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Short Communication

Assessing the technical efficiency of purse seine fisheries in North Sulawesi, Indonesia

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Introduction

Global fishing capacity and effort increased rapidly from the late 1970s to around 2010 before stabilizing. The Asian fleet is more than an order of magnitude larger than any other region in capacity and effort and continues to increase. Most other regions have stabilized, and there have been considerable declines in Europe and, to a lesser extent, in North America (Bell *et al*., 2017). Fishermen often increase their fishing capacity by increasing their production inputs and fishing capabilities without considering available resources (Akbari *et al*., 2023). Consequently, decrease in fish availability and ecological quality in several areas, the increasing capacity of fishing fleets in Indonesian waters has caused problems related to overcapacity and overfishing (Malik *et al*., 2019).

The primary cause of fisheries damage stems from controlling inputs, specifically fishing fleets. Therefore, the Food and Agriculture Organization (FAO) approaches fisheries management by regulating fishing gear's capacity a concept 'the management of fishing capacity' (International Institute for Sustainable Development, 2021). A number of variables, such as the size of the vessel, engine, and net, as well as auxiliary gear technology, determine the fishing effort's capacity. Constraining of variables unit can limit the fishing capacity (Cao *et al*., 2021). Each purse seine vessel, has different characteristics and efficiency. Exhaustive data and technical information are necessary to determine the performance of purse seine operations. The concept of capture capacity closely links to this efficiency, as uncontrolled fishing activities result in inefficient fisheries activities. Previous research reveals that the government controls purse seines through fishing permits, restricting the tonnage, number of vessels, mesh size, and fishing area, but it does not regulate the maximum engine power in relation to vessel tonnage. The purse seine fleets at Tumumpa Port, Sulawesi, have an average gross tonnage (GT) of 36 (10 - 99) . Based on daily fishing operations data from 2006 to 2020, the purse seine fleets averaged 2560 trips per year, totaling 7564 tons per year. The catch was primarily composed of mackerel scads, skipjack, kawa-kawa, and tuna. The fishermen's response to increasing the efficiency and effectiveness of their fishing businesses was to develop their fishing efforts.

Studies on technical efficiency and fishing capacity utilization are parameters for fisheries management. It has been studied how much fishing can be done in Morocco and Indonesian waters (Darasi and Aksissou, 2019;Wijayanto *et al*., 2020), as well as on Danish gill net fleets (Vestergaard *et al*., 2003), Chinese offshore fisheries, Egyptian Mediterranean fleets (Samy-Kamal and Mehanna, 2023), and handline tuna in the Philippines (Digal *et al*., 2017).

In small-scale fisheries in Indonesia, increasing the catch of fish resources with high economic value leads to interaction and competition among multiple fishing fleets. Fish stocks decline as a result of ongoing, unregulated competition between small-scale fishing fleets (Picaulima *et al*., 2020). Thus, it is essential to evaluate the application of input and output management strategies in order to determine the utilization capacity of Tumumpa purse seine fisheries (Bellido *et al*., 2020). This study aimed to assess the technical efficiency and capacity utilization of purse seine fishing gear located in Tumumpa and operating in the Sulawesi Sea. We analyzed the fishing efficiency and capacity utilization of purse seine based on fishing days and GT. Efficiency means the maximum resource utilization rate under certain technical or investment-level conditions (Zhaoqun *et al*., 2018; Gbigbi, 2019).

Materials and methods

We assessed the capacity of capture fisheries using the fisheries statistics data officially issued by Tumumpa Port, North Sulawesi, Indonesia. Additionally, we analyzed the productivity of purse seine fisheries in terms of catch per unit effort (CPUE) using the following equation, based on landing data from 2006 to 2020:

$$CPUE = \frac{Catch}{Effort} \qquad (1)$$

Where, *Catch*: Total vessel catch (tons), *Effort*: The number of active fishing vessels (trips, units)

Furthermore, one tool for fisheries control is the measurement of fisheries capacity (Cunningham and Gréboval, 2001). The capacity utilization (CU) indicator is one tool used to assess fisheries capacity. During 2010–2020, the general purse seine utilization capacity was measured using a peak-to-peak methodology. The trajectory of fisheries production data from 2010 to 2020 served as the basis for the measurement. The form is used to determine the trend coefficient (Fauzi, 2010):

$$\tau = \frac{(Y_{\rho 2} - Y_{\rho 1})}{(T_{\rho 2} - T_{\rho 1})} \quad (2)$$

Where, Y_{p2} is the CPUE at the second peak and Y_{p1} is the CPUE at the first peak. T_{p2} and T_{p1} is the year in which the two peaks occurred.

