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Department of Earth Science and Technology, Universitas Negeri Gorontalo

Spatial Study of Eel Larva Habitat in Ciletuh Bay, Sukabumi Regency, West Java

Illa Annisa[1], Supriatna[1], Iqbal Putut Ash Shidiq[1], Tito Latif Indra[1], Enrico Gracia[1] ORCID

[1] *Department of Geography, Universitas Indonesia, Depok 16424, Indonesia*

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Corresponding author:
Enrico Gracia
Email: enrico.gracia@ui.ac.id

ABSTRACT

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Eels (*Anguilla spp.*) are highly nutritious fish that are widely consumed. Ciletuh Bay, situated opposite the Indian Ocean, is a natural habitat for eel larvae. The migration of eel larvae is influenced by various oceanographic factors, including salinity, sea surface temperature, and chlorophyll-a. In order to support fisheries activities in Sukabumi Regency, it is important to identify the optimal habitat for eel larvae and obtain information about their abundance. This study used remote sensing techniques and two algorithms, the Cilamaya Algorithm to estimate salinity and the Wibowo Algorithm to estimate chlorophyll-a. The study was conducted during the wet, dry, and transitional months of 2019 and 2020 in Ciletuh Bay. The potential areas for eel larvae were found to be concentrated at the mouth of the river during the wet month, at the estuary and the shore during the dry month and the first transitional month, and tended to spread during the second transitional month. The largest potential area was found during the dry month of 2019, covering an area of 3.44 km^2, but the potential was more stable during the wet months.

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1. INTRODUCTION

Indonesia, the world's largest maritime country, has a territorial area estimated to be around 7.7 million km^2. It comprises approximately 17,500 small and large islands, with a coastline of 81,000 km (Marnani et al., 2021). This archipelagic country is also home to many bays, coastal areas separated from the sea by a barrier beach, and part of an estuary water system (Ramdhan et al., 2014). Estuaries are considered transition zones between marine and freshwater habitats. They provide a unique water characteristic due to their free connection to the open sea and the dissolved seawater content from rivers (Supriadi, 2001). The estuary environment is a naturally productive ecosystem with high productivity as a nutrient trap and provider throughout the year. It plays a significant role in fish life, serving as a spawning area, nursery area, and migration route, resulting in a rich diversity of fish species at various life cycle stages (Blaber, 2013). One such species is the eel (*Anguilla spp.*), making the estuary an important location during its life phase.

The *Anguilla spp*. genus is comprised of 18 species of eels, most of which are found in tropical regions (Aoyama, 2009). Eel is a nutritious fish for consumption, with a high protein content of 16.4% and vitamin A content of 4700 IU (Pratiwi, 1998). Eel also contains a high amount of DHA at 1,337 mg/100 grams, higher than that found in salmon at 820 mg/100 grams. This makes eels a valuable commodity in both local and international markets. With the world population increasing, there will be a greater need for protein sources from meat and fish, increasing the demand for eels. Developed countries such as America, European countries, Japan, Hong Kong, Taiwan, and China are showing an increasing demand for eels, with the ratio of demand and availability growing larger (Tabeta et al., 1979).

The number of eels present depends on the area's water conditions. As an estuary, Ciletuh Bay is where fresh water from the Ciletuh and Cimarinjung rivers mix with seawater from the bay. This location has the potential for eel migration as it is situated directly opposite the Indian Ocean and is part of South Java's coastal waters. The southern coastal area of Sukabumi is a well-known location for eel fishing due to its high potential and activity (Hakim et al., 2016). Eel fishing is typically done in the estuary (Walmsley et al., 2018), the downstream part of the river that connects directly to the sea (Wang et al., 2021). The local community often uses Ciletuh Bay to catch eels during the larval and glass eel stages.

To determine suitable habitats for eel larvae, analyzing the levels of chlorophyll-a and salinity in a specific area is necessary (Faulia, 2020; Supriatna et al., 2018). Thanks to technological advancements, calculating these values can now be done without extensive fieldwork, making research more cost-effective. Remote sensing technology is one such tool that can assist in estimating chlorophyll-a and salinity values accurately.

