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The potential feasibility of mangrove crab (*Scylla serrata*) silvofishery aquaculture

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Abstract. *Rinaldy H, Iskandar J, Cahyandito MF, Sunardi. 2023. The potential feasibility of mangrove crab* (Scylla serrata) *silvofishery aquaculture. Biodiversitas 24: 3344-3354.* The degradation of mangrove forests in Indonesia has reached more than 50%, and increases continuously. Sei Beduk is one of the Sub-districts in Batam City, Indonesia, that has mangrove forest damage where the density of trees per hectare is below the normal value of <1,000 trees per hectare. One approach that can be applied to overcome forest degradation is fisheries management with an ecosystem approach. This study aims to determine the suitable location for cultivating mangrove crab (*Scylla serrata* Forskål, 1775) and analyze the potential feasibility of *S. serrata* silvofishery cultivation using a quantitative approach with the Ecosystem Approach to Fisheries Management (EAFM) method. According to Slovin's calculations, a minimum of 100 people samples were obtained, and 147 samples were obtained at the time of data collection. The results showed that the location of the Perahu was highly potential for silvofishery *S. serrata* cultivation. The overall potential feasibility of silvofishery *S. serrata* cultivation in Sei Beduk, Batam was 53.10% or moderate/relatively good. The potential feasibility of *S. serrata* cultivation management planning is sufficient to support the sustainability of mangrove forests and allow it to be implemented. The feasible plan for managing *S. serrata* cultivation is to preserve ecology while improving and considering aquaculture policies and regulations. The relatively appropriate mangrove silvofishery cultivation in Sei Beduk, Batam, can provide community solutions to carry out silvofishery cultivation as a measure to overcome the problem of mangrove forest degradation, particularly in Sei Beduk, Batam.

Keywords: Batam, cultivation, EAFM, mud crab, silvofishery

Abbreviations: BOD: Biological Oxygen Demand, DO: Dissolved Oxygen, EAFM: Ecosystem Approach to Fisheries Management, pH: Acidity, TDS: Total Dissolved Solid, TSS: Total Suspended Solid

INTRODUCTION

The degradation of mangrove forests in Indonesia has exceeded 50% (Sihotang 2019), where critical conditions are found in 637,624 hectares of rove ecosystems, including 460,210 hectares of forest areas and 177,415 hectares of areas outside the forest. Damage to the mangrove ecosystem also occurs in Batam City, Indonesia (KLKH 2020). Batam, Tanjungpinang, and Karimun Regencies suffered from soil damage that exceeds the critical threshold of erosion with a soil thickness of 20-50 cm (DLHK 2021) due to illegal logging activities, residential development, and other unauthorized use of forest areas (Eddy et al. 2019). Mangrove forest damage has further caused soil damage, erosion, and floods. Severe mangrove forest damage has impacted many subdistricts in Batam City, including Sei Beduk Sub-district such as tree density was below normal or <1,000 trees per hectare (Efendi 2013). The common factors to this damage are mangrove logging and hoarding for charcoal, the conversion of mangrove forests into residential land (DLHK 2021), and allegedly illegal stockpiling of mangroves in Java Village, Piayu Laut area, Batam City (Dodo 2019). Other factors contributing to mangrove forest destruction include the economy and a lack of public understanding of the ecological function of mangrove forests (Muryani et al. 2011; Amin et al. 2016). It is critical to comprehend the gravity of mangrove forest degradation and the numerous consequences that must be addressed (Hasan et al. 2023; Isroni et al. 2023).

The management of mangrove crab (*Scylla serrata* Forskål, 1775) cultivation aims to protect the sustainability of mangrove forests and their multifold benefits. In accordance with Law Number 32 of 2009 concerning Environmental Protection, and Management, the efforts to preserve forests must integrate environmental, social, and economic aspects. The current fisheries management has not considered the balance between fishery resources and ecosystems, ecological, social, economic, and even regulations. To overcome forest degradation, fisheries management with an ecosystem approach can be a potential solution, for example, the Ecosystem Approach to Fisheries Management (EAFM) which considers the impact of aquaculture management on all components of the ecosystem. Generally, EAFM is used to evaluate the ongoing cultivation (Ramírez-Monsalve et al. 2016; Tarigan et al. 2019; Cahyadinata et al. 2020; Azis et al. 2022; Islam et al. 2022; Dudayev et al. 2023). Meanwhile, the current study employs EAFM to assess the feasibility of developing an *S. serrata* silvofishery, which is still in the planning stages. Aquaculture management planning or fisheries management planning is a hierarchical process that translates objectives into 'what' strategies will be carried out in fisheries management planning that pays attention to ecosystems (Gavaris 2009).

Since this research was conducted at the planning stage of *S. serrata* silvofishery cultivation, it is important to select the right location for mangrove silvofishery cultivation based on the quality of water, soil, and litter (Shelley and Lovatelli 2011; Setiawan and Tri 2012) Previous research has demonstrated the positive effects of well-managed *S. serrata* cultivation on the environment, such as lagoon colonization, which results in beneficial changes in the ecosystem of mangrove forest areas (Leite et al. 2021) providing socioeconomic and environmental benefits to the local community, and contributing to the transfer of organic matter from land to marine environment (Giri et al. 2015; Masood et al. 2015). Ecology, social elements, and economy are the contributing factors to environmental sustainability (Pattimahu et al. 2010; Feka 2015; Karlina et al. 2016), the parameters for evaluating environmental sustainability (Pattimahu et al. 2010; Feka 2015; Karlina et al. 2016; Pattimahu et al. 2017; Idajati and Widiyahwati 2018; Chen and Shih 2019; Hema and Devi 2020; Melo et al. 2020), and the complementary institutional aspects to the management of *S. serrata* aquaculture (Purwanti et al. 2018; Kusmana et al. 2020). While other studies discuss the aspects of environment, economy, social, regulation, and technology of environmental sustainability, this research focused on maritime tourism sector instead of the management of crab cultivation (Kapuangan et al. 2016). This study also fills a research gap by emphasizing regulatory aspects to assess the potential feasibility of *S. serrata* silvofishery cultivation, which were lacking in previous studies.

