

# Habitat characteristics and abundance of juvenile *Siganus canaliculatus* in Kulisusu Bay, Southeast Sulawesi, Indonesia

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**Abstract.** In Kulisusu Bay waters, coastal ecosystem degradation caused by overfishing and destructive fishing gear has damaged critical marine habitats, including nursery grounds for juvenile rabbitfish (*Siganus canaliculatus*). These anthropogenic pressures have reduced both food availability and shelter for juvenile fish, threatening the species long-term sustainability. This study analyzes the habitat characteristics and the distribution of juvenile *S. canaliculatus* abundance across three distinct habitats (A, B, and C). Samples were collected four times in each habitat using modified juvenile nets in the seagrass ecosystem, with concurrent measurements of environmental parameters. Environmental parameters measured included current speed, water depth, salinity, total dissolved solids (TDS), seagrass density, and substrate. The results showed significant differences ( $p < 0.05$ ) in habitat characteristics and juvenile abundance between habitats. The highest abundance was found in habitat C, which has low salinity (average 29.1 ppt), high TDS ( $47.0 \text{ mg L}^{-1}$ ), moderate current speed (average  $0.34 \text{ m s}^{-1}$ ), high seagrass density (average  $471.3 \text{ stands m}^{-2}$ ), and clayey sand substrate, with an abundance of  $0.074 \text{ individuals m}^{-3}$ . In contrast, habitat B, which has moderate salinity (average 31.2 ppt), low current speed (average  $0.11 \text{ m s}^{-1}$ ), low seagrass density (average  $313.1 \text{ stands m}^{-2}$ ), and sandy substrate, showed the lowest juvenile abundance of  $0.030 \text{ individuals m}^{-3}$ . The results of this study confirm the importance of habitat conditions, especially salinity, current speed, TDS, seagrass density, and substrate type, in supporting the abundance of *S. canaliculatus* juveniles. These findings provide a basis for habitat-based management and conservation strategies to support the sustainability of *S. canaliculatus* populations in Kulisusu Bay.

**Key Words:** coastal ecosystems, fish nurseries, habitat preference, juvenile fish, tropical fisheries.

**Introduction.** Kulisusu Bay is an open water directly connected to the Banda Sea and is included in the Fisheries Management Area-WPP 714. This area is known to have high biodiversity and extraordinary marine productivity (Marpaung et al 2020; Rachman et al 2020; Trisianto et al 2021; Ahkam & Tarya 2023; Lumuindong et al 2023; Novriansyah et al 2023). Kulisusu Bay plays an important role in the life cycle of various economic fish species, including *Siganus canaliculatus*, especially in the juvenile phase. The juvenile phase is a very important developmental stage in the life cycle of fish because it determines the success of recruitment and survival of fish populations (Pierre et al 2018; Pepin 2023). In this phase, fish show clearer physiological and behavioral characteristics, which provide an overview of their adaptation, growth, and interaction with the environment (Bignami et al 2017; Greer et al 2018; Hinchliffe et al 2021).

Understanding environmental factors that influence juvenile distribution and abundance is highly relevant to support sustainable fisheries management. Factors such as temperature and salinity (Djurichkovic et al 2019; Sharpe et al 2019; Murmu et al 2020; Casey et al 2021), food availability (Le Pape & Bonhommeau 2015; Sihombing et al 2022), currents (Sucipto et al 2021), habitat (Yeung & Yang 2017; Macário et al 2021), predation

(Sorel et al 2016), anthropogenic (Mercader et al 2018), turbidity (Biefel et al 2024), substrate and organic matter (Escalas et al 2015; Páez et al 2018), and climate change (Pasquaud et al 2012) are known to influence juvenile fish distribution and abundance. However, research on *S. canaliculatus* in Southeast Sulawesi is still limited, especially those discussing the habitat characteristics and abundance distribution of juvenile *S. canaliculatus* in Kulisusu Bay waters.

Several studies on *S. canaliculatus* in Indonesia have primarily focused on growth (Sudarno et al 2018; Tresnati et al 2021), reproductive biology (Suwarni et al 2019), and stock and population dynamics (Latuconsina et al 2020). Although biodiversity and distribution patterns have been documented (Madduppa et al 2019; Awaluddin et al 2024; Latuconsina et al 2024), critical knowledge gaps remain regarding the species habitat specific requirements and spatial ecology, particularly for juveniles in understudied regions like Kulisusu Bay.

