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Estimation of Stock Status Using CMSY Method for the Sword Prawn (*Mierspenaeopsis hardwickii*) in Samboja Waters, East Kalimantan

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ABSTRACT

In this study, the CMSY method, a data-poor fish stock assessment method, was used to assess the current stock status of the Sword Prawn in Samboja Waters. A total of 13 years of catch data (from 2012 to 2024) were used in the study's analysis. Estimated CMSY model parameters with confidence intervals are as folloe: r=0.47 (0.29-0.7) year^{-1}, k=14.9 (10.1-22) ton, MSY=1.75 (1.23-2.36) ton, B_{2024}=4.2 (0.43-5.89) ton, B_{MSY}=7.45 (5.05-11) ton, F_{2024}=0.28 (0.2-2.71) year^{-1}, F_{MSY}=0.23 (0.14-0.38) year^{-1}, B_{2024}/B_{MSY}=0.56 (0.05-0.79) and F_{2024}/F_{MSY}=1.18 (0.84-11.4). Our study has found that the sword prawn population in Samboja waters has been declining due to overfishing since 2017. Until now, regulations regarding catch quotas have not been established or implemented. Therefore, it is recommended to establish catch quotas based on research findings and to reduce fishing mortality to maintain populations and prevent further biomass decline.

Keywords: CMSY method; Samboja waters; fisheries management

INTRODUCTION

National and regional fisheries regulations have changed in recent years to mandate science-based management not only for the most valuable fish stocks, but also for all exploited fish stocks (MSA, 2007; CFP, 2013). This has revived interest in simple stock reduction analysis (SRA, Kimura and Tagart, 1982) which uses available catch trends and life history data to provide estimates of exploitation and sustainable catch limits (e.g., Dick and MacCall, 2011; Costello *et al*., 2012; Martell & Froese, 2013; Thorson *et al*., 2013; Thorson & Cope, 2015; Froese et al., 2016; Free *et al*., 2017; Zhou *et al*., 2017). Most of these methods require, as input, an independent estimate of relative biomass compared to unharvested biomass in the previous year, and their performance is poor if this estimate is incorrect (Wetzel & Punt, 2011; Thorson & Cope, 2015). Using expert advice as the basis for the latest stock status is problematic, as it can be criticised as subjective or as a cyclical exercise, given the strong influence of this basis on the analysis results (see similar criticism of the best estimates for natural mortality and steepness in full stock assessments in Mangel *et al*., 2013).

The CMSY (Catch-Maximum Sustainable Yield) method is an innovative approach developed to address data limitations in assessing fish stock status. This method uses catch data and species resilience information to estimate key parameters, including Maximum Sustainable Yield (MSY), carrying capacity (K), and relative biomass (Froese *et al.,* 2017). CMSY has proven effective in assessing the stock status of various fish and marine invertebrate species worldwide (Palmores *et al*., 2018). Productivity refers to the ability to recover quickly when stocks are depleted, while susceptibility is the potential for stocks to be affected by fishing activity (Yonvitner, 2020). The advantage of CMSY lies in its ability to analyse limited data, which is often a constraint in developing countries like Indonesia. Shrimp fisheries are one of the high-value economic sectors in Indonesia, particularly in East Kalimantan. *Mierspenaeopsis hardwickii*, also known as the Sword Prawn, is a commercially important prawn species widely distributed in the waters of the Western Indo-Pacific, from Pakistan to Japan and Borneo (Froese & Pauly, 2023). This

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species is found from the coastline to a depth of 90 meters, typically on muddy, sandy-muddy, or sandy bottoms, with juveniles abundant in estuaries.

The waters of Samboja, East Kalimantan, are one of the most intensive shrimp fishing areas, but information regarding the stock status of sword prawn in these waters is still limited. Sustainable fisheries management requires accurate stock assessments to prevent overfishing and ensure the sustainability of fisheries resources (Hilborn & Ovando, 2014). However, the limitations of comprehensive biological and fisheries data often constrain the conduct of conventional stock assessments. Research on shrimp stock status using the CMSY method in Indonesian waters is still very limited, even though this information is crucial for supporting sustainable fisheries management policies. Sword prawns exhibit moderate to high resilience, allowing relatively rapid population recovery when managed well. However, excessive exploitation levels can lead to a significant decline in stocks. This study aims to estimate the stock status of the sword prawn in the waters of Samboja, East Kalimantan, using the CMSY method. The results of this study are expected to provide accurate scientific information on the current condition of the sword prawn stock and sustainable management recommendations. Additionally, this research is also expected to serve as a reference for applying the CMSY method to other shrimp species in Indonesian waters, given the importance of stock status assessment in supporting sustainable fisheries management in the era of the blue economy.

