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Habitat Preferences of the Banggai Cardinal fish (*Pterapogon kauderni*, Koumans, 1933) in Gilimanuk Bay, Bali, Indonesia

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ABSTRACT

The Banggai cardinal fish (*Pterapogon kauderni*, BCF) is an endemic ornamental fish species native to the Banggai Archipelago. Due to trade activities, this species has been introduced to various non-native waters, including Gilimanuk Bay, Bali, where it has successfully survived, grown, and reproduced, indicating that the ecosystem is suitable for its habitat. This study aimed to analyze the population distribution of the BCF in Gilimanuk Bay and to assess the environmental parameters that influence its habitat preference. Fish population data were obtained through a visual census using the belt transect method at 14 stations, grouped by location: inner Bay, southwest Bay, and Mouth Bay. Habitat characteristics data, including water depth, substrate, current, and waves, were collected using a remote sensing approach and a hydrodynamic model. The research revealed that the preferred habitat of BGF in Gilimanuk Bay was in the southwest part of the Bay, at a depth of 2–3 meters with low waves and weak currents, which was the initial introduction site of the fish. These areas also represented the most sea urchin-populated regions, and the most BCF-preferred habitats were found. Although sandy substrate is the broadest type of bottom in the sea, the BCF prefers coral rubble substrates, indicated by the highest preferences index value of 3.97, which are also suitable habitats for sea urchins.

INTRODUCTION

The Banggai cardinal fish (*Pterapogon kauderni*), also known as BCF, is a reef-associated fish species with endemic characteristics, initially found in the waters of the Banggai Archipelago, Indonesia. In 2007, the International Union for Conservation of Nature (IUCN) classified the Banggai cardinal fish as an endangered species. This classification was followed by its designation as a protected species under limited conservation measures by the Indonesian Ministry of Marine Affairs and Fisheries in 2018. The protection restrictions include a ban on catching Banggai cardinal fish in the waters of the Banggai Archipelago, which encompasses the waters of Banggai Regency, Banggai Islands Regency, and Banggai Laut Regency during the peak spawning season, i.e., February, March, October, and November. Meanwhile, in other areas, fishing restrictions are enforced through a provincial catch quota mechanism. Since then, research on the Banggai cardinal fish has gained significant interest among stakeholders, including academics and practitioners.

Although the species is endemic to the Banggai Archipelago, it has been introduced to various locations, primarily due to trade activities, including Gilimanuk Bay. There are no official records of when the species was introduced to Gilimanuk Bay; however, information from local fishers suggests that the introduction of Banggai cardinal fish to Gilimanuk Bay, particularly at Secret Bay, occurred as early as 1995 **(Syakir *et al.*, 2018; Arbi *et al.*, 2022)**.

This fish has a unique morphology and is named Pterapogon, as the term "Pterapogon" refers to an Apogon fish with elongated fins **(Vagelli, 2011)**. The presence of these long fins limits the Banggai cardinal fish's ability to migrate over long distances. The Banggai cardinal fish exhibits a male mouthbrooding behavior, where the male protects the offspring inside its mouth. Consequently, this species lacks a pelagic larval phase. Both its morphology and reproductive behavior prevent the Banggai cardinal fish from migrating far from its original habitat.

Gilimanuk Bay, located in western Bali, is a natural boundary between the Jembrana and Buleleng Regencies. The bay falls under the management of West Bali National Park (TNBB). Historically, the bay was used as a holding area for ornamental corals by several coral trading companies before exportation. Alongside coral trading, these companies engaged in the trade of reef fish including the BGF. Individuals who did not meet export standards, such as those with physical deformities, were often released into Gilimanuk Bay, contributing to establishing and expanding the species' population in the area.

Marine biota, including the Banggai cardinal fish, require suitable habitats for optimal growth and reproduction. Besides, the BCF exhibits strong habitat preferences, favoring specific depths, substrate types, and oceanographic conditions, such as current velocity and wave dynamics **(Vagelli, 2011)**. Data on population distribution, including habitat characteristics, are essential for government authorities responsible for managing the conservation of the BGF. The data on the distribution of fish populations, including their habitat, are necessary for the government as the management authority (MA) responsible for protecting the Banggai cardinal fish.

Several studies have examined the BCF population, primarily focusing on densities in its native waters, as reported by **Kasim *et al.* (2012)** and Bilalang Bay **(Rahman *et al.*, 2024)**. Population distribution studies have been conducted in several introduced locations, including Gilimanuk Bay, Bali **(Arbi *et al.*, 2019)**, Inner Ambon Bay **(Huwae *et al.*, 2019)**, Mejar Jaya waters, Konawe **(Faisal *et al*., 2023)**, and Lembeh Strait, Bitung **(Huwae *et al.*, 2023)**. Research on the habitat preferences of the BCF has been conducted in Kendari waters **(Kusumawardhani *et al.*, 2019)**, which revealed that the species prefers specific habitat criteria. Recruit-stage individuals prefer Heliofungia corals, juveniles prefer sea anemones, and adults favor seagrass habitats. In addition, Banggai cardinal fish in Gilimanuk Bay are strongly associated with the sea urchin *Diadema setosum* **(Arbi *et al.*, 2019; Tambunan *et al.*, 2022)**. However, despite these studies, no research has specifically examined habitat preferences based on their characteristics. Therefore, this study aimed to analyze the preferred habitat of the Banggai cardinal fish in Gilimanuk Bay, Bali.

