The multi-species competition model of Bali sardinella and fringescale sardinella in Pati Regency, Indonesia

Dian Wijayanto, Azis N. Bambang, Faik Kurohman

Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia.
Corresponding author: D. Wijayanto, dianwijayanto@gmail.com

Abstract. Pelagic fish commodity is a leading marine fishery commodity in Pati Regency including fringescale sardinella fish (*Sardinella fimbriata*) and Bali sardinella fish (*S. lemuru*). Both types of fish are plankton eaters. Therefore, it is suspected that there is a multi-species relationship (competition) between Bali sardinella and fringescale sardinella. This study aims to develop the multi-species model (especially the competition model) of Bali sardinella and fringescale sardinella in Pati Regency. Time series data from 2008 to 2017 related to fisheries production and fishing effort data were used in this study. Furthermore, in-depth interviews with key stakeholders and field observation at Bajomulyo fishing port were conducted. The results of this study prove that there is a competition, biological interaction, between Bali sardinella and fringescale sardinella. The production function of Bali sardinella is influenced by the amount of purse seine (as the fishing effort) and the production of fringescale sardinella. The production function of fringescale sardinella is influenced by the number of purse seine (as the fishing effort) and the production of Bali sardinella. The optimal effort for Bali sardinella production is 191 units of purse seine and the optimal effort for fringescale sardinella production is 176 units of purse seine. The management of Bali sardinella and fringescale sardinella resources for capture fisheries cannot be separated. Several possible policies can be used to control the exploitation of Bali sardinella and fringescale sardinella resources, including minimum size, protection of spawning grounds, protection of nursery grounds, close season, quotas, and taxes.

Key Words: competition model, purse seine, Pati Regency, *Sardinella fimbriata, Sardinella lemuru*.

Introduction. The marine fishery in Pati Regency (Central Java Province, Indonesia) is dominated by small pelagic fish. In 2017, the production of small pelagic fisheries in Pati Regency was 21,941 tons (82% of total marine fishery production). These types of small pelagic fish include Bali sardinella (*Sardinella lemuru*) and fringescale sardinella (*S. fimbriata*) which are caught using a purse seine (DMF of Pati Regency 2020). Bali sardinella and fringescale sardinella are the second and third largest marine fishery products for Pati Regency, while the largest production is shortfin scad or *Decapterus macrosoma* (BPS-Statistics of Pati Regency 2018; DMF of Pati Regency 2020).

Fringescale sardinella and Bali sardinella are classified as small pelagic fish. Bali sardinella is distributed in the territorial waters of the Eastern Indian Ocean and Western Pacific, namely from the waters of southern Japan, Hong Kong, Taiwan, Thailand, Indonesia (including the Java Sea and Bali Strait), the Philippines, and Western Australia. Meanwhile, fringescale sardinella is distributed in the Indo-West Pacific waters, including Kuwait, southern India, Indonesia (including the Java Sea), Philippines and Papua New Guinea (https://www.fishbase.se/, accessed on December 8, 2020). Both types of fish live in large schools in coastal waters and are plankton eaters (Bennet 1967; Whitehead 1985).

Purse seine is active fishing gear that captures schooling fish using a fish aggregating device of a light attractor. Purse seine circles the fish schools to be harvested. The immersing process in purse seine operation is conducted after the setting process. During immersing, fishermen wait for the target fish to be collected using fish aggregation device or light attractor, then hauling is carried out (Wijayanto et al 2020a). The purse seine from fishermen in Pati Regency is able to catch shortfin scad (*Decapterus* *macrosoma*), short mackerel (*Rastrelliger brachysoma*), yellowstripe scad (*Selaroides leptolepis*), fringescale sardinella, frigate tuna (*Auxis thazard*), Bali sardinella, and narrow-barred Spanish mackerel (*Scomberomorus commerson*) (DMF of Pati Regency 2020).

