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## Optimizing purse seine fishing operations in the Java Sea, Indonesia

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**Abstract**. In order to compete with others, fishermen adopt several fishing technics and tactics, and hence, occasionally, fishermen's' responses to environmental changes exceed the requirements. Thus, it is argued that this phenomenon will threaten sustainable fisheries activity. To manage fisheries to be sustainable, we need a study on the factors that influence the success of fishing operations and management. To answer this problem, we have conducted a research on purse seine fishing gear in Rembang, Central Java Indonesia. The results of this study showed that three factors affect purse seine fishing catches, i.e. length of trip ($p < 0.01$), ice ($p < 0.01$), and the cost of supplies for fishing operations ($p < 0.05$). However, the length of trip (days), ice (blocks) and the cost of supplies for fishing operations (Rp.) have a variable input utilization (VIU) number of less than 1. In order to optimize purse seine fishing operations, it is essential to reduce the policy of a fishing trip, ice and the cost of supplies for fishing operations.
**Key Words**: input production, Java sea, optimizing, purse seine, variable input utilization.

**Introduction**. Due to limitations in fish resources, competition between fishing gear has increased frequently. To be able to compete with others, fishermen have improved in terms of technology and their fishing methods. However, fishermen's responses to external factors are limited by internal factors, such as capital and fishing equipment. The fishermen utilize the external factors, especially climate and catches to adapt their behaviour. Hence, fishermen's understanding of the environmental conditions (weather, waves and currents) and fishing locations, as well as skills in the operation of fishing gear and fishing tools will determine the success of fishing activities (Salas & Gaertner 2004).

As a response to the increase in competition, the fishermen have attempted to improve the ability of their vessel's by influencing production factors, such as adding, enlarging or replacing the production factors that they consider to have an effect on the success of fishing production (Wiyono et al 2006). Typically, developing their production factor is not based on adequate needs analysis, but based on instinct and the desire to compete with competitors. On this basis, it is necessary to initiate an effective capacity management programme based on the understanding of the level of input factors usage during fishing operations. In several previous studies, fishing gears were usually analyzed by technical or physical attributes (Ali & Lee 1995; Purbayanto et al 2000; Almeida et al 2003). In fact, in order to increase their income revenue, fishermen tend to equip their fishing vessels with new technology and fishing methodology. Fishermen adapt their efforts to fluctuations in external factors, for instance, catch volumes, price of the catch, climate (Hilborn & Walters 1992; van Oostenbrugge et al 2002; Ulrich et al 2001) and as a result of the competition that arises (Jennings et al 2001).

Therefore, in order to help resource managers to have a better understanding on the condition of the fisheries, especially to determine the performance of fishing gears, which needs management attention, a study on the level of input factors used in fishing operations was extensively conducted. In order to understand fishermen's responses to external factors, the study was conducted in Rembang, Central Java. As in other developing countries, the uncontrolled, rapid expansion of the capacity of small scale fisheries in Indonesia has meant that currently there are challenges with overcapacity and reducing excessive capacity (Berkes et al 2001). This study has attempted to determine the internal factors that have significanly influenced fish catches and make the most effective use purse seine fisheries in Rembang, Indonesia.

**Material and Method**. The study was conducted at Tasik Agung coastal fishing port, Rembang Central Java during May–November 2012 (Figure 1). Data on fleet characteristics, including boat size, gear dimensions, and engine power of the vessel were collected over the course of the year by direct measurement and object observation of 125 purse seine samples and interviews with their owners or the captains' of the vessels. Related data corresponding to fishing operations include fishing boat trips; fishing tactics and their catch were also collected. In detail, the input factors which were collected were vessel tonnage, vessel dimensions, gear dimensions, engine power, number of trips, crew numbers, fuel consumption, and operation days, ice consumption and supplies. Conversely, for output data, we also collected a fish catch from a purse seine which had been landed in the fishing port.