This study determines the exact location of the station point for *S. serrata* silvofishery cultivation and analyzes the potential feasibility of *S. serrata* silvofishery farming. The existence of mangrove silvofishery cultivation that can be applied in Sei Beduk, Batam, is expected to be able to provide solutions to the problem of mangrove forest degradation, especially in the Sei Beduk, Batam.

MATERIALS AND METHODS

This research was conducted at Sei Beduk, one of the Sub-districts in Batam City, Riau Islands, Indonesia (Figure 1). To select the right location for mangrove silvofishery cultivation, this research analyzed the quality of water, soil, and litter (Shelley and Lovatelli 2011; Setiawan and Tri 2012) at three locations referred to as Station I (Piayu Laut), Station II (Tambak Udang), and Station III (Perahu). The parameters of water quality were indicated from the salinity, pH, O_2, temperature (°C), TSS (ppm), and DO (mg/L). The physical analysis, soil conditions were evaluated from the soil texture, pH, CO-organic (%), and N-total (%), and mangrove litter production (Tables 1 and 2).

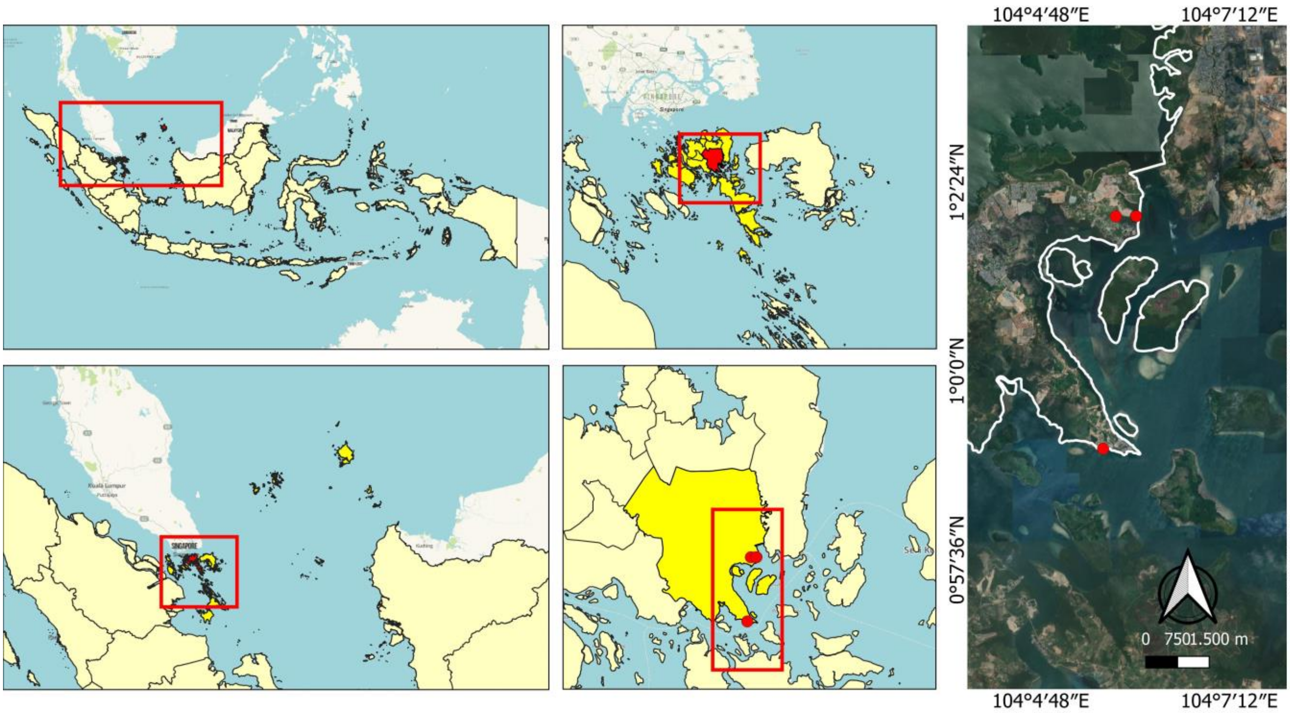

Figure 1. Map of Sei Beduk, Batam City, Riau Islands Province, Indonesia

Table 1. Land suitability level matrix for mangrove crab (*Scylla serrata*) cultivation silvofishery pattern

Parameters	Land suitability class				Weight
	S1	**S2**	**S3**	**N**	
	Score 4	**Score 3**	**Score 2**	**Score 1**	
Soil conditions					
Soil texture	Sandy clay, sandy clay, clay clay, dusty clay, dusty clay	Loamy sand, sandy loam, loam, dusty loam	Clay, dust	Sand	0.13
Ph	7.5-8.5	6.5-7.4	5.5-6.4	<5.5->8.5	0.12
CO-organic (%)	<6.0	6.0-12.0	12.1-15.0	>15.0	0.08
N-total (%)	>0.5	0.38-0.5	0.25-0.37	<0.25	0.07
Water quality					
Salinity	15.0-30.0	30.1-35.0 or 10-15	35.1-50.0 or 5.0-10.0	>50.0 or <5.0	0.08
pH	7.5-8.5	8.6-9.5 or 6.5-7.5	9.6-11.0 or 5.5-6.5	>11.0 or <5.0	0.12
O_2	>4.0	3.1-4.0	2.1-3.0	<2.0	0.18
Temperature (°C)	26.0-32.0	20.1-25.0	15.0-20.0	>32.0 or <15.0	0.14
TSS (ppm)	<25	25-80	81-400	>400	0.08
DO (mg/L)	> 5 mg/L (*S. serrata* are tolerant of low oxygen levels)				

Source: The Australian prawn farming manual (Shelley and Lovatelli 2011; Karim et al. 2012; Setiawan and Tri 2012)

Table 2. Land suitability classification

Land suitability classification	Total score (%)
Very suitable (S1)	76-100
Fairly suitable (S2)	51-75
Almost suitable (S3)	26-50
Not suitable (N)	0-25