Kulisusu Bay is known as an important habitat for *S. canaliculatus*. Dudi et al (2016) reported that there are six species of rabbitfish in Kulisusu Bay, with *S. canaliculatus* being the most frequently found. However, the condition of Kulisusu Bay is increasingly threatened by ongoing habitat degradation (Dwiputra et al 2019). Suharyanto & Utojo (2008) observed that the condition of the coral reefs in the bay were historically classified as moderate to good but are now undergoing severe decline. Notably, bomb explosions were still audible during data collection, underscoring immediate threats to this ecosystem (Chan & Hodgson 2017). Habitat degradation can alter the physical, chemical, and biological properties of the waters, ultimately impacting juvenile fish abundance (Glaser et al 2015; MacNeil et al 2019).

This study aims to analyze the habitat characteristics and distribution of the abundance of juvenile *S. canaliculatus* in three different types of habitats. It is hoped that the results of this study can provide useful information for the sustainable management of *S. canaliculatus* resources and the conservation of coastal habitats that support its survival in Kulisusu Bay.

## **Material and Method**

***Sampling locations and procedures.*** This research was conducted in Kulisusu Bay waters, Kulisusu District, North Buton Regency, Southeast Sulawesi Province, Indonesia (Figure 1).

Sampling was carried out four times, namely in March, May, August, and November 2022 in three habitats, namely: habitat A, located in the western part of the mouth of the bay, habitat B, located in the north of the bay and the middle of the bay, and habitat C, located in the western part of the bay. The habitat conditions at the study site can be seen in Figure 2. The samples taken included physical (current speed, water depth, substrate), chemical (salinity, total dissolved solids (TDS)), and biological (seagrass density, abundance of juvenile fish) parameters of the waters. Water temperature was excluded from analysis after preliminary Kruskal-Wallis tests ( $p > 0.05$ ) confirmed neither significant inter habitat variation nor correlation with juvenile abundance. All parameters were measured synchronously during four sampling campaigns (March, May, August, November), with replicate measurements taken in each habitat (A, B, C) during each sampling period.

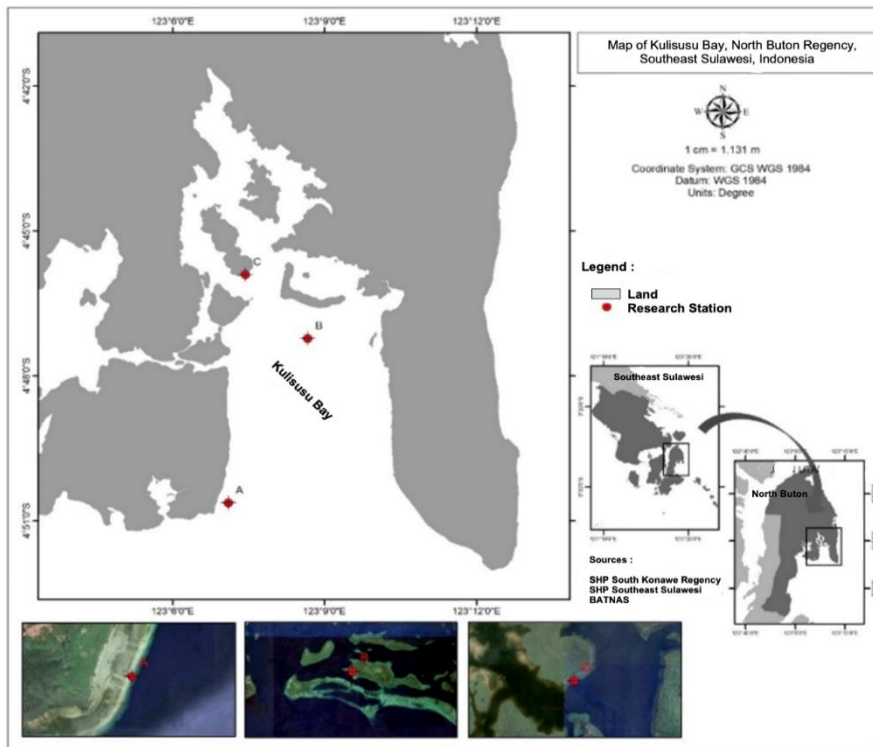


Figure 1. Map of research locations in Kulisusu Bay waters.

