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Analysis of Maximum Sustainable Yield of the Small-Scale Grouper (Serranidae) in Banggai Laut Waters to Promote Indonesian Marine Conservation

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ABSTRACT

In Indonesia, grouper fisheries play an important role both economically and ecologically. However, stock sustainability is threatened by uncontrolled fishing, especially by small-scale fishermen. The waters of Banggai Laut have high grouper fisheries potential, but the lack of data and studies on the status of grouper catches raises concerns. This study aimed to estimate the catch per unit effort (CPUE) and maximum sustainable yield (MSY) of groupers in Banggai Laut waters. The research method used field surveys and observations. Primary data were collected through direct observation and interviews using purposive sampling. Secondary data were obtained from related agency records and a literature review. The mean CPUE for groupers in Banggai Laut was 0.5395 tons/unit/year, with a mean annual production of 1964.8 tons, and fishing effort of 3592 units/year. The CPUE trend for 6 years (2018–2023) revealed a strong correlation (76.2%) between fishing effort and catch volume. Other influencing factors included seasonal differences and fishing grounds used by each vessel. Based on the Schaefer model, the estimated optimum fishing effort (F) was 1478 units/year with a maximum sustainable catch (CMSY) of 1855.1 tons/year. These results, based on catch values for 6 years, indicate that the number of fishing vessels exceeded the optimum limit F in 2020-2023, resulting in overfishing. Several factors influenced overfishing in grouper fisheries, including the increase in the number of fishing vessels each year, technical aspects of the fishing gear used, including fishing gear that is not environmentally friendly, thereby affecting the productivity.

INTRODUCTION

Indonesia is among the world's top suppliers of grouper with an average annual production of 117,959.7 tons during the past ten years **(FAO, 2021)**. In addition, grouper fisheries are one of Indonesia's top export commodities, which helps the nation's foreign exchange earnings.

According to **BPS's (2019)** data, Indonesian grouper exports were valued at 41.4 million dollars in 2018. According to **Mitcheson *et al.* (2013)**, demersal fisheries, particularly those of grouper and snapper, are significant global commodities that play a significant role in sustaining the livelihoods and food security of millions of people, including small-scale fishermen**.**

In Indonesia, grouper fisheries are primarily managed on a small scale by local fishermen **(Achmad *et al.*, 2022)**. However, unregulated small-scale fishermen's vast grouper fishing operations harm catches, which causes overfishing **(Efendi *et al.*, 2021)**. This matter poses a serious risk to the fishing industry's viability and has the potential to lead to extinction **(Khasanah *et al.*, 2019)**.

Banggai Laut Waters is a tallish potential area for groupers with 12,156.78km2 of area. Fish resources on the 119 islands that make up the Banggai Laut consist of large and small pelagic fish, demersal fish, coral fish, squid, and octopus. The islands are both populated and unpopulated. This location has varying potential for capturing fisheries based on the species of fish. With 29,410.2 tons, the small pelagic fish group is Banggai Laut Regency's largest fish resource, according to data for 2021. In the meantime, 21,870.2 tons of demersal and coral fish were produced, with grouper fish accounting for the largest portion at 4,982.8 tons **(Putra *et al.*, 2021)**.

There are 3704 local fishing vessels in the Banggai Laut Waters, each with a capacity of less than 5 GT. Additionally, data from the Banggai Laut Fisheries Agency indicate that small-scale fishermen increased their production of grouper commodities by 1460.7 tons during 2018-2022. This shows that captures have been rising annually, which raises the possibility of overfishing and devastating the sustainability of grouper commodities resources in Banggai Laut.

The biggest obstacle to managing small-scale grouper fisheries is the absence of indications that may be used to determine the maximum possible status of fish resources in the event of insufficient data. Furthermore, estimations of the maximum possible permissible capture have to form the foundation for the sustainable use of fish resources. Consequently, it is critical that this research be done to evaluate the maximum sustainable yield (MSY) and catch per unit effort (CPUE) of grouper fish in the Banggai Laut Waters. This study aimed to investigate the CPUE and MSY of grouper using landed catch data and catch data documented by the Banggai Laut Fisheries Agency. This research is anticipated to provide comprehensive information regarding the state of grouper resources and support sustainable management activities in the Banggai Laut Waters, given the dearth of data currently available regarding the CPUE and MSY of grouper fisheries in the Banggai Laut.

