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Measuring the Technical Efficiency of Purse Seine in Tropical Small-scale Fisheries in Indonesia

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Abstract

In response to external changes, fishermen usually change their fishing strategy and increase their input factors. This effort sometimes causes an excess of input factors and inefficiency in fishing operations. To determine both the impacts on fishing operations, technical efficiency is used. Small-scale fisheries play a significant role in the global fisheries industry; therefore, it is necessary to evaluate the excess of input factors and profligacy in fishing operations in small-scale fisheries in tropical areas. Consequently, data envelopment analysis (DEA) was used to calculate the technical efficiency of purse seine fisheries in Rembang, Central Java Province, Indonesia. The objectives of this study were to measure 1) technical efficiency and 2) variable input utilisation (VIU) of purse seines in the Java Sea. The results of this study showed that most purse seines in Rembang had an excess of input factors and were inefficient in fishing operations. In order to manage purse seine fisheries in Rembang, it is proposed that reducing certain input factors, for instance the length of fishing trips (14.3%), supplies (12.5%) and ice (9.2%) will be advantageous and achieve positive results.

Introduction

Small-scale fisheries[1] play a significant role in production and employment in the Indonesian fisheries. According to recent estimates (Ministry of Marine Affairs and Fisheries, Indonesia 2011) 99% of the total fishing boats (581,845) were small-scale and distributed throughout Indonesian waters. As in other developing countries, uncontrolled, rapid expansion of small-scale fisheries (both new entries and modernisation of existing equipment) in Indonesia has resulted in problems of overcapacity and a need to reduce excessive effort capacity (Berkes et al. 2001). The western parts

[1]Decree of the Minister of Marine Affairs and Fisheries, Republic of Indonesia No.22 of 2004 defines small-scale fisheries as activities carried out by fishermen who have boats with a cumulative capacity of less than 60GT.

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of the Indonesian waters along the northern Java and eastern Sumatera coasts have been identified as being exploited and overfished (Mous et al. 2005).

Despite the fact that fisheries management measures are limited, the Indonesian government has issued regulations to deal with small-scale fisheries. However, fisheries management in Indonesia was aimed primarily on a large scale rather than at small-scale fisheries. This is because the fisheries policy over the last decade focused on increasing fish production. Meanwhile, fishermen who operated small-scale fishing units were scattered throughout the remote islands and waters, resulting in difficulties in monitoring fishing activity. The fishing gear that is used has a tendency to increase and exceed the requirements of harvesting fish in a sustainable manner.

There is currently no management measure targeted at small-scale fisheries in developing countries that has been successful in reducing overcapacity. Therefore, for the implementation of fisheries management for multispecies-multi gear small-scale tropical coastal fisheries in developing countries, especially Indonesia, it is necessary to initiate an effective capacity management programme based on the understanding of their level of technical efficiency and capacity utilisation. Kumbhakar and Lovell (2000) defined technical efficiency as the ability of a decision-making unit (DMU) to obtain the maximum output from a set of inputs (output orientation) or to produce an output using the lowest possible amount of inputs (input orientation). The technical efficiency of a DMU and the degree of use of variable inputs determine the output and capacity utilisation. Determining the factors that are affecting the technical efficiency and the degree of use of variable inputs enables stakeholders to take measures to limit or improve it (Garcia del Hoyo et al. 2004). In previous studies, the technical efficiency of fishing gears was usually characterised by technological measures (Ali and Lee 1995; Purbayanto et al. 2000; Almeida et al. 2003). In fact, in order to increase their income revenue, fishermen generally tend to equip their fishing boats with new technology (fish aggregation devices, fish finders and electric lamps), and also engage in various fishing tactics. Therefore, in order to determine the factors that influence and to assess the effects of the fishing season in Indonesia on technical efficiency and the use of production inputs, it is important to conduct a study on the level of technical efficiency.

