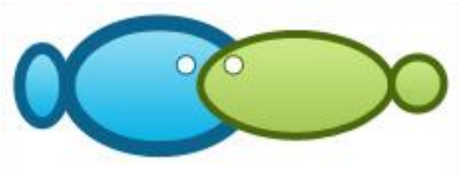

Sustainability of capture fisheries business based on bioeconomy in the coastal area of Batam Island, Indonesia

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Abstract. The coastal area of Batam Island have a fairly high potential for capture fisheries and contribute to the community's economy, especially in coastal areas. Capture fisheries businesses must pay attention to economic and ecological sustainability. The purpose of this study is to analyze the sustainability of the capture fisheries business on Batam Island based on bio-economic aspects in order to provide an overview of fisheries business management. The analysis was carried out descriptively through the Gordon-Schaefer model approach with the Gordon logistics growth function. The analysis was carried out on three management conditions, namely maximum sustainable yield (MSY), maximum economic yield (MEY), and open access equilibrium (OAE). The results of the study show that the optimal utilization of capture fisheries in the coastal area of Batam Island is around 7,823 units of fishing vessels every year. The production of catch in the maximum sustainable yield condition is around 36,982 tons, at the time of the maximum economic yield is around 36,977 tons, while at the time of open access equilibrium it is only around 1,646 tons.

Key Words: Gordon-Schaefer, maximum economic yield, maximum sustainable yield, open access equilibrium.

Introduction. Batam Island has a very strategic geographical location in the State Fisheries Management Area of the Republic of Indonesia (FMARI) 711 with the sea area of Batam Island around 318,298 ha (Rizieq et al 2023). Batam City is not only a producer of fishery production, but also a gateway for the import and export of fishery production in Indonesia (Devina & Panggabean 2024). Fishery production in Batam City has also experienced a significant increase from 2010 to 2016 (Malau & Hotman 2018). According to Siregar et al (2020), the gross regional domestic product of the fisheries sector in Batam City in 2013-2018 fluctuated, but overall increased by 126%. Statistical data from Riau Islands Province shows that the number of marine fisheries production in Batam City has continued to increase since 2018, from around 34,328.85 tons to 40,483.28 tons in 2022. In addition, there has been an increase in the number of fishing vessels of around 3,521 units from 2018 to 2022.

Increasing fishery production must consider the carrying capacity of the fish resource stock and the environment so that over-fishing does not occur, because the high and uncontrolled use of fish resources can lead to depletion of stocks, extinction of fish resource populations, excess capital accumulation, and a decrease in the productivity of fish catches. The decrease in the value of fishing productivity and high fishing efforts will result in over-exploited fishing (Arkham et al 2021) which usually occurs in coastal

areas with small fishing gear (> 5GT) (Limbong 2020; Panggabean et al 2023b; Telussa et al 2022). The management of fish resources by paying attention to the condition of fish stock is a must so that capture fisheries can continue to have a sustainable economic impact in the future. One of the methods that can be used for fish resource management related to fish stock is a catch approach that is able to describe the condition of fish resources (Panggabean & Nazzla 2022; Panggabean & Nazzla 2023). Estimation of the value of the maximum sustainable yield (MSY) of fish resources can be predicted using the data of the landed catch so that the policy regarding the value of the number of allowed catches can be implemented (Kristiana et al 2021).

The management of fish resources from the MSY study is able to provide an estimate of the level of utilization and sustainable fishing strategies. Estimation of MSY, catch productivity, level of utilization of fish resources, and level of catch capacity can estimate the condition of the status of fishery resources in a water (Kristiana et al 2021; Panggabean et al 2023a; Panggabean et al 2023c; Taher et al 2020). The management of fish resources in the coastal area of Batam Island is very necessary so that the stock of fish resources can be maintained, and the fishery business can still provide welfare in the future, although fishing activities in the coastal area of Batam City are dominated by environmentally friendly fishing gear, but ecosystem-based strategy recommendations need to be made for the management of fish resources in the coastal area of Batam Island (Devina & Panggabean 2024; Wijaya et al 2021).

Bio-economic model analysis can be used to develop management strategies for fishing businesses on Batam Island. So far, fisheries problems have focused more on maximizing fishing without considering production factors such as fishing operational costs. The purpose of this study is to analyze the sustainability of the capture fisheries business on Batam Island based on bio-economic aspects.