The total value of mangrove was calculated using the following formula:

$$\text{Total Score} = \frac{\sum total}{4} \text{ x } 100\% = \text{Maximum total value}$$

Where:

Score 4: Very suitable class, the land has no significant limiting factors for sustainable use; Score 3: Class is quite suitable, land has a rather significant limiting factor for sustainable use that can reduce productivity; Score 2: Class is almost appropriate, has severe limiting factors for continuous use and reduces productivity; Score 1: Inappropriate class, has a very severe and permanent limiting factor that can hinder the possibility of its utilization

The production of mangrove leaf litter using the following formula:

$$Xj = \frac{\sum Xi}{n}$$

Where:

Xj: Litter production each period (grams dry weight/m^2)

Xi: Dry weight of litter (grams dry weight) of 37.22 g (Station I: Piayu Laut), 33.5 g (Station II: Tambak Udang), and 42.16 (Station III: Perahu)

N: Area of litter-trap (m^2) of 1 m^2

Upon selecting the right locations, this study analyzed the potential feasibility of *S. serrata* silvofishery cultivation using the EAFM questionnaire EAFM (2014). The EAFM measurement refers to planning management efforts for *S. serrata* cultivation that meets the criteria of sustainable development while integrating economic interests and environmental sustainability. Previous studies have reported that the parameters for managing *S. serrata* cultivation are ecology, economy, social conditions, and institutional assessments (Pattimahu et al. 2017; Idajati and Widiyahwati 2018; Chen and Shih 2019; Hema and Devi 2020; Melo et al. 2020). Furthermore, the management of *S. serrata* cultivation is characterized by ecological, economic, social, and institutional assessments (Purwanti et al. 2018; Kusmana et al. 2020). The present study modified these aspects and came up with six domains: (i) *S. serrata* resources, (ii) ecology, (iii) social, (iv) economic, (v) institution, and (vi) policies/regulations. Tables 3 and 4 presents the detailed indicators of each domain.

The population in this study was 86.220 individuals using the mangrove forests in Sei Beduk, Batam. A purposive sampling was used to select representative participants for the study using the Slovin formula Sugiyono (2017) which required at least 100 people and at the time of data collection obtained 147 samples. The data were subjected to quantitative analysis using the Ecosystem Approach to Fisheries Management (EAFM) method (Table 3) with the following formula:

$$Nk_i = \frac{C_{at-i}}{C_{at-i}max * N} x\ 100\%$$

Where:

N : Number of domains in EAFM

C_{at-i}: Total EAFM value of an attribute in the domain

$C_{at-i}max$: Maximum value of EAFM in the score domain 3.

Table 3. Ecosystem Approach to Fisheries Management (EAFM)

Domain	Indicators	Definition
Mangrove crab (*Scylla serrata*) resources	CpEU Standard	The result of crab tagging per unit of fishing effort
	Availability of seedlings	Availability of *S. serrata* seedlings
	Crab Size Trends	The average size of crab tags per unit of fishing effort
	Juvenile Crab Proportions	Percentage of crabs caught before reaching adulthood
	The species composition is arrested	Species composition of mangrove crabs ever caught
	Range Collapse	Increasingly distant crab fishing locations
	ETP species (endangered, threatened, and protected)	Potential protection of endangered crabs
Ecology	Water quality	The degree of water suitability for *S. serrata* farming
	Availability of mangrove seedlings	Availability of mangrove seedlings
	Pollution	The presence of pollution in mangrove ecosystem areas
	Diversity of flora and organisms	Diversity of flora and organisms in mangrove forest ecosystems
	Changes in habitat or organism	The change in habitat or organisms in mangrove areas due to human intervention
	Specific/unique habitat	Availability of habitat for unique species
	Knowledge of climate changes in conditions	Knowledge about climate changes in conditions
	Bodies of water and habitat	Bodies of water and habitat
	Protection of rare species of flora and fauna	The protection of rare, endangered species of flora and fauna and those peculiar to the local area in mangrove forest areas
Social	Community education	The level of education of the community around the mangrove forest
	Community participation/engagement	High potential for community participation in fisheries management planning
	Public knowledge of ecosystem functions and benefits	The potential and perception of public knowledge about the functions and benefits of mangrove forest ecosystems
	Handling *S. serrata* farming conflicts	The capacity for handling potential conflicts in *S. serrata* cultivation
	Land conflict management	The mechanism for handling potential land conflict
	Public awareness	The potential high public awareness to conserve mangroves through local wisdom by planting or preserving mangroves, and silvofishery cultivation
	Activities that damage ecosystems	Community activities that potentially damage mangrove forest ecosystems
	Community organizations	The potential availability of community organizations in *S. serrata* aquaculture management
	Preservation practices	The potential for local cultural practices in the preservation of mangrove forest areas
Economics	Community income	Potential income obtained by the community from the management of *S. serrata* cultivation
	Government revenue	Potential revenue obtained by the government from *S. serrata* cultivation management
	Job opportunities	The potential availability of job opportunities in *S. serrata* cultivation areas
	A lot of production	The high potential production of aquaculture products through silvofishery sourced from mangrove areas
Institutional	The activeness of the managing institution	The high potential for the activity of institutions managing the *S. serrata* aquaculture
	Communication and coordination of managing agencies	The high potential for communication and coordination between management institutions and other related institutions in managing *S. serrata* cultivation
	Ecosystem utilization zones	The potential availability of utilization zones for mangrove forest ecosystem
	Extension officer/field officer	The potential availability of extension workers/field officers to manage mangrove forest ecosystems
	Training and counseling	The potential for training and counseling on the use of mangrove ecosystems through silvofishery cultivation
	Planning on management	High potential for planning the management of *S. serrata* aquaculture
	Stakeholder capacity	The potential multiplicity of stakeholders
	Coordination between managing agencies	High potential for coordination between managing agencies
	Role model	The potential for agencies to be the role models for the community
Policy/ regulation	Formal and informal regulations	Potential for formal and informal regulations
	Local and village government policies	The potential for local and village government policies on *S. serrata* cultivation management
	Management mechanism of *S. serrata* cultivation	The potential presence or absence of management mechanism for *S. serrata* cultivation that conforms with SOPs
	Obedience and Compliance	High potential for obedience and compliance with the regulations imposed on the management of *S. serrata* aquaculture
	Penalty	The potential sanctions and law enforcement for communities responsible for the damaged mangrove forest ecosystems