This study attempted to quantify the level of technical efficiency of purse seine in small-scale tropical coastal fisheries in theJava Sea, Indonesia. As the main fishing gear used to capture small pelagic fish in the Java Sea, purse seines play a great role in Indonesian fisheries. During the period 1980-1990, the fisheries contributed the largest share (approximately 30% of the total production) of small pelagic landings in the country. However, the contribution of fish landings from the Java Sea has continued to decline in recent years. In 2005, the Java Sea contributed approximately 18.9% of total fish landings, although by 2011 this contribution had decreased to 16.12% of the total landings (Ministry of Marine Affair and Fisheries, Indonesia 2011). Recognising the importance of these fisheries to the national economy has prompted us to evaluate the development of the fisheries. This paper attempts to measure the technical efficiency of purse seine, the main fishing gear operated in the Java Sea. The characteristics were investigated seasonally by calculating the activity of the daily fishing gears during each season.

Materials and Methods

Data Collection

The studywas conducted at the traditional fishing port of Tasikharjo, Rembang, Central Java, Indonesia (Fig. 1). With regards to the data collection, both catch and effort data were collected from January to December 2012. Data on fleet characteristics, including boat size, gear dimensions and engine power of the boat were collected over the course of the year by direct measurement and objective observations of 125 purse seine samples and interviews with their owners or, the captains of the vessels.

The related data on fishing operations, including fishing boat trips (trip·month^{-1}), fishing tactics and their catch (kg) were also collected. Data collected for the estimation of the input factors comprised of boat tonnage, boat dimensions, gear dimensions, engine power, the number of trips, number of crew, fuel consumption, days of operation, ice consumption and supplies. Moreover, data on purse seine fish catches landed in the traditional fishing port of Tasikharjo were also collected as output data. The descriptive statistics of variables for DEA analysis are presented in Table 1.

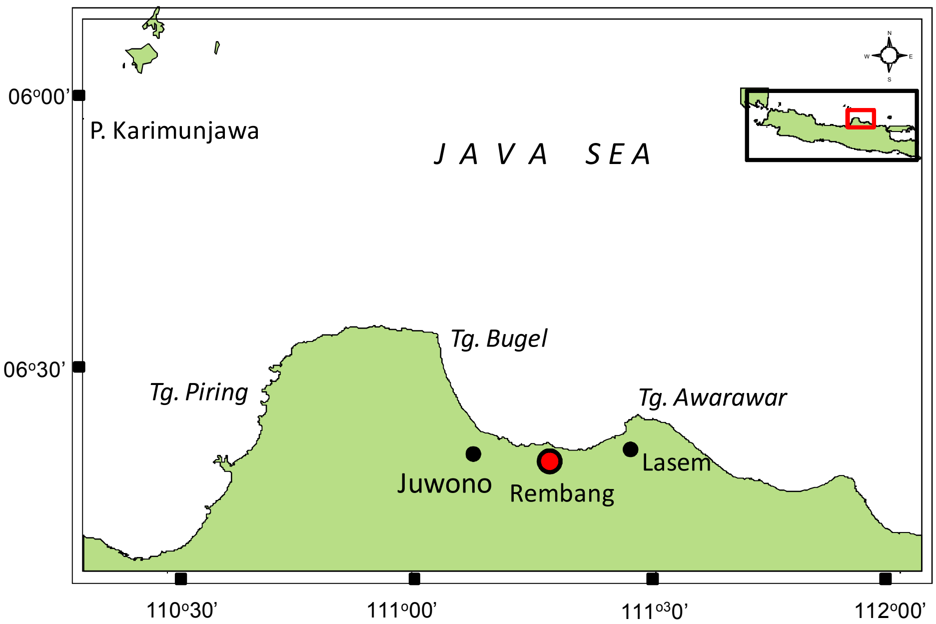

Fig. 1.Map of Rembang, Central Java Province, Indonesia.

Table 1. Descriptive statistics of variables used in analysis.

