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Bio-economic model of Danish seine and purse seine fisheries in Rembang Regency, Indonesia

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ABSTRACT

The fisheries in Indonesia is multi-gears fisheries, including in Rembang Regency. Rembang Regency had fishery production of 36,243 tons in 2017 and very dependent on purse seine and Danish seine fisheries. Although they have different fishing operation, but types of fish caught by purse seine and Danish seine are partly of the same species. The interrelation of fish species caught shows the risk of interrelation between purse seine and Danish seine (negative externalities) which can encourage overfishing. The purpose of this research was to make the model of relationship between Danish seine and purse seine fisheries in Rembang Regency with a bio-economic approach. We have modified Gordon-Schaefer model (single gear) to be a multi-gears model that can explain the reciprocal relationship between Danish seine and purse seine fisheries, and also we did optimization of production and profit. This research has proven that Danish seine fishing efforts have a negative impact on the production of purse seine fisheries, and vice versa. The combination of 328 units of purse seine and 304 units of Danish seine will produce optimal aggregate production (62,286 tons per year). While the combination of 176 units of Danish seine and 348 units of purse seine will generate an aggregate profit of IDR 510 billion per year as the win–win solution for both Danish seine and purse seine fisheries. The highest aggregate profit will occur at 370 units of purse seine fisheries and 0 units of Danish seine, which will generate a profit of IDR 535 billion per year.

Introduction

Indonesia is the second largest capture fisheries producer in the world (FAO, 2014) and has the second longest coastline in the world, i.e. 54,716 km (CEA, 2018). Therefore, fisheries development in Indonesia has a strategic role. The pattern of capture fisheries in Indonesia is multi species and multi gears. It is estimated that Indonesia has 8500 fish species (Kep No. 67/KEP-BKIPM/2015) and there are 67 types of fishing gear in Indonesia which are grouped into 12 types of fishing gear classifications (BBPPI, 2013). So, there are several types of fish and fishing gears that are operated in each of fishing grounds in Indonesia. Therefore, there is an inter-relation between several fishing gears.

Rembang Regency is one of the coastal regency in Indonesia with capture fisheries production of 36,243 tons in 2017 (DKP Kabupaten Rembang, 2017) and has a coastline length of 63 Km (BPS Kabupaten Rembang, 2018). Rembang Regency is very dependent on purse seine and Danish seine fisheries as the backbone of capture fisheries in Rembang Regency. In 2017, purse seine production in Rembang Regency was 72.07% and Danish seine production was 27.89% of Rembang Regency marine fisheries production (DKP Kabupaten Rembang, 2017). Both of these fishing gears have a greater fishing power than other fishing gears in Rembang Regency, i.e. gill net, fishing line, trammel net and traps.

Purse seine capture fish schools that are drawn to fish-attracting devices. The target of purse seine fisheries is pelagic fish, including skipjack, yellowfin tuna, and frigate (CEA, 2018). The use of drifting fish aggregating devices in purse seine operation since the early 1990s (Fonteneau et al., 2013). Purse seine operation has three steps, i.e. setting, immersing and hauling. The Danish seine was invented by the Danish fisherman (in 1848) and then became one of the most important fishing gears used in Denmark. Danish seining consists of three main steps, i.e. setting, collecting and closing phase (Herrmann et al., 2016). Purse seine and Danish seine are active fishing gear, that is, actively searching the target fish location.

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Purse seine and Danish seine have different fishing operation patterns. Purse seine has pelagic fish as target. While Danish seine chose demersal fish as target (BBPPI, 2013; Anggawangsa et al., 2014). Danish seine ('cantrang') in Indonesia has been modified by fishermen so that its characteristic is similar to trawl and can be categorized as mini trawl (Adhawati et al., 2017; Wijayanto et al., 2019). Although the pattern of fishing operation is different, the types of fish caught by purse seine and Danish seine are partly the same type. Several aquatic animals that catched both by purse seine and Danish seine include (DKP Kabupaten Rembang, 2017): *Restrelliger brachysoma* Bleeker (short mackerel), *Selaroides leptolepis* Cuvier (yellowstripe scad), *Loligo* sp (squid), *Leiognathus equulus* Forsskal (common ponyfish), *Trichiurus* spp (largehead hairtail), *Netuma thalassina* Ruppell (giant catfish), *Lutjanus* spp (red snapper), *Sphyraena barracuda* Edwards (great barracuda), *Megalaspis cordyla* Linnaeus (torpedo scad) and *Abalistes stellaris* Bloch and Schneider (starry triggerfish).

The fishing operations for Danish seine and purse seine fisheries from Rembang Regency fishermen are on FMA of 712 or Java Sea. The potential of fish resources in FMA of 712 is 981,680 tons per year. Demersal and small pelagic fish resources are the biggest potential of FMA of 712 (33% and 31%). While the potential of large pelagic fish resources is 11%, the rest is a combination of reef fish, shrimp, lobster, mud crab, blue crab and squid (Keputusan Menteri KP No. 79/2016).