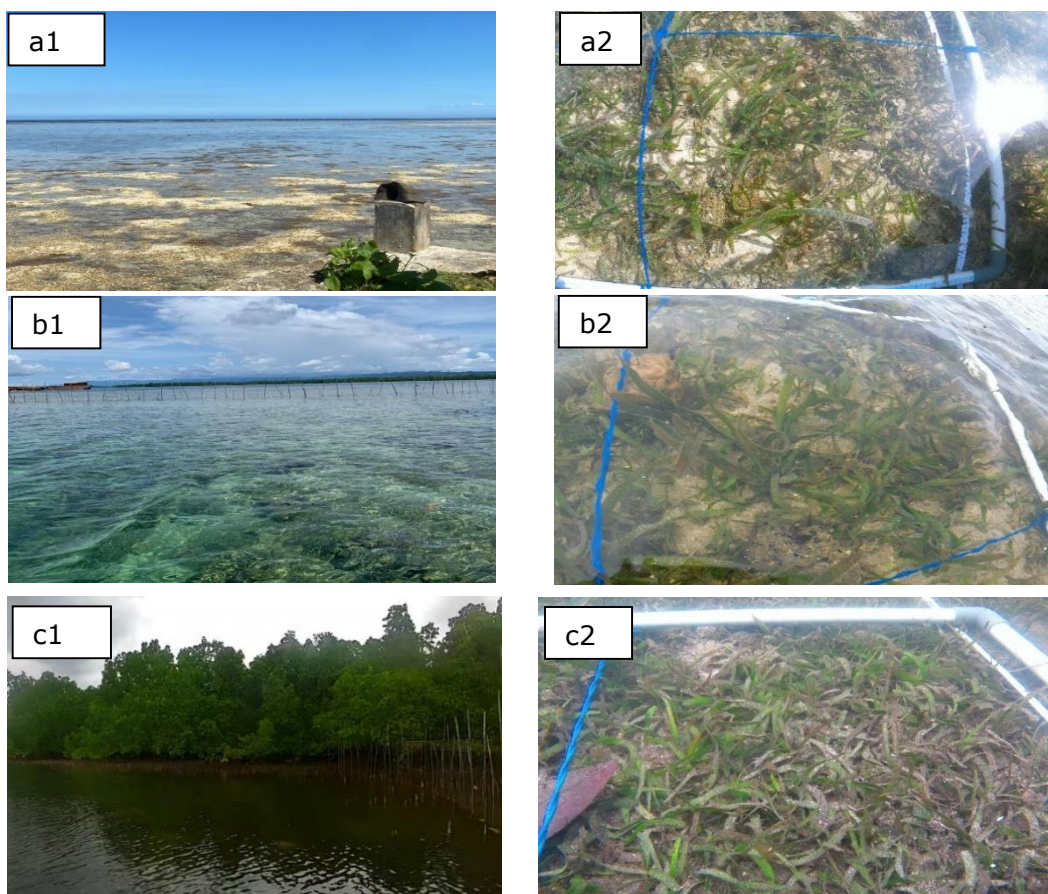


Figure 2. Habitat conditions in habitat A (a1 = low tide condition; a2 = seagrass condition), B (b1 = low tide condition; b2 = seagrass condition), and C (c1 = low tide condition; c2 = seagrass condition).

**Sampling of juvenile fish.** Juvenile *S. canaliculatus* were collected using a modified net with a mesh size of 500  $\mu\text{m}$ , a length of 5 m, a mouth opening diameter of 2 m, and a length of 3 m for the left and right support nets. The end of the net is equipped with a 4-inch diameter sample container (Figure 3). This net is operated by being pulled by two people parallel to the coastline for 100 m at high tide in the seagrass ecosystem (Polte & Asmus 2006). Combing was carried out three times according to a predetermined pattern.

