Saintek Perikanan: Indonesian Journal of Fisheries Science and Technology
Available at http://ejournal.undip.ac.id/index.php/saintek
Vol. 20 No. 3 : 127 - 132, October 2024

VERTICAL AND HORIZONTAL POPULATION DENSITY DISTRIBUTION OF BANGGAI CARDINALFISH *(Pterapogon kauderni, Koumans, 1933)* IN GILIMANUK BAY, BALI

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Received: 9 August 2024, Accepted: 24 September 2024

ABSTRACT

The Banggai cardinalfish (Pterapogon kauderni, Koumans, 1933) is an endemic coral reef fish species native to the waters of the Banggai Islands Regency. In 2007, the species was classified as endangered by the International Union for Conservation of Nature (IUCN), followed by its designation as a protected species with limited conservation status by Indonesia's Ministry of Marine Affairs and Fisheries in 2018. Research on the Banggai cardinalfish has been conducted in its native habitat in the Banggai Islands as well as in introduced locations. One of these introduction sites is Gilimanuk Bay, Bali, which serves as a temporary holding area for ornamental corals before export and as a release site for Banggai cardinalfish that do not meet export standards, typically due to physical deformities. This study aims to analyze the horizontal and vertical distribution of the Banggai cardinalfish in Gilimanuk Bay, Bali, with the expectation that the findings may provide insights for government policy formulation in terms of conservation efforts. The research employed a descriptive exploratory method to provide a comprehensive description of the subject and to establish a data foundation for further research or decision-making. The results showed a total population of 2,253 fish. The highest horizontal population density was observed in the southwestern part of Gilimanuk Bay, with 2.87 individuals/m² across a 500 m² observation area distributed over 5 stations. Meanwhile, the highest vertical population density was found at a depth of 6–7 meters, with a density of 3.88 individuals/m² over a 100 m² observation area at one station.

Keywords: Banggai Cardinalfish; Endemic; Gilimanuk Bay; Introduction

INTRODUCTION

The Banggai cardinalfish (BCF) is one of the coral reef fish with endemic characteristics. This endemic fish originates from the waters of the Banggai Islands Regency. In 2007, the BCF was classified as an endangered species by the IUCN, followed by its designation as a species under limited protection by the Ministry of Marine Affairs and Fisheries in 2018. Since then, research on the Banggai cardinalfish has become a prominent topic of interest among stakeholders, including academics and practitioners.

BCF, an endemic species in the waters of Banggai Islands Regency, has been introduced to various locations primarily due to trade activities. There is no official record of when the Banggai cardinalfish appeared in Gilimanuk Bay, but according to information from local fishermen, the introduction of this species to Secret Bay, Gilimanuk Bay, had already occurred by at least 1995 (Syakir et al., 2018; Arbi et al., 2022).

This fish exhibits unique morphological features and is named Pterapogon-meaning "apogon fish with elongated fins" (Vagelli, 2011). The presence of these elongated fins limits the BCF's ability to migrate over long distances. Additionally, the species is a male mouthbrooder, meaning the males protect their offspring inside their mouths. As a result, the BCF lacks a pelagic larval phase. Both its morphology and reproductive behavior make it unlikely for this species to migrate far from its original habitat.

Gilimanuk Bay is in the western part of Bali Province, serving as a boundary between Jembrana Regency and Buleleng Regency. It falls under the management of West Bali National Park (TNBB). The bay is a site for ornamental coral placement by several ornamental coral trade companies before shipment abroad. In addition to coral trade, these companies also trade reef fish, including the Banggai cardinalfish. Some fish that do not meet export standards, for example, due to deformities, are released into Gilimanuk Bay. This activity has contributed to the establishment and growth of the Banggai cardinalfish population in the bay.