MATERIALS AND METHODS

1. Time, location, and research methods

This study was conducted in 3 west coast villages of Banggai Laut (Peleng - Banggai Waters) namely Monsongan Village, Gonggong Villages, and Tinakin Laut Village. This study was carried out using survey and field observation methodologies. The data obtained include both primary and secondary data. Primary data were collected by direct observation of fishing units and interviews with a set of questions based on the research goals. Purposive sampling was used to choose fishermen who were still actively capturing and conducting grouper fishing commercial activities in the research area. The responders included grouper fishermen, local grouper collectors, and huge collectors from Banggai Laut Regency. Respondents to agencies and stakeholders were selected using a snowball sampling technique to identify key informants (respondents) with extensive knowledge of the research being done.

Secondary data were gathered through a literature review of activities carried out and records of related agencies, including the Banggai Laut Fisheries Agency, Central Sulawesi Province Maritime and Fisheries Agency, Fisheries Extension officer, BKIPM in the Banggai Laut working area, and other related agencies, as well as a search of various publications.

2. Data analysis

2.1. Analysis of CPUE

The analysis of fish capture data is used to determine the maximum catch per unit of effort (CPUE), as proposed by **Schaefer (1957)** and later applied by **Noija (2014)**. The CPUE was calculated using the following formula:

$$\text{CPUE} = \frac{Catch}{Effort}$$

Explanation:

CPUE = Number of catches per unit of the ith fishing effort
Catch = result of the ith catch
Effort = the ith arrest attempt

2.2. Estimation of MSY

The production surplus model was used to analyze demersal grouper catches by first categorizing fish production data into groups. After getting the results of the grouping of pelagic and demersal fish, the CPUE value was determined for each year by determining the standardization of fishing gear through the FPI value. Analyzing catch and effort can help assess the potential of grouper fish. According to **Sparre and Venema (1999)** and **Febriani (2014)**, the Schaefer production surplus approach can be used to calculate the relationship between catch and effort. The data processing steps were:

1. Plotting the value of f against c/f and estimating the intercept value (a) and slope value (b) using linear regression.
2. Calculating estimates of sustainable potential (CMSY) and optimal effort (EMSY).

Where, y represents the dependent variable (CPUE in kg/trip); X is the independent variable (effort), while a and b are the regression parameters. Then, parameters a and b were obtained using the formula:

$$a = \Sigma\frac{Xi}{n} - \Sigma\frac{Yi}{n}$$

$$b = \frac{n.\Sigma\big((xi)(yi)\big) - (\Sigma Yi)}{n.\Sigma(xi^2) - (\Sigma \mathrm{xi})^2}$$

Where, A is the intercept (constant), and b is the slope. In time i, xi represents fishing effort and yi represents catch per unit effort. The determination of optimum catch value (CMSY) and optimum effort (EMSY) was performed according to Schaefer **(Sparre & Veneme, 1999)** using the formula below:

$$E_{MSY} = \frac{a}{2b}$$

$$C_{MSY} = \frac{a^2}{4b}$$

RESULTS AND DISCUSSIONS

1. Potential grouper resources in Banggai Laut

There are seven sub-districts in the Banggai Laut Regency, four of which are on the mainland and three are on the islands. The majority of the regency is made up of sea, about 12,156.78km2 of the entire area of this region, which is 12,882.45km2. Therefore, according to the **Banggai Laut RMDP (2021–2026)**, 94.37% of the regency's entire area is made up of its sea area. This region has enormous fisheries potential. At least 119 islands, both populated and unpopulated, are located in the Banggai Laut waters; some of these waters are part of fisheries management area (WPP) 714.