MATERIALS AND METHODS

Site location

Data collection was conducted in June 2024 at Gilimanuk Bay, one of the introduced habitats of the Banggai cardinal fish. The selection of Gilimanuk Bay as the study site was based on its unique characteristics. The bay is administratively managed as part of the West Bali National Park, a conservation area, while simultaneously serving as a site for ornamental coral farming intended for export. This dual function contributes to the sustainability of the Banggai cardinal fish population in the Bay. There are 14 observation stations distributed throughout the Bay. Five stations are placed in the inner Bay (Stations 1, 2, 3, 4, and 5) to represent areas relatively undisturbed by human activities. Another five stations are positioned along the coastal area near Southwest Bay (Stations 6, 7, 8, 9, and 13) to represent the initial release sites of the fish. The remaining four stations (Stations 10, 11, 12, and 14) are at the Mouth of the Bay to represent the waters adjacent to the open sea. The sampling stations are presented in Fig. (1).

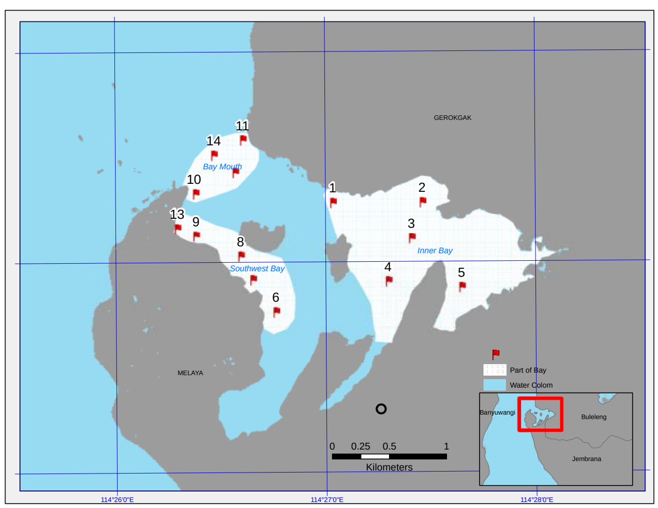

Fig. 1. Map of the study area at Gilimanuk Bay, Bali

Banggai cardinal fish and sea urchin population

Data on the BCF populations and sea urchins were obtained through direct field observations. Fish and sea urchin population data were collected using the Underwater Visual Census (UVC) method with a belt transect approach **(Suwardi *et al.*, 2019)** in a 5m x 20m area

(Fig. 2). The samples of BCF were counted and then categorized based on their visually observed sizes into three groups: recruits (<1.8cm), juveniles (1.8 – 3.5cm), and adults (>3.5cm). Fish population density was determined by dividing the total number of fishes by the observed area **(Suwardi *et al.*, 2019)**.

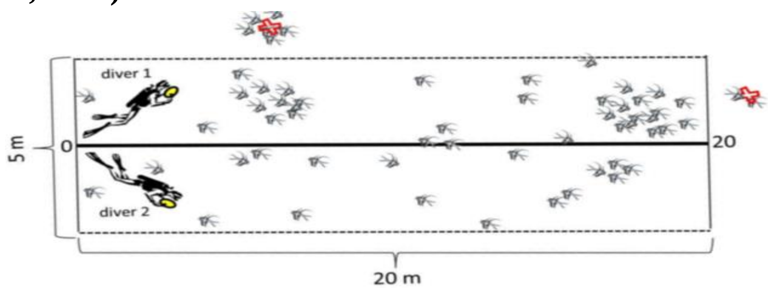

Fig. 2. Observation scheme of underwater visual census (UVC) using the belt transect method **(Suwardi *et al.*, 2019)**

At each observation station, fish samples representing 10% of the observed fish population were collected. The sex of the sampled fish was visually identified based on distinct characteristics, including body shape, buccal cavity size, and the length of the second dorsal fin. Male fish typically exhibit an elongated body shape, a large buccal cavity, and a long second dorsal fin, while females have a more rounded body, a smaller buccal cavity, and a shorter second dorsal fin **(Arbi *et al.*, 2022)**. The sex ratio was calculated as the percentage of males or females relative to the total sampled population.