MATERIAL AND METHOD

For this study, total catch data for sword prawns in Samboja waters over 13 years from 2012 to 2024 were used. The data used in the analysis were obtained from the catch logbooks of shrimp fishermen in Samboja waters. These records were considered the most effective way to collect annual catch data due to their relevance and the lack of data from local authorities.

The tools and materials used in this study are the logbooks of sword prawn catches from Samboja fishermen as data analysis material, R software as a data processing application, the CMSY Guide (Froese *et al*., 2019) as a guide for running the R program for CMSY analysis, writing tools for recording the data obtained, and other supporting materials. The data obtained from this study is secondary data. The data were obtained from the catch records of sword prawn fishermen in Samboja waters, recorded in their monthly logbooks. Data collection involved totalling catches for each year over 13 years.

The CMSY code model (version CMSY_2019_9f.R) used is from Froese *et al.* (2019) for the assessment of sword prawn stocks in Samboja waters. R software (v4.3.3) based on R Studio (v1.9.2025) was used for the calculations. This open-source model for assessing fish stocks can be used with limited fisheries data. This model uses historical data on catches and their resilience. Figure 2 shows the number of sword prawns caught in Samboja waters between 2012 and 2024, as well as their stock status as described in the results and discussion section. According to Holling (1973), resilience is generally defined as the ability to respond to and absorb disturbances while essentially maintaining its function and structure. This data is used to determine the model's initial parameters. Using resilience and catch data, the model predicts fisheries management parameters (MSY, BMSY, FMSY), the stock exploitation rate (F/FMSY), and the relative stock size (B/BMSY) (Froese *et al*., 2019).

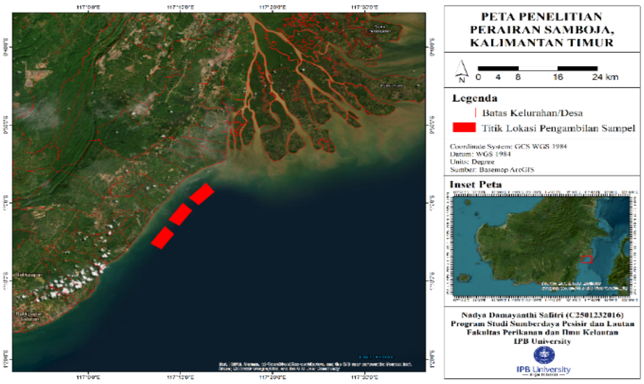

Figure 1. Research location at Samboja Waters, East Kalimantan

The CMSY model is based on the very simple and therefore very popular Schaefer surplus production model (Schaefer, 1954) (Andrašūnas *et al*., 2022).

$$B_{t+1} = B_t + r.(1 - B_t/k).B_t - C_t \quad (1)$$

Where Bt is the biomass, r is the intrinsic growth rate of the population, k is the environmental carrying capacity (unexploited or initial biomass B0), and Ct is the catch at time t. In this model, there are two unknown parameters: r and k. Since depletion (d) is:

$$d = 1 - B_t/k \quad (2)$$

The value of k in formula (1) can be found using prior knowledge about r and d (Zhou *et al.*, 2018).