Field data collection poses unique challenges for researchers and practitioners, including those in marine fisheries. Remote sensing offers a practical solution, enabling the monitoring of large areas in a short time. In this study, population density data were obtained through field observations, while aquatic and depth data were derived from remote sensing. Waterbody data were analyzed using the

Normalized Difference Water Index (NDWI), a method for monitoring land dryness or wetness (Simarmata, 2021). Water depth was estimated using the empirical bathymetry method, which involves the regression of field depth measurements with satellite imagery (Aji et al., 2021).

Data on fish population distribution, including their habitat, are essential for the government as the Management Authority (MA) is responsible for the protection of the Banggai cardinalfish. Currently, no research has been conducted on the horizontal and vertical distribution of the Banggai cardinalfish, particularly in Gilimanuk Bay. Therefore, this research is necessary. The objective of this study was to analyze the horizontal and vertical distribution of the Banggai cardinalfish population density in Gilimanuk Bay, Bali.

RESEARCH METHODS

Location and Time of the Research

This study was conducted in Gilimanuk Bay, located in the western part of Bali Island. Administratively, the bay is situated on the boundary between Jembrana Regency and Buleleng Regency. Gilimanuk Bay is located at 114.439° - 114.469° E and 8.155° - 8.181° S. Field data collection was carried out in June 2024.

Observation stations were selected based on their ability to represent the horizontal distribution of the fish population in Gilimanuk Bay evenly. The selection of stations also considered their ability to represent the vertical distribution of the fish population, ensuring that the fish are evenly distributed according to their depth range.

Extraction of Water Body

Waterbody data were obtained using the Normalized Difference Water Index (NDWI) method, which is a technique for distinguishing water bodies from land or vegetation. The principle of NDWI involves comparing the green band with the near-infrared band. The NDWI formula is expressed as follows:

$$NDWI = \frac{(NIR-SWIR)}{(NIR+SWIR)} \quad \text{..... (1)}$$

Where: NIR = Band Near Infrared; SWIR = Band Shortwave Infrared

The NDWI index above 0 is defined as a water body (Simarmata et al., 2021; Permata et al., 2022). All areas with this value within the mouth of Gilimanuk Bay are defined as the study area. The processing of water bodies was carried out using Sentinel-2A imagery, downloaded on June 23, 2024. Water body extraction was performed using the remote sensing software Sentinel Application Platform (SNAP).

Detection of Water Depth

Water depth data were obtained using the empirical bathymetry method (Aji et al., 2021). This method involves regression analysis developed using field-observed water depth data and image data. The imagery used includes the blue band (sensitive to substrate) and the green band (sensitive to turbidity) from Sentinel 2A imagery. Depth values were extracted using the remote sensing software SNAP.

