Multi species model (anchovy, yellowstripe scad and narrow-barred Spanish mackerel) in Semarang coastal

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Abstract. The fishery sector in Semarang has been mostly dominated by artisanal fisheries with multi-gears and multi-species. Although the fishery sector was not the major contributor to the GRDP of Semarang city, the population of fishermen reached 1,068 whose welfare should be concerned. The fishery sector helped the eradication of poverty and supported food security in Semarang city. Anchovy (*Stolephorus* sp.), yellowstripe scad (*Selaroides leptolepis*) and narrow-barred Spanish mackerel (*Scomberomorus commerson*) share an ecological relationship as predator and prey, which both have been major marine commodities in Semarang city. Proper management should be applied to these species in an integrated manner. This study developed and applied a multi-species (predator-prey) model for anchovies, yellowstripe scad and narrow-barred Spanish mackerel. In this study, the production and fishing activities were developed particularly for the three types of fish. The results indicated an interrelated relationship between anchovy, yellowstripe scad and narrow-barred Spanish mackerel productions. Optimal anchovy production (237,230 kg) was obtained when the fishing activities involved 779 fishermen. Whereas, the optimal yellowstripe scad production (6,873 kg) was obtained when 791 fishermen were involved, and the narrow-barred Spanish mackerel production was at the highest (159 kg) when 1,168 fishermen were involved.
Key Words: multi-species model, optimization, *Stolephorus* sp., *Scomberomorus commerson, Selaroides leptolepis*.

Introduction. Semarang city is the capital of the Central Java Province (Indonesia). Manufacture, construction and trade are sectors with the most dominant contribution to the economy of the city. Meanwhile, the agriculture, forestry and fisheries sectors only contributed 0.86% to the gross regional domestic product (GRDP) of Semarang city in 2020 (BPS-Statistics of Semarang Municipality 2021a). However, in 2020, there were 1,068 households in Semarang city relying upon marine fishery as main source of family income. Fishermen families in Semarang city are concentrated in two coastal sub-districts; namely North Semarang and Tugu (BPS-Statistics of Semarang Municipality 2021b). Furthermore, the majority of population under the poverty line also lives along coastal areas of Semarang city, including in fishermen settlement areas (Muktiali 2018). It is urgent that stakeholders improve the fishery sector in Semarang city, particularly improving fishermen welfare, eradicating poverty, and increasing food security (Wijayanto et al 2021).

Fishery business in Semarang city still runs traditionally (artisanal fisheries). Artisanal fishery is rather multi-gear, done in one day fishing and constrained by limited capital (Wijayanto et al 2019). There have been more than 13 types of aquatic animals caught by fishermen from coastal areas of Semarang city, including anchovies (*Stolephorus* sp.), yellowstripe scad (*Selaroides leptolepis*) and narrow-barred Spanish mackerel (*Scomberomorus commerson*) (BPS-Statistics of Central Java Province 2020). These fish share ecological relationship within the food chain. Therefore, the management of the three types of fish needs to be conducted using an integrative approach, especially in determining any policy regarding multi-species modeling.

Anchovy bring strategic value for fishery development in Semarang city for it has dominant contribution to the fishery sector in Semarang city (BPS-Statistics of Central

Java Province 2020). Narrow-barred Spanish mackerel is a fish with high selling value. In the nature, anchovy is the prey for yellowstripe scad and narrow-barred Spanish mackerel. Yellowstripe scad is also the prey for the narrow-barred Spanish mackerel. Anchovy, yellowstripe scad and narrow-barred Spanish mackerel are pelagic fish. Anchovy and yellowstripe scad are small pelagic fish, while narrow-barred Spanish mackerel is categorized a large pelagic fish. This study developed and applied a multi-species model (predator-prey) of anchovy, yellowstripe scad and narrow-barred Spanish mackerel in the context of Semarang City. This model can be used for optimal production and sustainable fisheries management, especially for anchovy, yellowstripe scad and narrow-barred Spanish mackerel.

Material and Method

Time and location of research. The study was conducted from July to August 2021 in Semarang City (see Figure 1).