Source: Ecosystem Approach to Fisheries Management (EAFM) indicator (EAFM 2014)

Table 4. Categorization of potential feasibility of silvofishery aquaculture (Riduwan et al. 2017)

Grade/score	Interpretation
0.00%-20%	Very bad
21%-40%	Bad
41%-60%	Good enough
61%-80%	Good
81%-100%	Excellent

RESULTS AND DISCUSSION

Mangrove crab (*Scylla serrata*)

The mangrove crab (*Scylla serrata*) is a type of mangrove crab that has a relative color similar to the color of mud, namely blackish-brown on the carapace and yellowish-white on the abdomen. In the upper propodus, there is a pair of pointed spines and 1 thorn on the lower propodus (Adriyani 2017) (Figure 2). *Scylla serrata* has a complex life cycle with dispersing larval phases, benthic juveniles, and adults. The first phase is stenohaline depends on high salinity conditions for survival, while the latter physiologically adapt well to changes in temperature and salinity, conditions that usually occur in mangrove habitats (Alberts-Hubatsch et al. 2016).

The location of silvofishery

This research was conducted in Sei Beduk, Batam City, a technical implementing element of Regional Autonomy in the Field of Public Services, based on Regional Regulation of Batam City Number 2 of 2005 concerning the Expansion, Change, and Formation of Districts and Sub-districts within the Batam City Region. Sei Beduk Sub-district is located between - 0° 55' 00″ - 1° 15' 00″ N - 103° 45' 00″- 104° 10' 00″ E (Figure 1). Sei Beduk Sub-district is bordered by Nongsa Sub-district and Batam City Sub-district to the north, Bulang Sub-district and Galang Sub-district to the south, Batu Aji Sub-district and Sagulung Sub-district to the west, and Nongsa Sub-district to the east.

Administratively, Sei Beduk Sub-district covers an area of 120,674 km^2 that includes 14,227 km^2 of water area and is divided into four Sub-districts and four villages including Tanjung Piayu Village (12,001 Km^2), Muka Kuning Village (42,093 Km^2), Duriangkang Village (9,999 Km^2), and Mangsang Village (56,581 Km^2).

The potential cultivation sites were selected by analyzing the quality of water, soil, and litter (Shelley and Lovatelli 2011; Setiawan and Tri 2012). Three locations for cultivation were Station I (Piayu Laut Station), Station II (Tambak Udang Station), and Station III (Perahu Station), and the water quality was analyzed based on six parameters. The measurement results of water qualities for the mud crab are presented in Table 5.

Water quality parameters based on pH are known to be between 6.8-8.1, while good pH criteria based on Shelley and Lovatelli (2011) and Setiawan and Tri (2012) are 7.5-9; <0.5 daily variations; Optimal around 7.8" therefore the entire location namely Piayu Laut, Tambak Udang and Perahu are suitable for *S. serrata* cultivation. The lowest pH condition is at Station I (Piayu Laut) while the highest pH is at Station III (Perahu). Water quality parameters based on TSS (mg/L) are known to be between 84-112, while good TSS criteria based on Shelley and Lovatelli (2011) and Setiawan and Tri (2012) are 25-80 (mg/L) on clay land, sandy loam, clay, dusty clay and 81-400 (mg/L) on clay, dust land. Based on this, it is known that all locations have the same potential to do silvofishery *S. serrata* farming. The lowest TSS condition is at Station III (Perahu) while the highest TSS is at Station I (Piayu Laut) (Table 5).

Water quality parameters based on temperature are known to be between 24.0°C-28.0°C. According to Shelley and Lovatelli (2011) and Setiawan and Tri (2012), the appropriate temperature criteria for cultivation are 20.1-32.0°C . Based on this, it is known that all locations have the same potential for silvofishery *S. serrata* cultivation. The lowest temperature conditions are at Station I (Piayu Laut) while the highest temperature is at Station III (Perahu). Water quality parameters based on O_2 are known to be between 2.6-4.5 ppm. According to Shelley and Lovatelli (2011) and Setiawan and Tri (2012) the appropriate^{O2} criteria for cultivation range from 3.1-4 ppm and >4 ppm. The lowest O_2 condition is at Station I (Piayu Laut) while the highest O_2 is at Station III (Perahu) (Table 5).

Analysis of the physical and chemical quality of soil is seen in the soil pH is between 5.79-6.71, while according to Shelley and Lovatelli (2011) and Setiawan and Tri (2012), the criteria for soil pH suitable for crab cultivation ranging (6.5-8.5) based on this it is known that all locations Potential for silvofishery *S. serrata* cultivation. The lowest soil pH condition is at Station III (Perahu) while the highest TSS is at Station I (Piayu Laut). Analysis of soil physical and chemical quality based on C-Organic parameters is between 1.54-5.28%. According to Shelley and Lovatelli (2011) and Setiawan and Tri (2012) the C-Organic criteria of the best soil for crab cultivation is <6 or quite good ranging from 6.0-12.0. Based on this, it is known that all locations have the potential to be cultivated silvofishery *S. serrata*. The lowest soil C-Organic condition is at Station II (Tambak Udang) while the highest TSS is at Station I (Piayu Laut) (Table 6).