There are various remote sensing data collection methods, but the most commonly used ones are satellite imagery and unmanned aerial vehicles (UAVs). Researchers have extensively studied the potential habitat of eel larvae using satellite imagery (Faqihuddin et al., 2018; Irianto et al., 2016; Takarina & Supriatna, 2017). Typically, Landsat satellite imagery with a spatial resolution of 30 meters is used to predict the potential habitat of eel larvae. However, in this study, Sentinel-2 satellite imagery with a spatial resolution of 10 meters was used, which is expected to provide more accurate research results. The study aims to analyze the potential distribution of eel larvae habitat based on oceanographic factors and remote sensing interpretation in relation to eel larvae catching activities in Ciletuh Bay waters. This research is part of efforts to increase eel production.

2. METHOD

2.1. Study Area

The research study takes place in Ciletuh Bay, which can be found on the southern coast of Java in Indonesia. Specifically, it is located within the Ciemas Sub-district of Sukabumi Regency. Ciletuh Bay sits approximately 30 km from Palabuhanratu Bay and is positioned at 7°11'0" S and 106°27'0" E on the map. The bay has a U-shape and a relatively small coastline measuring 6.3 km in length, as illustrated in Figure 1.

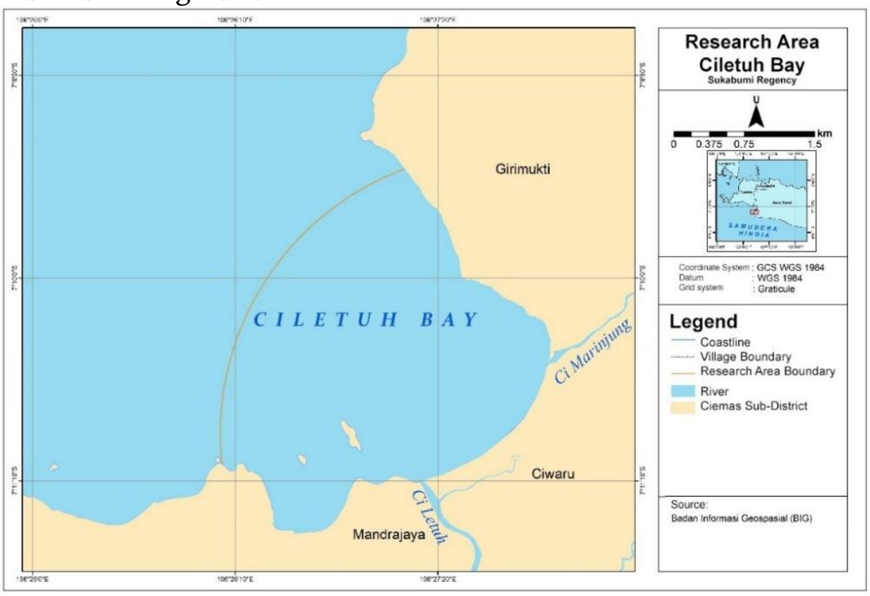

Figure 1. Research location.

2.2. Data

The remote sensing data used in this research are using satellite imagery and aerial photography with UAVs. The satellite imagery used is Sentinel-2, which has a spatial resolution of 10 meters by taking pictures in the wet month, first transitional month, dry month, and second transitional month in 2019 and 2020 (see Table 1). The aerial photography is taken using multispectral camera, which can capture RGB, red edge, and NIR data.

Table 1. Data collection dates

Months	Years	
	2019	**2020**
Wet months	5 January 2019	24 February 2020
Transitional month I	5 May 2019	24 May 2020
Dry month	27 July 2019	17 August 2020
Transitional month II	22 October 2019	21 October 2020

The satellite imagery will be used to extract salinity and chlorophyll-a values using an estimator algorithm. The salinity estimation algorithm used to extract information from Sentinel-2 satellite imagery in 2019 – 2020 is the Cilamaya algorithm (Kaffah et al., 2020).

$$Salinity\ (ppt) = 139.566970 + (86.21318 \times Band\ 2) - (24.62518 \times Band\ 4) \quad (1)$$

where: Band 2 is blue band; Band 4 is red band.

The chlorophyll-a concentration, which is a pigment found in phytoplankton cells, can be determined through remote sensing imageries. In this study, the Wibowo algorithm is used to estimate the value of chlorophyll-a (Wibowo et al., 1994).

$$Chlorophyll - a\ (mg/m^3) = 2.41 \times (\frac{TM4}{TM3}) + 0.18 \quad (2)$$

where: TM4 is red band; TM3 is green band.