Fish resources have ecological relationships pattern in the wild including between Bali sardinella and fringescale sardinella. According to Hollowed et al (2000), fish populations are influenced by food competition, cannibalism, predation (predator-prey), and environmental factors. In the case of fisheries in Pati Regency, Bali sardinella and fringescale sardinella are caught using the same fishing gear in the same fishing ground. It is suspected that the relationship between Bali sardinella and fringescale sardinella has a competitive nature because both are planktivorous fish (Bennet 1967; Whitehead 1985; Bintoro et al 2020). According to Pelletier et al (2009), the condition of fisheries that are the multi-species (especially in tropical waters) and multi-gears causes the management of fish resources to be complicated, including in Pati Regency. Therefore, it is important to conduct the study of multi-species fishery model to support fisheries resources management.

Fishery model can explore the relationships between species. There are lots of multi-species fishery models which were developed by many researchers. However, in developing countries, including Indonesia, the availability of data becomes an obstacle in the fishery model. Therefore, the development of fishery model should adapt with availability data (Wijayanto et al 2020b). Thus, this study aims to develop the multi-species fishery model (competition model) of Bali sardinella and fringescale sardinella in Pati Regency.

Material and Method

Research location*.* The study was conducted from December 2020 to January 2021 in Pati Regency which is located at coordinates of 100°50' to 111°15' east longitude and 06°25' to 07°00' south latitude (BPS-Statistics of Pati Regency 2020). Purse seine vessels in Pati Regency have a fishing base at Bajomulyo fishing port (Figure 1).

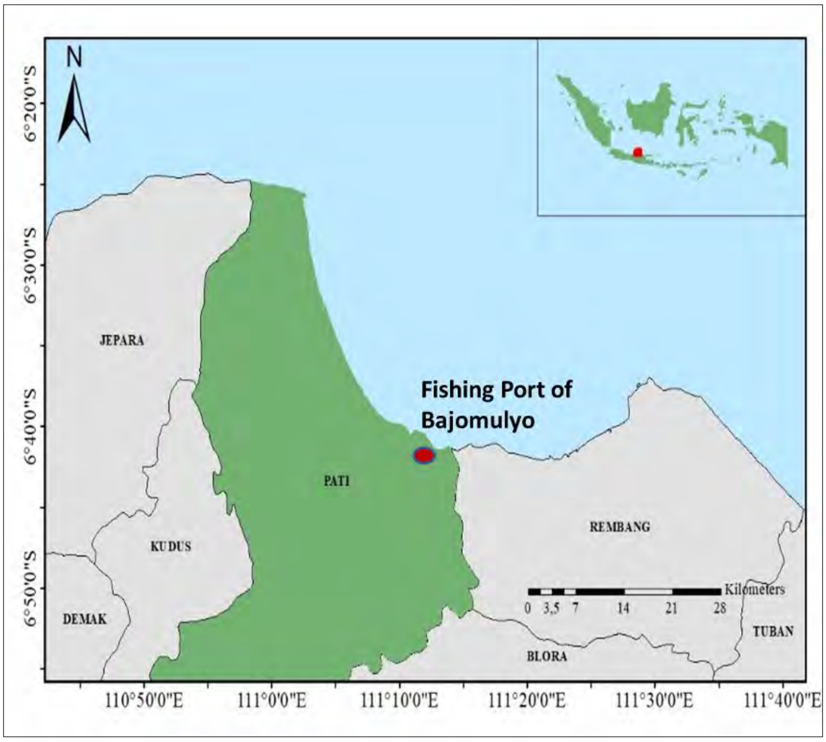


Figure 1. Pati Regency map.

Research data*.* Time series data from 2008 to 2017, including fisheries production data (both Bali sardinella and fringescale sardinella) and amount of purse seine in Pati

Regency were used in this study. The researchers conducted in-depth interviews with key stakeholders and field observations in the Bajomulyo fishing port.