A: Finding viable $r - k$ **B: Analysis of viable $r - k$**

growth rate (r), and environmental carrying capacity (k) via an iterative Markov Chain Monte Carlo approach. A pair of parameters (r, k) is applicable if the corresponding biomass trajectories predicted from the surplus production model are logical with catches in the sense that the biomass estimated by formula (1) does not take negative values, and is consistent with priors relating to the relative biomass amounts at the starting and end of the time series (Froese *et al.*, 2019). After finding an optimal pair of r and k, a time series of biomass (B) and fishing mortality (F) can be calculated, along with various indicators (Schaefer, 1954; Ricker, 1975; Andrašūnas *et al.*, 2022).

$$MSY = r.k/4 \quad (3)$$

$$F_{MSY} = 0.5.r \quad (4)$$

$$B_{MSY} = 0.5.k \quad (5)$$

Stocks' status can be characterised according to the F/FMSY and B/BMSY of the final year of a time series (Table 1). Prior relative biomass (B/k) and resilience of species ranges corresponding to depletion levels at the start, medium and end time series are used as input parameters in the model. Resilience is a prior prediction of the resilience of species, which is related to the intrinsic growth rate of the species. Suggested values are "very low", "low", "medium", and "high". The borders of these categories (rlow - rhigh) are shown in Table 1. The resilience value of the stock can be obtained from www.fishbase.org, or it can be calculated using the relations between r and other parameters.

$$r = 2F_{MSY} = 3/t_{gen} = 9/t_{max} = 3K \quad (6)$$

In the formula r is the growth rate of the population, M is the natural mortality, FMSY is the fishing mortality rate for MSY: FMSY = 0.5.r, tgen is the generation time of the population, tmax is the maximum age of individuals in the population and K is a parameter of the von Bertalanffy growth equation (Froese *et al.*, 2017).

RESULT AND DISCUSSION

Result

The CMSY method produces a report in two parts: the first is based on the analysis of r and k value pairs, and the second on fisheries management. Figure 2A illustrates all r-k pairs found in the analysis (shown in grey) and the feasible pairs (shown in dark grey) that are consistent with the catch data and other information used in the model. Figure 2B provides a more detailed view of the r-k pair analysis from Figure 2A. The dashed rectangle represents the range of values defined as the input parameter. The blue cross in the middle of the graph indicates the optimal r-k pair estimated by the CMSY model, and the horizontal and vertical lines represent the 95% confidence intervals for r and k. According to the CMSY model, the resilience (r) of the sword prawn population in Samboja waters is 0.475 year-1 (95% CL=0.291-0.776), and its carrying capacity (k) is 14.9 tons (95% CL=10.1-22).

Table 1. Resilience categories and r-values (Froese *et al.*, 2019)

Resiliensi	r_{low}-r_{high}
Very low	0.015-0.1
Low	0.05-0.2
Medium	0.2-0.8
High	0.6-1.5

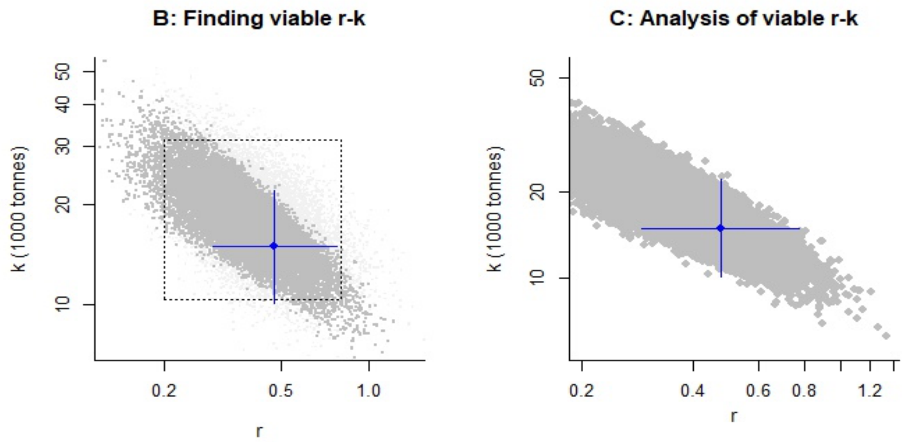

Figure 2. Viable r-k pairs.

Table 2. The results of CMSY analysis.