Water depth and bottom substrate

Water depth was obtained using the Satellite-Derived Bathymetry (SDB) **(Pratomo *et al.*, 2024)**. This method employs regression analysis that correlates *in situ* depth measurements with satellite imagery data. The imagery used includes the blue channel (sensitive to the substrate) and the green channel (sensitive to turbidity) from Sentinel-2A imagery. Depth extraction was conducted using the SNAP remote sensing software, and depth was classified at one-meter intervals.

Substrate data were processed using the Depth Variant Indices (DVI) method, which allows for the identification of underwater objects while minimizing the influence of depth and turbidity **(Karang *et al.*, 2019)**. This method produces seafloor pixel values independent of water depth effects. The pixel values were classified based on field observations of substrate types. The final classification included coral reefs, coral rubble, sand, mud, and other categories **(Putra *et al.*, 2023)**. Each depth class (at one-meter intervals) and substrate type were then quantified in terms of their spatial distribution.

Current velocity and wave data

Current velocity data were obtained using a 2D hydrodynamic model that simulates unsteady flow resulting from changes in sea surface elevation due to tidal fluctuations. This hydrodynamic model was developed using Delft3D software.

Wave height data were derived from the Simulating Waves Nearshore (SWAN) model, which incorporates input from tidal elevation, bathymetric data, wave height, wave period, and wave direction from the WaveWatch III model. Additionally, wave height modeling was conducted using Delft3D software. Model validation was performed using HF Radar data for currents and *in situ* field observations for wave height **(Deltares Systems, 2018)**.

Data analysis

Fish distribution

The Banggai cardinal Fish (BCF) distribution was analyzed descriptively by examining their habitat preferences based on location within the Bay, depth range, and substrate type. Current and wave conditions were also factored into the analysis to enhance understanding of their spatial distribution.

Habitat preference

The BCF's preferred habitat types were analyzed using the Neu method **(Neu *et al.*, 1974)**. This method compares the proportion of habitat occupied by the target species, the Banggai cardinal fish, with the available habitat in the study area.

Table 1. Habitat preference equation **(Neu *et al.*, 1974)**

Habitat Criteria	Area of Habitat	Proportion of Area	Number of Biota (n)	Proportion of Biota Number (u)	Expected Value (e)	Habitat Preference Index (w)	Standardized Habitat Preference (b)
Equation		$\frac{a}{\sum a}$		$\frac{n}{\sum n}$	$pi.\Sigma n$	$\frac{ui}{pi}$	$\frac{wi}{\sum w}$
Habitat Type Occupied by Biota	a_i a_{ii} ... a_n	p_i p_{ii} ... p_n	n_i n_{ii} ... n_n	u_i u_{ii} ... u_n	e_i e_{ii} ... e_n	w_i w_{ii} ... w_n	b_i b_{ii} ... b_n
Total	Σa		Σn	Σu		Σw	

RESULTS

Banggai cardinal fish and sea urchin population

From the total study area of 1,400m², there are 2,253 fish, consisting of 818 recruits (36.31%), 464 juveniles (20.59%), and 971 adults (43.10%). The highest total observed fish population was at Station 8, comprising 508 fish, with 248 juveniles, 198 recruits, and 62 adults; this also represented the highest number of recruits and juveniles. The highest adult population was observed at Station 9, with 282 fish. Overall, the fish density across all observations was

1.61 individuals per square meter, comprising 0.33 recruits per square meter, 0.58 juveniles per square meter, and 0.69 adults per square meter (Table 2 & Fig. 3). Among the sampled population, 117 fish were identified as males, and 41 were females, resulting in a male-to-female ratio of 74.35 to 25.68%. The highest percentage of males was recorded at Station 2, where all 12 sampled fish (100%) were male. Conversely, the highest percentage of females was observed at Station 6, which had 48.39%. This data indicates that the potential pairing rate among the total population is 25.68%.

Table 2. Distribution of Banggai cardinal fish population in Gilimanuk Bay

Station	Location	Observed Fish Count (individuals)				Depth (m)	Bottom Substrate
		Recruit	Juvenile	Adult	Total		
Station 1	Inner Bay	0	57	65	122	1.8	Sand
Station 2	Inner Bay	0	35	90	125	2	Rubble
Station 3	Inner Bay	0	11	103	114	2.2	Coral Reef
Station 4	Inner Bay	10	148	130	288	3	Rubble
Station 5	Inner Bay	0	0	0	0	2.2	Mud
Station 6	Southwest Bay	99	146	47	292	4	Sand
Station 7	Southwest Bay	92	119	57	268	4.5	Sand
Station 8	Southwest Bay	248	198	62	508	6	Lamun
Station 9	Southwest Bay	0	47	282	329	5	Sand
Station 10	Bay Mouth	0	0	0	0	6	Mud
Station 11	Bay Mouth	0	0	0	0	5	Sand
Station 12	Bay Mouth	15	42	110	167	1.5	Sand
Station 13	Southwest Bay	0	15	25	40	0.3	Sand
Station 14	Bay Mouth	0	0	0	0	11	Sand
Total		464	803	946	2,253		