To ensure the accuracy of data obtained from Sentinel-2 satellite imagery, it is crucial to validate the information through field survey testing. Surveys were conducted at 17 observation points to determine surface salinity values and at 10 observation points for chlorophyll-a values. A refractometer was used to measure surface salinity, while unmanned aerial vehicle (UAV) data with multispectral imaging was utilized to determine chlorophyll-a values and compare them to the values obtained from Sentinel-2 data. Multispectral aerial photos were then extracted to calculate the normalized difference vegetation index (NDVI). The NDVI value obtained was classified using the Malahlela classification scheme to determine the level of chlorophyll-a concentration (Malahlela et al., 2018). The aerial photos were taken during a field survey conducted to obtain in-situ values of chlorophyll-a on October 21, 2020, at 10:30 am local time, the same date and time that the Sentinel-2 imagery was recorded.

2.3. Analysis

Statistical tests were carried out to test the accuracy of the reflectance product of the Sentinel-2 imagery surface using the Normalized Mean Absolute Error (NMAE) index and the coefficient of determination (R^2) to see the correlation between in-situ data and estimates from the satellite imagery (Wyrtki, 1961). The NMAE index is used to determine the absolute error of the estimated value of the algorithm. The algorithm is stated to be able to be used to identify seawater parameters with remote sensing data, and then the resulting NMAE value must be below 30% (Wyrtki, 1961)

$$NMAE\ (\%) = \frac{1}{N} \times \sum \frac{x_{estimated} - x_{measured}}{x_{measured}} \times 100 \quad (3)$$

where: N is total number of data; $x_{estimated}$ is the value of algorithm processing result; $x_{measured}$ is the value of the field measurement results that are considered correct.

The coefficient of determination is used to determine the relationship between the data from the image algorithm and the data from the field survey results (Guilford, 1978). The larger the R^2 (closer to 1), the better the results of the regression model (Sapra, 2014).

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \quad (4)$$

where: y_i is observation results, $\hat{y}$ is average, and $\hat{y}_i$ is predicted results.

To determine the possible habitat for eel larvae, the overlay method was used on two spatial variables – surface salinity and surface chlorophyll-a. The distribution of these values was obtained using the Cilamaya and Wibowo algorithms on Sentinel-2 images. The resulting distribution maps were overlaid using ArcGIS 10.6 software. This process generated new information that included the attributes of the two variable layers, which helped in identifying potential habitat areas for eel larvae. Based on the suitability matrix of the eel larvae habitat (Septiawan, 2006; Sutrisno, 2008; Wibowo et al., 1994), the potential habitat was classified into three classes – high, medium, and low – as seen in Table 2.

Table 2. Suitability matrix of potential eel larvae habitat areas

Potential	High	Medium	Low
Salinity (ppt)	5 – 15	<5	>15
Chlorophyll-a (mg/m^3)	1.01 – 1.8	0.501 – 1.00	0.01 – 0.05

*Source: Septiawan (2006), Sutrisno (2008), Wibowo et al. (1994)

3. RESULTS AND DISCUSSION

After conducting validation tests at 17 points, the surface salinity estimator algorithm achieved an R^2 of 0.516 and an NMAE of 4.044%. Similarly, the chlorophyll-a estimator algorithm was validated at 10 points, resulting in an R2 of 0.864 and an NMAE of 0.06%. Based on these results, it can be concluded that the Cilamaya algorithm is effective in estimating surface salinity values, while the Wibowo algorithm is suitable for estimating chlorophyll-a values in Ciletuh Bay. This is due to both algorithms having an R^2 value greater than 0.5 and an NMAE value below 30%.

The abundance and migration of eel larvae are greatly affected by their habitat conditions. Each fish migrates to and from the place of reproduction, which occurs annually during spawning season (Kawabata et al., 2015). External factors, such as lunar cycles, temperature, salinity, and currents, can impact the migration process (Ordeix & Casals, 2024). By analyzing these external factors, potential habitats for the abundance of migratory eel larvae can be identified. Based on oceanographic factors, the waters of Ciletuh Bay are a potential habitat for eel larvae. Identifying potential habitats based on external oceanographic factors can help determine the optimal areas for eel larvae to thrive. The suitable area for eel larvae is characterized by salinity levels between 5-15 ppt and chlorophyll-a concentrations ranging from 1.01 to more than 1.8 mg/m^3.