$$Z = a + b \ln \frac{R_g}{R_b} \quad \text{.....(2)}$$

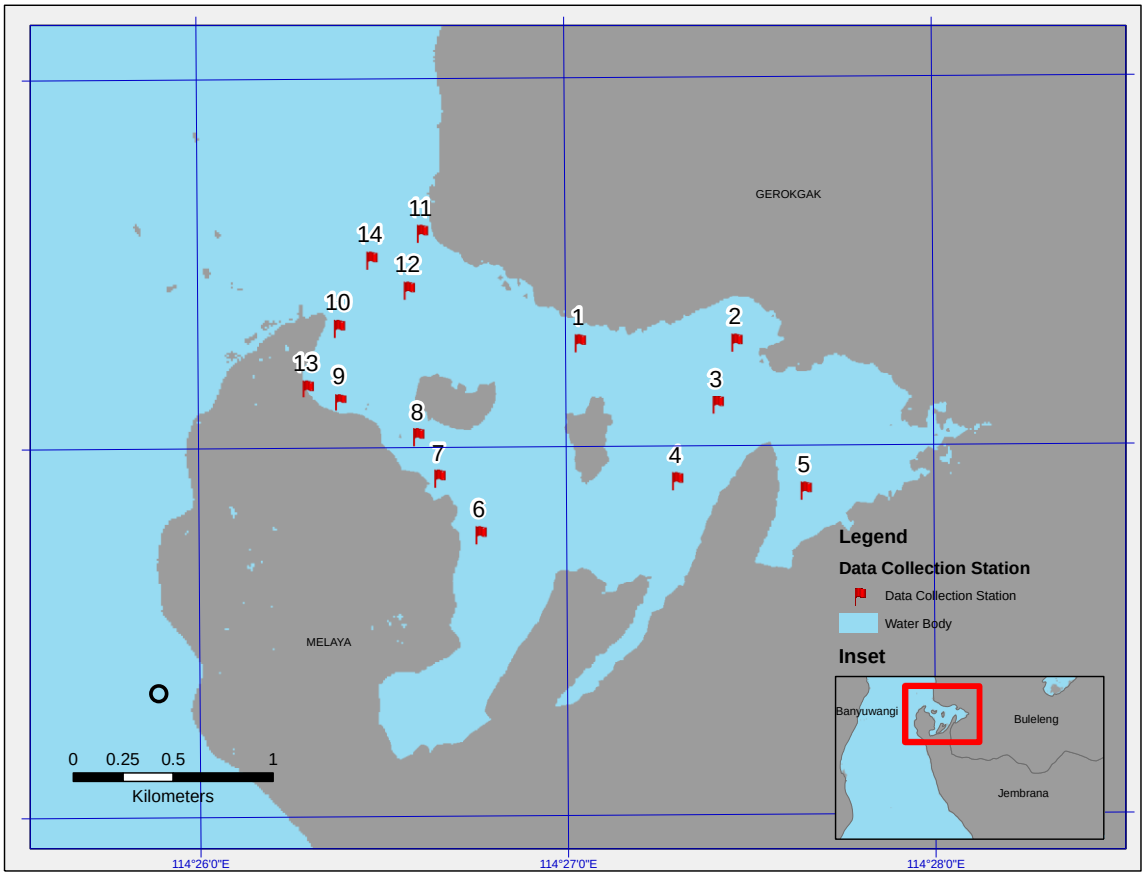

Figure 1. Research Location and Determination of Observation Stations in Gilimanuk Bay.

Where: Z = depth (m); Rg = Green-band reflectance; Rb = Blue-band reflectance; a = Regression intercept. B = Regression coefficient representing depth's dependence on reflectance ratio.

Exposure to Waves

The determination of station conditions regarding wave exposure was carried out through visual field observations. Stations with morphology exposed to external wave action will be categorized as open stations. Stations sheltered from wave exposure will be categorized as sheltered stations. Meanwhile, stations indirectly affected by wave exposure will be categorized as semi-sheltered stations.

Fish Population Density

Fish population distribution data were obtained using an underwater visual census with the belt transect method. The underwater visual census is a method used to count (census) the visible underwater biota population. The belt transect method is employed to estimate the distribution of a specific biota closely associated with a particular area. This method records the target biota found within a defined rectangular area of specific length and width (Suwardi, 2019).

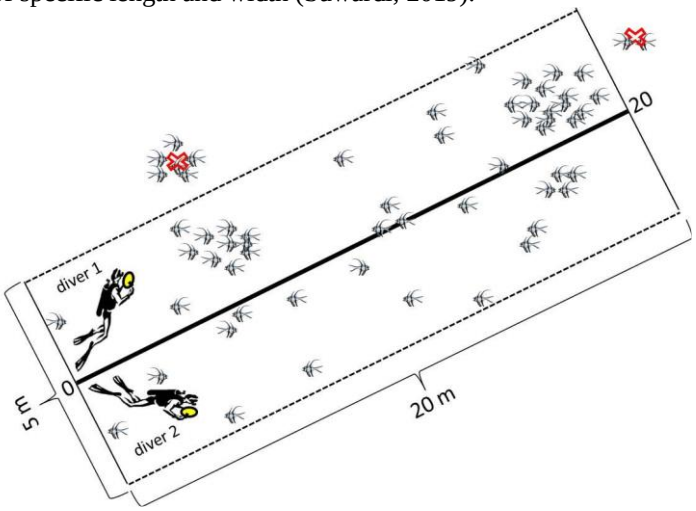

Figure 2. Schematic of Underwater Visual Census (UVC) Observations Using the Belt Transect Method (Suwardi, 2019).

