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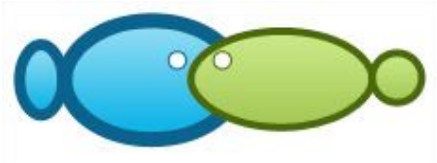

The multi-species fisheries model of fringescale sardinella and largehead hairtail in Rembang Regency, Indonesia

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Abstract. The characteristics of fisheries in Rembang Regency are multi-species fisheries. There is a production relationship between fringescale sardinella fish (*Sardinella* sp.) and largehead hairtail fish (*Trichiurus* sp.). It is suspected that the two types of fish have a predator-prey relationship (largehead hairtail fish as predator and fringescale sardinella fish as prey). The purpose of this study was to develop the multi-species model of fringescale sardinella and largehead hairtail in Rembang Regency. This study used time series data from 2010 to 2018, both production and fishing effort data. We also conducted observations and indepth interviews. This study produced a predator-prey model that can be used as a basis for fisheries management especially for fringescale sardinella and largehead hairtail fisheries. The results of the study can be used to estimate the optimal level of fishing effort for the production of fringescale sardinella (459 units of mini purse seine) and largehead hairtail (176 units of mini purse seine). While the optimal profit occurs in the fishing effort of 184 units of mini purse seine.
Key Words: mini purse seine, predator-prey model, Rembang Regency, *Sardinella* sp., *Trichiurus* sp.

Introduction. Fisheries are a complex systems due to multi-species and multi-gears aspects. Whereas many coastal people depend on fishery resources (Pelletier et al 2009), including the coastal community of Rembang Regency. Rembang Regency has a beach length of 63 km (the longest in Central Java Province, Indonesia). The coastal community of Rembang Regency relies on the capture fisheries business and the related fishing industry as one of the main livelihoods. There are more than 25 thousand fishermen in Rembang Regency (BPS-Statistics of Rembang Regency 2019).

Mini purse seine fishery is the biggest contributor (74% of total production) of marine fisheries in Rembang Regency, while Danish seine fishery is the second largest contributor (25% of total production) (DMF of Rembang Regency 2020). Small and large pelagic fish are the fish target of mini purse seine. While Danish seine is non-selective fishing gear that catch demersal fish, pelagic fish, squid, shrimps and crabs (Wijayanto et al 2020). Fringescale sardinella (*Sardinella* sp.) and largehead hairtail (*Trichiurus* sp.) are types of fish caught by mini purse seine. In 2018, largehead hairtail fish caught by mini purse seine in Rembang Regency were 263,913 kg, while fringescale sardinella fish were 5,645,972 kg (DMF of Rembang Regency 2020).

Tropical fisheries, including in Rembang Regency, are multi-species fisheries. Therefore, the relationship between species needs to be studied to optimize the sustainable exploitation of fish resources, including fringescale sardinella and largehead hairtail. Because both are caught by purse seine by the fishermen from Rembang Regency, it is an indication that the two types of fish have an ecological relation. Fringescale sardinella fish feed on plankton (Fischer et al 1990). While largehead hairtail is a carnivorous fish, including preying on smaller fish (Nakamura & Parin 1993). Fringescale sardinella and largehead hairtail are schooling fish. Fringescale sardinella is a pelagic fish. Whereas largehead hairtail is a demersal fish but adult fish can forage on the surface water during daytime and migrate to the bottom at night. So fringescale sardinella fish is one of food items of largehead hairtail fish.

Fisheries modeling can be used to study relationships between species. Optimizing sustainable production and maximizing profits is one of the challenges in fisheries management. Bioeconomic modeling emerged as a combination of biological studies (including population dynamics) and economics (Cahill & Robard 2014). Some bioeconomic analysis software has also been developed with specific data requirements (Prellezo et al 2009). However, in developing countries, including Indonesia, the availability of data is an obstacle in bioeconomic research. The purpose of this study was to develop the multi-species fisheries model of fringescale sardinella and largehead hairtail in Rembang Regency. The results of this study can be used as one of the considerations in the management of fishery resources, especially related to fringescale sardinella and largehead hairtail fish.

Material and Method

Research location. The research location was in Rembang Regency. Rembang Regency is located at coordinates of 111°00' to 111°30' east longitude and 06°30' to 07°00' south latitude (Figure 1). Mini purse seine vessels in Rembang Regency are based at Tasikagung coastal fishing port (CFP), Pandangan fish landing place (FLP), FLP of Karang Anyar and FLP of Sarang.