Based on the ideal levels of salinity and chlorophyll-a, the best location for potential growth is along the coast of Ciletuh Bay and the Ciletuh and Cimarinjung estuaries during the wet month. In 2019, the potential area reached up to 0.35 km from the Ciletuh estuary and 0.6 km from the Cimarinjung estuary, covering an area of 1.18 km^2. However, in 2020, the potential area shifted to the river mouth, reaching up to 0.16 km from the Ciletuh estuary and 0.3 km from the Cimarinjung estuary. The optimal areas with ideal salinity and chlorophyll-a levels in 2020 were found on the coast of Ciletuh Bay and river mouths, covering a decreased area of 0.56 km^2 compared to 2019's wet months.

In wet months, the ideal environment for eel larvae (*Leptocephalus*) is typically found near river estuaries and the coast (see Figure 2). This allows for easier migration from seawater to fresh water through river mouths. Wet conditions provide ample habitat areas for eel larvae due to the increased rainfall, which promotes the mixing of fresh water into the estuary. Additionally, river flows bring nutrients from the land, further supporting their growth.

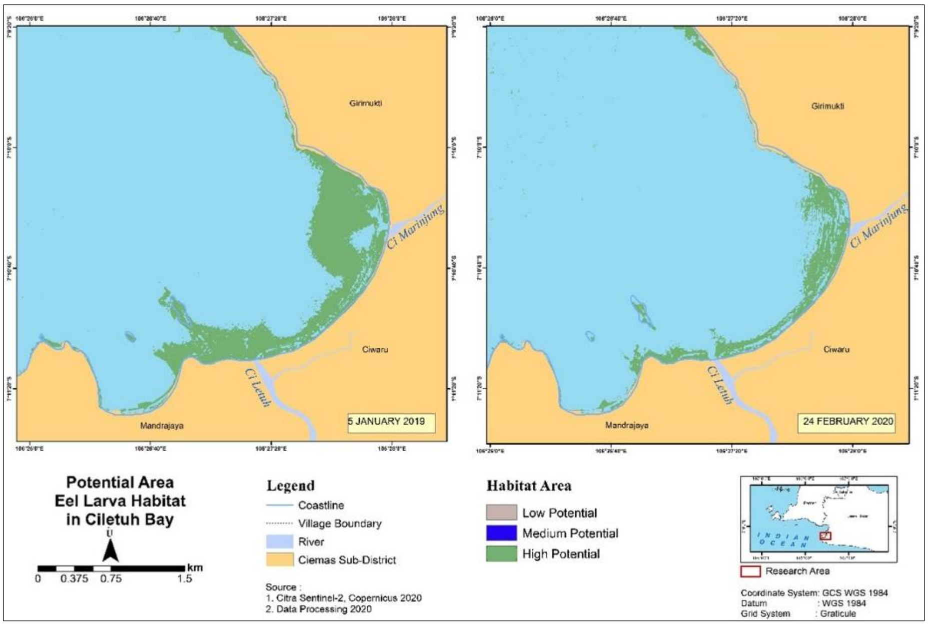

Figure 2. Potential area of habitat for eel larvae in wet months

During dry months, suitable areas for eel larvae can be found in the coastal waters of Ciletuh Bay and the Ciletuh and Cimarinjung estuaries, based on optimal levels of salinity and chlorophyll-a. Chlorophyll-a tends to spread partially towards open waters. On July 29, 2019, potential areas with supporting salinity and chlorophyll-a values for eel larvae were found up to 1.17 km from the Ciletuh estuary and 1.3 km from the Cimarinjung estuary, covering a habitat area of 3.44 km^2. In 2020, potential areas were found closer to river mouths, up to 0.3 km from the Ciletuh estuary and 0.18 km from the Cimarinjung estuary, and tended to decrease in size from the previous year. The potential area in 2020 was located on the coast of Ciletuh Bay and river mouths, with an area of 0.49 km^2.