Fish population density was obtained by dividing the number of fish by the area of observation. The formula is as follows (Suwardi, 2019):

$$D = \frac{x}{L} \quad \text{.....(3)}$$

Where: D = Fish density (individuals/m^2); x = Total number of fish individuals; L = Area of the observed transect (100 m^2)

Analysis of Horizontal and Vertical Distribution of Fish Population Density

Fish population density data at each station are presented in the form of graphs with information on the fish population size. The size of the circle chart at each station represents the number of fish visually recorded during the field observation. The larger the fish population, the larger the size of the circle chart on the spatial scale graph.

The analysis of water depth to fish population density is conducted by grouping the fish population density based on the observed depth. Depth is divided into several classes, with each class having a 1-meter interval. Each observed fish population density is then grouped into the corresponding depth class, and a graph of fish population density by depth class is created.

RESULT AND DISCUSSION

Study Area

The results from the NDWI, which separates water bodies from land and vegetation, were clipped to cover the area of Gilimanuk Bay, extending to the eastern side, resulting in a water area of 349.34 ha. In the middle of the waters, there are two shoals covered with mangroves. These shoals are locally known as Pulau Burung or the Bird Island and Pulau Kalong or the Bat Island. A similar calculation by Putra (2023) found an area of 355.45 ha. The difference in weather conditions between the imagery taken could result in differences in index values. Macklin (2023) reported that the area of Gilimanuk Bay is 370 ha. Currently, there is no official reference from the government that can be used as a benchmark for the area of Gilimanuk Bay.

Water Depth Distribution

Gilimanuk Bay is categorized as shallow water. The average water depth of the bay is approximately 6.3 m. The deepest point reaches 22.2 m, located at the mouth of the bay, directly facing the Bali Strait. Along the shoreline, the water depth is less than one meter. A similar statement was made by Thoha (2007), who mentioned that Gilimanuk Bay is relatively shallow, with depths ranging from 5 to 10 m. Depth conditions outside the bay show different results. At the mouth of the bay, depths greater than 20 m have been detected. As one moves west, the depth increases. The deepest point detected in the Bali Strait, as shown on the map, reaches 271 m.

Horizontal and Vertical Distribution of Banggai Cardinalfish

From 14 observation stations, a total of 2,253 fish were recorded. Each station had an observation area of 100 m², resulting in an overall population density of 1.60 individuals/m². The station with the highest fish population density was Station 9, with 5.08 individuals/m². Horizontally, stations with a high fish population density, with values greater than 2 individuals/m², were Station 4, 6, 7, 8, and 9. Four of these five stations were located on the southwest side of the bay. This area is sheltered from wave exposure and is also where community and fish exporter activities are concentrated. This location may serve as a release point for fish from companies.

Nearly all the observation stations were in sheltered waters, except for Stations 10, 11, 12, and 14. These four stations were located at the mouth of Gilimanuk Bay, exposed to wave action compared to the other stations within the bay. No Banggai cardinalfish were found at these four stations. Huwae (2023) stated that the habitat of Banggai cardinalfish is typically found in sheltered waters.