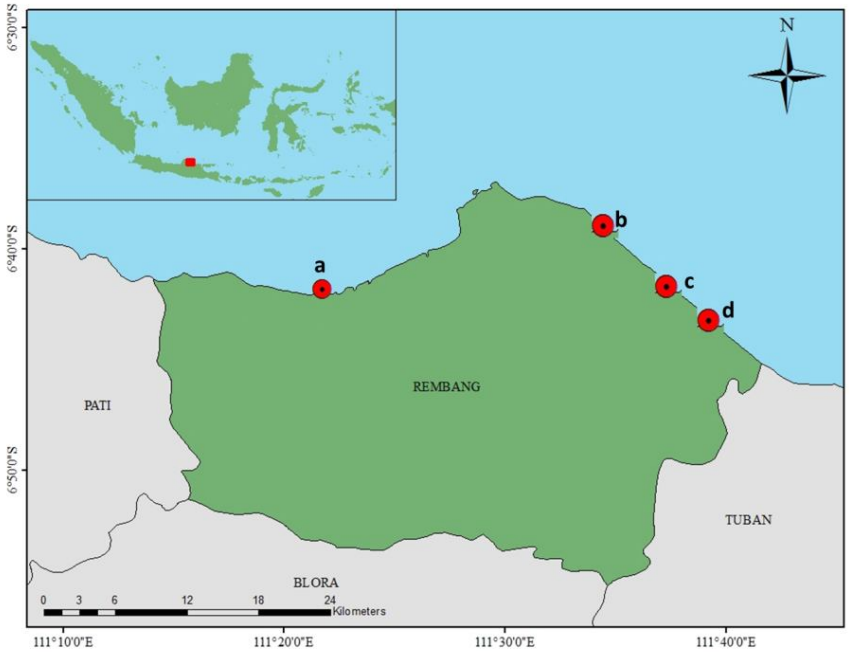


Figure 1. Rembang Regency map (Notes: (a) CSP of Tasikagung, (b) FLP of Pandangan, (c) FLP of Karang Anyar, (d) FLP of Sarang).

Research data. This research used time series data from 2010 to 2018, including production data (fringescale sardinella and largehead hairtail) and number of mini purse seine). We also conducted field observation and indepth interviews with key persons, both from government and business actors (fishermen).

Research model. Researchers have developed a multi-species fisheries model. There are several versions of the multi-species fisheries model, including analysing interactions between species (Wilson 2007). However, the development of fisheries models needs to be adjusted to the location of the study, including the availability of data. Based on the Schaefer model, capture fisheries production follows the following equations (Schaefer 1957):

$$C_{FS} = a\,E - b\,E^2 \quad (1)$$

$$C_{LH} = d\,E - e\,E^2 \quad (2)$$

C_{FS} is the production of fringescale sardinella (kg). C_{LH} is the production of largehead hairtail (kg). E is a fishing effort (mini purse seine unit). The notations a, b, d and e are constants. Equations (1) and (2) are assumed to have no ecological relationship between fringescale sardinella and largehead hairtail.

We modified the equations (1) and (2) into equations (3) and (4) assuming that the largehead hairtail preys on fringescale sardinella (predator-prey relationship). If the production of largehead hairtail catches up, it will cause the pressure on the stock of fringescale sardinella resources to decrease, so that the fishery production of fringescale sardinella can increase. Meanwhile, if the catch of fringescale sardinella increases then the availability of food for largehead hairtail fish decreases. This negatively affects the fish stocks and the production of largehead hairtail.

$$C_{FS} = a\,E - b\,E^2 + f\,C_{LH} \quad (3)$$

$$C_{LH} = d\,E - e\,E^2 - g\,C_{FS} \quad (4)$$

If equation (3) is added to equation (4), then equation (5) can be produced. Equation (5) can be modified into equations (6) and (7) which are different from equations (1) and (2). The process of maximizing equation (6) produces equation (8), while the process of maximizing equation (7) produces equation (9).