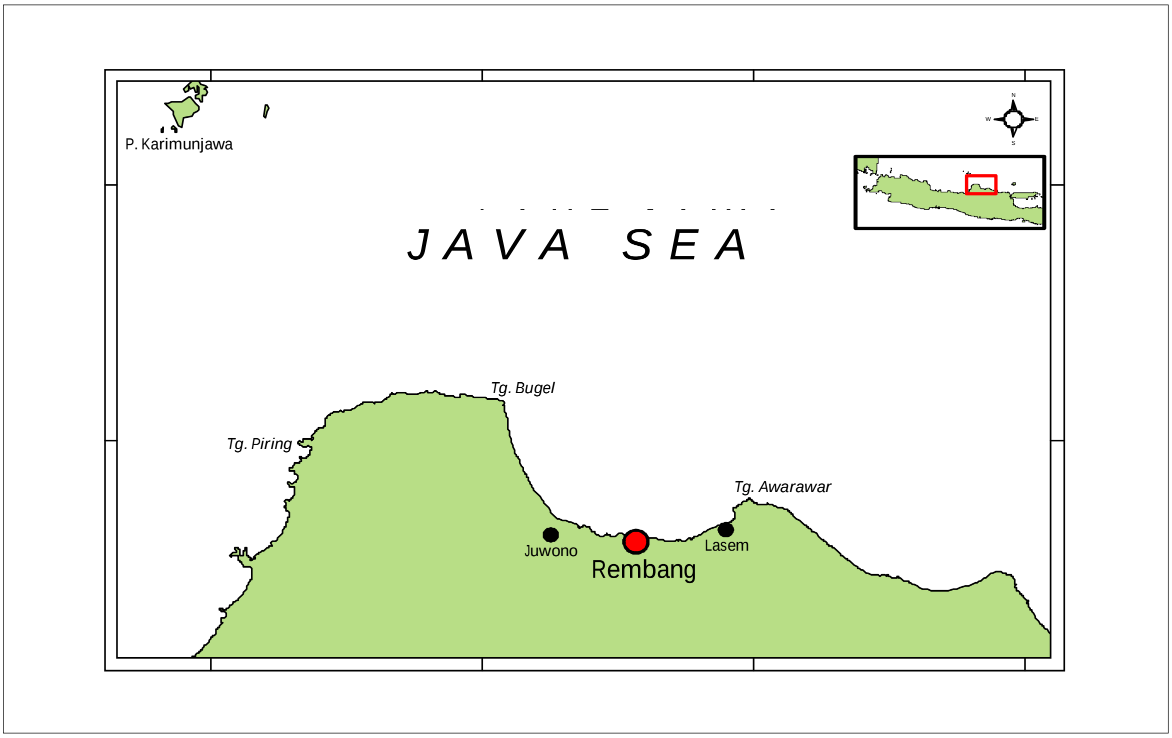


Figure 1. Map of Rembang, Central Java Province, Indonesia (Redrawned from earth map of Geospatial Information Agency of Indonesia 2014).

***Data analyses***. To determine the factors which influence fishing gear catches, we analyzed production factors by using the Cobb-Douglass production function (Soekartawi 1994), as follows:

$$Y = aX_1^{b_1} X_2^{b_2} \dots X_i^{b_i} \dots\dots X_n^{b_n} e$$

The Cobb–Douglas function form can be estimated as a linear relationship using the following expression:

$$LnY = Lna_0 + b_1 LnX_1 + b_2 LnX_2 + \cdots + b_n LnX_n + Ln\, e$$

where: Y = production factors;

$X_1 \dots X_n$ = input factors;

$a_0$ = intercept;

b1 … $b_n$ = regression coefficient;

e = errors.

We have chosen fish production as the dependent variable (Y) for the analysis, and the length of fishing boat (X1), machine engine (X2), length of trip (X3), number of crew (X4), ice (X5), fuel consumption (X6), and the supplies cost of fishing operations (X7) as the independent variables. To account for the presence of autocorrelation among error in regression formula and multicollinearity among explanatory variables, the Durbin-Watson test and variance inflation factor (VIF) were applied respectively (Ryan 1997). The Durbin-Watson test demonstrated that for the whole regression model, significant autocorrelation was often present. To reduce the presence of autocorrelation in the data, the analyses were conducted using the average from the monthly data set.