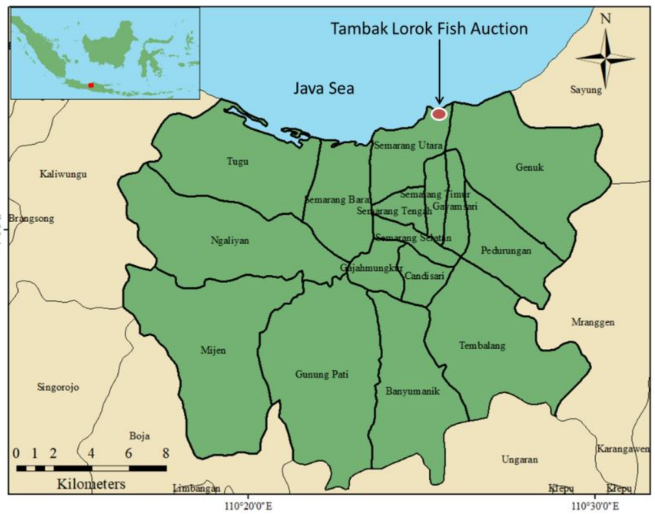

Figure 1. Semarang city map (note: Tambak Lorok Fish Auction (ret dot) as an observation location).

Data collection. Statistical data were collected through observations and discussions with fishermen at Tambak Lorok fish auction site. In the auction place, there are fishing bases and fishermen's settlements.

Research model. Schaefer model uses the single-species assumption. The following is the equation for the production of anchovy, yellowstripe scad and narrow-barred Spanish mackerel using the Schaefer model (Schaefer 1957):

$$C_A = a_1E - b_1E^2 \quad (1)$$

$$C_Y = a_2E - b_2E^2 \quad (2)$$

$$C_N = a_3E - b_3E^2 \quad (3)$$

where: C_A is anchovy production (kg); C_Y is yellowstripe scad production (kg); C_N is narrow-barred Spanish mackerel production (kg); E is fishing effort. In this study, the fishing effort refers to the number of fishermen involved. While a_1 , b_1, a_2, b_2, a_3, and b_3 are constants. In estimating constants, linear regression was used by dividing the two sides of equation (1), (2) and (3) by E.

The model developed in this study assumes a predator-prey relationship between anchovy, yellowstripe scad and narrow-barred Spanish mackerel (multi-species model). Previously, Wijayanto et al (2020a) had examined a multi-species (predator-prey) model for two types of fish with a case study of anchovy and squid fisheries on the coast of Jepara (71 km from Semarang city). Anchovies are prey to yellowstripe scad and narrow-barred Spanish mackerel which are larger in size, and yellowstripe scad are also prey to narrow-barred Spanish mackerel. Increases in the catch of narrow-barred Spanish mackerel will be followed by decreases in the stock of narrow-barred Spanish mackerel, reducing the pressure on the yellowstripe scad stock as prey of narrow-barred Spanish mackerel. Greater stock of yellowstripe scad can lead greater production of yellowstripe scad. Thus, there is a positive relationship between the production of narrow-barred Spanish mackerel and yellowstripe scad. Furthermore, if the production of yellowstripe scad increases, then the pressure on anchovy resources can be reduced where anchovy is the prey of yellowstripe scad. Furthermore, higher stock of anchovy is followed by higher potential for anchovy production to increase as well. Hence, anchovy production is positively correlated with yellowstripe scad and narrow-barred Spanish mackerel production as shown in equation (4):

$$C_A = a_4 + b_4 C_Y + b_5 C_N \quad (4)$$

The notations a_4, b_4 and b_5 are constants. Equations (1), (2), (3) and (4), showed that the production equation for yellowstripe scad and narrow-barred Spanish mackerel is related to the relationship between 3 species as follows (equations 5, 6 and 7):

$$C_A = a_4 + (a_2 b_4 + a_3 b_5)E - (b_2 b_4 + b_3 b_5)E^2 \quad (5)$$

$$C_Y = -\frac{a_4}{b_4} + \left(\frac{a_1}{b_4} - \frac{a_3 b_5}{b_4}\right)E - \left(\frac{b_1}{b_4} - \frac{b_3 b_5}{b_4}\right)E^2 \quad (6)$$

$$C_N = -\frac{a_4}{b_5} + \left(\frac{a_1}{b_5} - \frac{a_2 b_4}{b_5}\right)E - \left(\frac{b_1}{b_5} - \frac{b_2 b_4}{b_5}\right)E^2 \quad (7)$$