$$(1+g)\,C_{FS} + (1-f)\,C_{LH} = (a+d)\,E - (b+e)\,E^2 \quad (5)$$

$$C_{FS} = \frac{a+df}{1+gf}E - \frac{b+ef}{1+gf}E^2 \quad (6)$$

$$C_{LH} = \frac{d-ag}{1+gf}E - \frac{e-bg}{1+gf}E^2 \quad (7)$$

$$E_{C_{FS\,max}} = \frac{a+df}{2b+2ef} \quad (8)$$

$$E_{C_{LH\,max}} = \frac{d-ag}{2e-2bg} \quad (9)$$

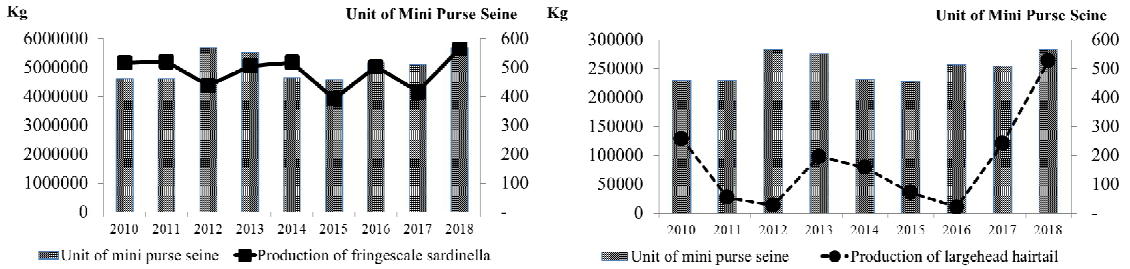
Profit (Π) is total revenue (TR) minus total cost (TC). In the case of a combination of fringescale sardinella and largehead hairtail fisheries using a mini purse seine, the profit equation can use equation (10). Profit maximization can be conducted by the first derivative procedure ($d\Pi / dE = 0$) which results in equation (11).

$$\Pi = C_{LH}.p_{LH} + C_{FS}.p_{FS} - cE \quad (10)$$

$$E_{\pi max} = \frac{p_{LH}(d-ag) + p_{FS}(a+df) - c - cfg}{2p_{FS}(b+ef) + 2p_{LH}(e-bg)} \quad (11)$$

Result and Discussions. Fisheries modelling provides very important benefits considering that natural fish resources are multispecies (Kar & Chaudhuri 2004). According to Puspita et al (2017), fringescale sardinella is a herbivorous fish. Whereas largehead hairtail is a carnivorous fish (Nakamura & Parin 1993; Nakamura 1995). The size of an adult fringescale sardinella fish is smaller than an adult largehead hairtail fish. Both of these fishes are caught with the same fishing gear. This indicates that both types of fish inhabit the same fishing ground, and there is a predator-prey interaction between the two types of fish.

The progress of fringescale sardinella and largehead hairtail production. The fringescale sardinella and largehead hairtail production in Rembang Regency fluctuates due to the number of mini purse seine in Rembang Regency. The progress of fringescale sardinella and largehead hairtail production can be seen in Figure 2. There is a pattern of productivity relationship (CPUE or catch per unit effort) between fringescale sardinella and largehead hairtail fisheries. This can be seen in Figure 3.



a. Production of fringescale sardinella b. Production of largehead hairtail

Figure 2. The progress of fringescale sardinella and largehead hairtail.

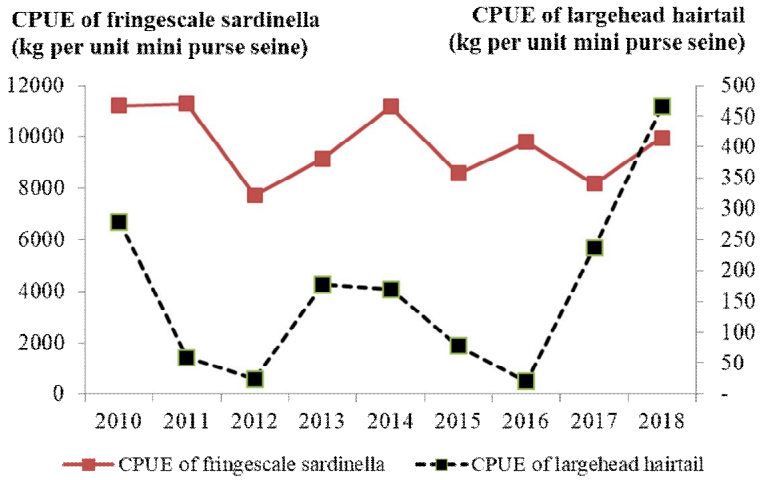


Figure 3. The progress of CPUE of fringescale sardinella and CPUE of largehead hairtail.