Furthermore, to optimize the input factors that extensively affect purse seine fishing operations, we calculated the variable input utilization (VIU) by using data envelopment analysis (DEA) (Cooper et al 2007; Kirkley et al 2001; Tingley et al 2003). The output component of this study is scad, the dominant fish caught by purse seine. Meanwhile, the volume of a boat (GT) was determined as the fixed input ($x_f$), while variable inputs ($x_v$) were determined from the results of the previous regression analysis, the variables that considerably affect the catch. The optimum or full input utilization values were solved by the following equations (Fare et al 1989):

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

subject to

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

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

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

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

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

where $z_j$ is the intensity variable for the *j*th observation; $\theta_1$ the technical efficiency score or the proportion by which output may be expanded when production is at full capacity; and $\lambda^*_{jn}$ the ratio of optimum use of input $x_{jn}$ to observed input use of $x_{jn}$.

The VIU 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 provides 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 (falls short of) 1.0 in value, there is a shortage (surplus) of the *i*th variable input currently employed and the firm should expand (contract) use of that input.

**Results and Discussion**. Purse seine fisheries have increasingly developed in Rembang (Central Java) in recent years. Firstly, purse seines are operated in traditional fishing grounds around the coastal area of Rembang. However, since the early 2000s, purse seines from Rembang have expanded their fishing grounds and compete with the purse seine industry in similar fishing areas (Karimunjawa and Bawean waters), and on occasion also operate in the northern waters of Madura, Kangean and Masalembo. Purse seine developed notably from 2006-2011 (Ameriyani 2014). The development was not only in terms of catch numbers, but also in terms of fishing tactics. To gather fish, purse seines in Rembang were equipped with fishing lights (mercury and halogen) that produced power of between 7000-18000 watts.

Purse seines in Rembang, were mainly located in three fishing ports, Sarang, Rembang and Kragan. Fishing boats in Rembang were 10–16.5 metres in length. To operate purse seine, fishing vessels were equipped with two main engines (60–190 HP).

Due to their size, purse seine in Rembang did not operate their gear far from the fishing base, typically operating around Rembang up to Bawean Island on one day trips.

Purse seine was the main fishing gear used in Rembang and played a significant role in the total pelagic production. The purse seine catch in Rembang was dominated by scad (*Decapterus* sp.) followed by sardine (*Sardinella* sp.) and mackerel (*Rastrelliger* sp.) (Nababan et al 2014; Statistics Indonesia of Rembang Regency 2012; Wijopriono & Genisa 2003). Based on their target species, the purse seine fishing season started in October and finished in March, while from April to September fishing activity was minimal. Due to competition between fishing gears, purse seine productivity in Rembang over the last 5 years (2007-2011) revealed a decline (16%). On the other hand, result of the analysis also indicated that purse seine productivity in 2007 was recorded to be approximately 3.618 kg $trip^{-1}$ and by 2011 had declined to 3.023 kg $trip^{-1}$ (Mahiswara et al 2012) (Figure 2).

