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Research Article

Harvest Control Rules of Multispecies Scads (*Decapterus* spp.) Fishery in Blitar Waters, East Java

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Abstract

Scads fishery in Blitar waters is a multispecies fishery applying harvest control rules (HCRs) from conventional single-species approaches which technically, may not be applicable to employ in such mixed-species data composed from the multispecies fishery. The feedback HCR is an alternative validated harvest control rule that can be applied for a multispecies fishery. The aim of this study was to technically compare the application of the feedback HCR and conventional single species approaches in terms of estimating the future allowable biological catch (ABC). Therefore, in this study, ABC was estimated by applying three HCRs, the feedback HCR, and two conventional HCRs which was based on single-species approaches applying surplus production models, Schaefer Model and Fox model into catch and effort of scads fisheries data series of 2011 – 2020. The results showed that the ABC estimation of the feedback HCR was a half lower than that of both conventional models. It was biologically safer to apply the feedback HCR to set the annual total allowable catch (TAC) than the other two HCRs. The feedback HCR presented an initial step toward sustainably managing multispecies fisheries while dealing with data-limited conditions.

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1. Introduction

Scads (*Decapterus* spp.) is one of the pelagic resources that are intensively exploited and contributed to fisheries productivity. It is widely distributed in the Arafura Sea, Sunda shelf covering the Java Sea, and the South China Sea, the Southern Indian Ocean covering Java Sea, Banda Sea, also inhabiting Southern Java. In the southern Java, the scads fishery has been experiencing high variability in catch production. Particularly in Blitar regency, in recent years, the scads catches have been fluctuating which lead to a decreasing trend (Department of Fisheries and Marine Affairs East Java Province, 2020; Suwarso and Zamroni, 2014).

In Blitar Regency, scads fishery comprises of four species, redbtail scads (*D. kuroides*), Indian scads (*D. ruselli*) and shortfin scads (*D. macrosoma*), Mackerel scads (*D. macarellus*). As fishing pressures increase, fishing capacity management has been applied to control and monitor the scads exploitation rate (Suwarso et al., 2014). A harvest control rule (HCR) system has been conducted to determine annual allowable biological catch (ABC) which based on some conventional surplus production models with single-species approaches (Yanto et al., 2020).

Generally, some conventional surplus production models with single-species approach such as the Schaefer and Fox model, the Walter-Hilborn model, and the yield per recruit (YPR) model which have been frequently applied worldwide, including in multispecies fishery (Harlyan et al., 2019; Hilborn and Ovando, 2014; Newman et al., 2018). The approaches require species-specific biological information to be conducted (Cadrin and Dickey-Collas, 2015), which might be severely hard to attain in the majority multispecies fishery. Some argue that these single-species approaches might be not properly fit to be applied in multispecies fishery or in fishery which species-specific data could not be clarified (Harlyan et al., 2020, 2021; Hilborn and Ovando, 2014; Shertzer and Williams, 2008).

In tropical fisheries, such as Indonesia, that commonly characterized as multispecies fishery, the assumptions of a single-species approach are relatively challenging to accomplish due to the use of multi-gear that catch various species (Harlyan et al., 2020; Punt et al., 2016). In fact, fisheries management remains based on what single-species model recommendation, where maximum sustainable yield (MSY) values are calculated for only a few key species without involving other minor species that are also parts of the multispecies fishery (Kvamsdal et al., 2016; Munehara et al., 2021).

In addition, some technical and financial limitations for performing species segregation are also caused by the unavailability of species-specific data (Yuniarta et al., 2017).

The feedback HCR (Tanaka, 1980; Chumchuen and Chumchuen, 2019; Ohshimo and Naya, 2014) is the successful HCR applied to Japanese fisheries management (Harlyan et al., 2019; Ichinokawa et al., 2017). It was introduced in 1997 as one of the fisheries management tools for data-poor fisheries, such as fisheries that biomass estimation is unavailable (Makino, 2011b). This feedback HCR was previously validated to be applied in multispecies fisheries with only mixed-species data available. Also, the sensitivity of the feedback HCR's performance over several scenarios of population dynamics was also examined and compared across other modified HCRs (Harlyan et al., 2019). This HCR can provide scientific recommendations to determine the annual ABC considering the previous stock abundance (Tanaka, 1980; Magnusson, 1992). In the feedback strategy, fish resources are assumed as a control system with catch quotas as output and stock abundance as inputs, so that the amount of catch quotas is determined to be close to the stock abundance (Goethel et al., 2019; Harlyan et al., 2019, 2020; Hoshino et al., 2012; Ohshimo and Naya, 2014).