The Banggai Laut Waters are home to a variety of fish species, including demersal fish, coral fish, octopus, squid, and large and tiny pelagic fish. Based on the fish species, Banggai Laut Water’s potential for catch fishery production varies. With a production of 29,410.2 tons in 2021, small pelagic fish groups are Banggai Laut Regency's most productive fish resource, according to data on fisheries production (Fig. 1). In the meantime, 21,870.2 tons of demersal and coral fish were produced, with grouper fish producing the most at 4,982.8 tons **(Putra *et al.*, 2021)**.

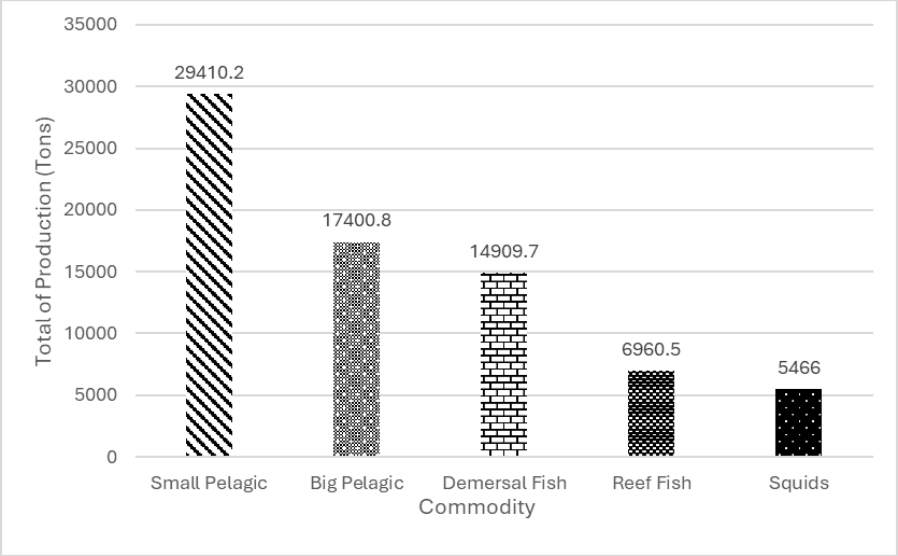

Fig. 1. Total fisheries production of Banggai Laut Seas **(Banggai Laut Fisheries Agency, 2021)**

The composition of grouper species caught by Banggai Laut small-scale fishermen shows that the proportion of target fish is greater than non-target fish. The target fish catch (total grouper catch) for 2023 is predicted to be approximately 3113 tons or 27.83% of the total catch. Approximately, 8073.9 tons or 72.17% of the total catch consisted of non-target fish.

Fish composition analysis conducted using data from the **Marine and Fisheries Agency of Central Sulawesi (2021–2023)** and verified by interviews with Banggai Laut fishermen in three sampling locations revealed that the most productive commodity was Lodi grouper, also known as spotted coral grouper. Over the last six years, total catches amounted to 4633.20 tons, or 41.7% of all grouper species caught (Fig. 2). Meanwhile, the grouper commodity that fishermen catch the least is the duck grouper (Humpack grouper), with a total catch of 44.8 tons or around 0.6% of the total catch of grouper species. The results of field observation show that grouper commodities have the second highest price after octopus among local and city collectors. Grouper and octopus caught by fishermen have several grade categories/price classes based on the weight per individual obtained.