Research model. The fishery model was developed by adjusting to the availability of data, including in the case of Bali sardinella and fringescale sardinella in Pati Regency. According to Schaefer (1957), fisheries production follows the following equations:

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

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

The C_{BS} notation is the production of Bali sardinella (kg), while C_{FS} is the production of fringescale sardinella (kg). The E notation is a fishing effort (units of purse seine) while the a, b, d, and e notations are constants. In equations (1) and (2), there is no ecological relationship between Bali sardinella and fringescale sardinella. Then, equations (1) and (2) were modified into equations (3) and (4) assuming there is a competition between Bali sardinella and fringescale sardinella. Both types of fish are plankton eaters (Bennet 1967; Whitehead 1985; Bintoro et al 2020). If the catch of Bali sardinella increases, it might cause the stock of Bali sardinella to decrease, which in turn has the potential to cause the stock of fringescale sardinella to increase, and vice versa. The quantity of fish stocks has a positive correlation with fishing productivity. Therefore, the intensity of Bali sardinella capture has a positive effect on the production of fringescale sardinella, and vice versa.

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

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

The f and g notations are constants. Adding equations (3) and (4) produces equation (5). Furthermore, equation (5) can produce equations (6) and (7). Maximization of equations (6) and (7) can produce equations (8) and (9). The process of maximizing equation (6) produces equation (8), while the process of maximizing equation (7) produces equation (9).

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

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

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

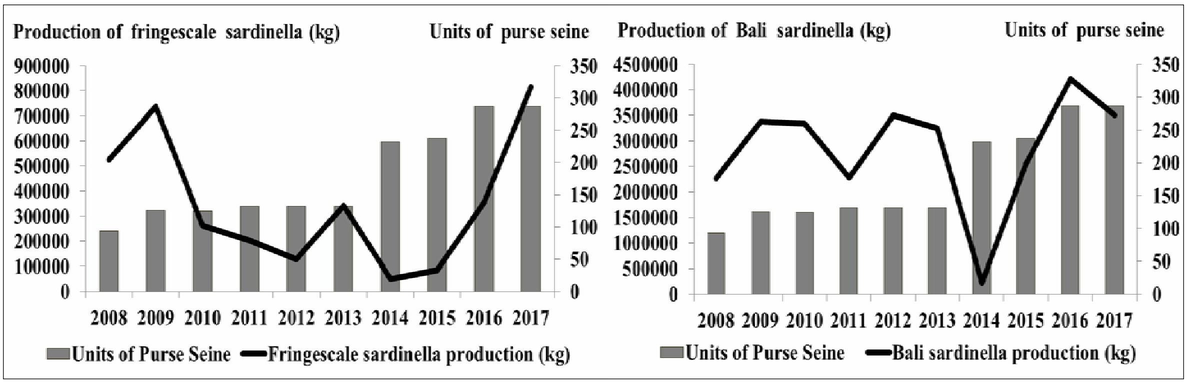
$$E_{C_{BSmax}} = \frac{a+df}{2b+2ef} \quad (8)$$

$$E_{C_{FSmax}} = \frac{d+ag}{2e+2bg} \quad (9)$$

Results and Discussion. There are 7 fishing bases in Pati Regency, namely Bajomulyo Coastal Fishing Port (CSP), Pecangaan Fish Landing Place (FLP), Margomulyo FLP, Sambiroto FLP, Banyutowo FLP, Alasdowo FLP, and Puncel FLP. Meanwhile, the fishing base for purse seine vessels is only at the CSP of Bajomulyo. According to Wijayanto et al (2020a), most of animal aquatic catches from purse seine in Rembang Regency (neighbor of Pati Regency) are *Decapterus macrosoma* (shortfin scad), *Sardinella fimbriata* (fringescale sardinella), *Auxis thazard* (frigate tuna), *Rastrelliger brachysoma* (short mackerel), *Selaroides leptolepis* (yellowstripe scad) and *Loligo* sp. (squid), indicating that fishes caught by purse seine are dominated by pelagic fish.

The number of fishermen in Pati Regency in 2018 was 1285 people (BPS-Statistics of Pati Regency 2018). The increasing number of fishermen has made fishery management even more complicated. Moreover, the conditions of the multi-species and multi-gears fisheries in Pati Regency make fishery management more complicated. Purse seine fishermen from Pati Regency have fishing grounds in the Java Sea and its surroundings. According to Wijayanto et al (2020a), the fish and other aquatic animals caught in the Java Sea have a relationship between one type and another. The multi-species relationship can be in the form of food competition, predator–prey (including cannibalism), and mutually beneficial relationships.