Stock Status	Parameters	Value	Dimension	95% CL
Fully overfished stock	C_{2024}	1.18	Ton	-
	r	0.475	$Year^{-1}$	0.29-0.77
	k	14.9	Ton	10.1-22
	MSY	1.75	Ton	1.23-2.36
	B_{2024}	4.2	Ton	0.43-5.89
	B_{MSY}	7.45	Ton	5.04-11
	F_{2024}	0.28	$Year^{-1}$	0.2-2.71
	F_{MSY}	0.23	$Year^{-1}$	0.14-0.38
	B_{2024}/B_{MSY}	0.56	-	0.05-0.79
	F_{2024}/F_{MSY}	1.18	-	0.84-11.4

The CMSY method estimates key parameters, including Maximum Sustainable Yield (MSY), fishing mortality (F), fishing mortality at MSY (FMSY), biomass (B), and biomass at MSY (BMSY), for fisheries management. Table 3 shows that the catch of sword prawn in 2024 (1.18 tons) is lower than the MSY (1.75 tons). The table also shows that the biomass in 2024 (4.2 tons) is lower than the sustainable biomass (BMSY) of 7.45 tons, but the fishing mortality in 2024 (0.28 year-1) is higher than the fishing mortality corresponding to MSY (FMSY: 0.23 year-1). This indicates that the sword prawn population is severely depleted and that fishing pressure on it is increasing.

The B/BMSY and F/FMSY ratios can be used to classify stock status according to the definitions in Table 2. In the case of sword prawn stocks in Samboja waters, the B/BMSY and F/FMSY values were calculated to be 1.18 and 0.56, respectively. According to Table 2, these values do not align with the established categories. Since the B/BMSY value is less than 1 and the F/FMSY value is greater than 1, the stock can be considered overfished, and overfishing is indicated based on 2024 data.

Figure 3 presents the results of the CMSY analysis through a series of graphs. Graph A (upper left) shows catch relative to maximum sustainable yield (MSY), with 95% confidence intervals indicated in grey. Graph B (upper right) shows relative exploitation (F/FMSY), and Graph C (lower left) shows relative biomass development (B/BMSY), with the grey area indicating uncertainty. Graph D (lower right) is a Kobe diagram, showing the time series of fishing pressure (F/FMSY) on the Y-axis and stock size (B/BMSY) on the X-axis. The Kobe diagram is divided into four zones: the orange zone indicates that the stock is not overfished but is overfishing, the red zone indicates that the stock is overfished and overfishing, the yellow zone indicates that the stock is overfished but not overfishing, and the green zone, which is the target for fisheries management, indicates that the stock is not overfished and not overfishing, meaning that fishing pressure and stock size are sufficient to achieve maximum sustainable yield. The yellow area around the triangle indicates a 50% confidence interval; the grey area, an 80% confidence interval; and the dark grey area, a 95% confidence interval. The legend in the upper right corner of the graph shows the percentage of the 95% confidence interval area that falls within each colored zone (Froese *et al*., 2019).