The application of the feedback HCR may provide the estimation of ABC with precautionary principle as single-species surplus production models. However, few reviews have demonstrated a scientific comparison of how the feedback HCR and the surplus production models produce the annual ABC. This study estimated the annual ABC for scads multispecies fishery in Blitar Regency by applying the validated feedback HCR. Therefore, the aim of this study is to generate a technical comparison between the feedback HCR and two surplus production models in terms of estimating the annual ABC.

2. Materials and Methods

2.1 Catch and Effort Data

The source data was time-series catch-effort data gathered from the annual reports of the fisheries statistics data from 2011 to 2020 collected under the authority of the Department of Marine and Fisheries (DMF) East Java Province. The catch-effort data were collected from all sub-districts by enumerators based on the fishery logbook filled by fishers then were tabulated, validated, and verified in the districts and delivered to be published under the DMF East Java Province. The catch

data was the scads landing data, while the effort data was the fishing trips of scads fishery in Tambakrejo fishing port, Blitar Regency (Figure 1). The fishing trips per year were calculated from all fishing gears employed to catch scads. There were six fishing gears operated in scad fisheries in Blitar Regency. They were purse seine, *payang*, drift gillnet, fixed gillnet, *klitik* net, and drift longline.

2.2 Data Analysis

Several data analyses were conducted to estimate the annual TAC by applying the feedback HCR, and a common HCR with conventional surplus production model approaches. The common HCR was performed by two models, Schaefer and Fox models. The catch per unit effort ratio was applied to express the stock abundance index for all scads species. Below are the details of formulas of each method, as follows:

2.2.1 Catch per unit effort

Catch per unit effort (CPUE) indicates the stock abundance index of scads that is calculated by this following formula:

$$CPUE = \frac{c}{f} \quad (1)$$

where *c* and *f* indicate catch (ton) and effort (fishing trips), respectively (Sparre and Venema, 1992).

2.2.2 Effort standardization

Effort standardization is data treatment to provide the standard of fishing effort of various fishing gears, which may differ from one to another. This method is practically used to find the standard fishing gear that produces the highest fishing effort over all gears. To compare the productivity of all gears, the fishing power index (FPI) is calculated for each gear. For the standard gear, the FPI is equal to 1 (Susanti et al., 2020).

$$FPI = \frac{CPUE \text{ of gear}}{CPUE \text{ of standard gear}} \quad (2)$$

The standardized effort for each fishing gear is calculated by the following formula:

$$\text{The standardized effort} = FPI \times \text{effort} \quad (3)$$

2.2.3 Harvest control rules

The annual ABC was estimated by applying three HCRs (i.e., two surplus production models, Schaefer and Fox models; and the feedback HCR) into catch and effort data of scads fishery in Blitar Regency as follows

(Harlyan et al., 2019; Ohshimo and Naya, 2014; Tanaka, 1980).

2.2.3.1 Surplus production model

In this study, two models were applied, Schaefer and Fox models. The calculation of surplus production models determines the MSY where the condition of stock can be exploited without any impacts for the following stock production. Under these models, it was assumed that the relationship between CPUE and effort has a negative correlation (Sparre and Venema, 1992).

2.2.3.1a Schaefer model

The model is applied linear regression for CPUE and effort with the following formula:

$$\frac{c}{f} = a - b \cdot f \quad (4)$$

$$f_{MSY} = -\frac{a}{2b} \quad (5)$$

$$C_{MSY} = -\frac{a^2}{4b} \quad (6)$$

The *a* and *b* are the regression intercept and coefficient, respectively. The f_{MSY} indicates the effort that is consistent with achieving *MSY*. In contrast, the C_{MSY} indicates the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions.

2.2.3.1b Fox model

The Fox model also applied linear regression to estimate the MSY condition. However, instead of using CPUE, the linear regression was conducted by applying the natural logarithm of CPUE (ln CPUE) and effort with the following formula:

$$\ln CPUE = a - b \cdot f \quad (7)$$

$$C_{MSY} = -\frac{1}{b} \cdot e^{a-1} \quad (8)$$

$$f_{MSY} = \frac{1}{b} \quad (9)$$

Technically, the annual TAC is set at 80% of the estimated either using Schaefer or Fox model (Sartimbul et al., 2016).