The progress of Bali sardinella and fringescale sardinella production. The production progress of fringescale sardinella and Bali sardinella is visualized in Figure 2. In general, during the period 2008 to 2015, the production of fringescale sardinella and Bali sardinella had fluctuated with a downward trend, but starting in 2016 it had an increasing trend. Meanwhile, Figure 3 shows the CPUE (catch per unit effort) progress for fringescale sardinella and Bali sardinella that caught with purse seine belonging to fishermen from Pati Regency. The CPUE between fringescale sardinella and Bali sardinella showed a certain pattern that proved an interrelation between the two fish types.



a. Production of fringescale sardinella b. Production of Bali sardinella

Figure 2. The progress of the production of Bali sardinella and fringescale sardinella.

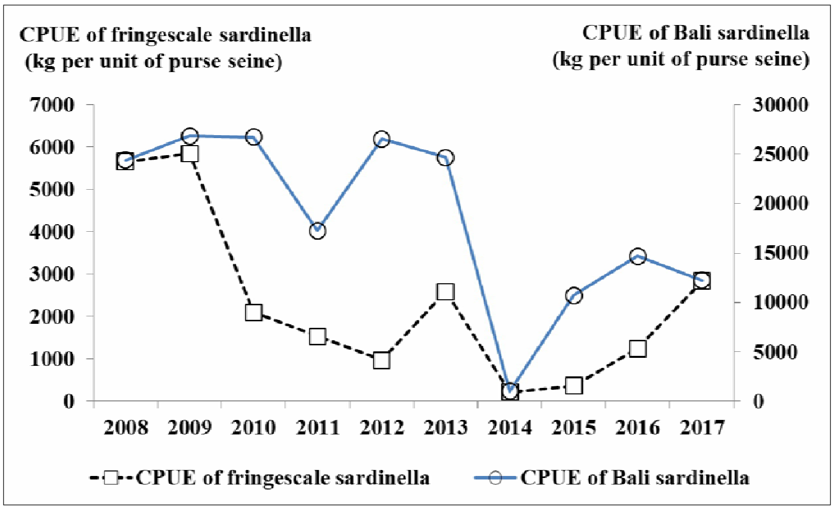


Figure 3. The progress of CPUE of fringescale sardinella and CPUE of Bali sardinella.

Sartimbul et al (2010) argue the CPUE of Bali sardinella is influenced by the interaction of environment variables, including sea surface temperature (SST) and chlorophyll-*a*. There is an anomaly between sea surface temperature and chlorophyll-*a* (as an indicator of food availability). Bali sardinella and fringescale sardinella fish migrate, including in search of prey. Both types of fish can be found in the Java Sea (Bintoro et al 2020; Wijayanto et al 2020a; Wijayanto et al 2020b; Sartimbul et al 2021a).

The production function and optimization. This study showed that there is a relationship between the production of Bali sardinella and fringescale sardinella which can be seen in equations (10) and (11), namely competition relation. Both types of fish eat plankton. According to Gaughan & Mitchell (2000), the diet of S. *lemuru* consisted of zooplankton, phytoplankton, and detritus. The study of Sartimbul's et al (2021b) has proven that the abundance of *S. lemuru* in Prigi waters (Java Sea) depends on the abundance of food availability (plankton). There is a strong relationship between the abundance of phytoplankton in Prigi waters and the abundance of phytoplankton in the stomach of Bali sardinella. Plankton in Prigi waters found 21 phytoplankton genera and 12 zooplankton genera. Phytoplankton in Prigi waters is divided into 8 classes, i.e. Bacillariophyceae, Dinophyceae, Mediophyceae, Clorophyceae, Trebouxiophyceae, Ciliatea, Euglenophycidae and Noctilucophyceae. While the zooplankton consists of Copepoda, Gastropoda and Globothalamea. According to Bintoro et al (2020), Arthropods are the main food of fringescale sardinella, while Bacillariophyta and Ocrhophyta are complementary food.