Many types of fish are caught different by Danish seine and purse seine, but possibly that fish catch have interaction because they live in the same ecological area, including food chain relationship. Lotka and Volterra are the pioneer scientists who develop of inter-species relationship models through their studies in 1925 and 1926. Several researchers also conducted multi-species bio-economic studies that explain the relationships between species. Kar and Pahar (2007) made a predator–prey model in a reserved marine environment. Verma et al. (2014) made predator–prey model in two different cases of aquatic environments (open access and reserved area). Das et al. (2009) developed a predatory model that follows the logistic growth model. Rojas-Palma et al. (2012) made predator–prey model in the case of open access where prey growth is influenced by the Allee-effect (low population density) and predators are general. Toaha and Azis (2018) developed a modified predator–prey model from the Leslie-Gower model. Singh and Weninger (2009) and Kasperski (2011) used a combination of multi-species and multi-gears. Smith et al. (2016) developed a model of 3 species to optimize fish harvest with several alternative scenarios.

In this research, the characteristic of multi species was ignored, and we used single stock assumption follow the Gordon-Schaefer Model. The linkage of the types of fish caught shows the risk of inter-relation between purse seine and Danish seine fisheries, i.e. technological (negative) externalities. The competition of fishermen to catch fish encourages overfishing. In the world, overfishing is getting higher, that is around 31.4% in 2013 (FAO, 2016).

In the case of Danish seine and purse seine fisheries in Rembang Regency, the two fishing gears have a mutually influential relationship. Therefore it is necessary to manage Danish seine and purse seine capture fisheries. The bio-economic model can be used to develop fisheries management of Danish seine and purse seine in Rembang Regency. Several researchers have conducted multi-gears bio-economic studies, including Campbell and Kennedy (2010), Kasperski (2011), Hammarlund et al. (2018), and Wijayanto et al. (2019). The purpose of this study was to analyses the interrelationship of Danish seine and purse seine fisheries in Rembang Regency with a bio-economic approach. The results of this study can be used to develop alternative policies in the fisheries management of Danish seine and purse seine in Rembang Regency.

Research methods

Research location

The main location of our research were at 'Tasik Agung' fishing port and also 'Pandangan', 'Karang Anyar' and 'Sarang' fish landing places (Fig. 1). Tasik Agung' fishing port is fishing base of Danish seine fisheries. 'Pandangan', 'Karang Anyar' and 'Sarang' fish landing places are main fishing base of purse seine fisheries (Fig. 2).

The collecting data

This research used statistical data on capture fisheries in Rembang Regency issued by the Maritime and Fisheries Office (government agency, namely 'Dinas Kelautan dan Perikanan' or DKP) of Rembang Regency, i.e. production and fishing gears, both purse seine and Danish seine in 2010–2017. We were also survey and interview to purse seine fishermen (30 respondents) and Danish seine fishermen (30 respondents). We collected information about costs of capture fisheries business, and price of fish. The survey was conducted in April-May 2019.

The research model

We developed our bio-economic model based on the Gordon-Schaefer model. One of the assumptions of the Gordon-Schaefer model is single gear, and we modified to a multi-gears model in case of Danish seine and purse seine. If both Danish seine and purse seine fisheries production are affected by the effort of Danish seine and purse seine, then the equation is as follows (modified from Wijayanto et al., 2019):

$$C_{PS} = a.E_{PS} - b.E_{PS}^2 - e.E_{DS} \quad (1)$$

$$C_{DS} = f.E_{DS} - g.E_{DS}^2 - h.E_{PS} \quad (2)$$

C_{PS} is purse seine production (kg), C_{DS} is Danish seine production (kg), E_{PS} is purse seine effort (unit), and E_{DS} is Danish seine effort (unit). While a, b, e, f, g and h is a constant. Eq. (1) can be modified become Eq. (3):

$$E_{DS} = E_{PS} - E_{PS}^2 - C_{PS} \quad (3)$$

If Eq. (3) is embedded in Eq. (1), then the maximization ($dC_{DS}/dE_{DS} = 0$) can generate Eq. (4):

$$E_{DS}* = f/2g \quad (4)$$

E_{DS}^* is the number of Danish seine (unit) that produce maximum production if the number of purse seine (unit) is equal to zero. Eq. (4) is identical to the C_{MSY} (production at maximum sustainable yield) in the Gordon-Schaefer model. Likewise, the process of maximization in purse seine will produce Eq. (5).

$$E_{PS}* = a/2b \quad (5)$$

E_{PS}^* is the number of purse seine (unit) that produce maximum production if the number of Danish seine (unit) is equal to zero. If C_{PS} in Eq. (1) and C_{DS} in Eq. (2) are combined into C_{PSDS} (kg), then equation (6) is produced. The optimization process of equation (6), i.e. $dC_{PSDS}/dE_{PS} = 0$ and $dC_{PSDS}/dE_{DS} = 0$, could generate Eqs. (7) and (8):

$$C_{PSDS} = C_{PS} + C_{DS} = (a - h).E_{PS} - b.E_{PS}^2 + (f - e).E_{DS} - g.E_{DS}^2 \quad (6)$$