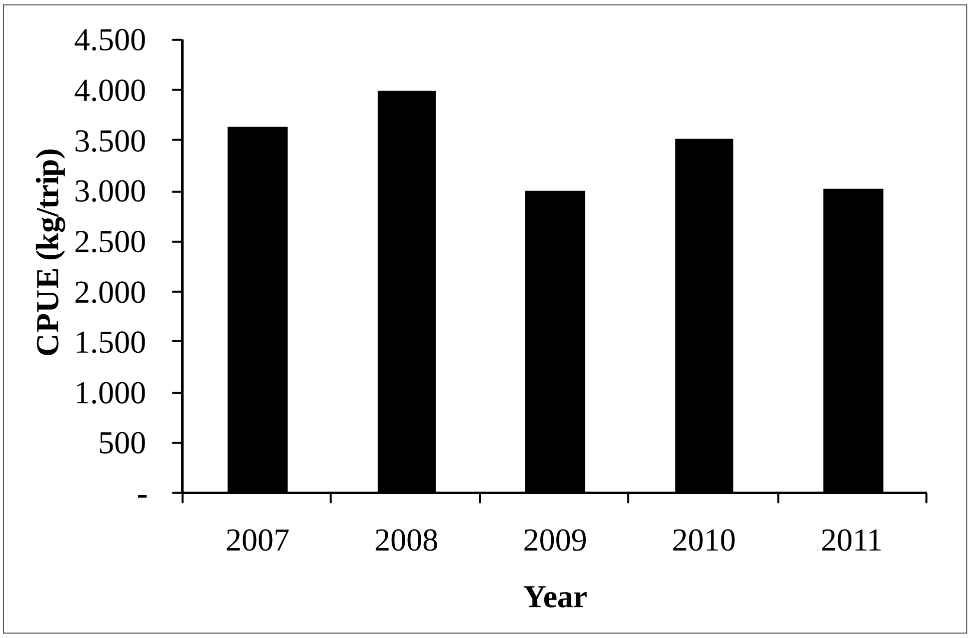


Figure 2. Purse seine productivity in Rembang from 2007-2011 (Mahiswara et al 2012).

As stated previously, this study has tried to consider seven factors in fishing operations that affect the fish production (Y), factors which have been noted from X1 to X7 as the independent variables. The results of this analysis indicate that not all of these factors significantly affect the total production of purse seine. There are only three factors that appreciably affect the total production; these are length of trip ($p < 0.01$), ice ($p < 0.01$) and the cost of fishing supplies ($p < 0.05$). These three aspects can explain 86.7% of all the factors that affect the total production of purse seine (R2 = 0.867), and only 13.3% were explained by other features (Table 1). The duration of a trip has a positive coefficient (b = 0.355), which means that the increase in the length of a trip resulted in an increase in the catch. Ice (b = 0.455) and the cost of fishing supplies (b = 0.179) also have a positive coefficient, which means that the increase in ice and the cost of fishing supplies will increase the catch. The results of this study also indicated that the length of trips has an elasticity of 0.355, whilst ice and the cost of fishing supplies have an elasticity of 0.455 and 0.179. Overall, the rate of return to scale in the production function equation produces a value of 0.989 (elasticity < 1). This means that the increase in input factors cannot produce an output greater than the input used proportionately.

Meanwhile, the results of the technical efficiency analysis revealed that the use of production inputs (length of fishing trip, ice and the cost of supplies for a fishing trip) were inefficient. Length of trip, ice and the cost of supplies for fishing operations have an average VIU of less than 1. This means that the use of inputs production has a surplus variable input that is currently being employed (Table 2). The highest surplus variable input usage was occupied by ice (87.1%), followed by the cost of supplies for fishing operations (90.5%) and the duration of the fishing trip (95.2%). In general, the results from this study demonstrated that the level of inefficiency of variable input usage occurred at a VIU range of 0.75 - <1 (Table 3).

Table 1

Parameters estimated for the fish production model

| *Model* | *Unstandardized coefficients* | | *t-statistics* | *Significantly* | *Collinearity statistics* | |
|---|---|---|---|---|---|---|
| | *B* | *Std. error* | | | *Tolerance* | *VIF* |
| (Constant) | 1.844 | 0.356 | 5.185 | 0.000 | - | - |
| X3 | 0.355 | 0.115 | 3.097 | 0.003 | 0.200 | 4.991 |
| X5 | 0.455 | 0.110 | 4.119 | 0.000 | 0.132 | 7.590 |
| X7 | 0.179 | 0.069 | 2.602 | 0.011 | 0.239 | 4.178 |

Table 2

Variable input utilization of input factors

| *Input factors* | *VIU* | *Surplus* |
|---|---|---|
| Length of trip | 95.2 | 4.8 |
| Ice | 87.1 | 12.9 |
| Supplies | 90.5 | 9.5 |

Table 3

Distribution of Variable Input Utilization

| *Range of VIU* | *DMU's (%)* | | |
|---|---|---|---|
| | *Length of trip* | *Ice* | *Supplies* |
| < 0.25 | 0 | 1.6 | 0.00 |
| 0.25 - 0.50 | 0 | 0.8 | 2.40 |
| 0.50 - 0.75 | 4.8 | 18.4 | 9.60 |
| 0.75 - <1 | 29.6 | 43.2 | 37.60 |
| = 1 | 65.6 | 40 | 50.40 |