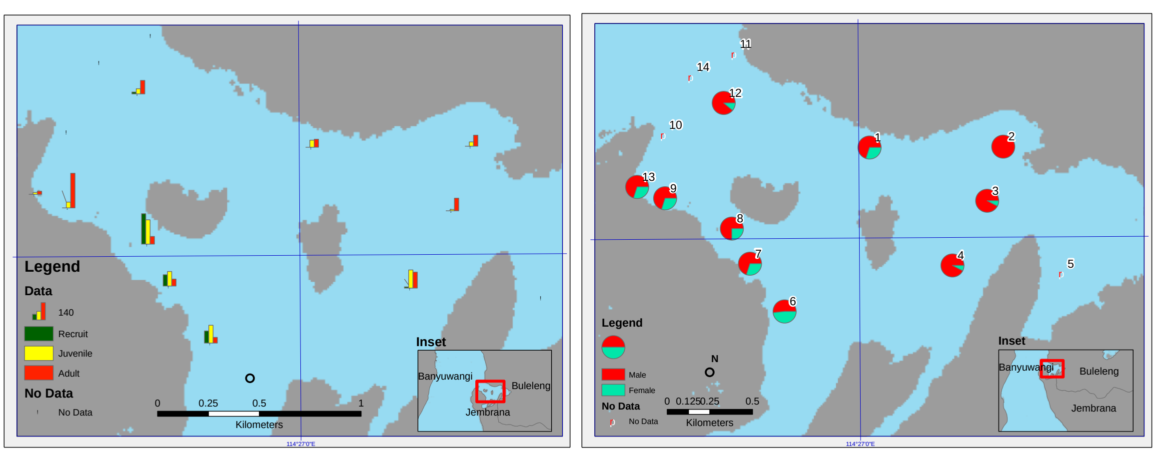

Fig. 3. Fish distribution in Gilimanuk Bay based on size stages (left) and based on sex ratio (right)

A total of 327 sea urchins were recorded across 14 observation stations in Gilimanuk Bay. The highest number of sea urchins was observed at Station 4, with 110 individuals, followed by Station 9 with 59 individuals, and Station 6 with 33 individuals. No sea urchins were found at Station 14. The overall sea urchin density in the Bay was 0.233 individuals per square meter.

Water depth and substrate composition

The total water area of Teluk Gilimanuk covers approximately 349.02 hectares. The Bay's depth range varies from 0 to 17.7 meters, with an average depth of approximately 9.0 meters. The deepest area is located near the bay's mouth, with depth decreasing toward the inner bay. Two shallow areas in the middle of the bay are covered with mangroves, known as Burung Island and Kalong Island (Fig. 4).

During data collection, five substrates were identified: sand, coral reefs, coral rubble, mud, and seagrass. The substrate in Gilimanuk Bay is predominantly composed of sand, covering an area of 213.64 hectares (61.21%). The next dominant substrate is mud, covering 78.91 hectares (22.61%). Coral reefs, coral rubble, and seagrass each cover 16.30 hectares, 16.10 hectares, and 24.07 hectares, or 4.67%, 4.61%, and 6.90% of the total area, respectively. The sand distribution is widespread throughout the research location. At the same time, mud is concentrated near the mouth of the bay and along the shoreline, particularly in the eastern and southern parts of the bay. Seagrass distribution is closely associated with the distribution of mud. On the other hand, coral reefs and coral rubble are found only near the mouth of Gilimanuk Bay (Fig. 4).

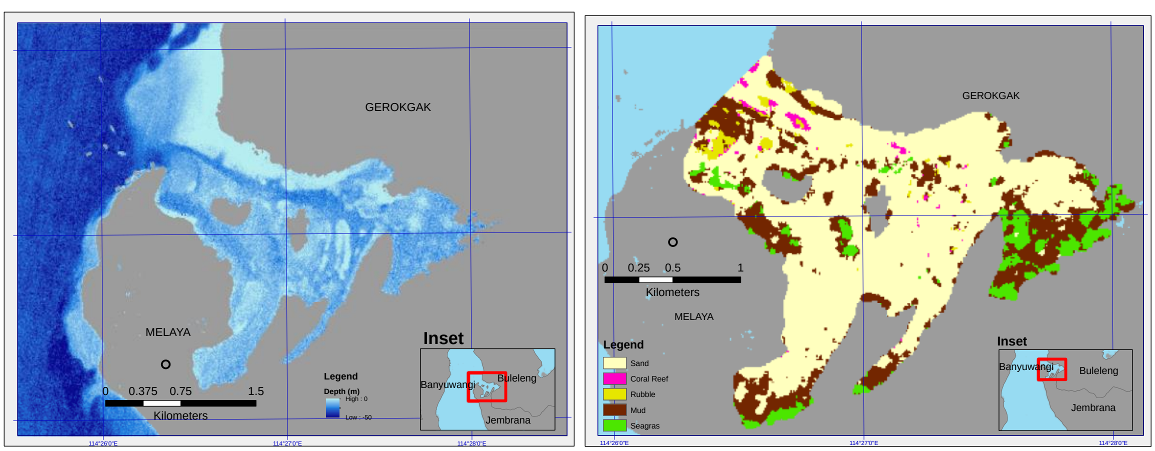

Fig. 4. Wave depth profile (Left) and bottom substrate distribution (Right) in Gilimanuk Bay, Bali