Variables	Mean	SD	Max	Min
Total catch (kg)	3,561.32	3,516.82	22,240.00	360.00
Volume of boat (GT)	20.09	5.99	30.00	12.00
Length of trip (days)	5	3	25	3
Number of crew (person)	20	3	33	15
Fuel consumption (litres)	443.49	248.82	1,910.00	90.00
Ice (blocks)	47	28	195	20
Supplies cost (million Rp)	4.36	2.90	24.00	1.00

Data analysis

This study attempted to measure the seasonal technical efficiency of purse seine fisheries by using the output-orientated model approach. Given that the inputs in fisheries are mostly fixed, the output-orientated approach is generally more appropriate for the estimation of capacity and capacity utilisation in fisheries. The input-orientated model considers how inputs may be reduced relative to the desired output level. Conversely, the output-orientated method indicates how inputs could be expanded to reach the maximum possible output level, given the capital stock and full utilisation of variable input. By using output-orientated measurements, technical efficiency is determined as the maximum possible expansion of output with no change in the fixed factors of production.For this purpose, the study wasperformed using the following steps:

(i) To determine the seasonal technical efficiency and variable input utilisation of purse seine, where data were agregated into a seasonal basis.In this study, seasons were categorised into three periods, specifically east monsoon (May - August), west monsoon (November-– February) and inter monsoon (September - October and March - April).

(ii) To compare the technical efficiency and variable input utilisation of the purse seine. The level of technical efficiency and variable input utilisation (VIU) of the purse seine were categorised into five classes ranging (from a low to high efficient level): 1) 0 - 0.25; 2) 0.25 - 0.50; 3) 0.50- 0.75; 4) 0.75 - <1; and 5) equal 1 (=1). In order to analyse the level of technical efficency and input production usage between seasons, the data analysis were separated into three seasons.

The seasonal technical efficiency and variableinput utilisation were analysed by data envelopment analysis (DEA), which is a mathematical or linear programming approach (Cooper et al. 2007; Kirkley et al. 2001; Tingley et al. 2002). Initially, the vector of outputs was designated as u and the vector of inputs as$x$. There were m outputs, n inputs, and j firms or observations. The inputs were divided into fixed inputs (x_f) and variable inputs (x_v). Components categorised as fixed input were the volume of the boat (GT), while variable inputs included the length of the trip (days), number of crew (person), fuel consumption (litres), ice (blocks) and the cost of supplies (food, cigarettes and water) of fishing operations (Rp). Furthermore, the output component factors of fishing activities with purse seine gear is the total catch (kg) of scad (*Decapterus* spp), the dominant fish caught during trips. Technically efficient capacity utilisation (TECU) and the optimum or full input utilisation values were calculated by using the following equations (Fare et al. 1989):

$$\underset{\theta,z,\lambda}{Max}\,\theta_1$$

Subject to

$$\theta_1\ u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, \qquad m = 1,2,...,M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, \qquad n \in x_f$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \qquad n \in x_v$$

$$z_j \ge 0, \qquad j = 1,2,...,J$$

$$\lambda_{jn} \ge 0, \qquad n \in x_v$$

Where z_j is the intensity variable for the jth observation; θ_1 the technical efficiency score or the proportion by which output may be expanded when production is at full capacity; and λ^*_{jn} the ratio of optimum use of input x_{jn} to observed input use of x_{jn}.

Capacity output is then determined by multiplying θ_1^* by actual production. Technically efficient capacity utilisation (TECU), based on observed output, may be calculated as follows:

$$TECU(observed) = \frac{u}{\theta_1^* u} = \frac{1}{\theta_1^*}$$

The measure of TECU ranges from 0 to 1, with 1 being full capacity utilisation. A value of less than 1 indicates that the DMU is operating at less than full capacity given the set of fixed inputs.

The variable input utilisation outcome, $\lambda_{jn}{}^*$, measures the ratio of optimal use of variable input to observed use; the optimal variable input usage is the variable input level which gives full technical efficiency at the full capacity output level. If the ratio of the optimal variable input level to the observed variable input level exceeds 1.0 in value, there is a shortage of the i^{th} variable input currently employed and the firm should expand (contract) use of that input. If the ratio is less than

1.0 in value, there is a surplus of the i^th^ variable input currently employed and the firm should reduce the use of that input. If the ratio equals 1.0 in value, the actual usage of the i^{th} variable input equals the optimal usage of the i^{th} variable input.