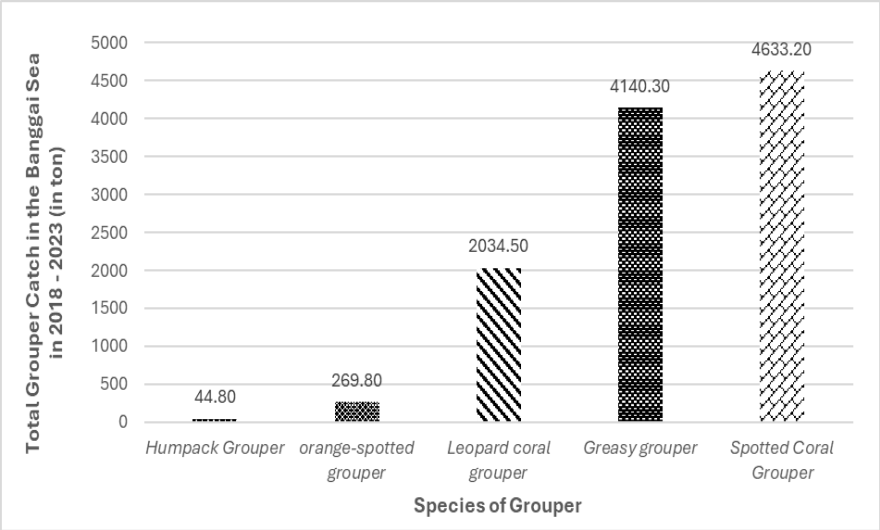

Fig. 2. Composition of grouper catches in Banggai Laut seas from 2018 to 2023 **(Data of Marine and Fisheries Agency of Central Sulawesi, 2023)**

2. Potential grouper resources in Banggai Laut

The results of coral fish capture, particularly grouper, employing small-scale fishing vessels (with a capacity of less than 5 GT) landed in the Banggai Laut from 2018 to 2023 demonstrate linear results (increase year after year). The peak production came in 2023, with a total grouper production of 3090.4 tons and a total of 3835 fishing vessels. Fishing efforts (number of vessels) have also increased year after year. In 2021, the total number of fishing vessels measuring <5 GT was 3704, representing a 9% increase from 2018 (Table 1). **Nurhayati (2013)** posits that an increase in fishing efforts yields a higher catch rate. The possibility of inefficient catches and the decline of fish stocks in the wild, on the other hand, are the detrimental effects. Furthermore, a peak of fishing efforts was anticipated to be reached by the year 2023 at 3835 units (Table 1).

Table 1. The state of the catch and the number of vessels in Banggai Laut seas from 2018 to 2022

Year	Effort/amount of vessels (unit)	Production (Ton)	CPUE (Ton/unit)
2018	3307	1080,7	0,3268
2019	3408	1139,3	0,3343
2020	3684	1960,2	0,5321
2021	3704	1977,0	0,5337
2022	3619	2541,4	0,7022
2023	3835	3090,6	0,8059

Source: Data on catch fisheries from **Banggai Laut Fishery Agency (2023)**

The catch per unit effort (CPUE) has been rising annually. This study's findings demonstrate during the previous five years, CPUE has increased by 19% annually. The

fishing effort had a 76.26% impact on fish output, according to the CPUE trend of grouper fish in the Banggai Laut (Fig. 3). This suggests that fishing effort has a significant impact on variations in catch production. This is consistent with the findings of a study conducted by **Cahyani *et al.* (2013)**, postulating that the CPUE value indicated signs of a decline in the catch output in proportion to the effort value. Differences in the seasons and fishing grounds for each ship contribute to the influence of other factors.

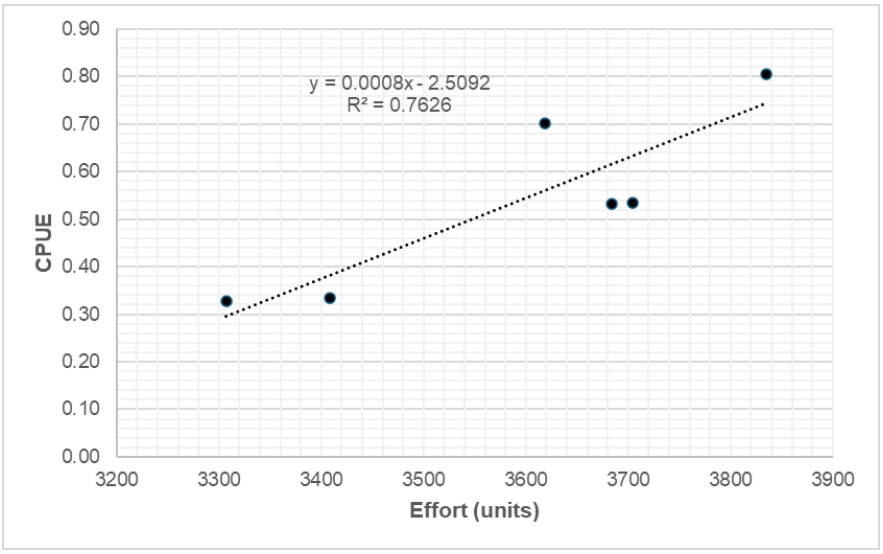

Fig. 3. Correlation between effort and CPUE of grouper in Banggai Laut seas from 2018 to 2023