Currents and waves

The hydrodynamic modeling results for Gilimanuk Bay in June 2024 indicate that periodic tidal movements predominantly drive the currents in the Bay. The highest current velocity occurs during the ebb tide, ranging from 0 to 0.237m. s^{-1}, with a dominant northwestward direction, flowing out of the bay. The highest current speeds were recorded at the mouth of Gilimanuk Bay, while the lowest speeds were observed in the innermost part of the bay. These tidal currents are primarily influenced by the water flow in the Bali Strait (Fig. 5).

The wave modeling results for June indicate that wave heights ranged from 0.02 to 2.6cm. The semi-enclosed nature of Gilimanuk Bay, surrounded by land, prevents direct wind influence on wave formation. The waves observed in the bay are primarily propagated waves from outside the bay, particularly from the northern part of the Bali Strait. These waves experience a reduction in height as they reach Gilimanuk Bay.

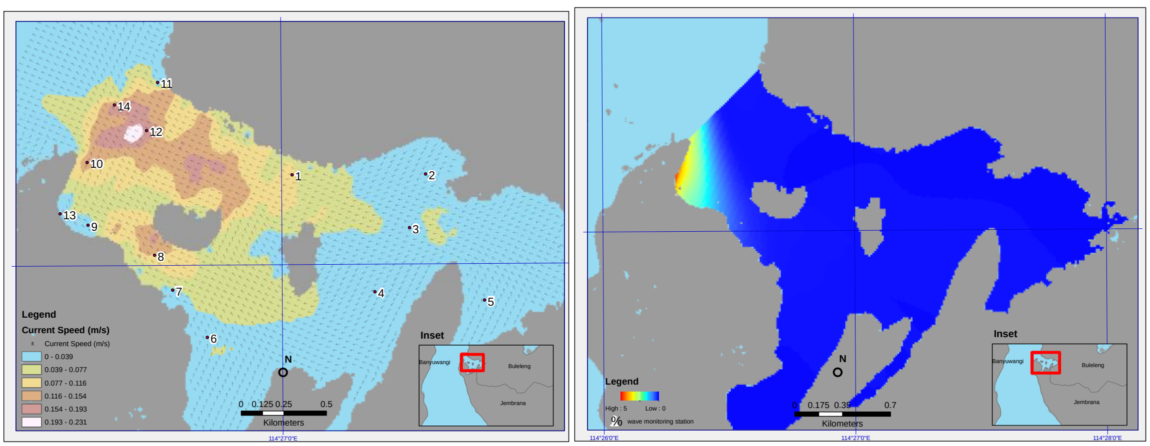

Fig. 5. Current velocity and wave height in Gilimanuk Bay, during fish data collection

Fish and sea urchin distribution based on the locations

The BCF population distribution was analyzed based on location in the Bay. In the mouth of the Bay Area, which encompasses Stations 10, 11, 12, and 14, fish populations were only observed at Station 12. The total fish population at this station consisted of 167 individuals, comprising 15 recruits, 42 juveniles, and 110 adults. This accounted for 7% of the total population. Recruits comprised 3% of the total recruit population, juveniles made up 11% of the total juvenile population, and adults constituted 7% of the total adult population (Fig. 6). Out of these 167 fish, 10 individuals were sampled for sex and size identification, and the results showed that 90% of the population consisted of males, while 10% were females. The number of sea urchins recorded in the Bay mouth was 37, representing 11.3% of the total sea urchin population.

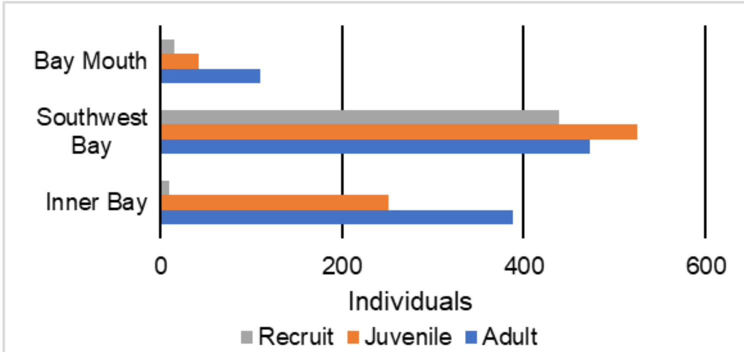

Fig. 6. Fish distribution based on location in Gilimanuk Bay, Bali

In the inner Bay area, fish populations were found at four observation stations: Stations 1, 2, 3, and 4. No fish populations were recorded at Station 5. The total fish population in the inner Bay consisted of 649 individuals, accounting for 29% of the total fish population in the Bay. This included 388 adults, 251 juveniles, and 10 recruits. Recruits comprised 2% of the total recruit population, juveniles accounted for 31% of the total juvenile population, and adults made up 40% of the total adult population (Fig. 6). Out of the 649 observed fish, 48 individuals were selected for sampling. The result revealed that in the inner bay, 89.58% of the fish were male, while only 10.42% were female.