Results

Technical efficiency

West monsoon season

The results from the calculations showed that the range of technical efficiency of purse seine in Rembang during the west monsoon season was between 0.13 and 1.00 and that the mean technical efficiency was 0.66. The results also indicated that roughly 64.7% of DMUs (purse seine) in Rembang were inefficient. The purse seine vessels were distributed with 17.6% in the range 0 - 0.25%; 19.12% in the range 0.25 - 0.50; 14.7% in the range 0.50-– 0.75 and 13.28% in the range 0.75 - <1. Conversely, the efficiency of the purse seine was 35.3% (Fig. 2).

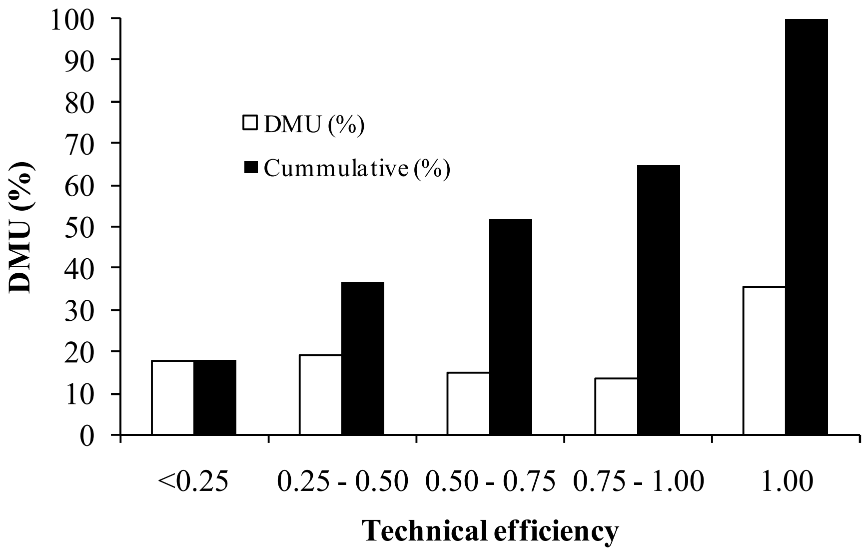

Fig. 2. Distribution of technical efficiency level (%) during the west monsoon.

During the western monsoon season, the decision of fishermen to increase the length of fishing trips (days) had the highest surplus input production. In contrast, the decision of fishermen to implement the number of fishing trips per year indicated lowest surplus input production of approximately 30.88% of DMUs which were distributed in the range VIU<1 (Fig. 3). The fishing strategy on the duration of the fishing trip, based on the results of the DEA analysis, showed that roughly 60% of the purse seine unit (DMU) was categorised as inefficient (surplus input production), with 2.94% of DMUs in the range of 0.25-0.50 VIU level; 20.59% of DMUs in the range of 0.50-0.75 VIU level and 36.76% of DMUs in the range 0.75 - < 1 VIU level. The use of fuel indicated the second level of inefficiency in usage of input production (57.35% of DMUs in the range under 1) and the use of supplies indicated the third level of inefficiency (50.00 % of DMUs in the range <1). In general, the majority of other production inputs such as crew, fuel and ice of DMUs were in the range of 0.75-< 1 (> 30 % DMU).

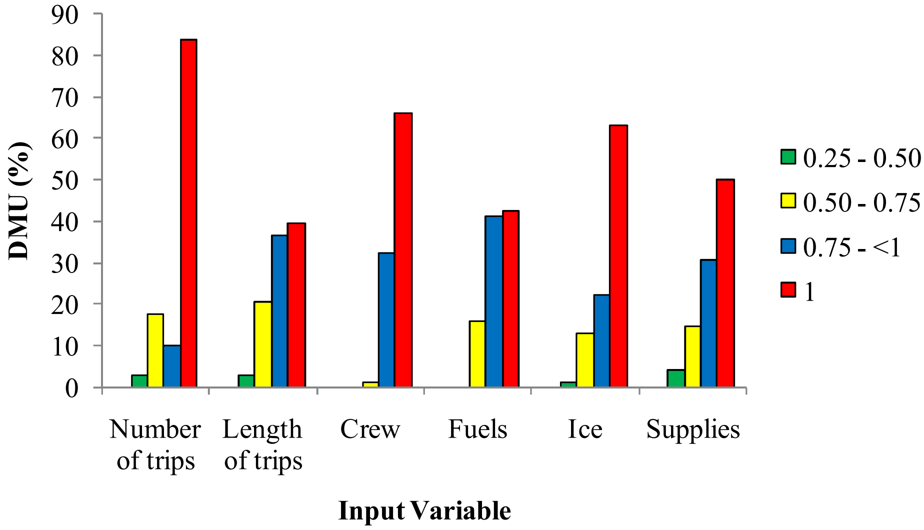

Fig.3. Distribution of variable input utilisation (VIU) (%) during the west monsoon.