$$E_{PS} ** = a - h/2.b \quad (7)$$

$$E_{DS} ** = f - e/2.g \quad (8)$$

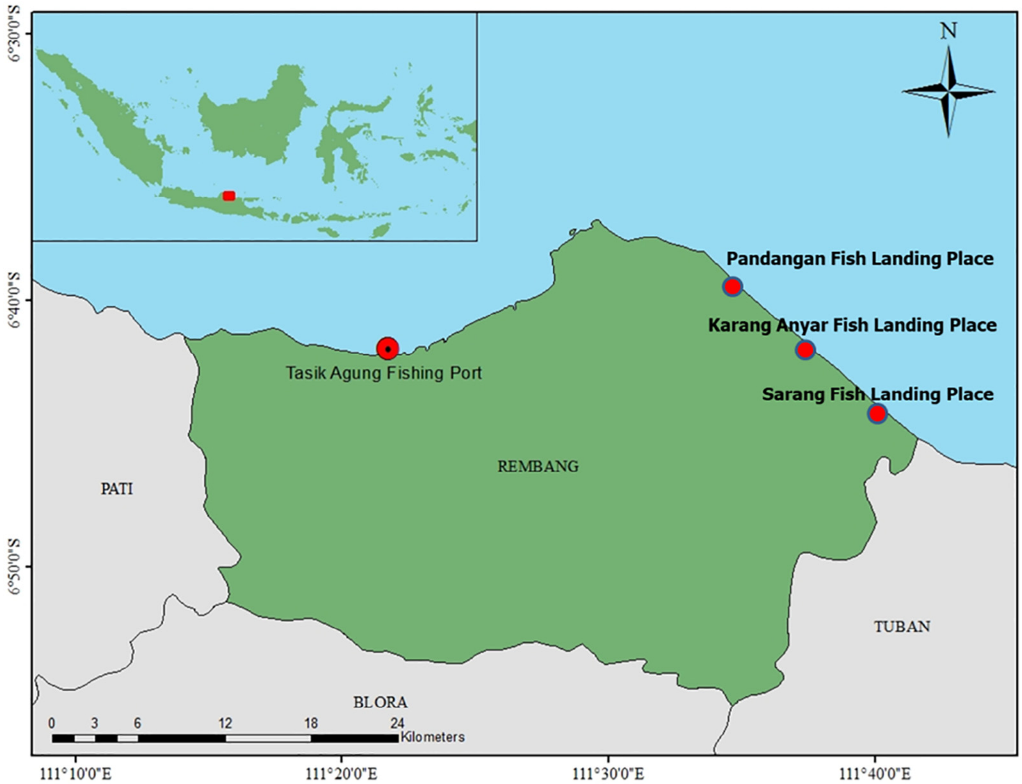

Fig. 1. The research location.

Fig. 2. Purse seine vessel and Danish seine vessel.

E_{PS}^{**} is the number of purse seine (unit) that produce maximum production if there is a Danish seine and purse seine reciprocal relationship. E_{DS}^{**} is the number of Danish seine (unit) that produce maximum production if there is a reciprocal relationship between the Danish seine and purse seine. If Eqs. (7) and (8) are included in Eq. (5) can generate Eq. (9), i.e. C_{PSDS}^{**} as maximum production of combined Danish seine and purse seine:

$$CPSDS** = \frac{a^2 - 2.a.h + h^2}{4.b} + \frac{e^2 - 2.e.f + ef^2}{4.g} \quad (9)$$

Then, we did the profit maximization. If each of fishing gears does not influence each other (or one of the gears is zero), then the profit equation uses Eqs. (10) and (11).

$$P_{DS} = C_{DS}.p_{DS} - E_{DS}.c_{DS} \quad (10)$$

$$P_{PS} = C_{PS}.p_{PS} - E_{PS}.c_{PS} \quad (11)$$

Π_{PS} is the profit of a purse seine if the number of Danish seine is equal to zero (IDR per year). Π_{DS} is profit of Danish seine if the number of purse seine is equal to zero (IDR per year). Notation p_{PS} is the price of fish caught by purse seine (IDR per kg, and p_{DS} is the price of fish caught by Danish seine (IDR per kg). Notation c_{PS} is the cost of purse seine (IDR per unit per year), and c_{DS} is the cost of Danish seine (IDR per unit per year). The cost components include fuel, consumption, asset depreciation, asset maintenance, licences, retribution or tax and remuneration, with standardized units in IDR per year. Purse seine and Danish seine catch several types of fish (multi species), but our model used the assumption of single species and single price. We used proportional average fish prices as a single price.

$$p_{PS} = \sum_{i}^{n} p_i.s_i \quad (12)$$

$$p_{DS} = \sum_{j}^{m} p_j.s_j \quad (13)$$

Notation p_i is the price of fish (IDR per kg) of the type i caught by purse seine, while n is the number of fish species caught by purse seine. Notation s_i is the biomass proportion of type i fish compared to the total biomass of purse seine fish catch (%). Notation p_j is the price of fish (IDR per kg) of type j caught by Danish seine, while m is the number of species of fish caught by Danish seine. Notation of s_j is the biomass proportion of fish type j compared to the total biomass of fish caught by Danish seine (%).