Figure 2. Mangrove crab (*Scylla serrata*)

The N-Total parameter is between 0.14-0.21%, while the best N-Total criteria for crab cultivation is >0.5% or quite good, ranging from 6, 0.38-0.5%. Based on this, it is known that all locations are potentially unfavorable/less suitable for silvofishery *S. serrata* cultivation. The lowest N-Total condition is at Station II (Tambak Udang) while the highest TSS is at Station I (Piayu Laut). The soil texture parameters at Station I have a sand content of 61.77%, dusty 19.19%, and clay 19.08% which means that it has a tendency that the soil is textured with dusty sand. The soil texture at Station II has a sand content of 78.06%, dusty 13.13%, and clay 8.81% which means that it has a tendency that the soil is sand-textured. The soil texture at Station III has a sand content of 50,74.06%, dusty 26.77%, and clay 26.77% which means that it has a tendency that the soil has a dusty clay texture. Based on this, it is known that Station II has the potential to be poor for silvofishery *S. serrata* cultivation. While Station I and Station III are quite suitable for silvofishery *S. serrata* cultivation (Table 6).

Based on the land suitability classification (Table 2), it is known that land suitability at Station I (Piayu Laut) was obtained by 81.75%. When related to the category of land suitability, it is included in a very suitable category (S1) (Shelley and Lovatelli 2011; Setiawan and Tri 2012). This is because the value of 81.75% is between 76-100% (Table 7).

Based on the land suitability classification, it is known that land suitability at Station II (Tambak Udang) was obtained by 88.50%. When related to the category of land suitability, it is included in a very suitable category (S1) (Shelley and Lovatelli 2011; Setiawan and Tri 2012). This is because the value of 88.50% is between 76-100% (Table 8).

Based on the land suitability classification, it is known that land suitability at Station III (Perahu) was obtained by 99.50% (Table 9). When related to the category of land suitability it is included in a very suitable category (S1) (Shelley and Lovatelli 2011; Setiawan and Tri 2012). This is because the value of 99.50% is between 76-100%. The quality of leaves seen in mangrove litter production with the following formula:

$$Xj = \frac{\sum xi}{n}$$

Where:

Xj: Litter production each period (grams dry weight/m^2)

xi: Dry weight of litter (grams dry weight) of 37.22 g (Piayu Laut), 33.5 g (Tambak Udang), and 42.16 (Perahu)

n: Area of litter-trap (m^2) of 1 m^2

Location I: Piayu Laut

$$Xj = \frac{37.22}{1} = 37.22$$

Location II: Tambak Udang

$$Xj = \frac{33.5}{1} = 33.5$$

Location III: Perahu

$$Xj = \frac{42.16}{1} = 42.16$$

The highest litter production has high potential for silvofishery *S. serrata* cultivation. The location with the highest litter production is the Perahu location of 42.16. While the location that has the lowest litter production is Station II (Tambak Udang). Based on some of the assessments above, it can be seen that the most suitable location is Station III (Perahu) this is because the location of the Perahu has the highest percentage of land suitability of 99.50% and has the highest litter production of 42.16.

The potential feasibility of silvofishery

Considering that resources are among many vital elements in *S. serrata* cultivation, this study analyzed six domains of resources to measure the potential feasibility of silvofishery in Batam City as presented in Figures 4-9. In the domain of *S. serrata* resources (Figure 3), the overall result was 54.49%, indicative of moderate or relatively good. The highest percentage is 61.2% on the indicator "Potential percentage of crabs caught before reaching adulthood" with an average answer of 30-60% potential catch before reaching adulthood. In other words, the respondents understood that only adult crabs are suitable for catching. In this domain, the indicator of "Potential protection of endangered crabs" had the lowest percentage (46.0%), where most respondents answered that they would less likely to release the crabs they have caught (Figure 3). In the ecology domain, the potential feasibility is 55.73%, indicative of moderate or relatively good level of planning. The highest percentage is 59.9% on the indicator "Potential availability of mangrove seedlings" where most participants claimed that mangrove tree seedlings were many but not managed properly. The lowest percentage was 52.2% on the indicator "The potential for knowledge about climate change in water and habitat conditions" in which the respondents generally agreed that there were studies and impacts on mangrove cultivation but no mitigation has been undertaken (Figure 4).

Table 5. Water quality test

Sample code	Test results							
	DO (mg/L)	BOD (mg/L)	TDS (ppm)	Salinity (PPT)	pH	TSS (mg/L)	Temperature (°C)	O_2 (ppm)
Station I (Piayu Laut)	5.712	1.632	1.137	14	6.8	102	24.0	2.6
Station II (Tambak Udang)	6.528	3.264	1.524	29	7.4	87	26.5	3.2
Station III (Perahu)	7.752	4.080	1.541	30	8.1	84	28.0	4.5

Notes: DO: Dissolved Oxygen, BOD: Biological Oxygen Demand, TDS: Total Dissolved Solid, pH: Acidity, TSS: Total Suspended Solid

Table 6. Physical analysis, soil chemistry, and litter test

Sample code	Results of physical analysis, and soil chemistry							Results of leaf analysis		Litter
	Extract 1:2		Walkley & Black	Kjeldhal	Texture (Piper)			Wet weight (g)	Dry weight (g)	
	pH H_2O	pH KCI	C-Organic (%)	N-Total (%)	Sand (%)	Dust (%)	Clay (%)			
Station I (Piayu Laut)	6.71	6.43	5.28	0.21	61.73	19.19	19.08	86.89	37.22	37.22
Station II (Tambak Udang)	6.60	6.15	1.54	0.14	78.06	13.13	8.81	80.96	33.53	33.53
Station III (Perahu)	6.23	5.79	4.40	0.20	50.74	26.77	26.77	52.46	42.16	42.16

Note: pH H_2O: Potential Hydrogen, pH KCI: Acidity, N-Total: Nitrogen Total

Table 7. Results of land suitability test at Station I (Piayu Laut), Sei Beduk, Batam City, Indonesia