East monsoon season

During the east monsoon season the values of the technical efficiency were distributed between 0.0 -1.00 with an average efficiency of 0.57. Using DEA analysis, approximately 21% of the purse seine boats were categorised as efficient DMUs, while 79% of the purse seine boats were categorised as inefficient vessels (Fig. 4).

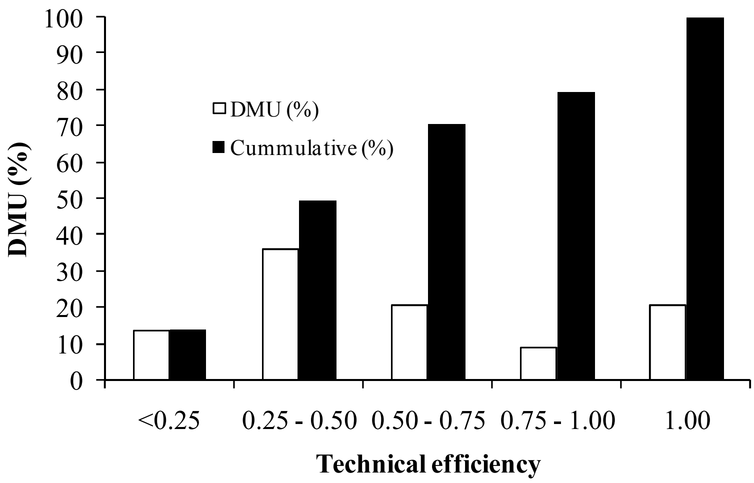

Fig. 4. Distribution of technical efficiency (%) during the east monsoon.

The results of the study during the east monsoon season generally showed a similar pattern to the western monsoon season (Fig. 5). In the east monsoon season, the implementation of an increase in the length of fishing trips demonstrated the highest level of inefficiency, followed by the use of fuel and ice. In the east monsoon season, the numbers of DMUs were in the inefficiency level of (VIU < 1), which was higher than those in the west monsoon season. In this season, roughly 70% of the DMUs were in the inefficient range in implementing the strategy regarding the duration of the fishing trip and about 61.60% of DMUs were not efficient in fuel use, while about 1.80% of DMUs were inefficient in the use of ice. The use of other production inputs such as crew and supplies illustrated that more than 40% of DMUs were in the inefficient range. Similar to the west monsoon season, the majority of the DMUs ineffectiveness was in the range of the interval 0.75-<1 VIU level.

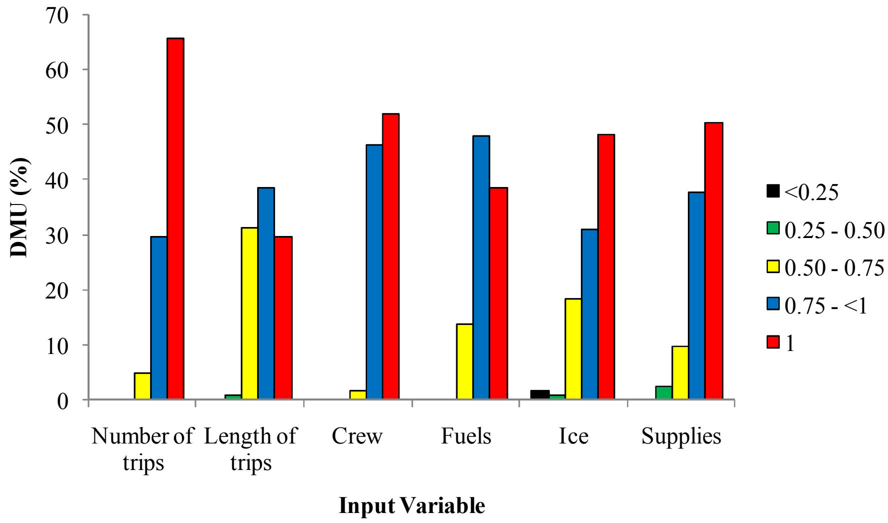

Fig. 5. Distribution of variable input utilisation (VIU) (%) during the east monsoon.