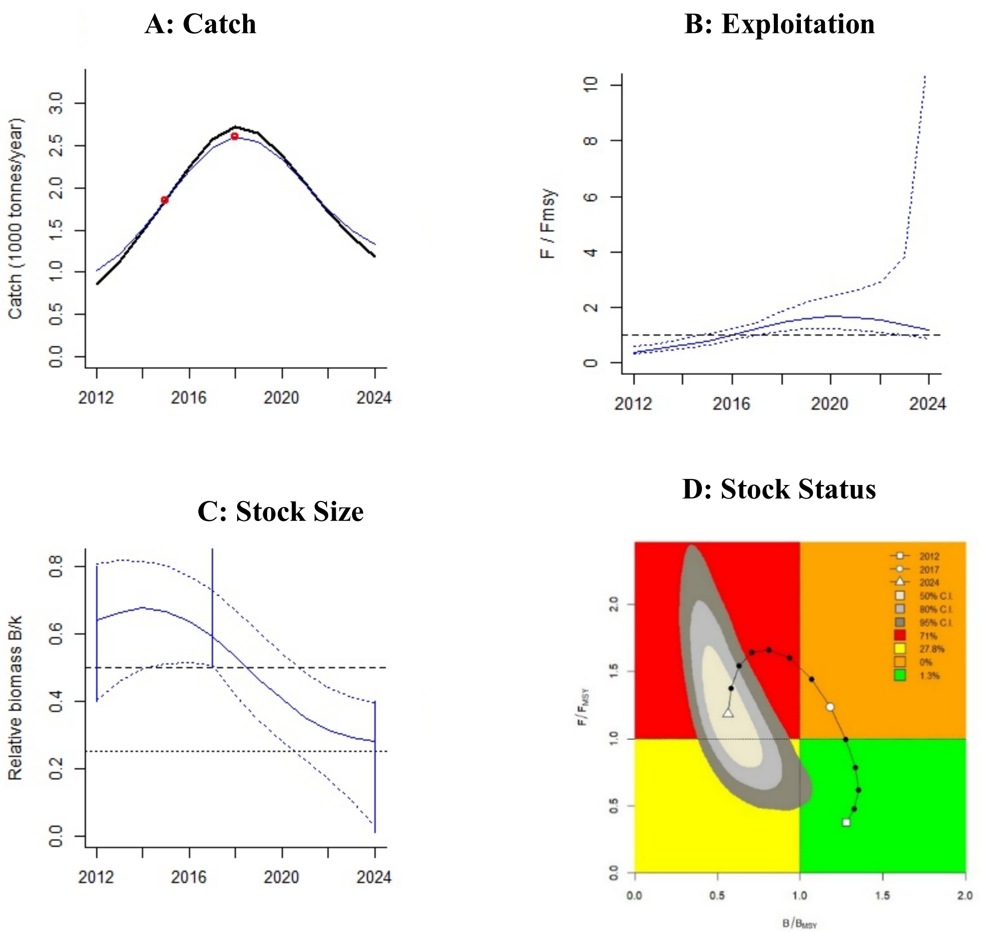

Figure 3. Result graphs of CMSY analysis. Figure A displays the annual catch trends ($\times 10^3$ tonnes·year^{-1})from 2012 to 2024. Figure B shows the exploitation rate, expressed as the ratio of fishing mortality to the maximum sustainable yield (F/FMSY), over the study period. Figure C displays the relative stock size represented by biomass relative to biomass at maximum sustainable yield (B/BMSY). Figure D shows the Stock status (Kobe plot) illustrating the relationship between B/BMSY and F/FMSY, with colored quadrants indicating stock condition and probability distributions of stock status.

Figure 3A shows the annual catch of sword prawn in Samboja waters from 2012 to 2024. The dashed line in Figure 3B, which is parallel in the middle of the graph, represents the maximum sustainable yield (MSY) of 1.75 tons, as calculated using CMSY. The dark grey area indicates the 95% confidence interval for MSY, which ranges from 1.23 to 2.36 tons. As shown in the graph, annual catches exceeded the upper limit of MSY (2.36 tons) in 2017, 2018, 2019, and 2020. Figure 3B illustrates the utilisation of stock during the analysed period. The dashed line on the graph indicates the maximum acceptable level of the F/FMSY ratio, which is 1. When the value is above 1, the stock is overfished, as shown in the graph. It appears the stock was overfished from 2017 to 2024. Figure 3C shows the relative variation in biomass over time. In an unexploited stock, the B/BMSY value is estimated to be high, as seen in 2012. However, as fishing pressure increased, this value dropped below 1 from 2019 to 2024. Figure 3D shows that the sword prawn population was in the green zone in 2012 when fishing began. In subsequent years, as fishing pressure increased, the population shifted from the orange zone to the red zone. The CMSY model shows that the sword prawn stock in Samboja waters has been overexploited. The F/FMSY value is above 1 for most periods, and the B/BMSY value has been below 1 since 2019 until now. The MSY determined by the analysis (1.75 tons, 95% CI = 1.23-2.36) was exceeded in the following periods: 2015, 2016, 2017, 2018, 2019, 2020, 2021, and 2022.

Discussion

Evaluating the state of natural aquatic resources is crucial to achieving FAO's sustainability objectives. However, in many cases, the available data is limited. For example, for sword prawn cases in Samboja waters, we only have annual catch data. Sword prawn fishing began in 2012, and the number of shrimp caught in some seasons has increased dramatically year after year. This is due to several factors, including the fact that each fisherman has a divided fishing area. As a result, when the price of sword prawns decreases, fishermen may choose not to catch them and instead store the prawns in their area for a season when prices are more favourable. According to Fitzgerald *et al*. (2018), the initial biomass reduction range should be set to 0.5-0.9 if the initial catch is less than one-fifth of the maximum catch, and 0.3-0.7 otherwise. In this case, the initial reduction rate is set to 0.3-0.7, as the ratio of initial catch to maximum catch is approximately 1/3.