Material and Method

Description of the study sites. This research was carried out on Batam Island, Indonesia from April to June 2024. The Berelang Fishing Port and the Telaga Punggur Fishing Port on Batam Island are the locations of the data collection ports (Figure 1). The collection of data and information in this study was carried out by field observation methods, literature studies and in-depth interviews with fishing boat captains, fishermen, and related agencies. Primary data consists of fishing productivity data and fisheries economic aspects, while secondary data on fishing and economic aspects are also collected for nine years from fisheries services and related agencies.

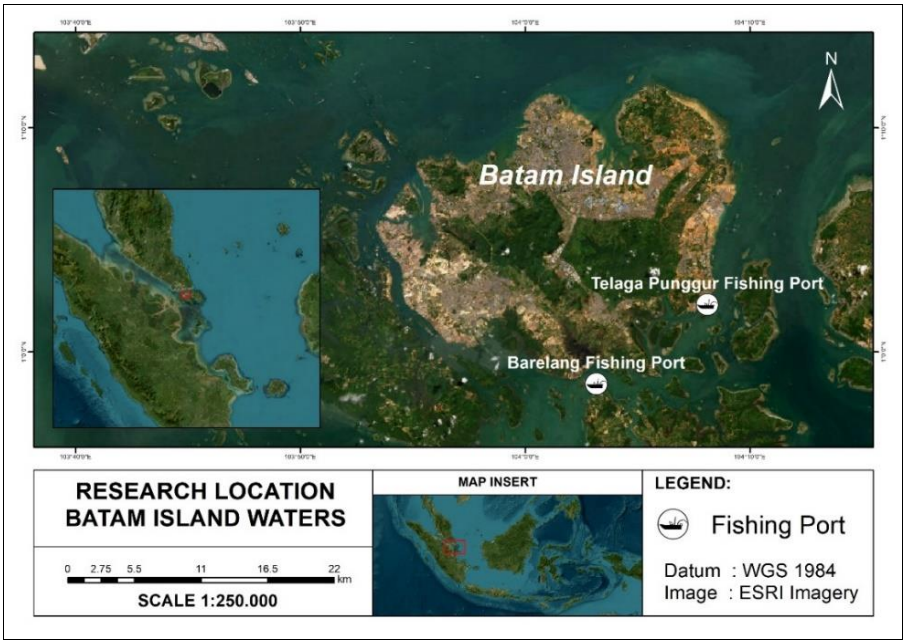

Figure 1. Location of Batam Island coastal area and fishing ports (generated with ArcGIS 10.8).

Productivity. Quantitative data on fishing productivity was used to determine the value of catch per unit of effort (CPUE), the level of utilization of fish resources, and the optimal fishing effort in the coastal area of Batam Island. The CPUE calculation aims to determine the abundance and level of fishery utilization based on the division of the total catch (catch) with the catch (effort). The formula used to calculate CPUE is as follows:

$$CPUE = \frac{catch_i}{effort_i}$$

where $catch_i$ is the catch of the *i* year (tons), $effort_i$ is the effort of the *i* year (unit) and *i* years are from the inverval 2014-2022.

Utilization rate. The utilization rate is the fish resources that have been utilized calculated per year. The value of the percentage of fish resources that have been utilized can be found with the following formula:

$$Tp = \frac{C_i}{TAC} x100\%$$

Where Tp is the fish resource utilization rate, C_i is the catch of the *i* year and TAC is the total allowable catch (80% of maximum sustainable yield value).

Fisheries bio-economy. Static bio-economic analysis uses the Gordon-Schaefer model with the Gordon logistic growth function. Catch and catch unit data were used with the surplus production model approach through linear regression analysis or the Gordon-Schaefer surplus model. There are three equilibrium conditions in the Gordon-Schaefer model, namely, maximum sustainable yield (MSY), maximum economic yield (MEY), and open access equilibrium (OAE). The bio-economic analysis formula of various management regimes can be seen in Table 1.