$$C_{BS} = 29{,}089.2\ E - 74.8\ E^2 + 1.2\ C_{FS} \quad (10)$$

$$C_{FS} = 919.2\ E - 3.5\ E^2 + 0.1\ C_{BS} \quad (11)$$

Equations (10) and (11) are production functions of Bali sardinella and fringescale sardinella caught by purse seine fishermen in Pati Regency. The model is a simplification, in which many factors that influenced fish biomass and fisheries production. In the reality, the production of Bali sardinella and fringescale sardinella are influenced by many complex factors. According to Hollowed et al (2000), the benefits of multispecies models include improved natural mortality and recruitment estimation, the spawner-recruit relationship, and growth rate variability. However, multi-species relationships are also influenced by different life-history stages, both locally or regionally. Moreover, most multispecies models are only using a subset of these factors, often aggregated over functionally different species or age groups.

Referring to equations (6) and (7), the equations (10) and (11) can be modified into equations (12) and (13). Estimation of optimal fishing efforts to maximize fish production of Bali sardinella and fringescale sardinella is presented in Table 1. Meanwhile, the simulation of equations (12) and (13) can be seen in Figure 4.

$$C_{BS} = 34{,}670.9\ E - 90.7\ E^2 \quad (12)$$

$$C_{FS} = 4{,}723.8\ E - 13.4\ E^2 \quad (13)$$

Table 1

The simulation of optimization

The type of fish	*The optimal fishing effort*	*Production (kg per year)*
Bali sardinella	191 units of purse seine	BS: 3,314,173; FS: 413,055
Fringescale sardinella	176 units of purse seine	BS: 3,293,728; FS: 416,078

Notes: BS is Bali sardinella; FS is fringescale sardinella.

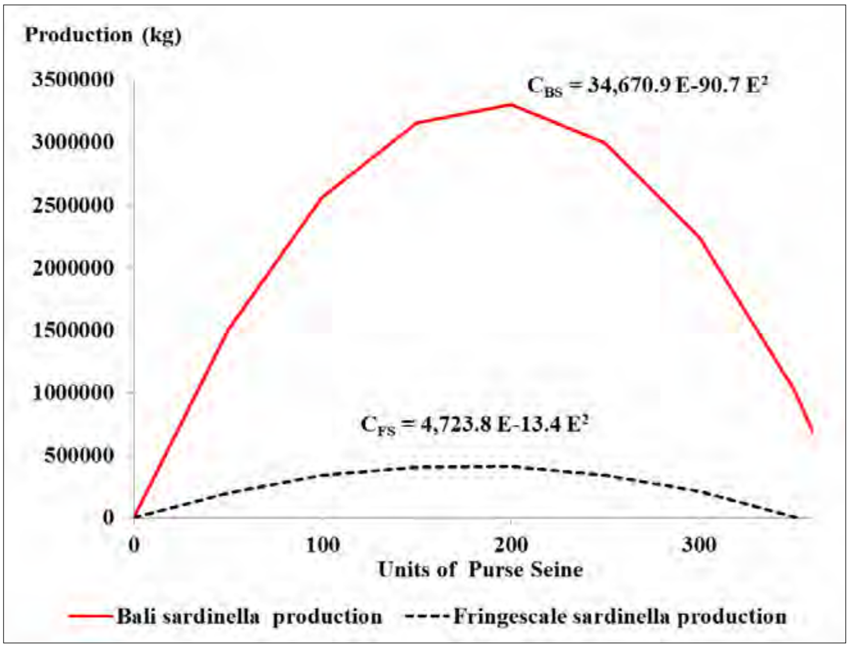


Figure 4. The production simulation of Bali sardinella and fringescale sardinella.

According to Shelton (1992) a consequence of biological interaction in multi-species is trade-offs in biological, economic, and social interests. The multi-species model can predict the trade-offs quantitatively. Then, the fisheries managers can make fisheries policy to manage the interaction species to maximize benefit.

The fishery model is focused on estimating the best management to maintain the sustainability of the fisheries resources (Natsir 2015). Maximum sustainable yield (MSY) analysis is still dominantly used as the basis for making fisheries management policies in the world. According to May et al (1979), MSY focus on long-term management to maintain sustainable fisheries yield (using an undiscounted approach). Yet, the application of MSY in each species cannot serve as the harvesting guide when two or more species have strong interactions.