The production of each type can be optimized by first differentiating the procedure of the production function (equations 5, 6 and 7) with E equal to zero. The production optimization process resulted in the optimal fishing effort for each type of fish, as shown in equations (8), (9) and (10):

$$E_A = \frac{a_2 b_4 + a_3 b_5}{2(b_2 b_4 + b_3 b_5)} \quad (8)$$

$$E_Y = \frac{a_1 - a_3 b_5}{2(b_1 - b_3 b_5)} \quad (9)$$

$$E_N = \frac{a_1 - a_2 b_4}{2(b_1 - b_2 b_4)} \quad (10)$$

Meanwhile, based on the Schaefer model, the optimal fishing effort for each type of fish follows these equations (11), (12) and (13):

$$E_A = a_1 / 2\,b_1 \quad (11)$$

$$E_Y = a_2 / 2\,b_2 \quad (12)$$

$$E_N = a_3 / 2\,b_3$$

Results. The improvement of the production and catch per unit effort (CPUE) of anchovy, yellowstripe scad and narrow-barred Spanish mackerel in Semarang city can be seen in Figure 2. CPUE is an indicator of capture fisheries productivity that also reflects the fish resources abundance (Headley 2020), although CPUE cannot be used to predict the abundance of fish resources of all species (Wright et al 2006). The decrease in CPUE of the three types of fish indicates lower stock of these fish. Compared to the number of fishermen between 2011 and 2018, the number of fishermen increased from 1,315 persons to 1,575 persons (3% per year), while the population growth of Semarang city in 2018 was 1.71% per year (BPS-Statistics of Semarang Municipality 2021b).

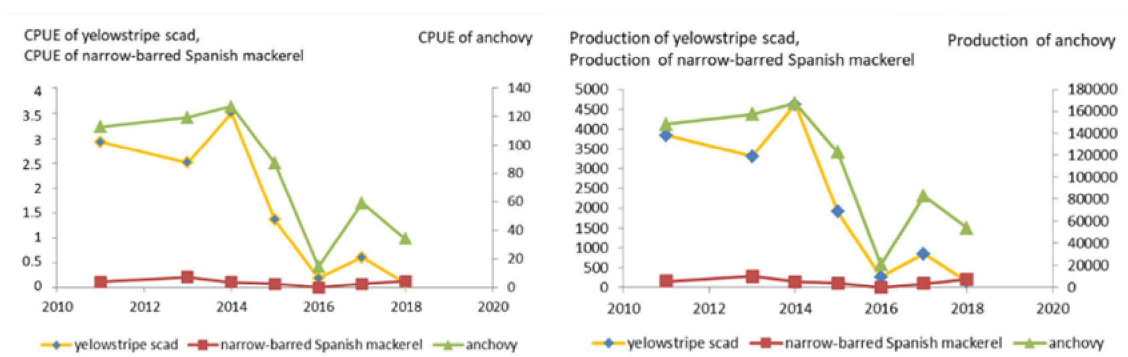

Figure 2. The progress of production (kg) and CPUE (kg per fishermen) of anchovy, yellowstripe scad and narrow-barred Spanish mackerel in Semarang city.

The multi-species modeling is presented in Table 1. For comparison, the production function was also estimated using the Schaefer model. Statistically, the multi-species model developed in this study has better R^2 than the Schaefer model. The results of this study indicated a relationship between anchovy, yellowstripe scad and narrow-barred Spanish mackerel caught by fishermen in the coastal waters of Semarang.

Table 1

Production function of anchovy, yellowstripe scad and narrow-barred Spanish mackerel with Schaefer model and multi species model

Schaefer model	*Multi-species model*
C_A = 578.46 E – 0.36 E^2 (R^2 = 0.56)	C_A = 31,197.15 + 26.27 C_Y + 141.87 C_N (R^2 = 0.92)
	C_A = 31,197.15 + 528.99 E - 0.34 E^2
C_Y = 18.51 E – 0.01 E^2 (R^2 = 0.65)	C_Y = -1,188.52 + 20.39 E – 0.00077 E^2
C_N = 0.30 E – 0.0001 E^2 (R^2 = 0.04)	C_N = -219.90 + 0.65 E – 0.0003 E^2

The simulation results of anchovy, yellowstripe scad and narrow-barred Spanish mackerel production using the Schaefer and multi-species model (Table 1) can be seen in Figure 3. Whereas, Table 2 presents the estimated optimal fishing effort for each type of fish.