In general, eel larvae tend to inhabit potential habitats near the estuary, coast, and some areas that extend towards the open sea in dry months (see Figure 3). The direction of the current, which is influenced by the east monsoon wind, plays a crucial role in this condition. The wind moves away from the bay to the northwest, affecting the larvae's potential habitat. Moreover, low rainfall leads to low-value salinity due to a lack of fresh water mixing from river flows during dry months (Gasim et al., 2015).

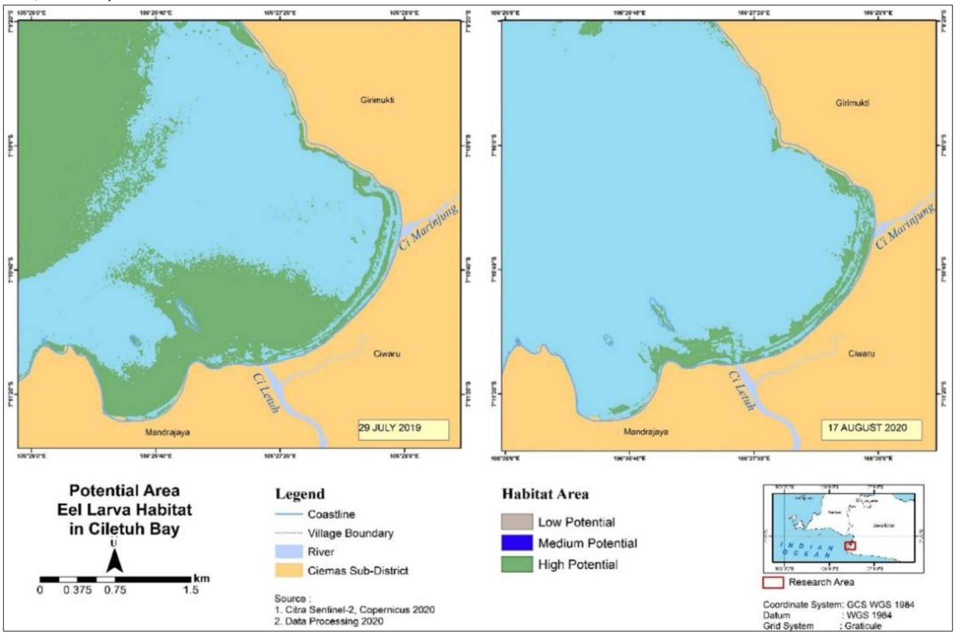

Figure 3. Potential area of habitat for eel larvae in dry months

During the transitional period between May 5, 2019 and May 24, 2020, certain areas near the Ciletuh estuary, Cimarinjung, and the edge of Ciletuh Bay showed similar patterns, although with varying ranges and sizes. In 2019, the eel larvae habitat extended up to 0.4 km from the Ciletuh estuary and 0.1 km from the Cimarinjung estuary, with a potential area of 0.67 km2 around the river mouth. The same pattern was observed in the first transitional month of 2020, with potential areas around the Ciletuh estuary, Cimarinjung, and parts of the bay's edge. The eel larvae habitat in the first transitional month of 2020 covered up to 0.5 km from the Ciletuh estuary and 0.3 km from the Cimarinjung estuary, with a total area of 1.0 km^2 around the river mouth.

During the second month of transition, the potential area for eel larvae typically decreases compared to the preceding month. In 2019, the potential area was primarily located at river mouths, covering a relatively small area of 0.24 km2 and extending up to 0.1 km from the Ciletuh estuary and 0.09 km from the Cimarinjung estuary. However, in the second transitional month of 2020, eel larvae were found in life support areas that tended to be towards open waters instead of around river mouths. Overall, during the first transitional month, the potential habitat for eel larvae is usually found in the estuary and along the coast, while in the second transitional month, their potential habitat is spread out in the estuary and open waters (see Figure 4).