There are several policies that can be used to control the exploitation of fish resources, including minimum size, spawning ground protection, nursery ground protection, closed season, quotas, input tax, and output tax (Bhatia et al 2017; Wijayanto et al 2019; Wijayanto et al 2020b). Unfortunately, fisheries management practices in developing countries are relatively more difficult than in developed countries. There are poverty and employment issues in developing countries, not only multi-species, multi-gears, and overfishing problems (Wijayanto et al 2020b; Wijayanto et al 2020c), including in Pati Regency. Therefore, fisheries managers need to estimate the impact on fish resources, social, economic, and political in the short term and long term.

Conclusions. There is a relationship (competition interaction) between Bali sardinella fish and fringescale sardinella fish caught using purse seine by fishermen from Pati Regency. Bali sardinella fish and fringescale sardinella fish are plankton feeders. The production function of Bali sardinella which is influenced by the amount of purse seine (as the fishing effort) and the production of fringescale sardinella follows the equation C_{BS} = 29,089.2 E-74.8 E^2+1.2 C_{FS} or C_{BS} = 34,670.9 E-90.7 E^2. The optimal effort for Bali sardinella production is 191 units of the purse seine. The production function of fringescale sardinella which is influenced by the amount of purse seine (as the fishing effort) and the production of Bali sardinella follows the equation C_{FS} = 919.2 E-3.5 E^2-0.1 C_{BS} or C_{FS} = 4,723.8 E-13.4 E^2. The optimal effort for fringescale sardinella production is 176 units of the purse seine. A study on the fisheries management of fringescale sardinella and Bali sardinella using a bio-economic approach can be conducted as a follow-up study of the fisheries model produced in this study. Several possible policies can be used to control the exploitation of Bali sardinella and fringescale sardinella resources, including minimum size, protection of spawning grounds, protection of nursery grounds, close season, quotas, and taxes.

Acknowledgements. The researchers would like to thank for financial support from the Ministry of Research and Higher Education and data support from the Department of Marine and Fisheries (DMF) of Pati Regency for this study. This study was funded by the basic research scheme (contract number: 225-63/UN7/6/1/PP/2020).

References

Bennet S. P., 1967 Some observations on the fishery and biology of *Sardinella fimbriata* (Val.) at Vizhingam. Indian Journal of Fisheries 14(1-2):145-158.

Bhatia S. K., Chauhan S., Agarwal A., 2017 A stage-structured prey-predator fishery model in the presence of toxicity with taxation as a control parameter of harvesting effort. Journal Nonlinear Analysis and Application 2:83-104.

Bintoro G., Lelono T. D., Deafatmi L., 2020 Biological aspect and dynamic population of fringescale sardine (*Sardinella fimbriata*: Valenciennes, 1847) in Prigi waters Trenggalek, East Java, Indonesia. IOP Conferences Series: Earth and Environmental Science 493:012017.

BPS-Statistics of Pati Regency, 2018 Pati Regency in Figures 2018. BPS-Statistics of Pati Regency, 316 pp. ISSN: 0215573-7, 2018. [bi-lingual in Indonesian and English]