The regression equation y = 0.0008x - 2.5092 with R2 = 0.9952 is derived from the graph showing the link between grouper effort and CPUE for the years 2018-2023. According to this equation, the determinant coefficient (R2) is 0.7626, or nearly 1%, meaning the effort value accounts for 76.26% of the CPUE fluctuation and that other variables not covered in the model account for the remaining portion. Furthermore, a substantial association between CPUE and effort is indicated by the correlation coefficient (R) of 0.8959. In terms of CPUE values, the maximum was 0.8 tons/unit in 2023 and the lowest was 0.32 tons/unit in 2018. The reason for the high and low CPUE values over this period was the changes in the number of vessels (effort) and the amount of fishing gear used. The CPUE value rises annually; in 2020, it increased by the greatest amount, or 0.20 tons/unit, or around 59%, over the year before.

Persistent fishing pressure can cause a fall in CPUE, which would lead to further declines in the finite fish stocks. According to **Suryaman *et al.* (2017)**, the catch per trip will rise with an abundance of fish resources and increased fishing effort. On the other hand, if fish populations decline, more fishing will result in a lower amount of fish caught per fishing vessels. The declining trend in CPUE suggests that overfishing will result from the continued utilization of fish populations. The quantity of work put in could cause fisheries resources to drastically diminish if it keeps getting bigger **(Munica *et al.*,**

2016). A significant effort may yield a large number of catches, but if the proper environmental conditions are not met in marine waters or fishing grounds, the number of catches will be modest. Moreover, alterations to the aquatic environment may have an impact on the quantity of fish resources available.

3. Maximum sustainable yield (MSY)

The maximum catch that a fishery is capable of producing year after year is known as MSY. The MSY idea is predicated on an extremely basic model of a fish population viewed as a single entity. A management parameter known as MSY is determined by evaluating fisheries resources. Annual production capture data (time series) is needed to estimate these parameters. The last five years' worth of data (2018–2023) are utilized to calculate the MSY. The Schaefer surplus production method can be used to calculate the MSY, or sustainable fisheries production, based on grouper production data from the last six years (2018–2023). By comparing efforts and catches year over year, it is possible to establish the sustainable potential value and optimal effort of grouper in the Banggai Laut Waters, which will help decide when overfishing occurs.

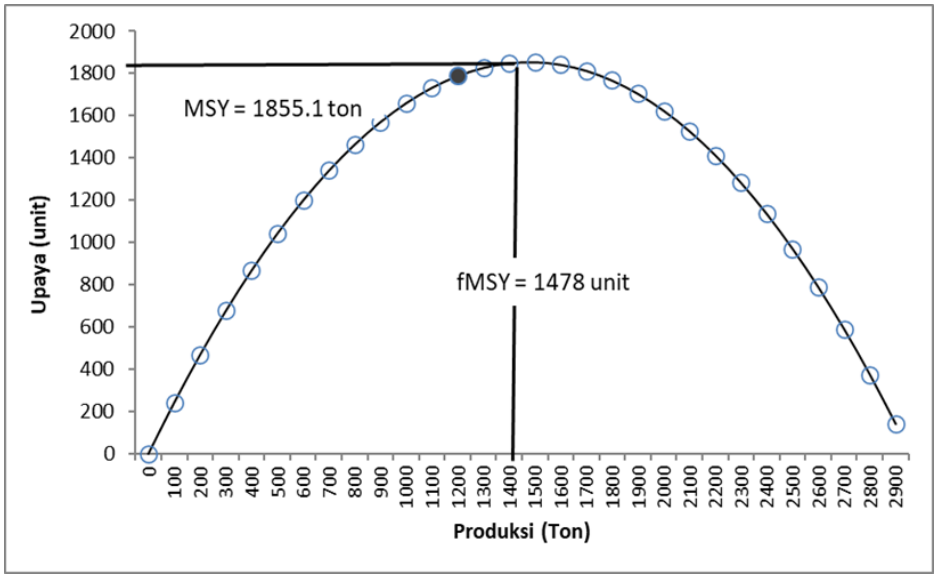

Fig. 4. MSY (Maximum sustainable yield) curve of grouper (Serranidae) in Banggai Laut Waters