Due to its highly sheltered conditions, the inner Bay had the lowest wave height, reaching only 0.02cm, indicating very calm waters. The highest recorded current speed in this area was also minimal, at just 0.02m. s^{-1}.

The southwestern Bay area had the highest Banggai cardinal fish population among the three studied locations, accounting for 64% of the total fish population. The numbers of recruits (439 individuals), juveniles (525 individuals), and adults (473 individuals) (Fig. 6) were all higher than those recorded in the other two locations (Fig. 6).

The sea urchin population in the southwestern Bay reached 143 individuals, accounting for 44.95% of the total recorded sea urchin population.

Wave heights in the southwestern Bay were relatively low, averaging 0.65cm across five stations. Although this area is close to the Bay's mouth, it remains more sheltered from incoming waves. The current speed in this region was also lower than in the Bay mouth during peak tidal conditions. This is because the primary water exchange pathways do not directly influence the area.

Fish distribution based on water depth

The Banggai cardinal fish population was evenly distributed across depths ranging from 0.51 to 6.44m. At depths greater than 7 meters, no fish populations were recorded. The highest fish abundance was observed at depths of 2–3 meters, with a total of 816 individuals across five stations (Stations 1, 2, 3, 4, and 12). However, no fish were found at depths of 1–2 meters or 3–4 meters (Fig. 7). The recruit class fish were most abundant at depths of 6–7 meters, with a total of 340 individuals, accounting for 73.28% of the total observed recruits. Juvenile fish were also primarily found at depths of 6–7 meters, with 317 individuals, representing 47.10% of the total observed juveniles. In contrast, adult fish were most abundant at depths of 2–3 meters, comprising 498 individuals, which accounted for 51.29% of the total observed adults.

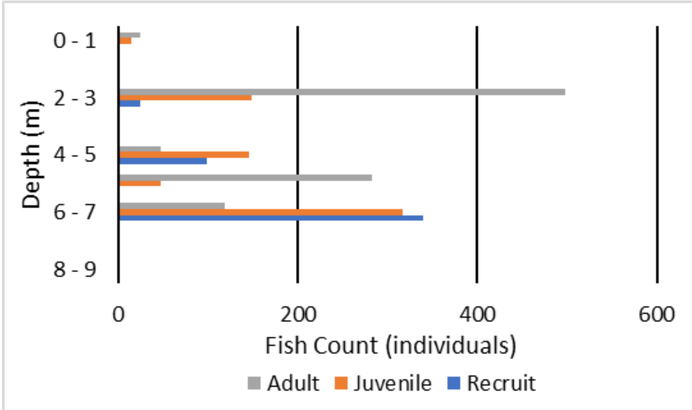

Fig. 7. Fish distribution based on depth

The analyses of habitat preferences showed that the BCF favored a depth range of 2–3 meters, with a preference index (w) of 4.31. The fish were also found at depths of 4–5 meters, 5–6 meters, and 6–7 meters, although they showed a low preference for depths of 0–2 meters and 3–4 meters, as well as depths exceeding 7 meters (Table 3).

Table 3. Depth as a habitat preference

Depth (m)	Area (ha)	*P*	n	u	e	w	B
0 - 1	53.15	0.15	40	0.02	343.09	0.12	0.01
1 - 2	27.91	0.08	0	0.00	180.17	0.00	0.00
2 - 3	**29.33**	**0.08**	**816**	**0.36**	**189.33**	**4.31**	**0.40**
3 - 4	39.64	0.11	0	0.00	255.88	0.00	0.00
4 - 5	31.85	0.09	292	0.13	205.60	1.42	0.13
5 - 6	33.62	0.10	329	0.15	217.02	1.52	0.14
6 - 7	34.66	0.10	776	0.34	223.74	3.47	0.32
7 - 8	98.86	0.28	0	0.00	638.16	0.00	0.00
Total	349.02		2,253			10.83	1.00

Fish distribution based on bottom substrate

Five categories of the bottom substrate of Gilimanuk Bay were identified during data collection: sand, coral reefs, coral rubble, mud, and seagrass beds. The substrate in Gilimanuk Bay was predominantly sand, covering an area of 213.64 hectares, or 61.21% of the total bay area. The second most dominant substrate was mud, covering 78.91 hectares or 22.61% of the bay. Coral reefs, coral rubble, and seagrass beds covered 16.30 hectares, 16.10 hectares, and 24.07 hectares, accounting for 4.67, 4.61, and 6.90% of the bay, respectively.