Table 1

Bio-economic model formula of Gordon-Schaefer

Variables	*Conditions*		
	MSY	*MEY*	*OAE*
Biomass (x)	$\frac{K}{2}$	$\frac{K}{2}\left(1+\frac{c}{pqK}\right)$	$\frac{c}{pq}$
Effort (E)	$\frac{r}{2q}$	$\frac{r}{2q}\left(1-\frac{c}{pqK}\right)$	$\frac{r}{q}\left(1-\frac{c}{pqK}\right)$
Catch (h)	$\frac{rK}{4}$	$\frac{rK}{4}\left(1+\frac{c}{pqK}\right)\left(1-\frac{c}{pqK}\right)$	$\left(\frac{rc}{pq}\right)\left(1-\frac{c}{pqK}\right)$
Economic rent (π)	$p.h_{MSY}-c.E_{MSY}$	$p.h_{MEY}-c.E_{MEY}$	$p.h_{OAE}-c.E_{OAE}$

Note: K is the environmental carrying capacity (tons/year); q is the catch ability coefficient (1 per units effors); r is the percentage of fish biomass growth rate (%/year); c is the cost of fishing (IDR/efforts); p is the fish selling price (IDR/tons).

Results. The production of marine fisheries catches on Batam Island has continued to increase from 2014 to 2022 by around 34.51%. The catch in 2012 was around 26,193 tons and in 2022 it reached 40,483.28 tons, while the production value increased by around 34.22%, where in 2014 it was around IDR 850.274 billion to IDR 1,374.427 billion in 2022. The production of catches on Batam Island mostly comes from Galang, Bulang, and Belakang Padang Districts. This is because most of the fishing households on Batam Island are domiciled in the three sub-districts. The productivity of capture fisheries in the coastal area of Batam Island has continued to increase from 2014 to 2022 (Figure 2). The production of catches from the sea in 2022 reached 40,483.28 tons with a

productivity of around 4.39 units every year. The results of the study show that the level of utilization of fish resources from the sea in the coastal area of Batam Island has exceeded the limit, which is around 119.02%, while the optimal utilization of capture fisheries at sea is around 7,823 units of fishing vessels every year.

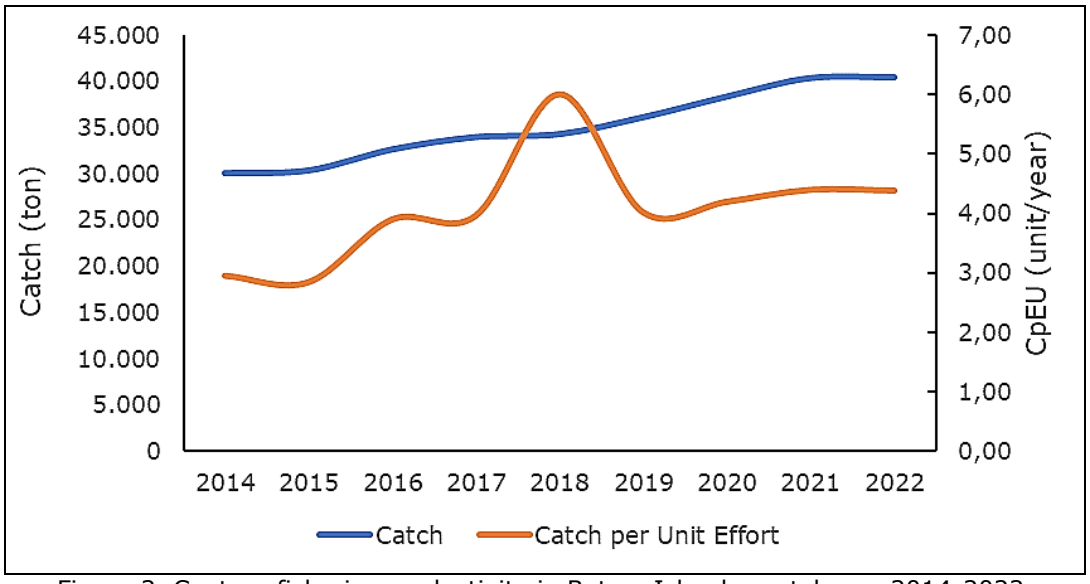

Figure 2. Capture fisheries productivity in Batam Island coastal area 2014-2022.

The bio-economics of fish resources in the Gordon-Schaefer model was analyzed using three management regimes, namely MEY, MSY, and OAE. The parameters used in the results of the bio-economic analysis of fish resources are resource biomass (x), catch (h), fishing efforts (E), and economic rent (ɲ). The results of the calculation of the bio-economic analysis of fish resources in the coastal area of Batam Island in the three management regimes can be seen in Table 2. The average production of catches from 2014 to 2022 is around 35,214 tons every year, the production value of catches is around IDR 1,047,593,512,544, and the catch is around 8,906 units.