The Schaefer model indicates that the maximum sustainable catch value (CMSY) is 1855.1 tons per year, and the optimal F fishing effort value is 1478 units annually. The quantity of captures produced over six years, based on the maximum sustainable catch value (CMSY), indicates that overfishing occurred in 2020–2023. Additionally, the total fishing effort of the number of vessel units annually surpasses the optimum fishing effort (EMSY), where a yearly increase in vessel units is typically observed. The annual rise in catch is directly correlated with the annual increase in fishing effort. This suggests that no attempt has been made to maximize fishing efforts (number of vessels) to recover resources in the research location.

The overfishing that occurred in 2020–2023 is the result of vessel units annual fishing effort exceeding the optimal limit of 1478 units. This annual increase in vessel units is the cause of the excess number of catches. The reason for overfishing is that fishing has gone beyond what is ideal for producing MSY. According to **Noija (2014)**, several technical factors, such as fishing season and the selectivity of fishing gear, as well as market demand and relatively high prices for fish resources, all have an impact on the high catch rates and fishing efforts for grouper fish commodities. Conversely, **Supriadi *et al.* (2020)** state that many factors, such as fewer fishermen going to sea, fewer trips that are not ideal because of unpredictable seasons, an annual increase in the number of fishing vessels units, and environmentally unfriendly fishing gear, all contribute to the decline in fish production. Therefore, policies for managing the grouper fisheries must be founded on the ecological, social, and economic sustainability of the resources currently in use.

The notable reduction in grouper fish stocks is another factor contributing to overfishing. As a result, there are still fish that are too young to be harvested, endangering the waters' ability to replenish their fish populations. **Sulistiyawati (2011)** predicted that overfishing would probably result from catching more small fish with immature gonads. To ensure the sustainability of grouper fish, captured juveniles must be able to reach the appropriate size to be ready for capture. This will not only increase the biomass of the catch but also enable adult fish to procreate.

CONCLUSION

The production of small-scale grouper fish resources (vessel capacity <5 GT) in Banggai Laut was recorded with an annual increase between 2018 and 2023. The catch per unit effort (CPUE) witnessed a remarkable annual rise. According to the Banggai Laut grouper fish CPUE trend, fishing effort has a 76% impact on catch. This demonstrates how fishing efforts have a significant impact on variations in catch production.

According to the MSY estimation results from the Schaefer model, small-scale grouper fisheries in Banggai Laut either exceeded the maximum sustainable yield (CMSY) or experienced overfishing in the four years between 2018 & 2023. Several factors contribute to the overfishing of grouper fisheries, including a decline in active fishermen, unproductive fishing trips due to unpredictable seasons, an annual increase in the number of fishing fleet units, and the use of environmentally harmful fishing gear, which undermines both productivity and the technical efficiency of the gear.

RECOMENDATIONS

These findings show that the enhancement of vessel numbers in Banggai Laut Waters may be contributing to overfishing. This indicates that to preserve the sustainability of grouper resources in the area, more effective management techniques are required. In light of these conclusions, researchers suggest some actions that can be taken, including:

1. Tight regulations and oversight regarding the augmentation of fishing vessels in Banggai Laut Regency to manage the growing fishing strain on grouper fish stocks.
2. The implementation of sustainable fishing quotas, which guarantee that the level of fishing does not surpass the capacity for resource recovery, is based on the findings of the maximum sustainable potential (MSY) analysis of the status of grouper fish resources in the area.
3. Encouraging law enforcement and supervision to combat unlawful arrest practices, such as those involving the use of destructive tools or in areas that are forbidden.

Promote the creation of an electronic recording system that small-scale fishermen can easily use and access. By using this technology, fishermen can log their catches in real-time, ensuring that the data they collect are more accurate and current.

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