Due to mechanization, modernization and the application of other fabricated inputs, purse seine fisheries in Rembang have grown steadily in number. More recently, the purse seine fisheries have reached over capacity, which is characterized by an increase in the number of fishing vessels, catches and the expansion of fishing grounds. Thus, the uncontrolled, rapid expansion in the capacity of purse seines has been confronted by challenges in overcapacity and in reducing excessive effort capacity (Berkes 2001). To reduce the impact of over capacity, the Indonesian government has applied management measures, although these methods have not been well implemented. In other words, the fisheries are *de jure* under a government-managed regime, but *de facto,* enjoy open access with no restrictions on fishing practices (Nikijuluw 2002). The productivity of the fisheries has been decreasing in recent years, resulting in increasing levels of impoverishment among fishers.

As a first step in optimizing fishing operations, this study on optimizing input factors in purse seine fisheries was conducted in Rembang, Central Java. In this particular case, fishing operations should take account of both economic and biological sustainability. Besides the development and improvement of their production inputs, fishermen have also developed fishing strategies/tactics in fishing operations (Andersen & Christensen 2006; Cinner et al 2009). Fishermen tend to respond in different ways depending on their understanding of weather, the market, fish resources, boat/fishing gear and the skills they possess (Salas & Gaertner 2004; Béné & Tewfik 2001; Charles 2001; Daw et al 2011). Finally, an economic approach is expected to be able to solve an excess of input factors, so as to become efficient in the use of production factors, which could lead to overcapacity.

The results from the technical efficiency analysis showed that the three factors (length of trip, ice and the cost of supplies for fishing operations) have a VIU value of less than 1, which means that the use of input production factors have a surplus of the variable input currently being used. In the long term, these symptoms tend to lead to overcapacity and over fishing. To make the most of purse seine fishing operations, a strategic policy to reduce fishing trips, ice and the cost of supplies for fishing operations is required. Based on the analysis of the results, fishing trips should be reduced by approximately 14.3% from the current condition, while ice and the cost of supplies for fishing operations should be reduced by 9.2% and 12.5% respectively.

Furthermore, in order to guarantee the continuity of fishing business activity, it is necessary to reform the purse seine operation strategy. Given that catches are decreasing and competition between fishing gear has become more intense, reducing input factors during fishing operations is necessary. This is because the profligacy of input production usage in fishing operations tends to lead to the occurrence of overcapacity symptoms (Wiyono & Wahju 2006; Hufiadi & Wiyono 2009, 2010). Operationally, because the fish production of fishing gear cannot be controlled directly and depends on external factors, to ensure the continuity of fishing activity and fish production, the allocation of fishing inputs during fishing operations must be taken into account during the fishing season (Primyastanto et al 2014). The management strategy for the purse seine fishing operations is more appropriate and productive if it is based on monthly rather than annual activity. In addition, a more efficient and beneficial, monthly fleet arrangement can also control the optimum use of inputs production more easily. Moreover, from the variable input factors, the efficiency of the fishing can also be initiated by the development of the fishermen's abilities (Shen et al 2013); and increasing the added value of fish and other sea products by means of enhancing the storage capability, packing and processing (Ceyhan & Gene 2014).

**Conclusions**. Purse seine fisheries in the Java Sea, especially in Rembang have been decreasing year on year. In order to understand the fisheries performance, it was necessary to conduct a study that can explain the factors that influence purse seine catches. The study used the Cobb-Douglas and DEA model to investigate the input variables and their efficiency in purse seine fishing operations. The results show that from the seven input variables that are considered to influence purse seine hauls, only three input variables significantly influence purse seine fish catches, specifically the length of a trips ($p < 0.01$), ice ($p < 0.01$), and the cost of fishing supplies for operations ($p < 0.05$). Furthermore, the results from the technical efficiency analysis of the three input variables demonstrate that the variable inputs were not fully technically efficient. The length of the trip, ice and the cost of fishing supplies for operations have a VIU number of less than 1, which means that the input production factors are surplus consumption. To optimize purse seine fishing operations, the length of a fishing trip (4.8%), ice (12.9%), and the cost of fishing supplies for operations (9.5%) need to be reduced.

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