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INOVASI BUDIDAYA KEPITING BAKAU: PENGGUNAAN SISTEM MODULAR BERBASIS ALIRAN AIR TERKENDALI *(CRAB FLOW SYSTEM)* DI KABUPATEN TAPANULI TENGAH, SUMATERA UTARA

Innovation In Mud Crab Aquaculture: Implementation Of A Modular Culture System Based On Controlled Water Flow (Crab Flow System) In Tapanuli Tengah Regency, North Sumatra

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ABSTRAK

Budidaya kepiting bakau *(Scylla spp.)* memiliki potensi ekonomi tinggi, namun pelaksanaannya di wilayah pesisir seperti Kabupaten Tapanuli Tengah masih menghadapi tantangan, antara lain keterbatasan lahan, fluktuasi kualitas air, dan efisiensi pemeliharaan. Penelitian ini bertujuan mengembangkan dan menguji efektivitas *Crab Flow System* (CFS), yaitu sistem budidaya kepiting modular berbasis aliran air terkendali yang dirancang untuk meningkatkan performa pertumbuhan dan kelangsungan hidup kepiting. Penelitian dilaksanakan pada Januari–Maret 2025 di Laboratorium Sekolah Tinggi Perikanan dan Kelautan Matauli, Sumatera Utara, menggunakan metode eksperimen dengan dua perlakuan: (1) budidaya konvensional dan (2) budidaya menggunakan CFS, masing-masing dengan tiga ulangan. Parameter yang diamati meliputi laju pertumbuhan harian (SGR), kelangsungan hidup, dan kualitas air (suhu, pH, DO, amonia). Hasil menunjukkan bahwa penggunaan CFS menghasilkan pertumbuhan harian rata-rata 18,4% lebih tinggi dan tingkat kelangsungan hidup 92%, dibandingkan sistem konvensional. Kualitas air dalam sistem CFS juga lebih stabil dan berada dalam kisaran optimal untuk pertumbuhan kepiting. Kesimpulannya, sistem CFS terbukti efektif dalam meningkatkan efisiensi dan produktivitas budidaya kepiting, serta berpotensi menjadi solusi inovatif bagi pengembangan akuakultur berkelanjutan di wilayah pesisir.

ABSTRACT

Mangrove crab aquaculture (*Scylla* spp.) has high economic potential; however, its implementation in coastal areas such as Central Tapanuli Regency still faces challenges, including limited land availability, fluctuations in water quality, and maintenance efficiency. This study aimed to develop and test the effectiveness of the Crab Flow System (CFS), namely a modular crab aquaculture system based on controlled water flow designed to improve growth performance and survival of crabs. The study was conducted from January to March 2025 at the Laboratory of the Matauli College of Fisheries and Marine Sciences, North Sumatra, using an experimental method with two treatments: (1) conventional aquaculture and (2) aquaculture using CFS, each with three replications. The observed parameters included specific growth rate (SGR), survival rate, and water quality (temperature, pH, DO, ammonia). The results showed that the use of CFS produced an average daily growth that was 18.4% higher and a survival rate of 92% compared to the conventional system. Water quality in the CFS system was also more stable and remained within the optimal range for crab growth. In conclusion, the CFS system was proven to be effective in improving the efficiency and productivity of crab aquaculture and has the potential to serve as an innovative solution for the development of sustainable aquaculture in coastal areas.

Kata Kunci	*Kepiting bakau, Crab Flow System, budidaya modular, aliran air terkendali, efisiensi pertumbuhan*
Keywords	*Mangrove crab, Crab Flow System, modular aquaculture, controlled water flow, growth efficiency*
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INTRODUCTION

Mangrove crab (*Scylla* spp.) is a fishery commodity with high economic value that is widely cultured in tropical coastal regions.