2.2.3.2 Feedback HCR

The calculation of the feedback HCR resulted in the annual allowable biological catch for the year *y* (C_y). The C_y is recommended based on the overfishing limit to account for scientific uncertainty. Afterwards, the TAC can be set at a certain level which cannot exceed the recommended C_y . The feedback HCR is applying the following formulas to calculate the (Harlyan et al., 2019):

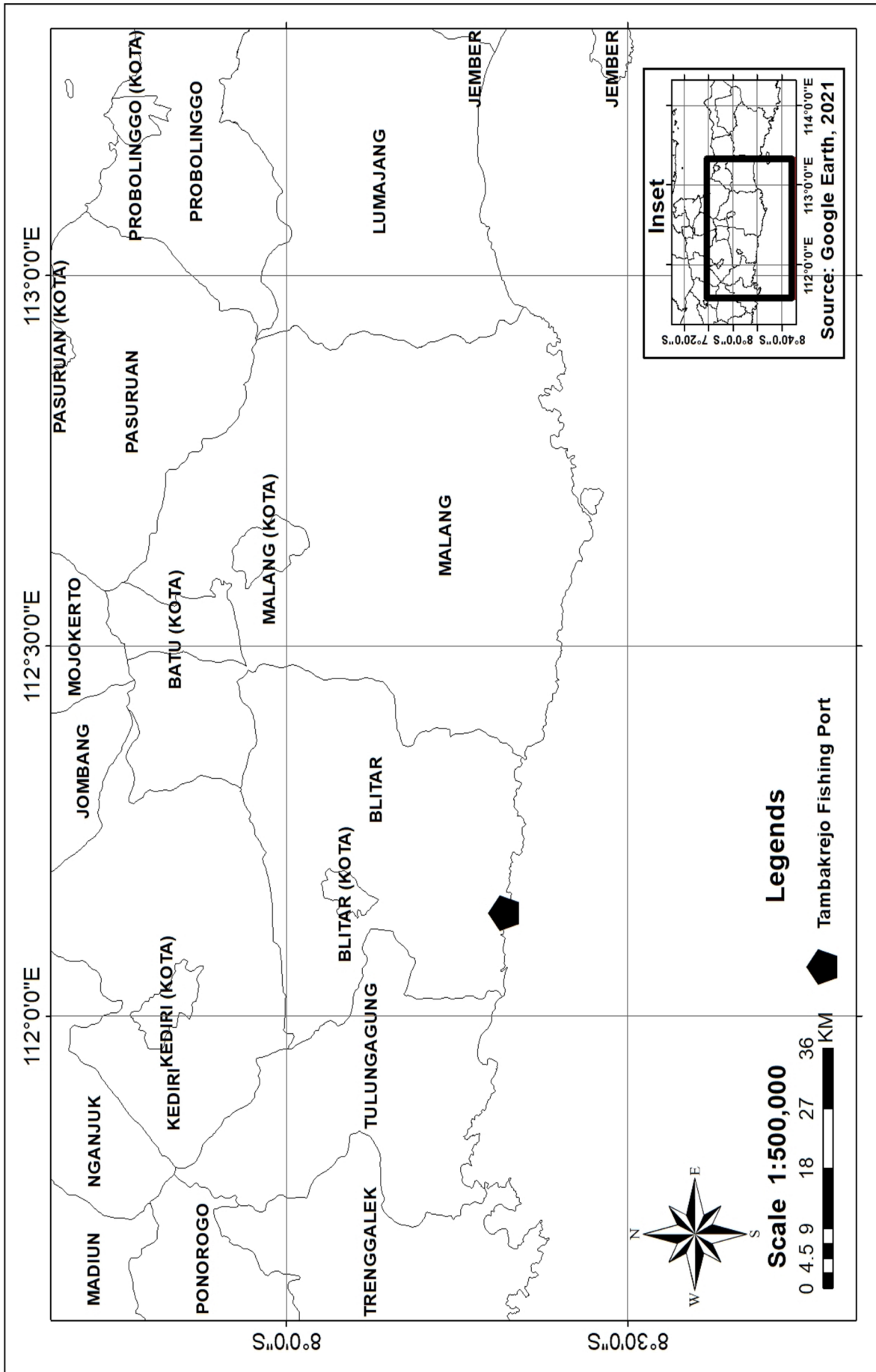


Figure 1. Research sites. The catch data was the scads landing data, while the effort data was the fishing trips of scads fishery in Tambakrejo fishing port, Blitar Regency.