Inter monsoon season

During the intermonsoon season, the calculation showed that about 56.8% of the purse seine in Rembang were inefficient, about 8.64% of the purse seine had a value under 0.25, while purse seine with a value between 0.25- 0.50 was approximately 24.69%, whilst between 0.50- 0.75 reached 16.05%. Conversely, a number of purse seine could attain efficiency of up to 43.21% (Fig. 6).

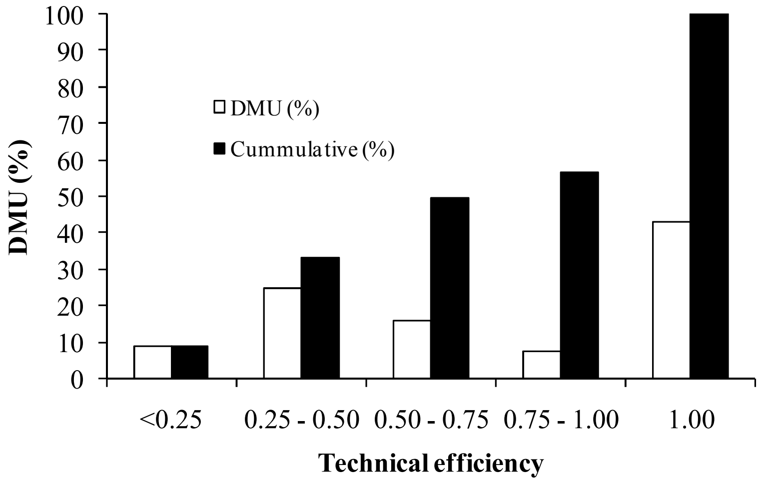

Fig. 6. Distribution of technical efficiency (%) during the inter monsoon season.

The results of the technical efficiency analysis in the inter monsoon seasons revealed that despite having a similar trend, the degree of inefficiency level in the use of production inputs during the inter monsoon season was lower than in other seasons. The highest in efficiencies were still exhibited by the length of fishing trip (53.09% of DMUs), followed by supplies (46.91% ofDMUs) and fuel (44.44% of DMUs). In general, the majority of profligacy occured at the range level of VIU between 0.75-<1 (Fig. 7).

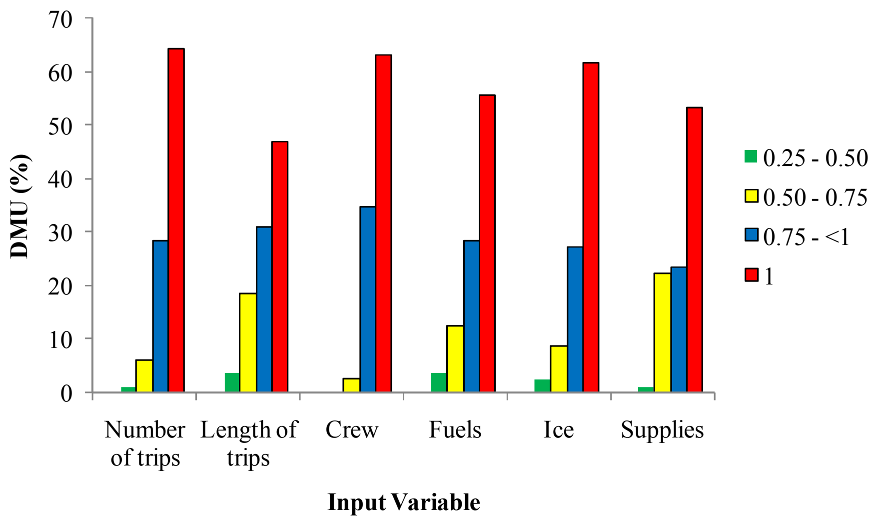

Fig. 7. Distribution of variable input utilisation (VIU) (%) during the intermonsoon season.