The combination Π_{DS} in equation (10) and Π_{PS} in equation (11) produces equation (14), i.e. Π_{PSDS} as follows:

$$P_{PSDS} = p_{DS}.f.E_{DS} - p_{DS}.g.E_{DS}^2 - p_{DS}.h.E_{PS} - E_{DS}.c_{DS} + p_{PS}.a.E_{PS} - p_{PS}.b.E_{PS}^2 - p_{PS}.e.E_{DS} - E_{PS}.c_{PS} \quad (14)$$

Π_{PSDS} is the aggregate profit of purse seine and Danish seine fisheries business if the two fishing gear have an interrelated relationship (IDR). The process of maximizing profits used $d\Pi_{PSDS}/dE_{DS} = 0$ and $d\Pi_{PSDS}/dE_{PS} = 0$ that generate Eqs. (15) and (16):

$$E_{DS} *** = (p_{DS}.f - c_{DS} - p_{PS}.e)/(2.p_{DS}.g) \quad (15)$$

$$E_{PS} *** = (p_{PS}.a - c_{PS} - p_{DS}.h)/(2.p_{PS}.b) \quad (16)$$

E_{PS}*** is the number of purse seine (unit) that produce maximum profit (Π_{PSDS}) if there is a reciprocal relationship between Danish seine and purse seine. E_{DS}*** is the maximum number of Danish seine (unit) that produce maximum profit (Π_{PSDS}) if there is a reciprocal relationship between Danish seine and purse seine. If Eq. (14) is optimized but in condition of $E_{DS} = 0$, then $C_{DS} = 0$ and the constants f, g and h are also zero, so that Eq. (17) is identical to E_{MEY} in the Gordon-Schaefer model. Similarly, the optimization of Eq. (14) with $E_{PS} = 0$ will produce Eq. (18):

$$E_{PS} **** = (p_{PS}.a - c_{PS})/(2.p_{PS}.b) \quad (17)$$

$$E_{DS} **** = (p_{DS}.e - c_{DS})/(2.p_{DS}.f) \quad (18)$$

E_{PS}**** is the number of purse seine (unit) that produce maximum profit of purse seine (Π_{PS}) if $E_{DS} = 0$ and $C_{DS} = 0$. E_{DS}**** is the number of Danish seine (unit) that produce maximum profit of Danish seine (Π_{DS}) if $E_{PS} = 0$ and $C_{PS} = 0$

Result and discussion

The progress of Danish seine and purse seine fisheries can be seen in Fig. 3. Purse seine fisheries are concentrated in the Fish Landing Place of Sarang, Pandangan and Kragan, and also in Coastal Fishing Port of Tasikagung. Purse seine vessels based in Rembang Regency have a length of 10.0–16.5 m, use 2 engines (60–190 HP), and lamps of 7000–18,000 W, i.e. mercury and halogen lamp (Wiyono and Hufiadi, 2014). Whereas Danish seine fisheries are concentrated in Coastal Fishing Port of Tasikagung. 'Cantrang' in Indonesia is a Danish seine that has been modified, therefore similar to trawl (CEA, 2018).

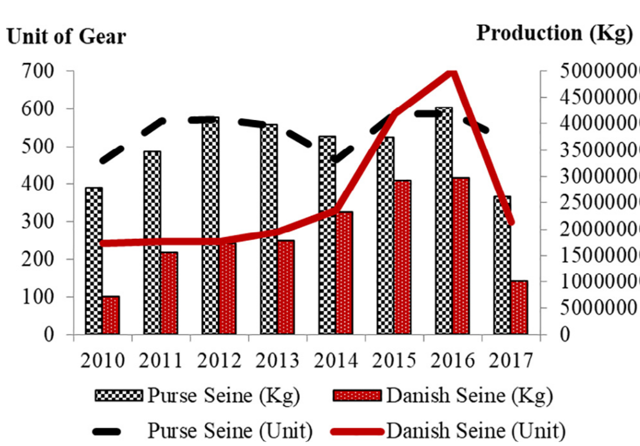

Fig. 3. The progress of purse seine and Danish seine in rembang regency.

Fishing ground of Danish seine and purse seine from Rembang Regency in Java Sea, where include in Fisheries Management Area (FMA) of 712. This is consistent with the results of interviews with respondents. Minister of Maritime and Fisheries Affair in 2015 had banned trawl and seine net operations (including Danish seine) through Ministerial Regulation No. 2/2015 because it is considered not environmentally friendly. However, the policy experienced pros and cons. Danish seine fishermen protest the ban of Danish seine operation (CEA, 2018), including Danish seine fishermen from Rembang Regency.

Costs and revenue

Based on the interviews results, an average of costs, fish prices and revenues of Danish seine and purse seine fisheries could be seen in Table 1. The size of Danish seine vessels in Rembang Regency is 50–80 GT (gross tons) with an investment cost of IDR 700–850 million (an average of IDR. 765 million). While the size of purse seine vessels in Rembang Regency is 25–30 GT (an average of 29 GT) with an investment cost of IDR. 500–650 million (an average of IDR. 580 million). All costs including investment costs were then converted into units of IDR per trip in the bioeconomic analysis (using Eqs. (10)–(18)). The average fish price of purse seine fishing gear is higher than Danish seine. Fish caught by Danish seine has a lower price because the partial of fish is under size and the fish is destroy (Wijayanto et al., 2019).

The relationship of Danish seine and purse seine

In this research, we made simulation using Eqs. (1) and (2). To simplify the linearization process, so Eq. (1) were divided by E_{PS} and Eq. (2) is divided by E_{DS} can produced Eqs. (20) and (22):

$$C_{PS}/E_{PS} = 273\ 131 - 363\ E_{PS} - 35\ 319\ (E_{DS}/E_{PS}) \quad (19)$$

Table 1
Average costs, revenues and fish prices.