$$ABC_y = \delta \times C_{y-2} \times \gamma \tag{10}$$

$$\gamma = 1 + k \frac{b}{I} \tag{11}$$

With δ is the weighting coefficient, which is set as 1, 1 and 0.8 for stock level high, medium, and low, respectively. The stock levels are estimated from the trend of the stock abundance index of scads in 2011 – 2020. In this study, CPUE was employed as the stock abundance index. The stock level determination was set by calculating the upper and the lower limit of the stock abundance index obtained from the 33rd and 67th percentiles of the 2011 – 2020 data. The high stock level is defined if the recent CPUE value is higher than the upper limit, while the medium is in between the upper and lower limit. The low stock level is defined if the recent CPUE is lower than the lower limit. The δ indicated the catch of $y - 2$ (ton), the k is the feedback factor (which is set =1), while b indicated the trend of CPUE during the study period. The symbols b and I are defined as regression coefficient and the average of CPUE in the $y - 4$ to $y - 2$ (ton/day).

2.2.4 Technical comparison among HCRs

Technical comparison among HCRs was conducted to analyse the precautionary approach of each HCR to provide the annual TAC from C . It was compared the amount of the TAC (TAC) and the total allowable effort (TAE), *i.e.*, the effort when achieving TAC (E). The calculation of E for two surplus production model were applied 0.8 of the C , while the E for the feedback HCR was the calculated ABC_y .

3. Results and Discussion

3.1 Results

3.1.1 Scads fishery in Blitar Regency

The scads fishery increased in the number of landings from 2011 and peaked in 2018 (Figure 2). In the recent years, there were an increase of the number of purse seine as the standard gear for catching Scads that led to an increase in the number of trips. As a consequence, this would reduce the allocation of landings per trip (CPUE). Since several gears caught scads, the effort of fishing gear that caught scads must be standardized before, which was applied to the calculation of the annual TAC (Table 1).

Purse seine was determined as the standard gears for scad fishery. It indicated that this gear was a dominant gear over the other gears. The effort provided by

purse seine was described in the ratio column. A purse seine trip was equal to 4 trips of *payang*, 61 trips of drift gillnet, 99 trips of fixed gillnet, 1779 trips of *klitik* gillnet and 800 trips of drift longline. As Tambakrejo fishers clarified, purse seine was frequently operated, since it produced the highest catch compared to other gears. Therefore, before further analyses, the effort of various gears was standardized into purse seine FPI (Table 1). To estimate the annual TAC using three model approaches; the Schaefer model, the Fox model, and the feedback HCR by applying into the catch–effort data in 2011 – 2020 (Table 2). The trend of CPUE has a negative slope indicating a decrease in CPUE due to increasing the number of trips.

Table 1. Effort standardization

Fishing gears	Fishing productivity	FPI	Ratio
Purse seine	4717.02	1	1
Payang	1105.23	0.23	4
Drift gillnet	77.81	0.016	61
Fixed gillnet	47.6	0.01	99
Klitik gillnet	2.65	0.001	1779
Drift longline	5.89	0.001	800

Description: Fishing productivity describes the amount of catch per trip (ton/trip), FPI (fishing power index) describes the comparison of productivity between gears.

3.1.2 The Schaefer Model

In the Schaefer model, the linear regression relationship between effort and CPUE showed a negative slope, which met the Schaefer model assumption (Figure 3). The linear regression model appears as, where the 95% confidence interval for the regression coefficient is ranged from -0.0008 , and for constant is ranged from 2.0367 to 3.0767. It showed that an increase in fishing trips generated a decreased amount of the CPUE by 0.0013 tons. The determination coefficient stated that the value of CPUE was dependent on the fishing trips about 79.76%, while the other 20.24% was affected by other factors.

The Schaefer curve was shaped parabolically to fit with the catch of scads during 2011 – 2020. Based on the model, the optimum catch was estimated about 1265.1 tons, while the optimum fishing effort was estimated about 990 trips. Therefore, the annual TAC was set at about 1012 tons and the allowable effort was 550 trips.