There were four stations where no BCF were found. These stations were Station 5, 10, 11, and 14. Stations 10, 11, and 14 were located at the mouth of the bay, while Station 5 was situated at the eastern tip of the bay. The absence of fish at

Station 5 was likely due to its isolated location, making it more difficult for fish distribution. The Apogonidae family, to which the Banggai cardinalfish belongs, is known for its tendency to remain in its microhabitat. BCF are inclined to stay within their microhabitat, especially in sea urchins. Banggai cardinalfish do not shift their population more than 50 meters (Vagelli, 2011). An experiment conducted by Kolm et al. (2005) found that 33% of Banggai cardinalfish separated from their microhabitat by 50 meters could still find their way back to their microhabitat within 24 hours.

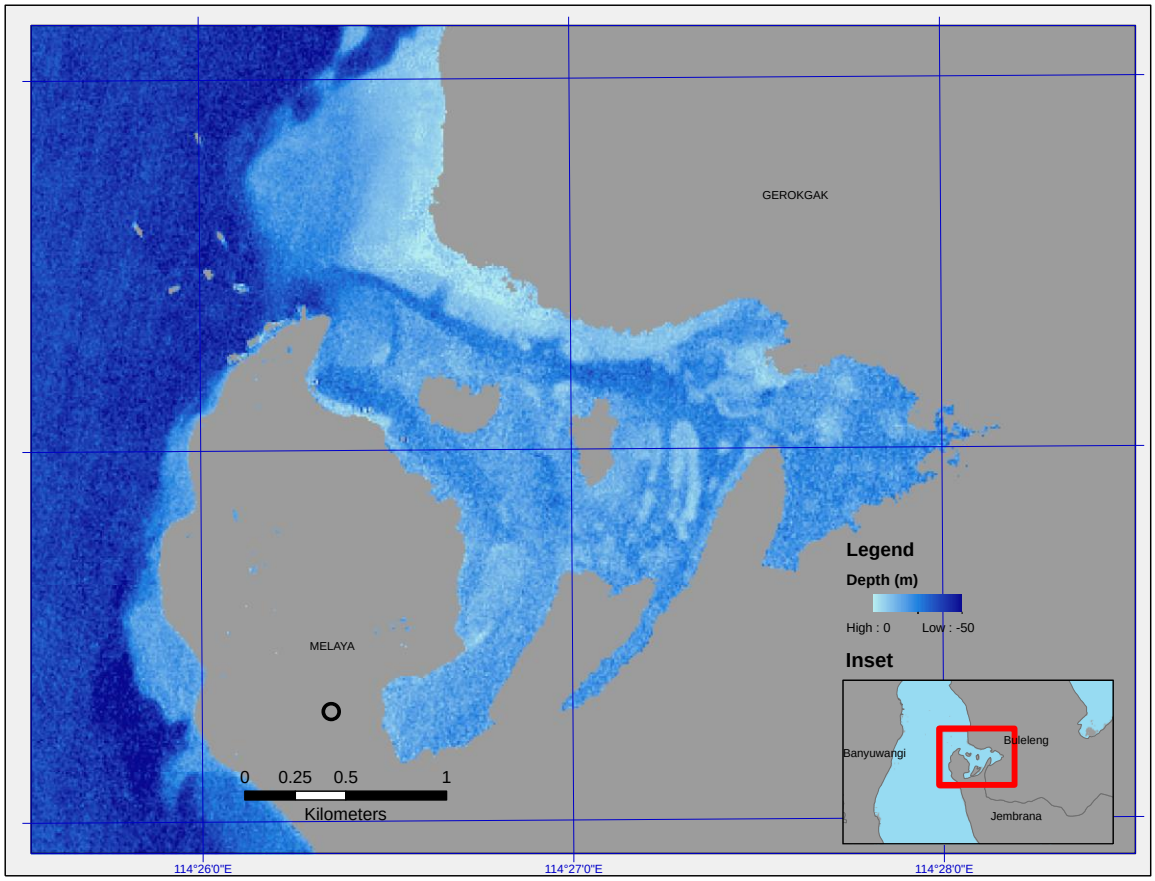

Figure 3. Depth Distribution of Gilimanuk Bay and Bali Strait

Table 1. Results of Observation Depth, Station Shelter Condition, and BCF Density