Sampling was adjusted to tidal data from BMKG (Indonesian Agency for Meteorology, Climatology and Geophysics). Data collection was conducted according to tidal phase information provided by BMKG to ensure consistency across varying tidal conditions. The captured juvenile fish were first euthanized through gradual cooling in an insulated container (maintained at 2-4  $^{\circ}\text{C}$  for 15 minutes), then preserved in 4% formalin (Amin et al 2016) to maintain sample integrity during subsequent identification and chilled storage. The samples were then transferred to a Petri dish that had been cleaned with distilled water to be observed and identified based on morphology such as body size and shape, color and pattern, and spines and fins. After identification, juvenile samples were stored in bottles containing 70% alcohol (Amin et al 2016; Schnell et al 2016) for long-term storage.

Environmental parameters were measured using standardized methods as follows: salinity was measured in situ using Water Quality Checker (AZ 86031); current speed was determined through the floating dredge, compass, and stopwatch; TDS were analyzed via gravimetric method; seagrass density was quantified using the quadrant transect method; substrate composition was characterized through granulometric analysis; and water depth was measured at each sampling location using a calibrated staff gauge (accuracy  $\pm 0.5$  cm).

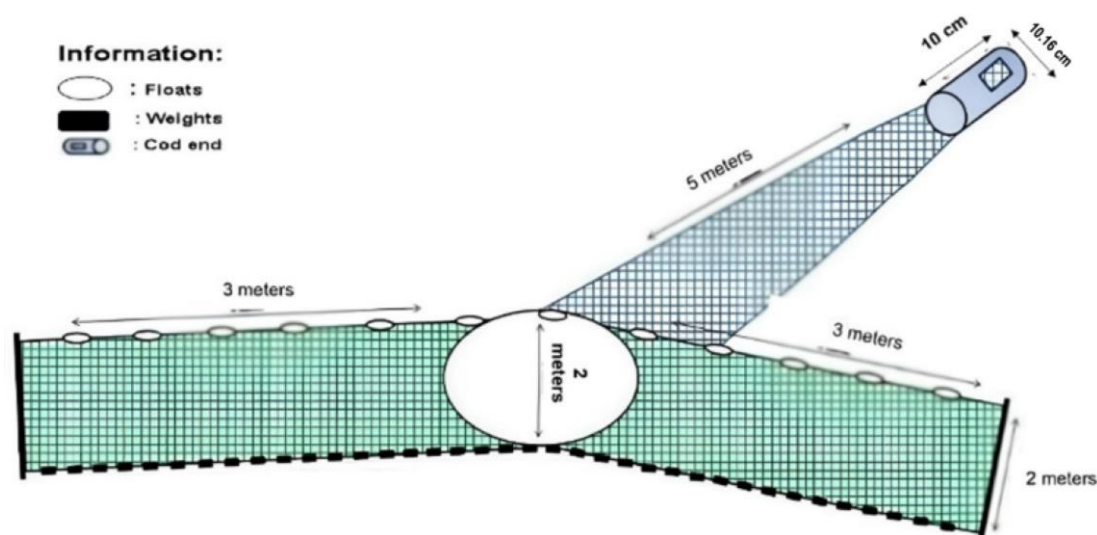


Figure 3. Modified juvenile net used.

**Calculations and statistical analysis.** Juvenile abundance was calculated using the formula of Zavala-Garcia & Flores-Coto (1989) in Espinosa-Fuentes et al (2009):

$$N = \frac{n}{V_{tsr}} \quad (1)$$

where:  $N$  = abundance of juvenile fish ( $\text{ind m}^{-3}$ );  
 $n$  = number of juvenile fish counted (ind);  
 $V_{tsr}$  = filtered water volume ( $V_{tsr} = l \times t \times v$ );  
 $l$  = the width of the filter mouth opening ( $\text{mm}^2$ );  
 $t$  = filter withdrawal time (minutes), average 6 minutes;  
 $v$  = pulling speed ( $\text{m min}^{-1}$ ), average  $16.7 \text{ m min}^{-1}$ .

Seagrass density was calculated using the formula (English et al 1997):

$$D_i = \frac{N_i}{A} \quad (2)$$

where:  $D_i$  = density of species ( $\text{ind m}^{-2}$ );  
 $N_i$  = total number of individuals of type  $i$  (individual);  
 $A$  = total area of sampling ( $\text{m}^2$ ).

Data analysis used the nonparametric Kruskal-Wallis test at the 95% level ( $p < 0.05$ ) using SPSS version 16.0 software to determine whether there were differences in the abundance of *S. canaliculatus* juveniles between habitats, juvenile abundance between sampling months, water quality parameter values (Asriyana et al 2020) and seagrass density between habitats.