In Rembang Regency fisheries statistics, fringescale sardinella is called 'tembang' or 'jui' fish (local name). In this statistical data, the *Sardinella fimbriata* (fringescale sardinella) and *Sardinella gibbosa* (goldstripe sardinella) are put together as 'tembang' fish. *S. fimbriata* and *S. gibbosa* have similar forms. The way to distinguish the two types of fish in the field is through tongue observation. In *S. gibbosa*, the black chromatophores are distributed on all surfaces of the tongue. Whereas in *S. fimbriata*, the black chromatophores are distributed on the basis of the tongue (Dharmamba 1963). There is competition in foraging between *S. gibbosa* and *S. fimbriata* (Ghosh et al 2013). According to Puspita et al (2017), fringescale sardinella fish have low trophic level values and belong to the herbivorous group. Herbivorous fish with low trophic levels if overexploited can disturb the balance of the ecosystem.

Largehead hairtail or 'layur' fish (local name) is a demersal fish that migrate to the surface waters for feeding (vertical diurnal feeding migration). Adult largehead hairtail (*Trichiurus lepturus*) prey on fish (as a main food), squid and crustaceans. Whereas juvenile largehead hairtail fish prey on euphausiids, small pelagic planktonic crustaceans and small fish (Nakamura & Parin 1993; Nakamura 1995). *T. lepturus* has a maximum total length of 234 cm (Claro 1994). Whereas *S. fimbriata* has a maximum standard length of 13.0 cm, and *S. gibbosa* has a maximum total length of 29.6 cm (Whitehead 1985).

The production function and optimization. The results of analysis show that there is a relationship between the production of fringescale sardinella fish and largehead hairtail fish which can be seen in equations (12) and (13). This pattern of relationship strengthens the suspicion that there is a predator-prey relationship between largehead hairtail fish (as predators) and fringescale sardinella fish (as prey). Equations (12) and (13) are production functions of fringescale sardinella and largehead hairtail caught by

mini purse seine fishermen in Rembang Regency. The production function is a simplification, which the production of fringescale sardinella and largehead hairtail is actually influenced by many complex factors.

$$C_{FS} = 18{,}736\ E - 18.90\ E^2 + 3.27\ C_{LH} \quad (12)$$

$$C_{LH} = 1{,}109\ E - 1.67\ E^2 - 0.04\ C_{FS} \quad (13)$$

Equations (12) and (13) can be modified into equations (14) and (15) by referring to equations (6) and (7). Estimation of optimal fishing efforts to maximize fish production of fringescale sardinella and largehead hairtail can be seen in Table 1. While the results of simulation of equations (14) and (15) can be seen in Figure 4. The results of the profit simulation can be seen in Figure 5.

$$C_{FS} = 19{,}602\ E - 21.37\ E^2 \quad (14)$$

$$C_{LH} = 265\ E - 0.75\ E^2 \quad (15)$$

Table 1

The simulation of optimization

The optimal fishing effort	*Unit of mini purse seine*	*Production (kg per year)*
Production of FS	459	FS: 4,495,673
Production of LH	176	LH: 23,307
Optimal profit	184	FS: 2,883,374
		LH: 23,255
		Profit: IDR 6,857,526,368

Notes: FH is fringescale sardinella. LH is largehead hairtail. Assuming the average price of fringescale sardinella fish is IDR 8,510 per kg, the average price of largehead hairtail fish is IDR 27,535 per kg and the average cost per unit effort (mini purse seine) is IDR 99,574,470 per unit per year (proportional to fringescale sardinella and largehead hairtail production with total production).

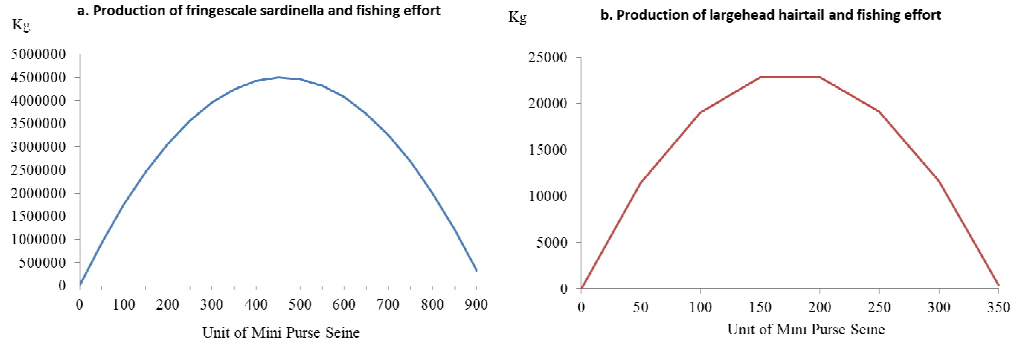


Figure 4. The production simulation of fringescale sardinella and largehead hairtail with fishing effort.