Table 2

Bio-economic model formula of Gordon-Schaefer

Variables	*Condition*		
	MEY	*MSY*	*OAE*
Biomass (tons)	78.813	77.936	1.754
Effort (unit)	7.735	7.823	15.469
Catch (tons)	36.977	36.982	1.646
Economic rent (IDR)	1.073.862.416.652	1.073.723.296.563	-

The highest amount of biomass of fish resources in the coastal area of Batam Island occurs during the MEY condition, because the amount of biomass is inversely proportional to the number of catches. The amount of biomass of fish resources under the MEY condition is 78,813 tons, when the total catch is 36,977 tons/year. The higher the value of fish resource biomass in the coastal area of Batam Island, the more positive the impact on the aquatic ecosystem. The maximum economic rent that can be obtained from catches on Batam Island is IDR 1,073,862,416,652 with efforts made of 7,735 fishing units (vessels)/year.

The biomass of fish resources in the MSY condition is 77,936 tons. Fish resource biomass in the MSY management regime is an ideal condition for biological resource utilization by maximizing the number of catches and allowable fishing efforts, however, still paying attention to the availability of fish resources in the coastal area to remain sustainable. The economic rate produced during the MSY condition is IDR

1,073,723,296,563 with a total catch of 36,982 tons and the level of effort made is 7,823 fishing units.

The highest arrest attempt occurred in the OAE condition, which was around 15,469 units. The biomass of fish resources in the coastal area of Batam Island in the OAE condition is around 1,754 tons, while the catch is around 1,646 tons. The cost incurred by fishermen to utilize fishery resources in the coastal area of Batam Island is around IDR 3,160,500 per fishing attempt, and the selling price of the catch reaches IDR 29,702,177 per ton.

Discussion. The development of the fishery business on Batam Island continues to experience a significant increase. Batam City is a growing business hub, especially in processing high-quality foodstuffs into snacks and ready-to-eat meals that can be sold to increase family income. This can be seen from the increasing number of coastal sub-districts that have been developed into fisheries production centers, especially capture fisheries. According to Wibowo et al (2016), Galang District, Kuala Kampar District, Bulang District, Belakang Padang District, and Nongsa District have great potential for fisheries development on Batam Island. Fisheries centers in Nongsa District always receive training on business planning, packaging, marketing, simple bookkeeping, and processing of marine products such as fish, seaweed, and edible sea snail (Asmirelda et al 2020). In addition, it regularly conducts product packaging training in accordance with specified standards, as well as simple bookkeeping training for financial management.

The ever-increasing production of capture fisheries makes the fishery business on Batam Island increasingly attractive to many investors. The coastal population of Batam Island is highly dependent on marine resources, as indicated by the fact that most of their income comes from capture fisheries (Noveria & Malamassam 2015; Devina & Panggabean 2024). Fisheries production is positively related to investment in the fisheries sub-sector, the number of fishing houses, fisheries sector technology and fisheries production last year, and has a significant effect on fisheries production (Malau & Hotman 2018). The increase in capture fisheries production on Batam Island is dominated by purse seine fisheries to capture pelagic fishery resources. The capture fisheries sector with purse seine fishing vessels is one of the leading sectors to increase regional income (Rizieq et al 2023).

Fisheries management under the MEY regime is the optimal condition for fishing with the use of more efficient efforts so that the economic rent obtained is at the maximum condition. The MEY condition is an ideal condition for capturing fishery resources both economically and biologically because it is economically efficient and the amount of catch produced does not exceed the maximum sustainable limit (Holma et al 2019; Hoshino et al 2018). According to Pattiasina et al (2020), the increase in biomass of fish resources has a positive impact on aquatic ecosystems, especially the increase in live coral cover that is the habitat of various marine biota.

Actual catches that exceed or undertake the amount of catches and efforts under the maximum economic yield regime will reduce the resulting economic rent (Muawanah et al 2018). According to Sheaves et al (2017) that biomass is related to ecosystem productivity and directly affects fish species. The number of efforts and catches that exceed the MSY condition can threaten the sustainability of fishery resources in the long term (Hilborn et al 2015). The number of efforts made and the allowable catch in the MSY regime is greater than the MEY condition, but the rent value generated in the MSY condition is smaller than the rent value condition in the MEY condition.