## Results

**Habitat characteristics of *S. canaliculatus*.** Habitat A had the highest salinity (average 34.5 ppt) compared to habitat B (31.3 ppt) and habitat C (29.3 ppt). The high salinity in habitat A is due to its location close to the open sea (Banda Sea), which has a higher salinity compared to coastal waters. In contrast, habitat C has the lowest salinity because it is located near the estuary in the inner part of the Bay, which has a lower salinity. The current speed in habitat B was lower (average  $0.11 \text{ m s}^{-1}$ ) compared to habitat A ( $0.20 \text{ m s}^{-1}$ ) and habitat C ( $0.34 \text{ m s}^{-1}$ ). The slow current speed in habitat B is caused by the relatively shallow water depth (average 2.1 m), where friction with the substrate significantly restricts water flow. In contrast, the greater depth in habitat A (average 2.9 m) allows for better vertical mixing, while the shallower depth in habitat C (average 1.9 m) makes it more susceptible to wind and wave influences. In these shallow aquatic systems, hydrodynamic regimes are predominantly influenced by wind and tidal forces, generating horizontally concentrated flow energy due to limited vertical development.

In addition, TDS in habitat C was higher (average  $47.0 \text{ mg L}^{-1}$ ) compared to Habitat A ( $31.1 \text{ mg L}^{-1}$ ) and habitat B ( $28.5 \text{ mg L}^{-1}$ ). The high TDS in habitat C was due to its shallow waters and strong surface currents ( $0.34 \text{ m s}^{-1}$ ), which mixed the water evenly and kept particles suspended. The sandy-loamy substrate in habitat C also supported the resuspension of fine particles due to the strong currents. In addition, land runoff from the estuary brought non-salt solutes that increased TDS. In contrast, TDS in habitat B was lower because the slow currents allowed particles to settle more easily. Seagrass density in habitat C was higher (average  $471.4 \text{ stands m}^{-2}$ ) compared to habitat A ( $337.9 \text{ stands m}^{-2}$ ) and habitat B ( $313.2 \text{ stands m}^{-2}$ ). Habitat C has a sandy loamy substrate rich in minerals, supported by high currents that help distribute nutrients and prevent excessive sedimentation on seagrass leaves. High TDS in habitat C enriches the nutrient supply, while fine particles from the substrate provide essential minerals for seagrass growth. In contrast, the sandy substrate in habitats A and B is poorer in minerals, which causes seagrass densities in both habitats to be lower, as shown in Figure 4.

The Kruskal-Wallis nonparametric test showed that salinity, current speed, TDS, and seagrass density were significantly different ( $p < 0.05$ ) between habitats A, B, and C. These differences in environmental conditions may affect the dynamics of juvenile fish abundance in each habitat.