Income, Fish Price and Cost	Danish Seine	Purse Seine
Gross Income (IDR per trip)	154,844,625	42,662,746
Harvest (tons per trip)	30	4
Fish price (IDR per kg)	5,161	10,666
Trip per years	8	32
Total cost per trip (IDR per trip)	139,311,835	35,158,334
Vessel depreciation (IDR per trip)	6,379,167	1,209,077
Main machine depreciation (IDR per trip)	658,750	327,009
Supporting machine depreciation (IDR per trip)	447,500	40,402
Fishing gear depreciation (IDR per trip)	486,875	1,399,554
Fishing aids depreciation (IDR per trip)	402,500	98,438
Vessel maintenance (IDR per trip)	5,815,625	181,052
Machine maintenance (IDR per trip)	2,097,500	181,845
Fishing gear maintenance (IDR per trip)	931,250	1,016,865
Fishing aids maintenance (IDR per trip)	245,000	86,409
Diesel fuel (IDR per trip)	16,347,500	3,412,500
Oil (IDR per trip)	1,125,000	1,660,714
Consumption of crews (IDR per trip)	51,300,000	8,232,143
Licences and administration (IDR per trip)	2,296,875	500,496
Harvest tax (IDR per trip)	7,742,231	2,133,137
Profit sharing for crews (IDR per trip)	43,036,063	14,678,694

Notes: assuming the economic life for vessel of 15 years, machine of 10 years, and fishing gear of 5 years.

$$C_{PS} = 273\,131\,E_{PS} - 363\,E_{PS}^2 - 35\,319\,E_{DS} \quad (20)$$

$$C_{DS}/E_{DS} = 188\,696 - 252\,E_{DS} - 35\,211\,E_{PS}/E_{DS} \quad (21)$$

$$C_{DS} = 188\,696\,E_{DS} - 252\,E_{DS}^2 - 35\,211\,E_{PS} \quad (22)$$

Based on Eqs. (20) and (22), it is evident that the fishing effort of Danish seine influences (decreases) the production of purse seine fisheries, and vice versa. Several research results also showed that Danish seine (including mini trawl) and trawl influencing the productivity of other fishing gear (Adhawati et al., 2017; Hammarlund et al., 2018; Wijayanto et al., 2019). That conditions need to be considered by the government to manage Danish seine and purse seine fisheries for the fishermen welfare in Rembang Regency, as well as the wider area. The study of Hammarlund et al. (2018) also proved that two fishing gear with the same target can cause negative externalities. It is proven that a multi-gears bio-economic study is needed for the purposes of optimizing production and economy.

Purse seine productivity is influenced by factors of production, including time of trip, supplies and ice that will affect the operating costs of fishing (Wiyono and Hufiadi, 2014). Purse seine is also a productive fishing gear to catch tuna and other large pelagic fish, thus providing greater profit compared to pole and line, hand line and troll line fisheries, both in MSY (maximum sustainable yield) and MEY (maximum economic yield) conditions (Natsir, 2018). Purse seine is also proven to be an effective fishing gear to catch small pelagic fish compared to trawl and drift net (FAO, 2001).

By using Eqs. (20) and (22), it can be simulated the production of purse seine and Danish seine, including if it is assumed that $E_{DS} = 0$ or $E_{PS} = 0$. The simulation showed that if $E_{DS} = 0$, it will make increased C_{PS}, and vice versa. However, the combination of E_{DS} and E_{PS} tends to produce higher amounts of C_{DS} and C_{PS} in aggregate production. That is due to a part of fish caught by purse seine and Danish seine is different types of fish. Simulation results from Eqs. (20) and (22) can be seen in Table 2 and Fig. 4.

The optimization of production

By using Eqs. (4), (5), (20) and (22), it can be estimated that the optimal fishing effort per fishing gear. The simulation result showed that when $E_{PS} = 376$ units can produce a maximum C_{PS}, which is 51,367 tons per year if it is assumed to be $E_{DS} = 0$. While the optimal E_{DS} at 374 units that can produce an optimal C_{DS}, which is 35,280 tons per year if $E_{PS} = 0$. By using Eqs. (6), (7), (8) and (9), we can estimate the optimal combination of E_{PS} and E_{DS} that produce optimal C_{PS} and C_{DS} in aggregate, namely $E_{PS} = 328$ units and $E_{DS} = 304$ units which will produce an aggregate production of 62,286 tons per year. Simulation of purse seine and Danish seine production can be seen in Table 3 and Fig. 5.