The sand was evenly distributed throughout Gilimanuk Bay. At the same time, the mud was mainly found near the bay mouth and along the coastal areas, particularly in the eastern and southern parts of the bay. Seagrass beds were located near muddy areas, whereas coral reefs and coral rubble were only found near the bay entrance.

Out of the 2,253 visually observed fish, 1,397 individuals (61.3%) inhabited sandy substrates. The remaining 413 fish (18.7%) occupied coral rubble, while 329 fish (14.9%) were found in seagrass beds. Only 114 fish (5.2%) were recorded in coral reef areas (Fig. 8). No Banggai cardinal fish were found in areas with muddy substrates.

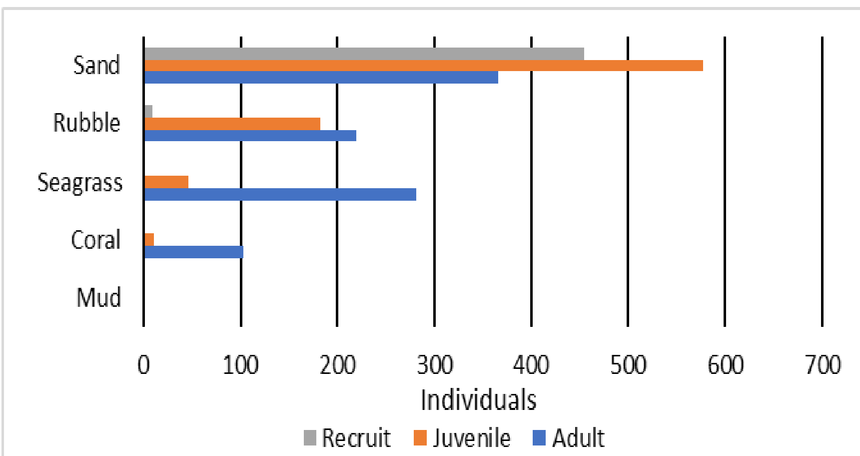

Fig. 8. Fish distribution based on substrate type

Bottom substrate as habitat preference

Based on the habitat preference index calculated for the Banggai cardinal fish regarding bottom substrate types, the species exhibited a preference for all substrate types except mud. Among the four preferred substrate types, sand, coral reefs, coral rubble, and seagrass beds, Banggai cardinal fish showed the highest preference for coral rubble, with a preference index (w) of 3.97. The least favored substrate was mud (Table 4). Although the highest observed fish distribution was in sandy substrates, with 1,397 individuals recorded (62% of the total fish population), this distribution spanned an area of 213.64 hectares, accounting for 61% of the total study area. In contrast, only 413 individuals (18% of the total fish observed) were found in coral rubble, which covered just 0.05% of the total area. This resulted in a high habitat preference index for coral rubble.

Table 4. Substrate as a habitat preference

Substrate	Area (ha)	*P*	n	u	e	w	b
Sand	213.64	0.61	1,397	0.62	1.379.09	1.01	0.12
Mud	78.91	0.23	0	0.00	509.38	0.00	0.00
Coral Reef	16.30	0.05	114	0.05	105.22	1.08	0.13
Rubble	**16.10**	**0.05**	**413**	**0.18**	**103.93**	**3.97**	**0.49**
Seagrass	24.07	0.07	329	0.15	155.38	2.12	0.26
Total	349.02	1.00	2,253	1.00		8.19	1.00

DISCUSSION

Banggai cardinal fish and sea urchin population

Fish population density is higher than the findings of **Arbi *et al.* (2019)**, who recorded a density of only 0.208 individuals/ m^{-2} in the same area in 2018. This increase is likely due to the implementation of Ministerial Decree No. 49/2018 by the Ministry of Marine Affairs and Fisheries, which established the limited protection status of the BCF (*P. kauderni*). As a result, the collection of Banggai cardinal fish from the wild, including in Gilimanuk Bay, has been restricted. A higher number of males compared to females was also reported by **Ndobe *et al.* (2013)**, who found a sex ratio of up to 1.67 in the waters of the Banggai Archipelago. However, in general, BCF (*P. kauderni*) individuals are known to have a balanced sex ratio of 1:1 **(Mogontha *et al.*, 2020)**. Moreover, **Arbi *et al.* (2019)** reported that 96.52% of Banggai cardinal fish in Gilimanuk Bay inhabit sea urchin colonies, further supporting the suitability of the southwestern Bay for this species.

Sea urchin density is significantly higher than the density reported by **Tambunan *et al.* (2022)**, which was 0.088 individuals.m^{-2}. There is no information on the type of substrate where the sea urchin distribution data were collected in the study by **Tambunan *et al.* (2022)**. It is possible that the data were obtained from a substrate unsuitable for sea urchins. **Suryanti *et al.* (2020)** stated that sea urchins are commonly found living in clusters in areas with dead coral holes or coral rubble.