We measured the capacity among Tumumpa purse seine vessel units in 2020 based on Technical Efficiency (TE), which we calculated using Data Envelopment Analysis (DEA). We then calculated the output capacity and the optimal utilization of the input using the following equation. Initially, design the factor of outputs as µ and the factor of inputs as *x*. There are *m* outputs, *n* inputs, and *j* firms or observations. The inputs are divided into fixed inputs (α) and variable inputs ($\hat{\alpha}$). Capacity output and optimum or full input utilization values required solving the following equation (Vestergaard *et al*., 2003):

$$\text{TE} = \text{Max}\theta_1 \quad (3)$$

$$\theta_1 \mu_{jm} \sum_{J=1}^{J} z_j \, x_{jn} \leq x_{jn} \quad m = 1.2. \ldots,, M$$

Where, z_j represents the intensity variable for the j_{th} observation; θ_1 technical efficiency refers to the proportion by which output can be increased; and λ^*_{jn} was the average variable unit utilization VIU, represents the ratio between the optimal input utilization of x_{jn} and input utilization from x_{jn} observation.

We defined the technical efficiency capacity output (TECU) by multiplying θ_1^* the actual production with an equation (Fare *et al*., 1989):

$$TECU = \frac{\mu}{\theta_1^* \mu} = \frac{1}{\theta_1^*} \quad (4)$$

Capacity utilization, based on the observed output, was then calculated using the following equation:

$$CU = \frac{\theta_2^* \mu}{\theta_1^* \mu} = \frac{\theta_2^*}{\theta_1^*} \quad (5)$$

The technical efficiency analysis compared the efficiency of the fishing vessels'tonnages'
used as a DMU (decision-making unit). To do analysis, the content value of the output (µ), fixed input (x), and variable input (ƛ) in each DMU were found. The capture efficiency was then found by combining the capture capacity utilization rate and VIU. The study primarily calculated the input (effort) factor based on the number of days at sea and the number of fishing trips. In contrast, the output was primarily composed of dominant catches, such as tuna, mackerel scads, skipjack, and kawa-kawa. We subsequently tabulated, analyzed, and categorized the information for each vessel by gross tonnage (GT), separating those less than or equal to 30 and those exceeding 30. Initially, we identified the output vector and the input vector as *x*. There were also *m* outputs, *n* inputs, and *j* fishing or observation units. The inputs were divided into fixed input (x_f) and variable input (x_v) (Cunningham and Gréboval, 2001).

Results

Purse seine productivity and capacity

The number of fishing efforts utilizing pelagic fish resources in North Sulawesi waters tends to increase from 2006 to 2020. The average increase in the number of trips per year was 6.7 (Fig. 1). The decrease in the CPUE (2015 - 2020) corresponded with a decrease in the resource stock abundance index.

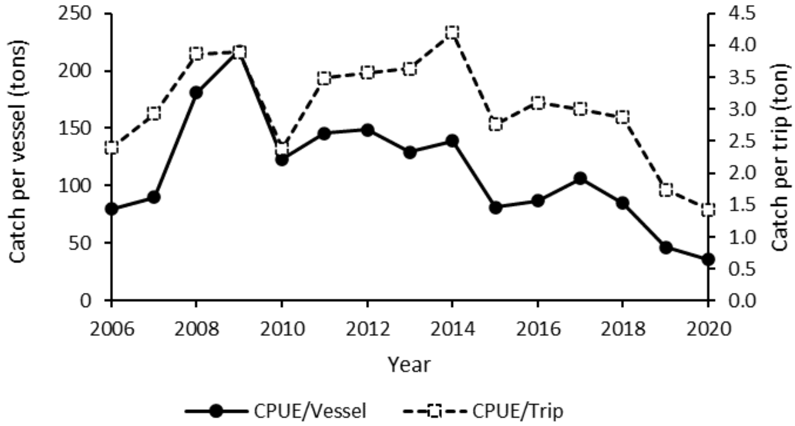

Figure 1: illustrates the dynamic of catch per unit effort from 2006–2020.

On the other hand, fishermen or business actors modified their fishing strategies in response to the declining abundance to achieve their goals. The decrease in the CPUE suggested that pelagic fish resource utilization activities in the Sulawesi Sea during the period were increasingly inefficient, and the fish resources the fishermen could utilize were becoming more limited. Fishing effort that exceeds the optimum effort can lead to overfishing. The increasing energy, funds, and time spent on fishing and vessel productivity due to poor stock status indicated inefficiencies, resulting in a decrease in both effort and capacity (Guillen and Maynou, 2016).