Station Name	Depth (m)	Station Shelter Condition	Population Density (individuals/m^2)
Station 1	2.24	Sheltered	1.22
Station 2	2.29	Sheltered	1.25
Station 3	2.32	Sheltered	1.14
Station 4	2.23	Sheltered	2.88
Station 5	4.44	Sheltered	0
Station 6	4.62	Sheltered	2.92
Station 7	8.03	Sheltered	2.68
Station 8	4.62	Sheltered	3.29
Station 9	6.44	Semi-Sheltered	5.08
Station 10	5.29	Exposed	0
Station 11	1.93	Exposed	0
Station 12	2.43	Exposed	1.67
Station 13	0.56	Semi-Sheltered	0.4
Station 14	9.00	Exposed	1.22

The BCF is a species that lives and operates near the seafloor and can hover in the water. The highest population density of the Banggai Cardinalfish is found at a depth of 6–7 meters, with 3.88 individuals/m². The next highest population density is found at a depth of 5–6 meters, with 1.65 individuals/m². At a depth of 0–1 meter, the population density recorded is 0.40 individuals/m². No BCF were found at depths of 7–8 meters and 8–9 meters. No fish population was recorded at depths of 1–2 meters and 3–4 meters. The absence of population data at these depths is because none of the 14 observation stations were placed at these depths.

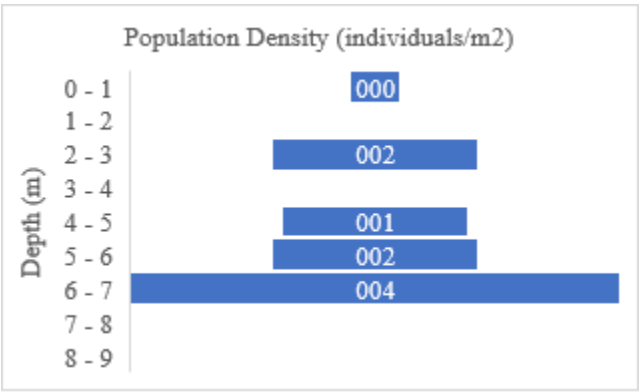

Figure 5. Vertical Distribution of BCF Population Density in Gilimanuk Bay

This distribution is somewhat different from the natural habitat of the Banggai Cardinalfish. In its native waters of the Banggai Islands, the Banggai Cardinalfish is found at depths of 0.5 to 4 meters (Kasim, 2012; Buatan, 2022). The distribution of the Banggai Cardinalfish also shows variations

in depth based on its introduction locations. According to Arbi (2019), the highest population density in Gilimanuk Bay was recorded at a depth of 1–2 meters, with 941 individuals. At a depth of 8–9 meters, one Banggai Cardinalfish was still recorded. Kusumawardhani (2019) reported that the Banggai Cardinalfish distribution at the introduction site in Kendari was found at depths of 0.5 to 2.5 meters. Observations in the Lembeh Strait showed that the Banggai Cardinalfish population was found at depths of less than 5 meters. These studies indicate that the Banggai Cardinalfish is found in relatively shallow waters.