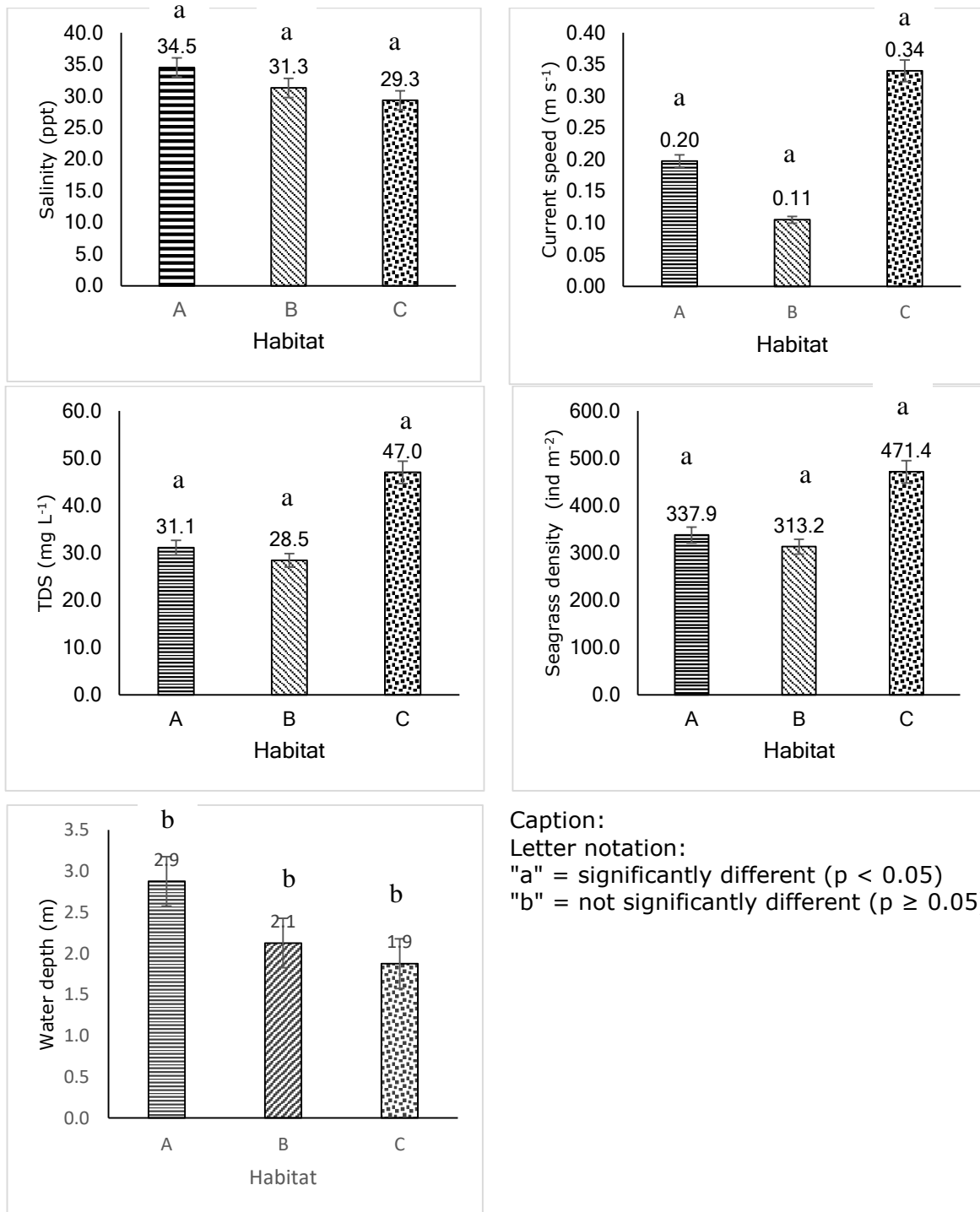


Figure 4. Environmental parameters measured in various habitats.

**Abundance of *S. canaliculatus* juveniles.** The highest abundance of juveniles was found in habitat C (average 0.074 ind m<sup>-3</sup>), followed by habitat A (0.045 ind m<sup>-3</sup>) and habitat B (0.030 ind m<sup>-3</sup>), as shown in Figure 5. Habitat C had low salinity (29.3 ppt), high TDS (47.0 mg L<sup>-1</sup>), moderate to high current speed (0.34 m s<sup>-1</sup>), and high seagrass density (471.4 stands m<sup>-2</sup>). These factors created conditions that were more supportive for juvenile abundance. In contrast, habitat B, which had moderate salinity (31.3 ppt), slow current (0.11 m s<sup>-1</sup>), and lower seagrass density (313.2 stands m<sup>-2</sup>), showed lower juvenile abundance. Small differences in environmental factors such as salinity, TDS, current speed, seagrass density, and substrate type can affect the carrying capacity of a habitat for juvenile fish (Bœuf & Payan 2001; Piccolo et al 2008; Nagelkerken et al 2015; Whitfield

2017; Unsworth et al 2019). The Kruskal-Wallis test showed that the abundance of juvenile fish differed significantly between habitats A, B, and C.