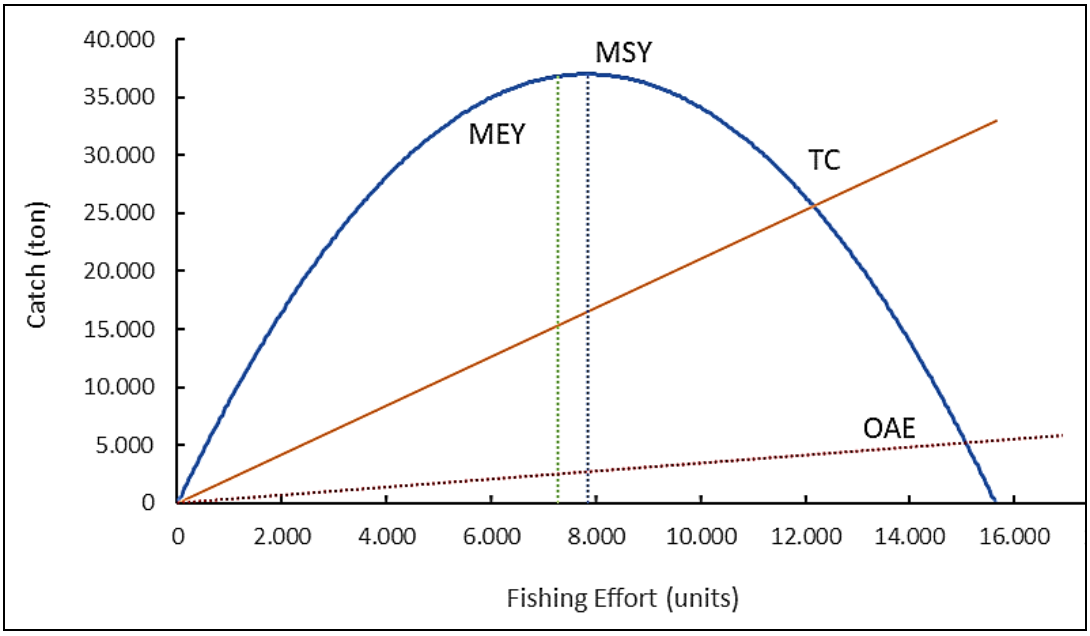

Figure 3. Total cost for the bio-economic model of the Gordon-Schaefer formula.

The open access fish resource management regime occurs when there are no clear restrictions on fishery resource fishing activities both from the number of inputs and the number of outputs allowed. The resource management conditions in the OAE regime provide space for everyone to be able to fish, thereby increasing the extraction of fishery resources. Resource extraction in open access conditions will result in overfishing of resources that are the target of capture. The use of fish resources in open access conditions illustrates the occurrence of fishing inefficiencies both economically and biologically. Based on the graph in Figure 3, fishermen do not get economic rent during the OAE condition, because the revenue from the catch is the same as the cost of the catch. This is due to the fact that a positive economic rent will encourage other vessels to participate in fishing activities until the economic rent is depleted.

Open access conditions cause degradation of the availability of fish resources in the coastal area which is shown through a significant decrease in the amount of biomass when compared to the MEY and MSY management regimes. The actual condition of the utilization of fish resources in the coastal area of Batam Island is close to overfishing economically and biologically. Overfishing of fish resources is shown through the number of actual fishing attempts that exceed the fishing efforts during the MEY and MSY regimes. The number of arrest attempts that exceed the MEY regime has an impact on the decrease in the economic rent of the catch because with greater efforts, the value of the economic rent obtained becomes less. Fisheries management through output control regulations in the form of minimum legal size and prohibition of fishing for fish resources that are spawning are the right steps taken by the government so that the existence of fish resources can remain sustainable.

Conclusions. The actual condition of the utilization of fish resources in the coastal area of Batam Island is close to overfishing economically and biologically. The catch of fishery resources in the coastal area of Batam Island reaches 40,483.28 tons, while the MSY value is only around 36,982 tons every year. The sustainability of the capture fisheries business in the coastal area of Batam Island can only occur if a policy is implemented to reduce fishing efforts of around 1,083 units of fishing vessels.

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

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