Mangrove crab has high market demand at both domestic and international levels due to its high nutritional value and distinctive taste. This commodity has become one of the leading fishery export products from Indonesia and contributes significantly to the income of coastal communities. In North Sumatra, particularly in Central Tapanuli Regency, the potential of brackish waters and mangrove ecosystems supports mangrove crab aquaculture. However, aquaculture productivity is often not optimal due to limited land, conventional cultivation techniques, and dependence on tidal cycles and fluctuating water quality (Budiardi and Sari, 2021).

Conventional crab aquaculture faces various technical and environmental constraints that impact low growth efficiency and survival.

Traditional systems such as ponds or cages remain vulnerable to environmental changes, such as fluctuations in temperature, dissolved oxygen (DO), and ammonia concentrations that can reduce productivity. In addition, extensive maintenance models make disease monitoring and control difficult and cause the accumulation of organic waste. According to Scabra *et al*., (2022), the efficiency of crab aquaculture is strongly influenced by the stability of water quality and optimal feed distribution patterns. Therefore, an aquaculture system that can control the environment more precisely and sustainably is required.

Technological innovation in modular systems based on controlled water flow represents a potential solution to overcome problems in crab aquaculture.

The Crab Flow System (CFS) is a cultivation system design with a modular approach and controlled water flow that allows space efficiency, real-time water quality monitoring, and multilayer filtration. This system adopts recirculation principles widely applied in Recirculating Aquaculture Systems (RAS), but is adjusted to the morphological characteristics and behavior of crabs, which tend to be aggressive and territorial. A study by Nugroho and Kurniawan (2020) stated that the use of water recirculation systems was able to increase survival by up to 20% compared to static systems, while simultaneously reducing ammonia levels in the water. The implementation of such systems is also in line with the concept of sustainable aquaculture, which has become the direction of national policy in the fisheries sector.

Studies and applications of the CFS system remain very limited, especially in the context of coastal areas of North Sumatra.

Most innovations in closed and modular systems have been more widely applied to food fish or ornamental fish culture. In fact, the characteristics of crabs as benthic and aggressive organisms require a specific system design. In addition, there are still limited studies that empirically compare the effectiveness of the CFS system with conventional systems in terms of growth, survival, and stability of water quality parameters in mangrove crabs. Therefore, this study is important to fill data gaps and provide a scientific basis for the development of more efficient mangrove crab aquaculture technology.

Based on the description above, experimental research is required to assess the performance of mangrove crab aquaculture in the CFS system.

This study not only tested growth performance and survival, but also evaluated how water quality stability could be maintained through a sustainable modular system design. With a controlled approach, the results of this system are expected to serve as a prototype for crab aquaculture in limited land areas, particularly for coastal communities with limited space and resources. This study also supports the implementation of appropriate technology in the field of aquaculture that is aligned with the principles of efficiency and environmental conservation (Wijayanti *et al*., 2021).

This study aimed to develop and test the effectiveness of a modular mangrove crab aquaculture system based on controlled water flow (Crab Flow System/CFS) in improving growth performance, survival, and water quality stability of aquaculture in Central Tapanuli Regency, North Sumatra.

METHODS

This study employed an experimental approach using a Completely Randomized Design (CRD) consisting of two treatments with three replications each. The treatments applied in this study were:

- P1 (control): Mangrove crab aquaculture using a conventional system (without a controlled water flow system).
- P2 (treatment): Mangrove crab aquaculture using the Crab Flow System (CFS), namely a modular aquaculture system based on controlled water flow with multilayer filtration.

The study was conducted for 60 days from January to March 2025 at the Aquaculture Laboratory of the Matauli College of Fisheries and Marine Sciences, Central Tapanuli Regency, North Sumatra.