The combination of purse seine and Danish seine in scenario 3 generate optimal production, because catches of purse seine and Danish seine are partly different. Elimination of one fishing gear (purse seine or Danish seine) will eliminate the production of certain types of fish. The most of aquatic animal catches from purse seine in Rembang Regency are *Decapterus macrosoma* Bleeker (shortfin scad), *Sardinella fimbriata* Valenciennes (fringescale sardinella), *Auxis thazard* Lacepède (frigate tuna), *Restrelliger brachysoma* Bleeker, *Selaroides leptolepis* Cuvier and *Loligo* sp (dominated by pelagic resources). *Decapterus macrosoma* Bleeker and *Sardinella fimbriata* Valenciennes are not caught by Danish seine. While *Restrelliger brachysoma* Bleeker, *Selaroides leptolepis* Cuvier and *Loligo* sp are also caught by Danish seine. The main catches of Danish seine are *Priacanthus tayenus* Richardson (purple-spotted bigeye), *Nemipterus hexodon* Quoy and Gaimard (ornate threadfin bream), *Lutjanus* spp, *Saurida tumbil* Bloch (greater lizardfish), *Leiognathus equulus* Forsskal, *Gerres* sp, *Caranx tille* Cuvier (tille trevally), *Netuma thalassina* Ruppel, *Gymnara* sp, grouper fish, *Selar crumenophthalmus* Bloch (bigeye scad), *Megalaspis cordyla* Linnaeus and *Trichiurus sp*. So the Danish seine catches are dominated by demersal fish. However, *Leiognathus equulus* Forsskal, stingray, *Selar crumenophthalmus* Bloch and *Trichiurus sp* are also caught by purse seine (Anggawangsa et al., 2014; DKP Kabupaten Rembang, 2017).

The fish resources caught in Java Sea have links between one type of fish and another. The relationship can be in the form of predator–prey, food and space competition and mutually beneficial relationships. Carnivorous fish will eat smaller fish. Large pelagic fish are generally carnivores (Anggawangsa et al., 2014). Even some types of fish are cannibal, which is to eat a smaller type of fish, including *Trichiurus sp* (Bittar et al., 2012). *Trichiurus sp* is known as fish that have a very broad geographical distribution, i.e. tropical waters (including Indonesia) and sub-tropical (Hsu et al., 2009). *Selaroides leptolepis* Cuvier is small pelagic fish which live in groups, can reach an individual length of 20 cm and is indicated to have been overfishing in sea-waters of Banten, that is also part of FMA of 712 (Mayalibit et al., 2014). Likewise, anchovies in the Malacca Strait bordering the Java Sea have also been overfishing (Tambun et al., 2018). It is recommended to catch fish that can be caught larger than 11.9 cm in length (Sala et al., 2018). While *Restrelliger brachysoma* Bleeker in the Java Sea is partly native to the Java Sea, i.e. partly comes from the South China Sea. *Restrelliger brachysoma* Bleeker from the South China Sea migrates to the Java Sea, but is not found in sea-waters of Banyuwangi or the eastern end of the Java Sea (Indaryanto et al., 2015). Squid include positive photo taxis that is attracted to the light used in purse seine operations. *Leiognathus equulus* Forsskal live in groups in sandy or muddy sand at a depth of 10–50 m. *Leiognathus equulus* Forsskal has high growth and recruitment. The main food of *Leiognathus equulus* Forsskal is copepod (zooplankton) and phytoplankton (Prihatiningsih et al., 2014).

The optimization of profit

We used Eqs. (10)–(18) to develop scenarios for optimizing the profitability of Danish seine and purse seine fisheries businesses. The simulation results can be seen in Table 4 and Fig. 6. The simulation showed that $E_{DS} = 0$ will produce greater aggregate profit

Table 2
The aggregate production simulation of purse seine and Danish seine.

Years A	Unit of Purse Seine (E_{PS}) B	Unit of Danish Seine (E_{DS}) C	Production of Purse Seine (kg) D	Production of Danish Seine (kg) E	Production of Purse Seine (kg) if $E_{DS} = 0$ F	Production of Danish Seine (kg) if $E_{PS} = 0$ G	$C_{PS} + C_{DS}$ (kg) H = D + E
2010	461	243	40 170 037	14 722 220	48 752 543	30 954 393	54 892 257
2011	568	246	29 313 614	11 150 612	38 002 077	31 150 339	40 464 226
2012	572	246	28 750 523	11 009 769	37 438 986	31 150 339	39 760 292
2013	553	272	30 403 437	13 186 728	40 010 193	32 658 293	43 590 165
2014	464	331	36 873 833	18 477 035	48 564 407	34 814 840	55 350 868

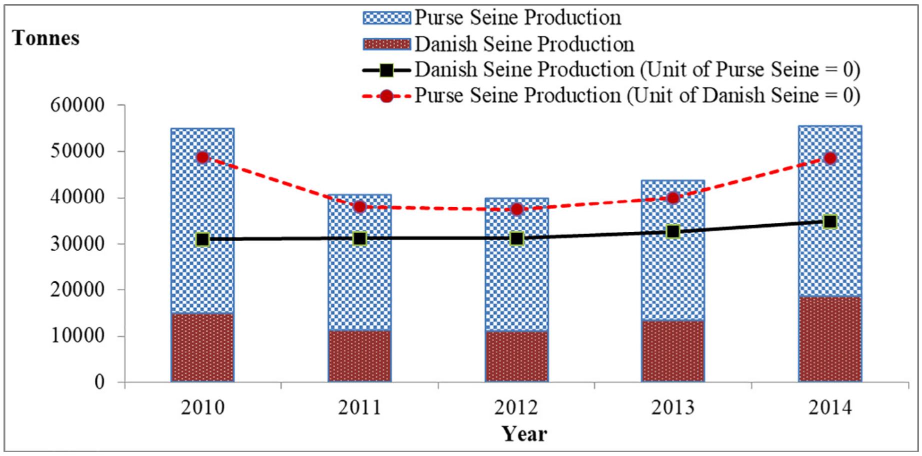

Fig. 4. The simulation of purse seine and Danish seine production.