Parameters	Land suitability class				Weight	Field analysis results	Score	Value
	S1	S2	S3	N				
	Score 4	Score 3	Score 2	Score 1				
Soil condition								
Soil texture	Sandy clay, sandy clay, clay, dusty clay, dusty clay	Loamy sand, sandy loam, loamy, dusty clay	Clay, dust, sandy dust,	Sand	0.13	61.73% sand, 19.19% dust, 19.08 clay	2	0.26
pH	7.5-8.5	6.5-7.4	5.5-6.4	<5.5->8.5	0.12	6.71	3	0.36
CO-organic (%)	<6.0	6.0-12.0	12.1-15.0	>15.0	0.08	5.28	4	0.32
N-total (%)	>0.5	0.38-0.5	0.25-0.37	<0.25	0.07	0.21	1	0.07
Water quality								
Salinity	15.0-30.0	30.1-35.0 or 10.0-15.0	35.1-50.0 or 5.0-10.0	>50.0 or <5.0	0.08	14	3	0.24
pH	7.5-8.5	8.6-9.5 or 6.5-7.5	9.6-11.0 or 5.5-6.5	>11.0 or <5.0	0.12	6.8	3	0.36
O_2	>4.0	3.1-4.0	2.1-3.0	<2.0	0.18	2.6	2	0.36
Temperature (°C)	26.0-32.0	20.1-25.0	15.0-20.0	>32.0 or <15.0	0.14	24,0	3	0.42
TSS (ppm)	<25	25-80	81-400	>400	0.08	102	2	0.16
DO(mg/L)	> 5 mg/L (*S. serrata* are tolerant of low oxygen levels)				0.18	5.712	4	0.72
Total								3.27
Total Percentage = x 100% $\frac{\sum total}{4} = \frac{3,27}{4}$ x 100%								81.75

Table 8. Results of land suitability test at Station II (Tambak Udang), Sei Beduk, Batam City, Indonesia

Parameters	Land suitability class				Weight	Field analysis results	Score	Value
	S1	S2	S3	N				
	Score 4	Score 3	Score 2	Score 1				
Soil condition								
Soil texture	Sandy clay, sandy clay, clay, dusty clay, dusty clay.	Loamy sand, sandy loam, sandy dust, clay, dusty clay	Clay, dust, sandy dust,	Sand	0.13	78.06% sand; 13.13% dust; 8.81 clay	1	0.13
pH	7.5-8.5	6.5-7.4	5.5-6.4	<5.5->8.5	0.12	6.60	3	0.36
CO-organic (%)	<6.0	6.0-12.0	12.1-15.0	>15.0	0.08	1.54	4	0.32
N-total (%)	>0.5	0.38-0.5	0.25-0.37	<0.25	0.07	0.14	1	0.07
Water quality								
Salinity	15.0-30.0	30.1-35.0 or 10.0-15.0	35.1-50.0 or 5.0-10.0	>50.0 or <5.0	0.08	29	4	0.32
pH	7.5-8.5	8.6-9.5 or 6.5-7.5	9.6-11.0 or 5.5-6.5	>11.0 or <5.0	0.12	7.4	3	0.36
O_2	>4.0	3.1-4.0	2.1-3.0	<2.0	0.18	3.2	3	0.54
Temperature (°C)	26.0-32.0	20.1-25.0	15.0-20.0	>32.0 or <15.0	0.14	26.5	4	0.56
TSS (ppm)	<25	25-80	81-400	>400	0.08	87	2	0.16
DO(mg/L)	> 5 mg/L (*S. serrata* are tolerant of low oxygen levels)				0.18	6.528	4	0.72
Total								3.54
Total Percentage = x 100% $\frac{\sum total}{4} = \frac{3,54}{4}$ x 100%								88.50

Table 9. Results of land suitability test at Station III (Perahu), Sei Beduk, Batam City, Indonesia

Parameters	Land suitability class					Field analysis results	Score	Value
	S1	S2	S3	N	Weight			
	Score 4	Score 3	Score 2	Score 1				
Soil condition								
Soil texture	Sandy clay, sandy clay, clay, dusty clay, dusty clay	Loamy sand, sandy loam, sandy dust, clay, dusty clay	Clay, dust, sandy dust,	Sand	0.13	50.74% sand, 26.77% dust, 26.77% clay	3	0,39
pH	7.5-8.5	6.5-7.4	5.5-6.4	<5.5->8.5	0.12	6.23	2	0.24
CO-organic (%)	<6.0	6.0-12.0	12.1-15.0	>15.0	0.08	4.4	4	0.32
N-total (%)	>0.5	0.38-0.5	0.25-0.37	<0.25	0.07	0.2	1	0.07
Water quality								
Salinity	15.0-30.0	30.1-35.0 or 10.0-15.0	35.1-50.0 or 5.0-10.0	>50.0 or <5.0	0.08	30	4	0.32
pH	7.5-8.5	8.6-9.5 or 6.5-7.5	9.6-11.0 or 5.5-6.5	>11.0 or <5.0	0.12	8.1	4	0.48
O_2	>4.0	3.1-4.0	2.1-3.0	<2.0	0.18	4.5	4	0.72
Temperature (°C)	26.0-32.0	20.1-25.0	15.0-20.0	>32.0 or <15.0	0.14	28	4	0.56
TSS (ppm)	<25	25-80	81-400	>400	0.08	84	2	0.16
DO(mg/L)	> 5 mg/L (*S. serrata* are tolerant of low oxygen levels)				0.18	7.752	4	0.72
Total								3.98
Total Percentage = x 100% $\frac{\sum total}{4} = \frac{3,98}{4}$ x 100%								99.50

Social factors in the social domain refer to the potential of the community in a social group, including family, community environment, or other fellows. The potential feasibility in the social domain is 54.45%, indicative of moderate or relatively good level of planning. The highest percentage of 60.5% was related to the "Potential mechanism for handling land conflict" with the average answer having the potential of 2-5 times/year is the level of moderate conflict. These results show that communities have the potential to understand land conflict handling mechanisms. While the lowest percentage was 40.6% on the indicator "Potential level of education of communities living around mangrove forests". Most of the respondents graduated from elementary school or junior high school, or relatively low level of education (Figure 5). In the economy domain, the potential feasibility is 53.46%, indicative of moderate or relatively good level of planning. The indicator “Potential availability of job opportunities in *S. serrata* cultivation areas” had the highest percentage of 71.7% while 100% of the respondents believed that *S. serrata* cultivation has provided high job opportunities. While the lowest percentage is 40.6% on the indicator "Potential income obtained by the community from *S. serrata* aquaculture management" to which the respondents generally answered ‘lower than minimum wage’ (Figure 6).