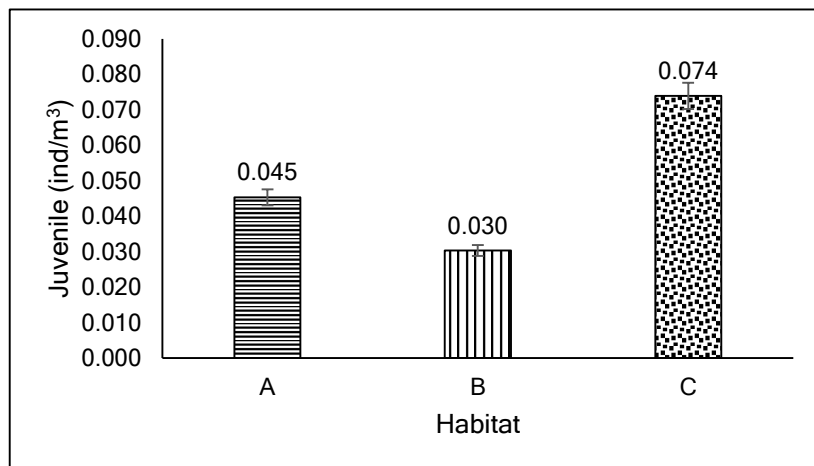


Figure 5. Abundance of juvenile *S. canaliculatus* in Kulisusu Bay.

**Discussion.** The abundance of *S. canaliculatus* juveniles in habitats A, B, and C showed different variations. The differences in juvenile abundance are likely influenced by factors such as salinity, current speed, seagrass density, and substrate type. Habitat C, with low salinity, is thought to support brackish habitats that are preferred by juveniles. Although *S. canaliculatus*, including its juveniles, is a euryhaline species that can survive at salinities between 15.8-55 ppt (Martin et al 2024), juveniles of this fish are more often found in habitats with salinities between 15-30 ppt. Low salinity is considered more osmotically stable for juveniles because the osmoregulation mechanism at this stage is not fully developed, so osmotic pressure can be minimized. Previous studies have shown that juvenile fish are more tolerant to low salinity fluctuations than high salinity, which supports osmotic stability, increases metabolic efficiency, and reduces physiological stress (Ayson et al 2014). In contrast, salinity in habitat A (average 34.5 ppt) is close to the tolerance limit of juveniles (optimal < 30 ppt), which can increase osmotic pressure and reduce the energy that can be allocated to growth and other activities (Webster & Dill 2006).

Juvenile *S. canaliculatus* also tends to prefer habitats with high seagrass density, such as those found in habitat C (average 471.4 stands m<sup>-3</sup>). In contrast, habitats with low seagrass density (habitats A and B) show lower juvenile abundance. Seagrass provides protection from predators and substrate for epiphytes and microalgae, which are important food sources for juveniles. This is following previous studies showing that high seagrass density supports the survival and growth of *S. canaliculatus* juveniles (Saraswati et al 2016; Du et al 2018; Hidayati & Suparmoko 2018; Syukur et al 2021). High seagrass density provides more surfaces for epiphytes to attach, which increases the diversity of epiphyte species (Baillie et al 2015; Barcelona et al 2023). These epiphytes are a food source for *S. canaliculatus* juveniles (Kwak et al 2015; Yalindua et al 2023). In addition, high seagrass density also provides a complex physical structure, providing hiding places for fish, including *S. canaliculatus* juveniles from predators (Schultz et al 2009).

The high density of seagrass in habitat C is supported by the loamy sand substrate, which is stable for seagrass root growth compared to the sandy substrate in habitats A and B. Loamy sand contains fine particles that increase the substrate's resistance to seagrass roots, while sandy substrates are more vulnerable to currents and waves, which can inhibit seagrass growth. In addition, the higher organic matter content in loamy sand also supports increased seagrass density (Mazarrasa et al 2015; Saderne et al 2019; Qin et al 2021). In contrast, sandy substrates tend to be poor in nutrients and less stable, thus supporting lower seagrass and fish abundance (Horinouchi et al 2012). Substrate characteristics greatly influence seagrass structure and density (Hidayatullah et al 2018; Nordlund et al 2018; Mukmin et al 2023; Nor et al 2024) in addition to providing physical support, substrates also help manage nutrients and maintain ecosystem stability. Thus,