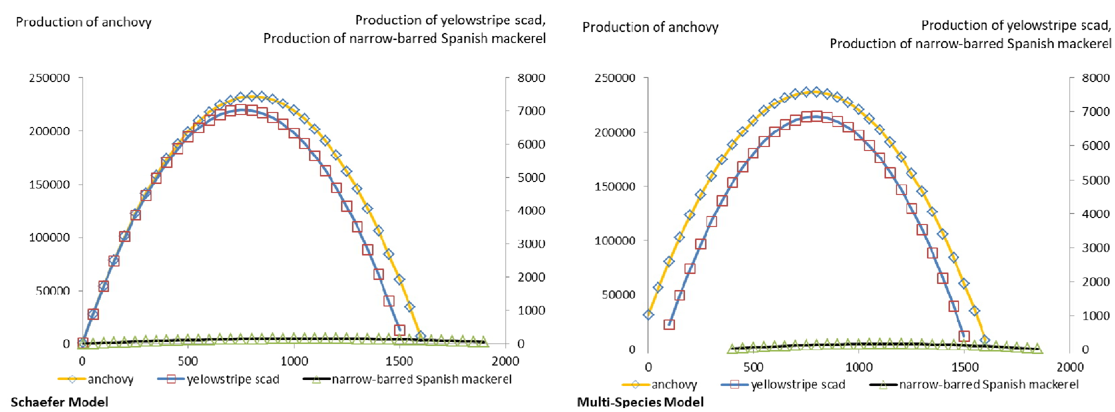

Figure 3. Simulation of the Schaefer model and multi-species model (note: the Y axis is the fish production (kg) and the X axis is the number of fishermen).

Table 2

Results of optimization of production and fishing effort

Type of fish	*Schaefer model*		*Multi-species model*	
	E optimal	*C optimal*	*E optimal*	*C optimal*
Anchovy	806	233,076	779	237,230
Yellowstripe scad	761	7,043	791	6,873
Narrow-barred Spanish mackerel	1,063	160	1,168	159

Note: the fishing effort unit is fisherman and the production unit is kg.

Table 2 shows the optimization results which indicate over-fishing of anchovy, yellowstripe scad and narrow-barred Spanish mackerel fisheries based on both Schaefer and multi-species models. Regarding this fact, Semarang city Government should manage the resources of anchovy, yellowstripe scad and narrow-barred Spanish mackerel in an environmentally friendly manner. Fish resource management policies must be carried out based on multidimensional approach by concerning the aspects of fish resources, aquatic environment, technology, social, and economy (Ulrich et al 2002; Wijayanto et al 2019). Poverty along the coastal areas of Semarang city makes management of fish resources on the coast of Semarang more complicated.

Discussion. Anchovy, yellowstripe scad and narrow-barred Spanish mackerel found in coastal areas of Semarang share an ecological relationship. Therefore, multi-species modeling can be applied to study this relationship. Some types of anchovy have been found in Indonesia, including *Stolephorus andhraensis*, *S. baganensis*, *S. chinensis*, *S. commersonnii*, S*. dubiosus*, *S. indicus*, *S. insularis*, *S. tri*, and *S. waitei*. Anchovy is a pelagic marine fish that moves in schools. Anchovies eat planktons, including copepods and prawn larvae. Anchovies are mostly found in coastal waters although they can also be found in river mouths (Whitehead et al 1988; Fuad et al 2019). The results of Pebruwanti & Fitrani (2021) research showed that anchovy found in the coast of Semarang city and Demak Regency (neighboring Semarang city) had a negative allometric growth pattern, showing that the growth of anchovy length is faster than its weight growth, with the longest length of 76.69 mm and the maximum weight of 8.8 g. On the other hand, Andamari et al (2002) stated that some types of anchovies had a positive allometric growth pattern.

Anchovies are prey to a wide variety of larger carnivorous fish, including yellowstripe scad and narrow-barred Spanish mackerel. Wijayanto et al (2020a) also found that anchovy and squid share predator-prey relationship. The peak season for anchovy fishing varies in different waters. The study done by Irnawati et al (2018) showed that the anchovy fishing season in the western of the Java Sea is between January to June with a peak in April, while the anchovy fishing season in the Sunda Strait is from April to September with a peak in April. The fishing equipment used in catching anchovies in the Java Sea include the lift net and 'waring' purse seine (using a small mesh size) (Chairunnisa et al 2018; Irnawati et al 2018; Wijayanto et al 2020a). In Java Sea, fishermen use lights at night because anchovies have positive phototactic properties (Chairunnisa et al 2018). Fitri et al (2018) found that *Stolephorus* sp. has a cone cell structure in the form of a regular square connected to each single cone surrounded by four double cones, indicating that anchovies are sensitive to light. Human activities can also affect their presence. In a study, Fricke et al (2012) proved that the opening of the Suez Canal in 1869 caused anchovy *S. insularis* to migrate from the Red Sea to the Mediterranean.