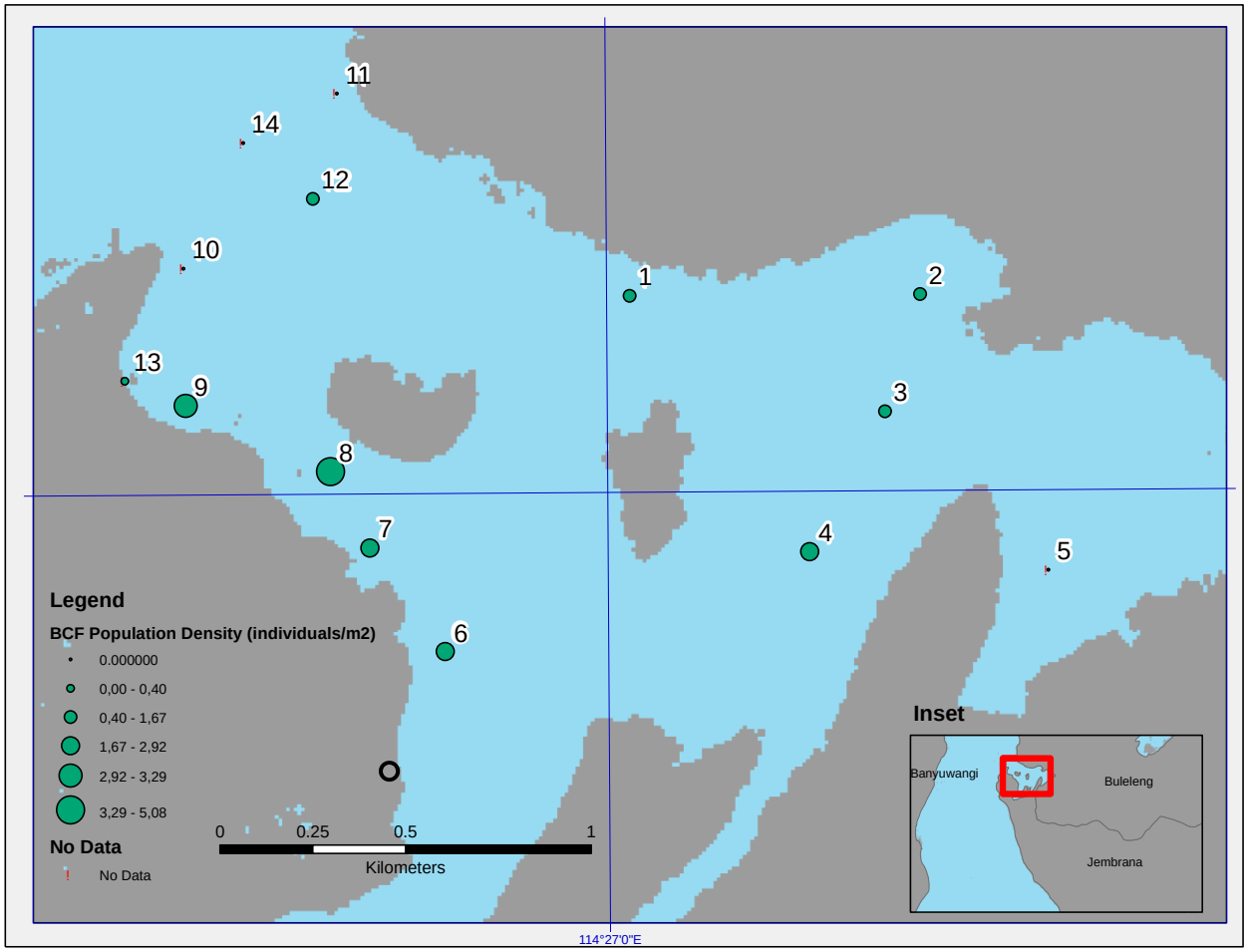

Figure 4. Horizontal Distribution of BCF Population Density in Gilimanuk Bay

CONCLUSION

The horizontal distribution of the Banggai Cardinalfish population was most abundant on the southwest side of Gilimanuk Bay, with a density of 2.87 individuals/m² over an observation area of 500 m² from 5 observation stations. The vertical distribution of the Banggai Cardinalfish population was most abundant at a depth of 6–7 meters, with a density of 3.88 individuals/m² over an observation area of 200 m² from two observation stations.

ACKNOWLEDGEMENT

The author would like to express gratitude to the Ministry of Marine Affairs and Fisheries through the Human Resources Development Agency (BPSDM-KP) for the educational scholarship provided.

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