Discussion

The results of this study indicated that the productivity of purse seine has decreased dramatically over the last 5 years. Purwanto and Nugroho (2011) reported that the purse seine fisheries exhibited over capacity, characterised by an increase in the number of fishing vessels, catches and the expansion of fishing grounds. This situation is disturbing and does not augur well for the sustainability of purse seine fisheries and fish resources. Unlike in the manufacturing industry whose products can be controlled directly, fish production from fishing gear cannot be controlled directly and is affected by external factors. Given that fish catches change periodically (month and year), to ensure the continuity of fishing activity and fish production, the allocation of fishing fleets during fishing operations must be adapted to the needs of each fishing season.

The results of this study indicated that the response of fishermen in anticipating the changes of the fishing seasons had different impacts on input production usage. During the east monsoon season when fishing reached its peak number of hauls, fishermen increase their input production, and thus, exceed the necessary input production factor, which caused inefficiency in the inputs production usage. During the east monsoon season, fisheries reached the highest inefficiency (79% of DMUs were inefficient) compared to other seasons. During this peak fishing season, fishermen tried to catch as much as possible, by increase input production (fishing trips, fuel and ice) respectively, which caused an excess in input production. In contrast, the inter monsoon season showed the highest efficiency (43.2%) compared to the other seasons.

From the results, it has become apparent that the management strategy for the purse seine fishing fleet is more efficient and productive based on the management of monthly activity, as opposed to annual activity. A monthly fleet arrangement can control the optimum use of inputs production more easily each month. Furthermore, in order to guarantee the continuity of fishing business activity, it is necessary to reform the strategy of the purse seine fishing operations. The decreasing amount of catches and increased competition between fishing gears, will lead to overcapacity. Hufiadi and Wiyono (2009, 2010), who conducted a study on purse seine gear in Pekalongan, concluded that under conditions of enhanced competition, the utilisation of fishery resources tends to lead to the occurrence of overcapacity.

In general, it can be said that the purse seine in Rembang has experienced more input or a surplus of production input, so there needs to be a reduction in production input to an optimum level, so that the purse seine fishery becomes more competent. The average value of VIU on purse seine vessels was under 1 VIU level ($1<VIU$), which indicates that the purse seine at the study site had a surplus of production inputs. The increased competition in capturing fish is believed to be the factor which causedan excessive input production. Decreasing fish catches and increasing operation costs encouraged fishermen to increase their fishing effort (both in number and catching capacity). Consequently, fishermen competed for limited fish resources and fishing grounds. To win in this

competitive environment, they have always attempted to improve their craft's ability by increasing or enhancing their inputs production (fishing trips, fuel and ice).

Similar phenomena in small-scale fisheries have also been observed in the Mediterranean Sea and Southeast Asia (Madau et al.2009; Salayo et al. 2008). Metzner (2005) explained that the change in fishing capacity was caused by changes in aspirations and methods of fishing operations, instead of aspects of fish biology. On this basis, it is necessary to decrease the number of input variables in order to obtain the optimum value for the operating capacity. Since the average value of VIU for the variable inputs used in this analysis as well as the length of fishing trips (0.857), supplies (0.875) and ice (0.908) are less than 1, thus improving fish production performance and ensuring sustainable levels of resources of the fisheries in the Java Sea can be initiated by reducing the duration of fishing trips (14.3%), supplies (12.5%) and ice (9.2%) respectively.

Conclusion

Our study has set forward a framework for evaluating the level of technical efficiency of purse seine between the different monsoon seasons in smallscale tropical coastal fisheries in Rembang, Indonesia. The technical efficiency was investigated seasonally by calculating the activity of the daily fishing gear in each season. The results of this study have provided new information, which showed that the levels of technical efficiency of the fishing gear responded to seasonal variations.

In general, the study showed that the levels of purse seine capacity in Rembang have a surplus of input usage. The use of inputs production during the east monsoon season confirmed the highest inefficiency, while during the inter monsoon season the use of inputs production was at its lowest point of ineffectiveness. Therefore, action to reduce the excessive input production, such as fishing trips (14.3%), supplies (12.5%) and ice (9.2%) respectively is required.

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