Research Procedures

a. Preparation of Media and Equipment

Aquaculture media were prepared in the form of six modular units (each with a volume of 30 liters), divided into three units for each treatment. The CFS units were equipped with a water recirculation system (pump, PVC pipes, mechanical-biological filters, and biofilter chambers). The filters consisted of three layers: gravel, zeolite, and bioballs. For the conventional system, units with minimal aeration and without water circulation were used. All units were sterilized using a 20 ppm $KMnO_4$ solution for 24 hours prior to use.

b. Crab Selection and Stocking

The mangrove crabs (*Scylla* spp.) used were healthy and active individuals with an average initial body weight of 100 ± 10 grams. The crabs were acclimatized for three days prior to stocking into the aquaculture units. Stocking was conducted at a density of 10 individuals per unit or equivalent to 50 individuals/m^3, adjusted to the characteristics of the closed system. Crabs were provided with shelters in the form of vertical PVC pipes (4 units per culture unit) to reduce aggressiveness and cannibalism.

c. Feeding

The feed used was fresh trash fish at a dosage of 5% of total biomass per day, divided into two feeding times (morning and afternoon). Uneaten feed and feces were siphoned every morning prior to new feeding to maintain optimal water quality.

d. Data Collection

Crab body weight measurements were conducted every 10 days by weighing individuals randomly selected from each unit (5 individuals per unit). Survival rate was calculated based on the number of live crabs at the end of the experimental period. Water quality was measured every three days, including temperature (digital thermometer), pH (pH meter), DO (dissolved oxygen meter), and ammonia concentration (spectrophotometric analysis using salicylate reagent).

Research Parameters and Measurement Methods:

1. **Specific Growth Rate (SGR)**

$$SGR\ (\%/hari) = \frac{\ln(W_t) - \ln(W_0)}{t} \times 100$$

Where:

$W0$: initial weight (g)

W_t : final weight (g)

t : maintenance period (days)

2. **Survival Rate (SR)**

$$SR\ (\%) = \frac{N_t}{N_0} \times 100$$

Where:

$N0$: initial number of crabs

Nt : final number of live crabs

3. **Water Quality**

The parameters measured include:

a. Temperature (°C)
b. pH
c. DO (mg/L)
d. Total ammonia (mg/L)

Measurements were carried out in situ and accompanied by laboratory documentation.

Data Analysis Methods

The data obtained were analyzed using an independent t-test (significant difference test) to compare differences between the two treatments (conventional and CFS) on growth and survival parameters. The test was conducted using SPSS version 25 software at a 5% significance level ($p < 0.05$).

Water quality data were analyzed descriptively, observing the trend of parameter stability within each system. The data are presented in tables and graphs for ease of interpretation.

RESULTS

This study aimed to evaluate the effect of the Crab Flow System (CFS) on the growth and survival of mud crabs (Scylla spp.) and the water quality of the culture medium. Observational data are presented in tables and graphs for easier analysis and understanding.

Table 1. Daily Growth and Survival of Mud Crabs

No	Parameter	Conventional	*Crab Flow system* (CSF)
1.	SGR (%/Day)	$1{,}21 \pm 0{,}05^{a}$	$1{,}43 \pm 0{,}03^{b}$
2.	Survival (%)	$78 \pm 3{,}6^{a}$	$92 \pm 2{,}1^{b}$

Note: Values with different superscript letters in the same row indicate significant differences (t-test, p < 0.05).

The table above shows that the CFS system produced a higher SGR (1.43%) compared to the conventional system (1.21%), as well as a better survival rate (92%) compared to 78% in the conventional system. This improvement indicates that the CFS system is able to provide an optimal aquaculture environment, particularly in terms of oxygen availability, stable temperature, and low concentrations of nitrogenous waste (Islam *et al*., 2019).

Faster growth in the CFS system is supported by the principle of a recirculating system that allows the water to remain clean and rich in oxygen, as explained by Nugroho and Kurniawan (2020) and Chen *et al*., (2017), who emphasized that nitrification in biofilters can maintain ammonia concentrations within safe limits and support the metabolism of cultured organisms.