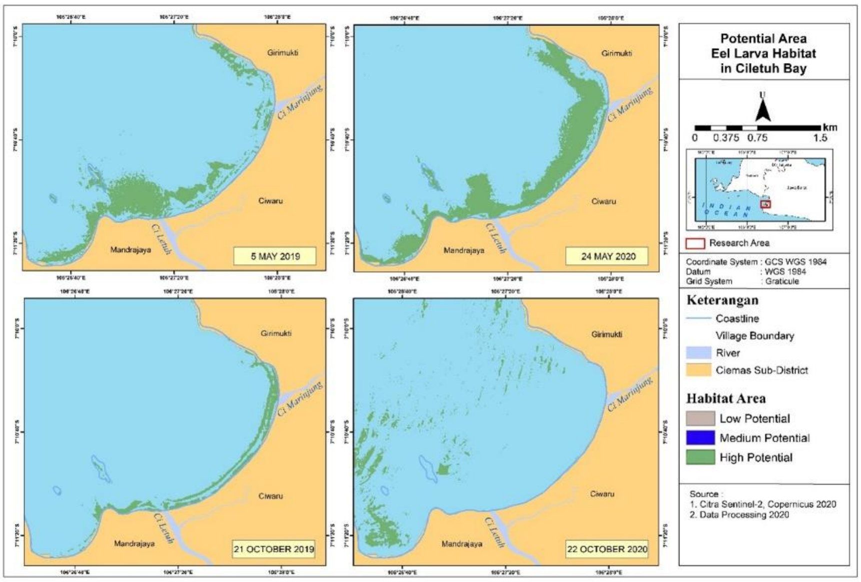

Figure 4. Potential area of habitat for eel larvae in transitional month

Table 3. Potential areas of habitat for eel larvae in the waters of Ciletuh Bay

Date	Potential area coverage (km^2)		Potential Area (km^2)	Months
	Ciletuh	Cimarinjung		
5 January 2019	0.35	0.6	1.18	Wet month
24 February 2020	0.16	0.3	0.56	Wet month
29 July 2019	1.17	1.3	3.44	Dry month
17 August 2020	0.3	0.18	0.49	Dry month
5 May 2019	0.4	0.1	0.67	Transitional month I
24 May 2020	0.5	0.3	1.0	Transitional month I
22 October 2019	0.1	0.09	0.24	Transitional month II
21October 2020	0.5	0.12	0.52	Transitional month II

In the Ciletuh and Cimarinjung estuaries, the oceanographic conditions such as salinity, chlorophyll, and sea surface temperature strongly support the life of eel larvae during the wet, transitional and dry months. The potential area of eel larvae habitat was found to be largest in the dry month of 2019 at 3.44 km^2, but decreased to 0.49 km^2 in 2020 (see Table 3). However, the potential area in the wet month remains stable. According to interviews with eel fishermen in

Ciletuh Bay, they catch eel larvae following seasonal patterns and only during the rainy season, which lasts from December to February.

Fishermen believe the Ciletuh estuary's rainy season is when eel larvae are abundant, and fishing activities occur between 1:00 a.m. and 5:00 a.m. Eel fishermen specifically focus on fishing for eel larvae in the Ciletuh estuary because it is larger in size and the river water flows throughout the year. On the other hand, the Cimarinjung estuary is a seasonal river where the water does not flow throughout the year and dries up during the dry season. Therefore, there is no fishing activity in the Cimarinjung estuary like in the Ciletuh estuary.

Based on the local customs and beliefs of eel larvae fishermen, the ideal location for catching eel larvae is only prevalent during the rainy season. This is because it is thought that the high rainfall levels will attract many eel larvae to the river mouth. Fishermen use hanco tools measuring 1m x 1m to catch eel larvae near the mouth of the Ciletuh river. The Ciletuh estuaries are also considered a promising habitat for eel larvae. Therefore, it is crucial to maintain environmental sustainability and the cultural traditions of eel larvae fishing as a source of livelihood for the surrounding communities, for agricultural purposes, and as a tourist attraction. By implementing proper management practices and regularly monitoring the rivers, we can ensure the preservation of the eel larva habitat and improve the overall health of Ciletuh Bay.

4. CONCLUSIONS

It has been observed that eel larvae tend to thrive in areas around the Ciletuh and Cimarinjung estuaries. These areas vary seasonally, with the predominant location being at the river's mouth during wet months, at the estuary and shore during dry months and the first month of transition, and then spreading during the second month of transition. The largest potential habitat area is during the dry month, covering an area of 3.44 km, however, the potential area is more stable during the wet months. For future research, it is recommended to conduct more in situ sampling and use advanced analysis methods to improve results.

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