The analysis of the fishing capacity of purse seine fisheries using the peak-to-peak method indicated that the input's average technology changes were 0.7 tons/vessel. An annual capacity rate ranged from 2.4 to 6.8 tons between 2006 and 2020. The average efficiency was 0.67, indicating a 33% excess in the fisheries' capacity. The most efficient trajectories of the fleets occurred in 2006, 2008, and 2014 (Fig. 2).

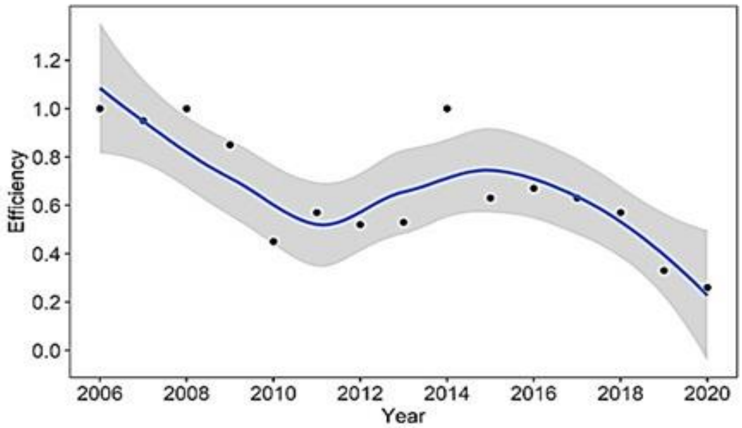

Figure 2: illustrates the dynamic of purse seine efficiency in Tumumpa, North Sulawesi.

The calculation of capture efficiency from the annual data (2006 – 2020) shows that sharp efficiency increases began after 2007, coinciding with an input expansion (increase in the number of trips) of up to 55%, which in turn led to an increase in output. When an increase in the expansion occurred again with the same pattern, i.e., accompanied by an increase in the number of trips, efficiency allegedly decreased again. This pattern involved an increase in efficiency between 2011 and 2016, followed by a subsequent decrease until 2020.

Technical efficiency (TE) and variable input utilization (VIU)

The data landing purse seine has a size range between 10 to 99 GT). Most fishing fleets exceed 30 GT in size. Purse seiners with a GT exceeding 30 accounts for 42% of the total, while ships with a GT less than 30 represent 58% of the total.

Using the DEA method (Fig. 3), the results of the Technical Efficiency calculation on the purse seines in Tumumpa of GT≤30 suggested that a total of 54 units (81%) of the 67 units of purse seines were inefficient (TE=0.50 ~ 1) and the rest 13 units (19%) were efficient (TE=1). Out of a total of 53 purse seine units in Tumumpa of GT>30, 42 units (79%) were inefficient, while 11 units (21%) were efficient DMU.

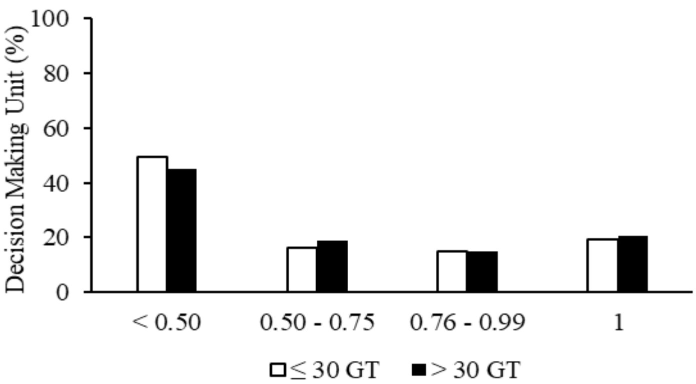

Figure 3: illustrates the distribution of technical efficiency for purse seine vessels in Tumumpa, North Sulawesi.

It found that management and market forces have caused capacity to drop, but this hasn't helped the targeted stocks or associated fishery landings much so far (Di Cintio *et al*., 2022). The way pelagic purse seine fishing works in Tumumpa, North Sulawesi, shows that there is already too much capacity. The excessive use of input factors such as GT, the number of days at sea, and the number of trips clearly demonstrates this. Numerous efforts to overfish have the potential to threaten and degrade the pelagic fish resources in the Sulawesi Sea.

The findings indicate that capacity utilization is lower when assessed using economic measures than physical measures. Nonetheless, the two metrics had no significant disparities in capacity utilization (Cao *et al*., 2021).