The survival rate of crabs in the CFS system reached 92%, which was significantly higher than that of the conventional system, which was only 78% (Table 1). This finding reinforces the opinion of Zahra and Fitriani (2020), that high mortality rates in crab aquaculture are largely caused by environmental stress, poor water quality, and cannibalism. In the CFS system, the use of modular units and shelters (PVC pipes) successfully reduced aggressive interactions among crabs.

In addition, Scabra *et al*., (2022) emphasized that a modular design combined with a water circulation system improves the comfort of the growth space and reduces stress pressure, which ultimately increases the survival rate.

Figure 1. Comparison of SGR and Survival Rate of Mangrove Crabs

The graph above visually illustrates that the CFS system provides dual advantages in terms of growth efficiency and crab survival success during the rearing period.

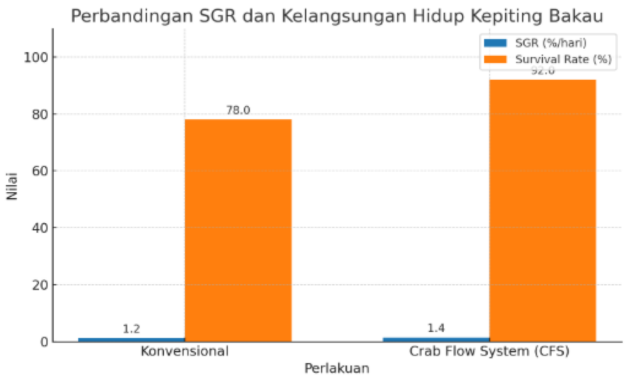

Figure 1. Comparison between two main parameters in mangrove crab cultivation

The figure above illustrates a comparison between two main parameters in mangrove crab aquaculture, namely the specific growth rate (SGR) and the survival rate, in two different aquaculture systems: the conventional system and the Crab Flow System (CFS). From the graph, it can be observed that:

a. The SGR in the CFS system reached 1.4%/day, which was higher than that of the conventional system, which was only 1.2%/day. This increase indicates that the aquaculture environment in the CFS system is more supportive of optimal individual crab growth, due to better oxygen supply, stable temperature and pH, and lower stress pressure.
b. The survival rate also showed a similar trend. The conventional system achieved only 78%, whereas the CFS system reached 92%, indicating a significant improvement. This result demonstrates the effectiveness of the filtration system and modular design in minimizing the risk of mortality due to poor water quality, cannibalism, or fluctuations in environmental parameters.

These results are consistent with the findings of Scabra *et al*., (2022) that modular-based closed aquaculture systems can improve growth efficiency and survival rates by effectively controlling environmental stressors. Boyd (2017) also emphasized that dissolved oxygen (DO) and ammonia are the main determining factors in the success of shrimp and crab aquaculture, which can be addressed through active filtration systems and water flow control such as those applied in the CFS.

Table 2. Average Water Quality During the Rearing Period

No	Parameter	Conventional	*Crab Flow system* (CSF)	Ideal Quality Standards *
1.	Suhu (°C)	29,1 ± 1,2	28,7 ± 0,8	26 – 30
2.	pH	7,4 ± 0,3	7,5 ± 0,2	7 – 8
3.	DO (mg/L)	3,9 ± 0,5	5,2 ± 0,3	> 4
4.	Ammonia (mg/L)	0,21 ± 0,08	0,09 ± 0,02	< 0,1

*Source: Budiardi and Sari (2021)

Table 2 presents data on the average water quality parameters observed during the cultivation of mud crabs (Scylla spp.) in two different cultivation systems: the conventional system and the Crab Flow System (CFS). Observed parameters included temperature, pH, dissolved oxygen (DO), and ammonia concentration, and were compared with the ideal water quality standards cited by Budiardi and Sari (2021). Water quality in the CFS system was more stable and within the optimal range according to the quality standards (Budiardi & Sari, 2021; Boyd, 2017).