As shown in Figure 3A, there were several years when the catch of sword prawn in Samboja waters exceeded the calculated MSY (1.75 tons) in this study, even reaching over 2.36 tons, which is the 95% confidence upper limit of the MSY. From Figure 3B, it is clear that annual catch fluctuations are driven by changes in fishing pressure resulting from increased market demand for shrimp. As shown in Figure 3C, the influence of fishing pressure on biomass is evident. As fishing pressure increased, biomass in the waters declined and fell below the minimum level required for maximum sustainable yield by 2019. When examining Figure 3D, which plots the values of stock utilisation rate (F/FMSY) and relative stock size (B/BMSY), it can be seen that in 2012, when fishing began in the waters of Samboja, the relative biomass was high but fishing pressure was low. As a result, the stock (represented by the white box) was in the green zone on the graph, indicating the "healthy stock" phase. In 2017, when the stock utilisation rate (F/FMSY) exceeded 1, the stock began to be overexploited. At this stage, indicated by the orange zone on the graph, the biomass is still in good condition but is inevitably thinning. Due to continued fishing pressure, biomass decline continued, and stocks entered the red zone on the graph, indicating an overfishing phase. The red zone on the graph represents an overexploited state in which biomass is insufficient to achieve maximum sustainable yields. In this case, it is crucial for fisheries management to immediately reduce fishing in order to protect stocks and ensure the long-term sustainability of the fishery.

The transition from green zone (sustainable) in 2012 to red zone (overfished and overfishing) demonstrates a concerning pattern consistent with "boom and bust" cycles in tropical shrimp fisheries (Pauly *et al*., 2013). The intrinsic rate of population increase ($r = 0.475$ year^{-1}) indicates moderate resilience, within the typical range for penaeid shrimps (Froese & Pauly, 2023). The carrying capacity ($k = 14.9$ tons) reflects environmental limitations in Samboja waters, comparable to other small-scale Indonesian shrimp fisheries (Badrudin & Aisyah, 2011). The MSY of 1.75 tons was exceeded in multiple years (2015-2022), causing persistent stock depletion (Hilborn & Walters, 1992). Current fishing mortality ($F_{2024} = 0.28$ year^{-1}) exceeds FMSY (0.23 year^{-1}) by 18%, indicating unsustainable exploitation. Studies show that even moderate increases in fishing mortality above FMSY can lead to significant biomass reduction and recruitment failure (Garcia & Le Reste, 1981). The prolonged overfishing from 2017-2024 has likely impacted population structure and reproductive potential (King, 2007).

Immediate management measures are needed: Implement seasonal closures during spawning periods and gear restrictions (Ye *et al*., 2008). Establish minimum size limits to protect juveniles and ensure adequate spawning stock (Garcia & Le Reste, 1981). Protect nursery grounds and mangrove areas to support stock recovery (Rönnbäck *et al*., 2007). The CMSY method has inherent uncertainties reflected in wide confidence intervals. Future assessments should incorporate biological sampling, environmental parameters, and fishing effort statistics to improve parameter estimation (Palomares *et al*., 2018). Long-term monitoring programs should be established to track stock trends and validate predictions.

CONCLUSION

In conclusion, the current study found that the sword prawn population in the waters of Samboja, an important source of sword prawn production in East Kalimantan, is not properly managed. Especially, regulations regarding catch quotas for the sword prawn species have not yet been established; the lack of regulations puts the stock at serious risk. It is estimated that an annual catch of 1.75 tons is suitable for sustainable stocks. Therefore, it is recommended that the quota be set immediately based on the results of this research. The studies by Free *et al*. (2020) and Andrašūnas *et al*. (2022) have demonstrated that the CMSY model, based on catch data, is effective for evaluating well-known fish populations. In this case, the CMSY model was also successful in evaluating the crayfish population in the Keban reservoir, and the results were consistent with those of other studies. Therefore, it is recommended that the CMSY model be used to assess other crayfish populations with limited data. To improve the precision of future stock assessments using the CMSY model, it is crucial to carefully monitor and record catch data, including illegal, unreported, and recreational catches, as well as CPUE (catch per unit effort) data.

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