Water depth and substrate composition

The depth average of Gilimanuk Bay is approximately 9.0 meters. Based on its depth characteristics, Gilimanuk Bay is classified as a neritic water body **(Thoha, 2007)**. A slightly different distribution pattern of bottom substrate was reported by **Putra *et al.* (2023)**, where sand was detected over 26.87 hectares, mud over 45.76 hectares, and coral reefs over 56.59 hectares. There was no information on the substrate in areas deeper than 10 meters **(Putra *et al.*, 2023)**.

Currents and Waves

The current speed and wave height of Gilimanuk Bay have been reported by **Pribadi *et al.* (2015)**, **Fajar *et al.* (2019)** and **Tsanyfadhila *et al.* (2022)** showing similar values. Current velocities in the Bali Strait during the east monsoon season exhibit no significant variation, ranging from 0.1 to 1.08m. s^{-1} **(Tsanyfadhila *et al.*, 2022)**. **Pribadi *et al.* (2015)** reported that wave heights in the northern Bali Strait during June are approximately 0.2 meters.

Fish distribution based on the locations

Fish distribution conditions in the Bay mouth have also been reported by **Arbi *et al.* (2019)** elucidating that 96.52% of Banggai cardinal fish in Gilimanuk Bay inhabit sea urchin colonies. This is believed to be one of the reasons why the fish population at the bay mouth only accounts for 7% of the total population. The wave height at the bay mouth was the highest among the four locations, with an average of 1.5cm. The highest current speed, occurring during ebb tide, was also the highest among all locations, reaching 0.38m. s^{-1}. The low abundance of Banggai cardinal fish at the Bay mouth is associated with habitat exposure to open waters. The bay's mouth directly borders the Bali Strait, which has higher waves and stronger currents than the inner bay. Exposed areas like this are generally unsuitable habitats for Banggai cardinal fish **(Arbi *et al.*, 2022)**.

In their native habitat, Banggai cardinal fish prefer calm waters such as bays. The sea urchin population in the inner Bay consisted of 147 individuals, accounting for 43.73% of the total sea urchin population in the Bay. These conditions are suitable for BCF, which are known to inhabit shallow and sheltered habitats **(Vagelli, 2011)**. However, the distance from the initial introduction site at Secret Bay studied by **Arbi *et al.* (2022)** contributed to the lower fish population in the inner Bay. BCFs tend to remain in their initial introduction locations rather than dispersing to new areas **(Fukumori *et al.*, 2010)**.

Fish distribution in the southwestern area suggests that this area provides a suitable habitat for the BCF. The high proportion of recruits, which comprised 95% of the total recruit population, suggests that this area supports the successful reproduction of the species. Of the 1,437 observed fish, 101 individuals were sampled for sex and size identification, revealing a sex ratio of 66.34% male and 33.66% female. This finding aligns with the fact that Banggai cardinal fish were first introduced to Gilimanuk Bay in the Secret Bay area **(Vagelli, 2011; Arbi *et al.*,**

2022). Banggai cardinal fish tend to remain within a limited home range, typically not exceeding a 40-meter radius **(Kolm *et al.*, 2005)**.

Fish distribution based on water depth and their preference

Fish distribution based on their depth aligns with the study by **Arbi *et al.* (2019)**, which reported that Banggai cardinal fish were generally found at depths not exceeding 8 meters. Sea urchins can still be found at depths of up to 24 meters **(Suryanti *et al.*, 2020)**. These results provide a clearer understanding that although sea urchins can be found at depths greater than 8 meters, no fish are present beyond this depth. According to **Arbi *et al.* (2019)** Banggai cardinal fish were observed at depths of 0.5–2 meters, whereas **Tambunan *et al.* (2022)** reported their presence at depths of 2–3 meters.

Fish distribution based on bottom substrate and their preference

A similar study by **Kusumawardani *et al.* (2019)** reported that Banggai cardinal fish in Kendari waters inhabited sandy and coral reef substrates. Meanwhile, research by **Huwae *et al.* (2023)** found that the BCF in Lembeh Strait, Bitung, was observed in various substrates, including sand, mud, coral rubble, and coral reefs. The strong preference for coral rubble is closely linked to the presence of sea urchins, which commonly inhabit dead coral flats, rocky areas, and coral rubble **(Suryanti *et al.*, 2020)**.

CONCLUSION

The total population of Banggai cardinal fish in Gilimanuk Bay consisted of 2,253 individuals, comprising 464 recruits, 818 juveniles, and 971 adults. The overall fish density was 1.61 individuals per square meter, with a density of 0.33 individuals per square meter for recruits, 0.58 individuals per square meter for juveniles, and 0.69 individuals per square meter for adults. Banggai cardinal fish in Gilimanuk Bay preferred to inhabit the southwestern part of the Bay at a depth of 2–3 meters, with a bottom substrate primarily composed of coral rubble.

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