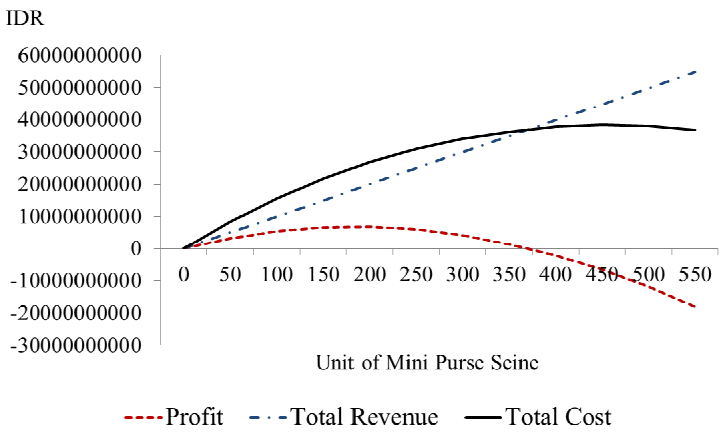


Figure 5. The simulation of revenue, cost, profit and fishing effort.

Largehead hairtail fish has a high selling value. The demand of largehead hairtail for international trading is relatively high. Although the price of fringescale sardinella fish is cheaper than the price of largehead hairtail fish, but the quantity of fringescale sardinella fish production is significant bigger than the production of largehead hairtail fish. Therefore, economically the production of fringescale sardinella and largehead hairtail fish has an important value for mini purse seine fishermen. Some of the simulation results above show that the fringescale sardinella and largehead hairtail fisheries using mini purse seine in Rembang Regency have exceeded the optimal fishing effort. That means inefficiencies have occurred in the exploitation of fringescale sardinella and largehead hairtail resources. Mini purse seine fisheries in Rembang Regency are multispecies fisheries, that there are more than 17 species of fish caught. However, to make a model with a large number of species has a very high level of difficulty.

In principle, the focus of fisheries modeling is to estimate the best management so that fish resources can be maintain sustainably by avoiding excessive utilization or overcapacity (Natsir 2015). Human greed in exploiting fish resources can cause the tragedy of the common. The gradual decline in fish populations leads to scarcity of resources. There are several ways that can be used to control the exploitation of fish resources, including minimum size fish harvest, protecting certain waters (spawning ground and nursery ground), closed season, fishing quotas and taxes. According to Bhatia et al (2017), fishing efforts can be reduced by applying taxes, both input and output taxes. According to Salmah et al (2012), fishing schedule can be applied to overfishing fisheries. Then, controlling the use of fish resources can affect the price of fish (Elfoutayeni & Khaladi 2012).

In multi-species fisheries, increased capture of prey species can affect other species (Purohit & Chaudhuri 2004; Nieminen 2012; Vidyanath et al 2017). Therefore, exploitation of fringescale sardinella needs to be controlled. According to Zulbainarni et al (2011), in order to achieve maximum economic profit from a fishery industry, it is necessary to separate the types of fish to be captured (the principle of selectivity). In practice, fisheries management in developing countries is relatively more difficult than developed countries. The problems of multi-species, multi-gears, and overfishing are complicated by the problem of poverty and employment. The number of fishermen in Indonesia, including in Rembang Regency, is relatively large. Therefore, regulation and restriction on fishery activities will have serious social, economic and political impacts. However, developing countries still need to manage the exploitation of fish resources for the long term interest.

Conclusions. There is a pattern of relationship between the production of fringescale sardinella and largehead hairtail what are captured using mini purse seine in Rembang Regency. The production function of fringescale sardinella fish which is influenced by the number of mini purse seine units and the production of largehead hairtail fish follows the equation C_{FS} = 18,736 E-18.90 E^2+3.27 C_{LH}. Whereas the production function of largehead hairtail fish which is influenced by the number of mini purse seine units and fringescale sardinella fish production follows the equation C_{LH} = 1,109 E-1.67 E^2-0.04 C_{FS}. The optimal level of effort for fringescale sardinella fish production is 459 units of mini purse seine. While the optimal level of effort for largehead hairtail fish production is 176 units of mini purse seine. The optimal profit of fringescale sardinella and largehead hairtail fisheries is estimated to occur in the amount of fishing effort of 184 units of mini purse seine.

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