Ostracods, euphausiids and gastropods are the main diet of yellowstripe scad. However, yellowstripe scad also eat smaller fish, including anchovies (https://www.fishbase.in, accessed 2 June 2021). The composition of yellowstripe scad feed includes Copepoda, Ochrophyta, Charophyta, Chlorophyta, Cyanobacteria and Myzozoa. The dominance of zooplankton eaten by yellowstripe scad indicates that yellowstripe scad is a carnivorous fish. In general, carnivorous fish have intestines that are shorter than their body length (Anugerah et al 2019). Yellowstripe scad can be caught using a variety of fishing gear, including the lift net, Danish seine, and trawler (Silvestre & Pauly 1997; Sala et al 2018; Wijayanto et al 2020b). The combination of LED lights with green and white colors has proven to be effective in attracting yellowstripe scad which can be applied to yellowstripe scad fishing operations using lift nets (Wisudo et al 2020). Yellowstripe scad is one of the main catches of small-scale fisheries in Indonesia (Wibowo et al 2017). Yellowstripe scad has positive allomeric growth characteristics, meaning that weight growth is faster than length growth (Sala et al 2018).

According to Collette & Nauen (1983), narrow-barred Spanish mackerel can be found in the waters of the Indo-West Pacific, from South Africa and the eastern Red Sea to the Indo-Australian Islands and Fiji (including in Indonesia). Narrow-barred Spanish mackerel include epipelagic and neritic fish that migrate longshore. The main diet of narrow-barred Spanish mackerel is smaller fish, including anchovies and yellowstripe scad. Narrow-barred Spanish mackerel also eats squid and shrimp. Narrow-barred Spanish mackerel can forage on days and night. Narrow-barred Spanish mackerel can reach a maximum length of 220 cm for a fork length and 90 cm for a common length.

The description above shows that anchovy, yellowstripe scad and narrow-barred Spanish mackerel share an ecological relationship as predator-prey. Therefore, the management of the three types of fish will influence their population. Table 2 shows that anchovy, yellowstripe scad and narrow-barred Spanish mackerel in the coast of

Semarang have been overfished. Overfishing is a problem in many countries that occurs due to improper management of fish resources, including in Indonesia (Coll et al 2008; Tangke et al 2018; Wijayanto et al 2019).

Proper fish production control should be applied. Disruptions to anchovy stock lead to disruption to its predators (including yellowstripe scad and narrow-barred Spanish mackerel), resulting in imbalance food chain in general (Wijayanto et al 2020a). This overfishing issue must be seriously addressed to maintain the sustainability of fish resources and fishermen's livelihoods. In addition, Semarang city residents who are fond of seafood will be affected due to rare supply of seafood for consumption (Wijayanto et al 2021). Food loss and food waste also affect the food security in the world. Food can be lost or wasted in the supply chain process. The causes of food loss in low-income countries include limited capital, managerial, technology and infrastructure (Gustavsson et al 2011).

The management of anchovy, yellowstripe scad and narrow-barred Spanish mackerel fisheries needs to be conducted using an integrative approach. Artisanal fisheries (including on the coast of Semarang) is a multi-gear and multi-species fishery that has a high complexity of problems (Wijayanto et al 2019). Ulrich et al (2002) confirmed the presence of a relationship between fish resource stocks, fleets, fishing gear, target species, and fishing grounds that need to be concerned in fishery bioeconomic modeling. Therefore, fisheries management policies in Semarang city need to use a multidimensional approach that integrates both biological, technological, aquatic, social and economic approaches. The coastal areas of Semarang are also prone to land subsidence and flood, making the socio-economic problems experienced by fishermen become more complicated. Relocation of fishermen's residences and directing fishermen to switch professions are difficult to implement (Nugraha et al 2015; Handayani et al 2019).

Conclusions. The productions of anchovy, yellowstripe scad and narrow-barred Spanish mackerel are inter-correlated. This relationship follows the equation $C_A = 31{,}197.15 + 26.27\ C_Y + 141.87\ C_N$. Anchovy production function in the multi-species model follows the equation $C_A = 31{,}197.15 + 528.99\ E - 0.34\ E^2$. While the yellowstripe scad production function follows the equation $C_Y = -1{,}188.52 + 20.39\ E - 0.00077\ E^2$. The production function of narrow-barred Spanish mackerel follows $C_N = -219.90 + 0.65\ E - 0.0003\ E^2$. Optimal anchovy production occurs at fishing effort involving 779 fishermen with a total production of 237,230 kg. Whereas, the optimal production of yellowstripe scad is gained with 791 fishermen (total production of 6,873 kg), and it requires 1,168 fishermen to gain an optimal production of narrow-barred Spanish mackerel of 159 kg. Regarding this inter-correlation in the productions of the three types of fish, the management of these three fish species cannot be planned and conducted separately.

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Conflict of interest. The authors declare that there is no conflict of interest.

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