1. **Temperature**

The temperature values in the conventional system and the CFS were 29.1 ± 1.2°C and 28.7 ± 0.8°C, respectively, both of which were still within the optimal range for crab aquaculture, namely 26–30°C. The slightly better temperature stability in the CFS can be attributed to the presence of water circulation and a closed system that helps reduce temperature fluctuations caused by external environmental factors (Nugroho & Kurniawan, 2020). Stable temperature is important for maintaining metabolism, molting, and crab growth (Jalil *et al*., 2020).

2. **Ph**

The average water pH in the conventional system was 7.4 ± 0.3, whereas in the CFS it was 7.5 ± 0.2. Both values fall within the ideal range (7–8). Stable and neutral pH in the CFS indicates the effectiveness of the filtration system in neutralizing waste compounds. Excessively low pH can cause a decrease in blood oxygenation capacity (hemocyanin) in crabs, while excessively high pH can increase ammonia toxicity (Boyd, 2017).

3. **Dissolved Oxygen (DO)**

The DO value in the conventional system was 3.9 ± 0.5 mg/L, whereas the CFS showed a higher value of 5.2 ± 0.3 mg/L. The DO level in the conventional system was close to the lower threshold that can cause physiological stress in crabs. According to Scabra *et al*., (2022), DO levels below 4 mg/L can disrupt respiration processes and slow growth. The CFS, which is equipped with circulation pumps and aeration, provides a more even and consistent distribution of oxygen.

4. **Ammonia**

Ammonia concentrations in the CFS were very low, at 0.09 mg/L, far below those in the conventional system, which reached 0.21 mg/L. Wahyuningsih and Asyari (2019) explained that multilayer biofilters are effective in reducing ammonia through the nitrification process. This effectiveness is also supported by the use of media such as zeolite and bioballs (Kusumawati & Handajani, 2021). The values above indicate that the CFS is capable of maintaining ammonia concentrations below the toxic threshold (<0.1 mg/L). Ammonia is the main metabolic waste that is toxic, especially in the form of unionized ammonia (NH_3), and its high presence can cause mortality in cultured organisms (Tacon & Metian, 2015). The biofilter system in the CFS effectively decomposes ammonia into safer nitrite and nitrate through nitrification processes carried out by nitrifying bacteria (Budiardi & Sari, 2021).

Based on the four observed parameters, the Crab Flow System (CFS) showed better performance in maintaining water quality stability compared to the conventional system. This is due to the closed circulation system design and filtration that allow waste control and better oxygen distribution. Stable water quality directly supports the health, growth, and survival of crabs during the rearing period (Wijayanti *et al*., 2021).

DISCUSSION

The results of this study indicate that the use of the Crab Flow System (CFS) in mangrove crab (*Scylla* spp.) aquaculture provides a significant positive impact on growth and survival parameters. This system clearly produced a higher specific growth rate (SGR) and a better survival rate compared to the conventional system. In addition, water quality parameters in the CFS were also more stable and closer to the optimal range according to brackishwater aquaculture standards.

Effectiveness of CFS on Crab Growth

The specific growth rate (SGR) is an important indicator in assessing the performance of an aquaculture system. The SGR value of 1.43% per day in the CFS treatment showed a significant increase in growth compared to the conventional system at 1.21%. These results reinforce the findings of Nugroho and Kurniawan (2020), who stated that water recirculation systems are able to support the growth of aquatic organisms by maintaining environmental stability.

The increase in SGR in the CFS was strongly influenced by the efficiency of space utilization and the improvement of culture media quality. The modular system allows for even space distribution and reduces competition among individuals. In addition, the presence of shelter media in the form of PVC pipes can reduce stress levels and cannibalism, which frequently occur in mangrove crabs (Wijayanti *et al*., 2021). With lower stress and a stable environment, crabs can focus more on metabolic processes and tissue growth.

Improvement in Survival Rate

The survival rate in the CFS reached 92%, much higher than that of the conventional system, which was only 78%. The main factors contributing to this increase were environmental stability and the water filtration system that was able to reduce ammonia levels. Ammonia is one of the main toxic compounds in aquaculture produced from uneaten feed and metabolic excretion.