BPS-Statistics of Pati Regency, 2020 Pati Regency in Figures 2020. BPS-Statistics of Pati Regency, 147 pp. ISBN: 978-602-71119-2-9, 2020. [bi-lingual in Indonesian and English]
D.M.F. of Pati Regency, 2020 [Fisheries data]. Unpublished. Department of Marine and Fisheries (DMF) of Pati Regency. [in Indonesian]
Gaughan D. J., Mitchell R. W. D., 2000 The biology and stock assessment of the tropical sardine, *Sardinella lemuru*, off the mid-west coast of Western Australia. Final Report, FRDC Project 95/037: Fisheries Research Report No. 119, 136 pp.
Hollowed A. B., Bax N., Beamish R., Collie J., Fogarty M., Livingston P., Pope J., Rice J. C., 2000 Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? ICES Journal of Marine Science 57:707-719.
May R. M., Beddington J. R., Clark C. W., Holt S. J., Laws R. M., 1979 Management of multispecies fisheries. Science 205(4403):267-276.
Natsir M., 2015 Bio-economic model and technical efficiency analysis for FAD-associated tuna fishery in Kendari fishing port – Indonesia. Final project. United Nations University Fisheries Training Programme, Iceland, 2015. Available at: https://www.grocentre.is/static/gro/publication/346/document/natsir15prf.pdf. Accessed: July, 2021.
Pelletier D., Mahevas S., Drouineau H., Vermard Y., Thebaud O., Guyader O., Poussin B., 2009 Evaluation of the bioeconomic sustainability of multi-species multi-fleet fisheries under a wide range of policy options using ISIS-Fish. Ecological Modelling 220(7):1013-1033.
Sartimbul A., Nakata H., Rohadi E., Yusuf B., Prasetyo H., Kadarisman, 2010 Variations in chlorophyll-*a* concentration and the impact on *Sardinella lemuru* catches in Bali Strait, Indonesia. Progress in Oceanography 87(1-4):168-174.
Sartimbul A., Amandani J. A., Yona D., Fuad M. A. Z., 2021a Mercury content of *Sardinella lemuru* caught in East Java and Bali waters. Journal of Physics: Conference Series 1869:012004.
Sartimbul A., Trishnayana E., Rohadi E., Muslihah N., Lutfi O. M., Iranawati F., Ika Harlyan L. I., Wulandari E., Sambah A. B., 2021b Plankton's abundance and its implications for *Sardinella lemuru* catch in Prigi waters. IOP Conference Series: Earth and Environmental Science 763:012049.
Schaefer M. B., 1957 A study of the dynamics of the fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean. Inter-American Tropical Tuna Commission Bulletin 2(6):243-285.
Shelton P. A., 1992 Detecting and incorporating multispecies effects into fisheries management in the north-west and south-East Atlantic, South African. Journal of Marine Science 12(1):723-737.
Whitehead P. J. P., 1985 FAO Species Catalogue. Vol. 7. Clupeoid fishes of the world (suborder Clupeoidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. FAO Fisheries Synopsis No. 125 Volume 7 Part 1, 303 pp.
Wijayanto D., Bambang A. N., Kurohman F., 2019 The impact of ‘cantrang’ (Danish seine) fisheries on gill net fisheries in Tegal coastal area, Indonesia. AACL Bioflux 12(4):1005-1014.
Wijayanto D., Setiyanto I., Setyawan H. A., 2020a Bio-economic model of Danish seine and purse seine fisheries in Rembang Regency, Indonesia. Egyptian Journal of Aquatic Research 46:63-70.
Wijayanto D., Bambang A. N., Kurohman F., 2020b The multi-species model of fringscale sardinella and largehead hairtail in Rembang Regency, Indonesia. AACL Bioflux 13(4):2312-2319.
Wijayanto D., Bambang A. N., Kurohman F., 2020c The predator-prey model on squids and anchovies fisheries in Jepara District, Central Java, Indonesia. Biodiversitas 21(12):5698-5703.
www.fishbase.se. *Sardinella fimbriata* (Valenciennes, 1847). Accessed: December, 2020.
www.fishbase.se. *Sardinella lemuru* Bleeker, 1853. Accessed: December, 2020.

Received: 04 July 2021. Accepted: 31 July 2021. Published online: 27 August 2021.
Authors:
Dian Wijayanto, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Jl. Prof. Soedarto S.H., Semarang, Central Java, Indonesia, e-mail: dianwijayanto@gmail.com; dianwijayanto@lecturer.undip.ac.id
Azis Nur Bambang, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Jl. Prof. Soedarto S.H., Semarang, Central Java, Indonesia, e-mail: azis_undip2013@yahoo.com
Faik Kurohman, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Jl. Prof. Soedarto S.H., Semarang, Central Java, Indonesia, e-mail: faikkurohman@gmail.com, faikkurohman@lecturer.undip.ac.id

How to cite this article:
Wijayanto D., Bambang A. N., Kurohman F., 2021 The multi-species competition model of Bali sardinella and fringescale sardinella in Pati Regency, Indonesia. AACL Bioflux 14(4):2335-2342.