Table 3
The aggregate production optimization simulation.

	E_{PS} (units)	E_{DS} (units)	C_{PS} (tonnes)	C_{DS} (tonnes)	$C_{PS} + C_{DS}$ (tonnes)
Scenario 1	0	374	0	35 280	35 280
Scenario 2	376	0	51 367	0	51 367
Scenario 3	328	304	39 779	22 507	62 286

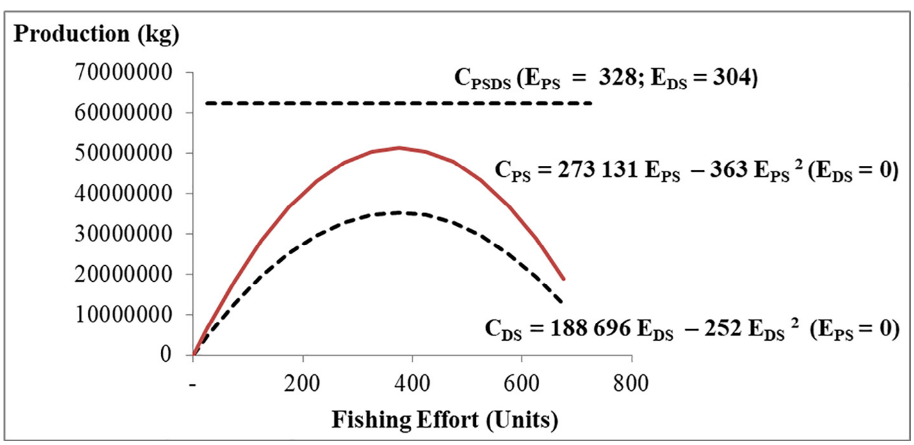

Fig. 5. The optimization simulation of purse seine and Danish seine production.

than $E_{PS} = 0$. This happens because the value of production and fish price of Danish seine is small compared to the fish price of purse seine.

In the case of the Tegal region (a distance of 277 km from Rembang Regency), the Danish seine operation has a negative impact on gill net production. The average of gill net production loss was 3814 tonnes per year. The loss production of gill net can be replaced by Danish seine production, but the loss value of gill net production (in IDR) is greater than Danish seine production value (Wijayanto et al., 2019).

Note: Assuming fish price that caught by Danish seine is IDR 5161per kg, and by purse seine of IDR 10,666 per kg, and also cost per trip of Danish seine is IDR. 139,311,835 and purse seine of IDR. 35,158,334.

The combination of purse seine and Danish seine fisheries that produce maximum aggregate profit occurs if $E_{DS} = 176$ units $E_{PS} = 348$ units as win–win solution. To clarify, a simulation of E_{DS} and E_{PS} is conducted, with two scenarios, i.e. the first scenario E_{DS} fixed at 176 units, while the second scenario E_{PS} fixed at 348 units (Fig. 7).

Table 4
The aggregate profit optimization simulation of purse seine and Danish seine.

	E_{PS} (units)	E_{DS} (units)	Π_{PS} (IDR Billions)	Π_{DS} (IDR Billions)	$\Pi_{PS} + \Pi_{DS}$ (IDR Billions)
Scenario 4	0	320	0	134	134
Scenario 5	370	0	427	0	535
Scenario 6	348	176	469	40	510

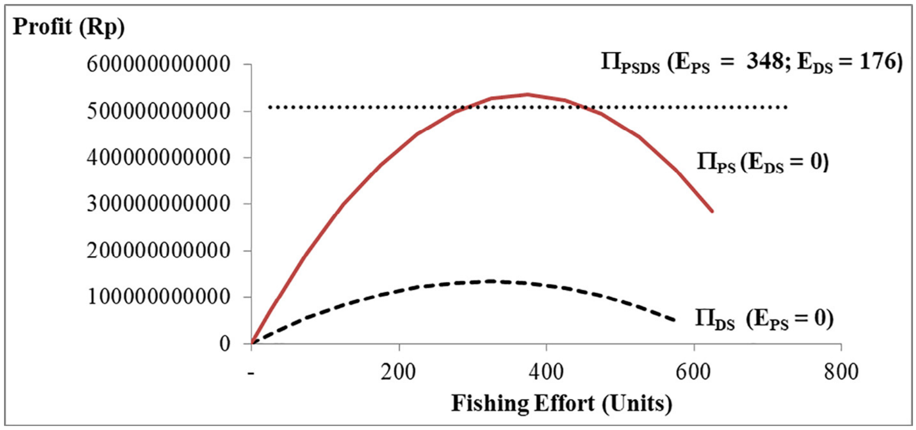

Fig. 6. The profit simulation of purse seine and Danish seine.