In conventional systems without filtration, ammonia accumulation can reach dangerous thresholds (>0.2 mg/L), which can cause respiratory disturbances and mortality in cultured organisms (Budiardi & Sari, 2021). In contrast, in the CFS, the average ammonia concentration was only 0.09 mg/L, far below this threshold. This indicates that the use of biofilters and water circulation in the CFS is highly effective in maintaining water quality that is safe and comfortable for crabs.

Water Quality as a Determining Factor of Aquaculture Performance

Water quality is a key environmental parameter that determines aquaculture success. Parameters such as temperature, pH, DO, and ammonia concentration have a direct influence on the physiology and behavior of crabs. Stable temperature within the range of 28–30°C and pH around 7.5 in the CFS represent optimal conditions for mangrove crab metabolism.

DO conditions in the conventional system tended to be low (3.9 mg/L) due to the lack of aeration and circulation, whereas in the CFS, DO remained stable at 5.2 mg/L. According to Scabra *et al*., (2022), sufficient dissolved oxygen availability is crucial in supporting respiratory activity and tissue growth. A decrease in DO below the threshold can cause stress and increase susceptibility to disease.

In addition, fluctuations in water quality in conventional systems can also increase the risk of acute and chronic stress. Prolonged stress not only reduces appetite and growth, but also weakens the crab immune system. The CFS, which applies controlled circulation and automatic filtration, is able to minimize these fluctuations and provide a more stable environment throughout the rearing period.

Advantages of the Modular System and Replication Potential

The advantages of the CFS lie not only in biological performance, but also in technical aspects and space efficiency. This system is designed in a modular manner, allowing its application at household as well as commercial scales. Culture units can be expanded horizontally or vertically as needed and can be operated with low electrical energy requirements.

The modular concept is highly suitable for application in coastal areas such as Central Tapanuli, which have limited land availability and access to clean water. This system can be modified with solar energy systems, automatic pH control, or IoT-based water quality sensors to improve efficiency and adaptation to climate change (Tacon & Metian, 2015).

Comparison with Previous Studies

The results of this study are consistent with previous findings that emphasize the importance of innovation in aquaculture systems based on environmental control. Wijayanti *et al*., (2021) emphasized that closed systems such as RAS or semi-RAS can reduce water use by up to 90% and increase yield per unit area. In the context of crab aquaculture, the modular approach in the CFS has proven to be more adaptive to the aggressive and semi-cannibalistic characteristics of crabs compared to conventional closed system designs commonly used for fish.

Unlike pond systems that require large investments and extensive land, the CFS can be operated in limited areas with more affordable capital. This opens up significant opportunities for microenterprise development and technology-based economic empowerment of coastal communities through aquaculture.

Relevance to Modular Systems and Technological Innovation

The CFS is also considered efficient in terms of space and energy consumption. Research by Kusrini and Sugianto (2022) showed that modular designs in RAS can reduce energy consumption by up to 25%. This is in line with renewable energy-based management models as proposed by Rahman and Saputra (2023).

CONCLUSION

This study proves that the Crab Flow System (CFS), designed as a modular aquaculture system based on controlled water flow, is capable of providing a significant positive effect on the performance of mangrove crab (*Scylla* spp.) aquaculture. Based on the observations and analysis, the CFS:

1. Significantly increased the specific growth rate (SGR) of mangrove crabs compared to the conventional system.
2. Significantly improved survival rates through environmental control and reduction of rearing stress.
3. Stabilized water quality parameters (temperature, pH, DO, and ammonia) so that they remained within the optimal range for crab aquaculture, particularly by suppressing ammonia levels below the toxic threshold.
4. Provided an efficient and sustainable alternative aquaculture system that can be applied in coastal areas with limited land and resources.

Thus, the CFS has great potential to be further developed as an innovative solution for mangrove crab aquaculture oriented toward efficiency, productivity, and sustainability.

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