The institutional domain refers to the potential performance of institutions involved in silvofishery and the potential benefits offered to the communities in the silvofishery neighborhood. The overall potential feasibility in the institutional domain is 54.30%, indicative of moderate or relatively good level of planning. The highest percentage is 70.5% in the indicator "The high potential for the “activeness of *S. serrata* aquaculture management institutions" with an average answer that has a potential of 100% is high participation. These results show that the community has the potential to participate. The lowest percentage is 49.4% on two indicators "The potential for high planning on *S. serrata* cultivation management” and “The potential for role models from agencies to the community." To these indicators, the respondents generally answered that management plans existed but not well implemented, and the management agencies played as role models but without significant contributions (Figure 7). Next, the overall potential feasibility regarding the policy/regulatory domain is 46.21%, indicative of moderate or relatively good level of planning. The highest percentage is 47.8% on the indicator "Potential sanctions and law enforcement for communities that damage mangrove forest ecosystems" with an average answer potentially 2-4 times/year subject to sanctions. These results show that communities have the potential to be penalized if they damage mangrove forest ecosystems. The lowest percentage is 45.4% in the indicator "The potential for local and village government policies on *S. serrata* aquaculture management" (Figure 8).

In general, this study has revealed that all six domains exist in ongoing management planning (Figure 9). Ecology is the highest contributing domain for management planning, while policy/regulation is the least supportive one and, therefore, needs to improve. The *S. serrata* resource domain has a potential feasibility of 54.49% (medium planning category), which implies that the current planning management of *S. serrata* cultivation in three stations is sufficient to support the sustainability of mangrove forests. These results confirm previous research (Idajati and Widiyahwati 2018) that management priorities should be focused on environmental/ecological aspects, which may include rehabilitation of conservation areas, increased monitoring of mangrove utilization, law enforcement, formation of management consortia, increased synchronization of coordination, and interaction between stakeholders. Furthermore, ten contributing factors to planning the sustainability status of mangrove forests (Karlina et al. 2016) are (i) delimitation of forest areas; (ii) suitability of the designation of the area; (iii) availability of mangrove seedlings; (iv) protection of flora, and fauna; (v) state revenue from management, and utilization; (vi) the income level of the community; (vii) effective land conflict resolution mechanisms; and (viii) local cultural practices in preservation; (ix) availability of community organizations, and (x) community involvement in forest management. Similarly, another study (Asante et al. 2017) reported that sustainable conservation and restoration efforts should take into account the formal laws governing mangrove forests at the Ramsar site, collaborative efforts between the Forestry Commission, and communities or individually owned mangrove areas that "formalize" mangrove management. These combined factors would present the best opportunity to regulate mangrove access and exploration at Songor and Keta Lagoon complexes of Ramsar site. Therefore, legal supports and regulatory governance for communities are essential in sustainable conservation and restoration.

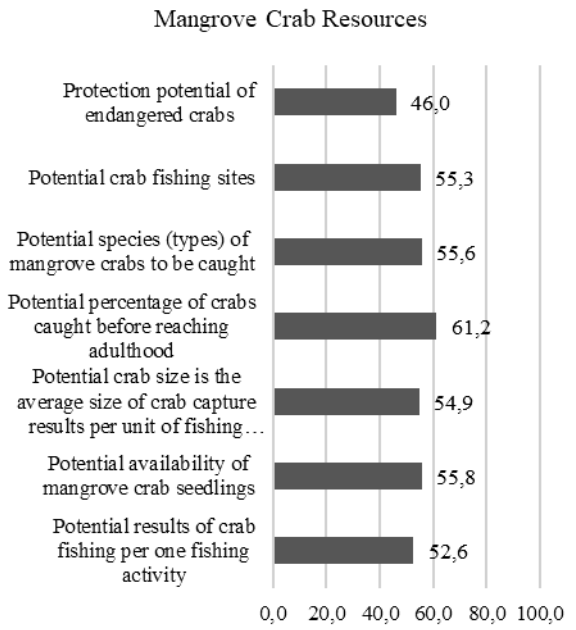

Figure 3. Potential feasibility of mangrove crab (*Scylla serrata*) resource

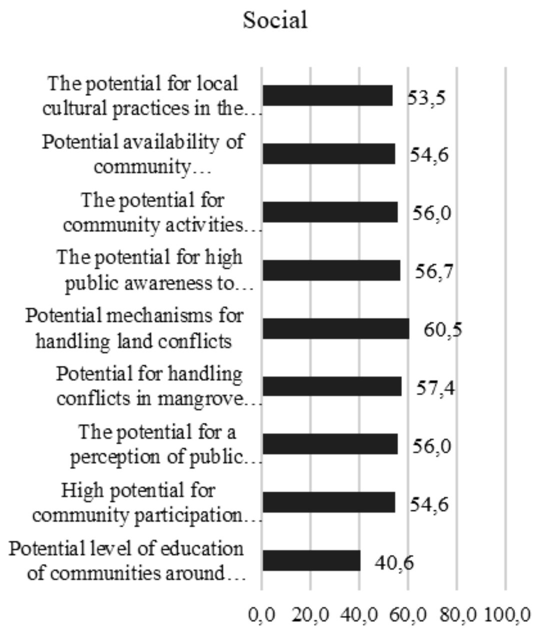

Figure 5. Potential feasibility of mangrove crab (*Scylla serrata*) based on social factors