The alternative policy of Danish seine and purse seine

Based on several simulations in scenarios 1–6, it can be seen the consequences in Danish seine and purse seine management. We can use the game theory approach. In the case of Danish seine and purse seine fisheries, it is similar to the game theory model of 'prisoner's dilemma', so there needs to be cooperation to optimize production and profits among actors, both Danish seine and purse seine fishermen. Collaborative fisheries cooperation between actors has been proven to be able to optimize the benefits of each actor, including through fishing quotas (Campbell and Kennedy, 2010).

If the Rembang Regency government select control toward purse seine for the optimizing Danish seine fisheries, then purse seine fishermen will feel disadvantaged. Based on the characteristics of purse seine and Danish seine, the government tends not to take this scenario, because the Danish seine is considered controversial (not environmentally friendly). Several disadvantages of trawl (including modified Danish seine) are seafloor pressure, fuel use, and bycatch (Hammarlund et al., 2018). Increased selectivity of fishing gear can affect the condition of fish resource stocks, both in quantity and distribution of age composition of fish (Prellezo et al., 2017). FAO (2001) also suggests the need for trawling restrictions (licensing). In this study, it is evident that the results of the simulation of a decrease in fishing effort (especially modified Danish seine) can produce greater economic benefits.

If the Rembang Regency government prefer to control Danish seine fisheries for the purpose of optimizing purse seine fisheries, then Danish seine fishermen will have feel disadvantaged. In reality, Danish seine fisheries absorb workers not only fishermen, but also transportation service providers, transport workers, supply of Danish seine fisheries inputs and the fish processing industry. Whereas if the government does not regulate Danish seine fisheries and purse seine, then both parties do not get optimal benefits.

Therefore, it is recommended that the Rembang Regency government and the Indonesia government be able to use the optimization of a combination of Danish seine and purse seine fisheries. If government of Rembang Regency want to optimize aggregate production, then can use the combination of $E_{DS} = 304$ units and $E_{PS} = 328$ units. However, if government want to optimize aggregate profits, so can use the combination of $E_{DS} = 176$ units and $E_{PS} = 348$ units.

Policies to increase production related to improving food safety can be invalid in the medium and long term, although in the short term it can increase production. That is because overfishing can reduce production and increase business uncertainty in the medium and long term, which in turn will reduce income and food security (Maouel et al., 2014). According to Kompas et al. (2007), a combination of policies is needed. Each alternative fish resources management policy has weaknesses. MEY as a target will not be optimal without the support of appropriate instruments (input control). TACs (total allowable catches) and ITQs (Individual Transfer Quotas) as input control cannot be optimized without an output target. Limiting the number of units will encourage fishermen to reproduce other fishing gears. Therefore, a combination of policies is needed.

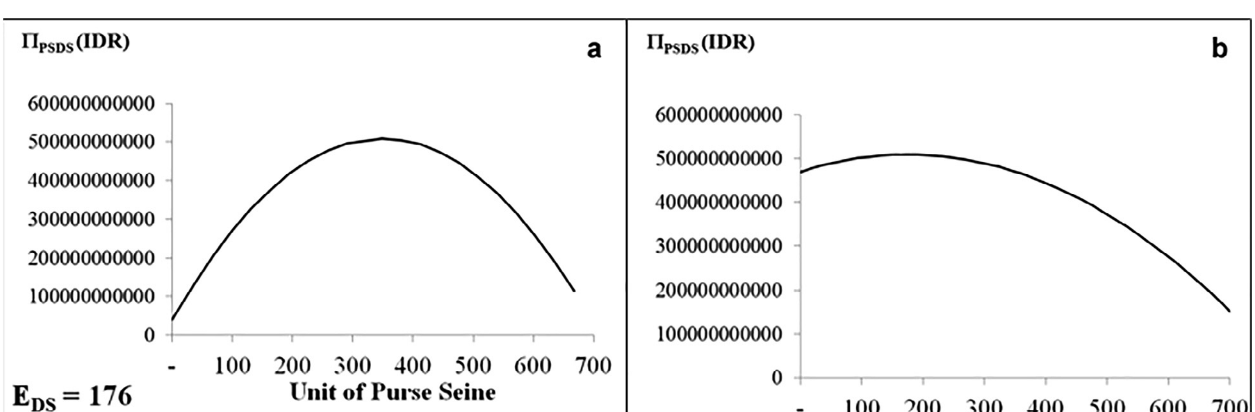

Fig. 7. The simulation of two optimization profit scenario.

Conclusion

This research proven that fishing effort of Danish seine has negative effect to purse seine production, and vice versa. The purse seine fisheries production function follows the equation: $C_{PS} = 273\ 131\ E_{PS} - 363\ E_{PS}^2 - 35\ 319\ E_{DS}$, while the Danish seine fisheries production function follows the equation: $C_{DS} = 188\ 696\ E_{DS} - 252\ E_{DS}^2 - 35\ 211\ E_{PS}$. The combination of $E_{PS} = 328$ units and $E_{DS} = 304$ units will produces an optimal aggregate of C_{PS} and C_{DS}, that is 62,286 tons per year. While the combination of $E_{DS} = 176$ units and $E_{PS} = 348$ units produces an optimal aggregate profit in win–win solution, that is IDR 510 billion per year, although this value is smaller than the optimization of the benefits of purse seine fisheries at $E_{PS} = 370$, $E_{DS} = 0$ and $C_{DS} = 0$ that produces profit of IDR 535 billion per year.

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