for use.	TS1

C. Result and Discussion

1. Physicochemical Water Parameters

A spatial analysis of the physicochemical properties of the waters at Karang Bolong Beach, Nusa Kambangan Island, revealed no significant variations. The parameters assessed included water depth, temperature, pH, salinity, water transparency, current speed, wave height, and substrate type. Overall, the results indicate ranges that are not markedly different. The data are presented in the following results (**Table 4**):

Table 4. Results of Physical-Chemical Water Parameter Measurements

Parameter	Stasiun 1	Stasiun 2
Depth (m)	7 – 8	7 – 8
Temperatur (˚C)	29,9	29,0
pH	5	5
Salinity (ppt)	32	32
Visibility (cm)	2,0 cm (Moderate)	1,5 cm (Low)
Current (m/s)	0,1	0,125
Waves	Moderate	Low
Substrate	Coral Sand-Mud	Rock Sand-Mud

The suitability of coral transplantation sites is greatly influenced by the physical-chemical parameters of the water. Suitable conditions encourage optimal coral growth (Pelasula et al., 2023). The results of the water depth measurements at the research stations show similar values, with depths ranging from 1.5 to 2.0 meters measured at low tide. Depth plays an important role in coral reef growth, closely related to the intensity of light entering the water, which is necessary for the mutualistic organisms of coral reefs, namely zooxanthellae (Rouzé et al., 2021). According to previous research, corals have optimal depth tolerance in the range of 2 to 15 meters, which means that the waters of Karang Bolong Beach, Nusa Kambangan Island still have potential sites for coral transplantation.

The results for the physical measurement of water temperature were similar, ranging from 29 to 30 ºC, likely due to the data collection being carried out at similar times and optimal sunlight conditions. Temperature has a significant impact on coral reef health; extreme sudden temperature changes can lead to coral bleaching (loss of zooxanthellae), which may result in coral disease or even death (Sully and Woesik, 2020). The measurements indicate that the waters of Karang Bolong Beach are still within the acceptable range for coral transplantation standards.

Similar results were obtained for the chemical measurement of water, specifically for pH, which consistently recorded a value of 5. The pH of the water also impacts coral reef growth, as extremely low (acidic) or high (alkaline) pH conditions can cause excessive stress leading to coral diseases (Allemand & Osborn, 2019). The pH measurements in the waters of Karang Bolong Beach indicate less than optimal results, but they are still within the tolerance range where corals can survive.

Similar results were obtained for the measurement of water salinity, with uniform values of 32 ppt. These measurements indicate a favorable condition for coral transplantation. Salinity ranging from 31 to 36 ppt is necessary for optimal coral growth. Extreme changes in salinity can affect coral health, so stable salinity values are crucial for normal coral growth and successful coral transplantation (Isdianto et al., 2020).

The measurements of water clarity showed slight differences between stations 1 and 2, with stations 1 having moderate clarity and station 2 having low clarity. The differences are suspected to be due to sedimentation processes occurring around the waters of Nusa Kambangan. Clarity is essential for corals to live optimally. High clarity indicates low turbidity,

which allows sunlight to reach the corals, necessary for the symbiotic organisms, zooxanthellae, to perform photosynthesis (Sully and Woesik, 2020). The results still indicate the potential of Karang Bolong Beach waters as a viable location for coral habitation and transplantation.

The measurements of current speed also showed variability, with values ranging from 0.1 to 0.125 m/s in Karang Bolong Beach. Strong currents are generally necessary for optimal coral health, but during coral transplantation, excessively strong currents can hinder the process (Pelasula et al., 2023). The current measurements in Karang Bolong Beach are still considered to be within the range of moderately suitable to highly suitable for coral growth, indicating that there is potential for these waters to serve as a transplantation site.

Similar to currents, excessively strong waves can hinder the coral transplantation process. Waves play a role in mixing nutrients at the bottom of the water and ensuring the even distribution of dissolved oxygen (Nafagha-Lawal et al., 2022). Optimal wave conditions for coral transplantation are those that are neither too large nor too calm (Pelasula et al., 2023). Measurements at Karang Bolong Beach revealed relatively calm wave conditions at both Station 1 and Station 2. Therefore, adjustments need to be made based on the suitability values of each station.

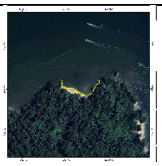
The final parameter measured, substrate type, showed little variation between stations. All stations exhibited a mix of hard and soft substrates, consisting primarily of coral sand or rocky substrates with a minor presence of muddy sediments. Substrate is a crucial factor for coral life, as corals generally thrive optimally on hard substrates like rocks (Hermansyah et al., 2020). However, during coral transplantation, substrate adjustments can be made, so sandy locations can still be utilized, indicating that Nusakambangan waters still have potential.

2. Suitability Assessment

The suitability assessment for coral reef transplantation sites at several stations in the waters of Karang Bolong Beach, Nusa Kambangan Island, revealed a consistent category of "Suitable" (S2) for both Station 1 and Station 2 (**Table 5**):

Table 5. The results of the suitability assessment for coral transplantation

Station	Value	Category	Explanation	Total Area (Ha)
1	74%	S2	**Suitable**	± 0.5
2	66%	S2	**Suitable**	



The measurement results yielded scoring values that fell into the same category of "Sufficiently Suitable" (S2) but with different scores between the two stations. Station 1 scored 74% and Station 2 scored 66%, with an area of approximately 0.5 hectares. These differences in results are suspected to be caused by variations in several parameters that influence the outcome (Prema, 2013). Although Station 1 showed fairly good results, it scored less optimally in terms of protection, waves, and currents. The strong currents and waves at Station 1 make it less sheltered and suboptimal for coral reef transplantation (Pelasula et al., 2023). In contrast, Station 1, with less intense currents and waves compared to Station 2, yielded better results and also fell into the "Sufficiently Suitable" category. The factor contributing to the difference in results between Station 1 and 2 is that has a more sheltered location and more optimal currents for the transplantation process (Kenyon et al., 2023).

D. Conclusion

Based on the results of the analysis, it is known that in general the location of Karang Bolong beach waters is moderately suitable category (S2: there are limiting factors, but can still

be manage or engineered) with scores ranging from 66–74% with a total area of approximately 0.5 hectares.

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