the clayey sand substrate in habitat C supports more fertile seagrass growth and creates ideal protection for juvenile fish, including *S. canaliculatus* (Unsworth et al 2019). In addition to the substrate, current speed also plays an important role in the abundance of juvenile *S. canaliculatus* in Kulisusu Bay. Habitat C has an average current speed of  $0.34 \text{ m s}^{-1}$ , which is included in the moderate current category and is considered ideal for the distribution of nutrients and oxygen needed for the growth of juvenile fish (Revika et al 2016). In contrast, habitats A and B, with weaker currents, tend to be less supportive of juvenile abundance. Moderate currents also play an important role in the development of seagrass beds as habitats for *S. canaliculatus*. According to Infantes et al (2009) and Inoue et al (2020), current speeds between  $0.02$  and  $0.5 \text{ m s}^{-1}$  are the optimal range for nutrient distribution and seagrass health. Seagrass not only protects from predators but is also the main food source through epiphytes that grow on seagrass leaves. High seagrass density ( $400\text{-}1100 \text{ stands m}^{-2}$ ) can slow down the current speed to around  $0.10 \text{ m s}^{-1}$  (Adhitya et al 2014). In contrast, habitats A and B with slower current speeds show lower juvenile abundance. Because the current speed is not optimal for the distribution of nutrients and oxygen. This study also found that TDS indirectly affects the abundance of *S. canaliculatus* juveniles. TDS contains minerals and organic compounds that support the abundance of food, such as microbes and plankton, which are important for juvenile growth. Habitat C has a higher TDS concentration (average  $47.0 \text{ mg L}^{-1}$ ) compared to habitat A (average  $31.1 \text{ mg L}^{-1}$ ) and habitat B (average  $28.5 \text{ mg L}^{-1}$ ). The high TDS in habitat C supports the growth and photosynthesis process of seagrass. However, if TDS is too high it can cause a decrease in the density and photosynthesis process of seagrass, especially if it exceeds the tolerance of certain species. Osmotic stress and changes in nutrient availability are negative impacts of TDS that are too high. Conversely, TDS that is too low can reduce nutrient availability and inhibit the growth and productivity of seagrass (Hartono et al 2021). TDS also affects the abundance of plankton (Wassie & Melese 2017; Asiddiqi et al 2019; Dey et al 2021; Nur Haliza et al 2022; Essa et al 2024), which plays a role in the availability of nutrients for juvenile fish.

The combination of low salinity, high TDS, optimal current speed, high seagrass density, and supportive substrate creates an ideal environment for feeding and sheltering *S. canaliculatus* juveniles. The abundance of juveniles in habitat C, Kulisusu Bay, reached an average of  $0.074 \text{ ind m}^{-3}$ , which is higher compared to the waters in Karimunjawa, Indonesia, which reported juvenile abundance in seagrass ecosystems ranging from  $0.03$  to  $0.05 \text{ ind m}^{-3}$  (Wizurai et al 2012). This difference is likely due to the more supportive environmental conditions in Kulisusu Bay, such as high TDS and more optimal seagrass density. The results of research in Cockle Bay, Queensland, Australia, showed that the abundance of juvenile fish in tropical seagrass beds reached an average of  $0.08 \text{ ind m}^{-3}$  (Kwak et al 2015), slightly higher compared to Kulisusu Bay. This may be due to the more complex seagrass structure in Cockle Bay and better protection from anthropogenic pressures. These differences in abundance indicate that juvenile abundance is strongly influenced by local ecosystem characteristics. Habitats with clayey sand substrates, low salinity, and high seagrass density create a positive synergy that supports ecosystem carrying capacity. In addition, these findings provide important implications for conservation, especially for coastal areas such as Kulisusu Bay that face environmental pressures. This study emphasizes the importance of maintaining seagrass density and managing anthropogenic factors that can affect habitat quality, such as land pollution that affects salinity and TDS. The results of this study also enrich insights into the osmotic adaptation of *S. canaliculatus* juveniles to lower salinity, which can be applied in coastal ecosystem restoration planning and sustainable use of fish resources.

**Conclusions.** The abundance of *S. canaliculatus* juveniles was influenced by differences in environmental conditions between habitats A, B, and C. Habitat C, with low salinity, moderate current speed, high TDS, high seagrass density, and clayey sand substrate, supported optimal juvenile abundance. Conversely, habitat B, with moderate salinity, low current speed, low seagrass density, and sandy substrate, showed lower juvenile abundance. Optimal environmental conditions, such as low salinity, sufficient current speed, and supportive substrate, played a significant role in increasing the abundance of

*S. canaliculatus* juveniles in habitat C. Our results lay the groundwork for further bioecological studies of *S. canaliculatus* in Kulisusu Bay, with applications in conservation, comparative ecology, and sustainable aquaculture.

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**Conflict of interest.** The authors declare that there is no conflict of interest.

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