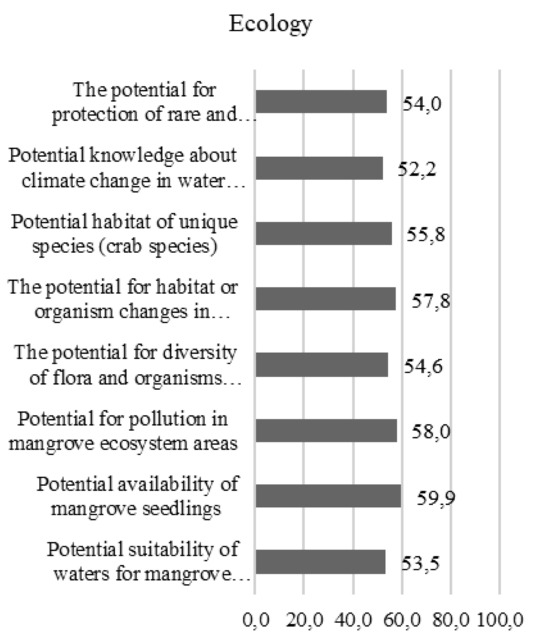

Figure 4. Potential feasibility of mangrove crab (*Scylla serrata*) based on ecology

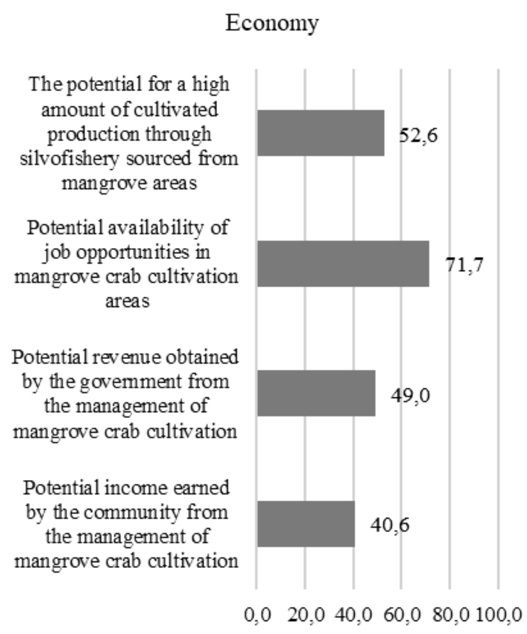

Figure 6. Potential feasibility of mangrove crab (*Scylla serrata*) based on economy

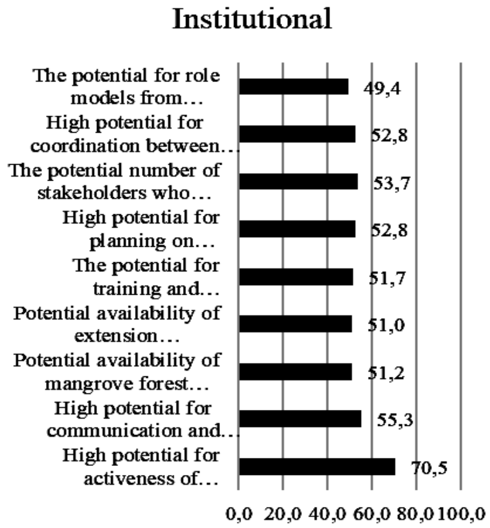

Figure 7. Potential feasibility based on institutional factors

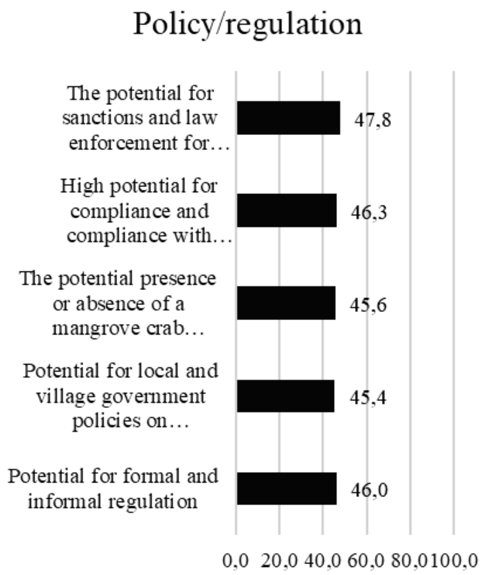

Figure 8. Potential feasibility based on policy/regulation

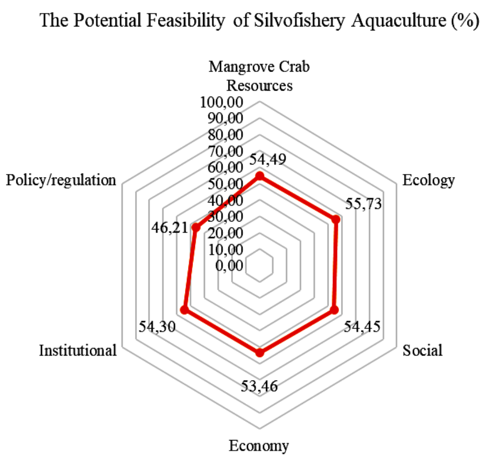

Figure 9. The domain of potential feasibility of silvofishery aquaculture

In the management of ecology domain, the *S. serrata* cultivation should consider factors, including (i) the suitability of waters for *S. serrata* cultivation; (ii) availability of mangrove seedlings; (iii) pollution in mangrove ecosystem areas; (iv) diversity of flora and organisms within the mangrove forest ecosystem; (v) changes in habitat or organisms in mangrove areas due to human intervention; (vi) the presence of habitats of unique species (types of crabs); (vii) knowledge of climate change in water, and habitat conditions; and (viii) protection of species of flora, and fauna. Meanwhile, the policy/regulation domains should improve some factors, namely (i) formal and informal regulations; (ii) local and village government policies on *S. serrata* aquaculture management; (iii) adherence of *S. serrata* aquaculture management mechanism to SOP; (iv) obedience and compliance with *S. serrata* aquaculture management regulations; and (v) sanctions and law enforcement for communities that damage mangrove forest ecosystems. The results of this study are in line with that ecology, social elements, and economy are the contributing factors to environmental sustainability (Pattimahu et al. 2010; Feka 2015; Karlina et al. 2016), the parameters for evaluating environmental (Pattimahu et al. 2017; Idajati and Widiyahwati 2018; Chen and Shih 2019; Hema and Indira 2020; Melo et al. 2020), and the complementary institutional aspects to the management of *S. serrata* aquaculture (Purwanti et al. 2018; Kusmana et al. 2020).

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