Based on the calculation, for purse seine vessels of GT≤30, the VIU for fishing day and trip variables were 0.89 and 0.91 on average, respectively. For 67 purse seine units, the VIU for the fishing day variable indicated that 58% were inefficient, and 42% were efficient. Similarly, based on the VIU for the trip variable, out of a total of 67 purse seine units, 37% were inefficient, and 63% were efficient. For 53 purse seine vessels with a GT>30, the average VIU values for the fishing day and trip variables were 0.92 and 0.96 respectively. The VIU for the fishing day variable indicated that out of a total of 53 purse seines, 43% were inefficient, and 57% were efficient. Similarly, the VIU for the trip variable showed that out of a total of 53 purse seines, 23% were inefficient, and 77% were efficient (Fig. 4).

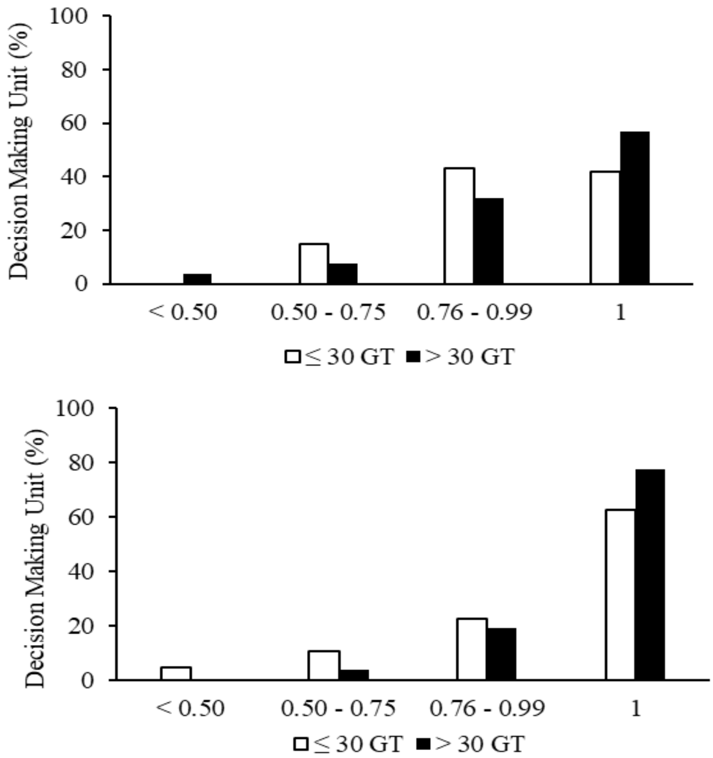

Figure 4: the distribution of variable input unit on days (left) and trips (right) in Tumumpa.

The relative variable input utilization between fishing days and trip variables for GT ≤ 30 vessels showed that the VIU for fishing days was 0.89 and for trips was 0.91. In total, the VIU indicated 19.95% excess capacity. For the vessels of GT>30, the average VIU for both variables was 0.92 and 0.96, respectively, indicating a total of 11.81% excess capacity.

Achieving optimal utilization of inputs in vessel size groups requires decreasing the days at sea by 53.84% (≤30 GT) and 67.51% (>30 GT). Simultaneously, a reduction of trips by 46.16% (≤30 GT) and 32.49% (>30 GT) is necessary.

Such input overcapacity of Tumumpa purse seine fishermen was allegedly triggered by competition among the fishing vessels in allocating inputs and capital to generate their desired catch output. The allocation of these inputs was relatively high, but it generated a quite low output in their fishing operations. The inputs were utilized through fishing strategies and tactics to reach the fishing grounds, fishing time, the number of trips, fishing days, fishing fleet technology, and operational supplies. The competition to utilize fisheries in open-access waters was uncontrollable due to the challenging nature of controlling inputs. Metzner (2005) explained that changes in aspirations and methods of fishing operations caused changes in fishing capacity.

The scenarios to enhance the efficiency in the utilization of output capacity and fishing inputs for Tumumpa purse seine vessels involve reducing excess inputs (inefficiency), and increasing output by increasing the production of purse seine vessels beyond what is actually produced (Kirkley *et al*., 2002).

The factual condition of the purse seine fisheries in Tumumpa indicated that excess capacity had occurred in several purse seine fleets. The minimal fish resources and the relatively high demand for fish triggered competition among purse seine fishing operations in the Sulawesi Sea, leading to a relatively high and uncontrolled allocation of inputs. The management of purse seine fishing required the control of excess inputs, which included reducing the number of sea days and trips, particularly during seasons with limited fish resources.

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