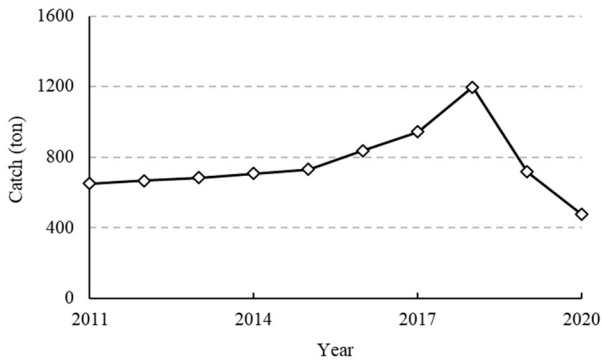


Figure 2. The catch of scads fishery in 2011 – 2020

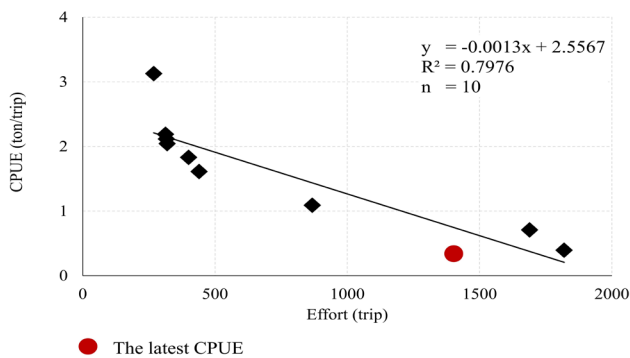


Figure 3. Linear regression of CPUE and effort

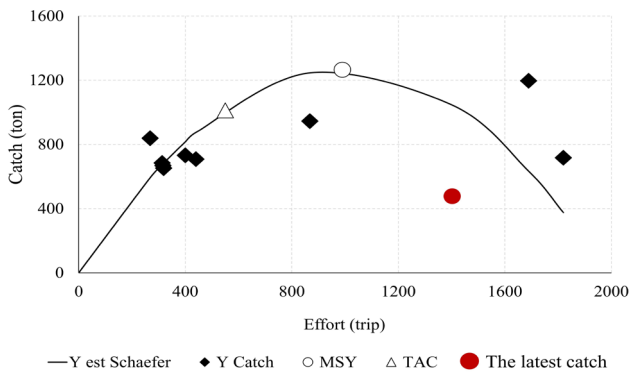


Figure 4. The relationship between catch and effort of scads fishery in Schaefer model

3.1.3 The Fox model

In the Fox model, the relationship between effort and ln CPUE was also portrayed in linear regression (Figure 5). The linear regression model appears as, where the 95% confidence interval for the regression coefficient is ranged from 0.00151 to 0.00078, and the constant ranged from 0.76 – 1.48. It was shown that an increase in fishing trips would lead to a decrease in the ln CPUE by 0.0011 tons. The relationship between these factors indicated the negative interaction, and it also met the assumptions of the Fox model (Figure 5). The determination coefficient gave 86.57%, indicating

that the increase of fishing trips affected the ln CPUE by 86.57%.

In the Fox model, the catch – effort data was shaped exponentially that determining the optimum was about 981.7 tons, while the optimum effort was set about 874 trips. Considering these estimations, the annual TAC based on the Fox model was estimated as 785.38 tons and the allowable effort was 440 trips.

3.1.4 The feedback HCR

The determination of the annual TAC was expressed as allowable biological catch (in the feedback HCR). The stock levels (δ) were illustrated by defining the trend of CPUE in 2011 – 2020 (Figure 7). The stock level (δ) performed in the low level so that it was set as 0.8 (Figure 7). The catch of two years before the estimated year (was 716.8 tons (Table 2)). The regression coefficient of $y - 4$ to $y - 2$ was -0.3475, while the average CPUE from $y - 4$ to $y - 2$ was 0.73 tons/trip. The annual TAC was 300.6 ton and the annual TAE was 763 trips.

3.1.5 The comparison among HCRs

The results of the annual TAC and TAE estimation were compared among HCRs (Table 3). In terms of the estimation of TAC, the Schaefer model provided the highest estimation at 1012 tons, while the feedback HCR generated the lowest estimation at 300.6 tons. In contrast, for the TAE estimation, the feedback HCR provided the higher estimation compared to the other two models.

3.2 Discussion

The feedback HCR is a practical application that can estimate the annual TAC or without assessing fish biomass as required by the common conventional surplus production models. In principle, this application considers stock abundance trends to determine the allowable biological catch for further use of catch quota policy (Harlyan et al., 2019; Ichinokawa et al., 2017).

Based on 10 to 20 years of historical data of fishing activities, the estimation of allowable biological catch and effort can be simply calculated. The historical data is the catch–effort data that has been validated. In some cases, the fishing effort could not be validated, instead of CPUE, catch data can be assumed as a stock abundance index (Harlyan et al., 2019; Ohshimo and Naya, 2014) which are categorized into two types depending on whether or not stock-size information is available. We evaluate management procedures (MPs).

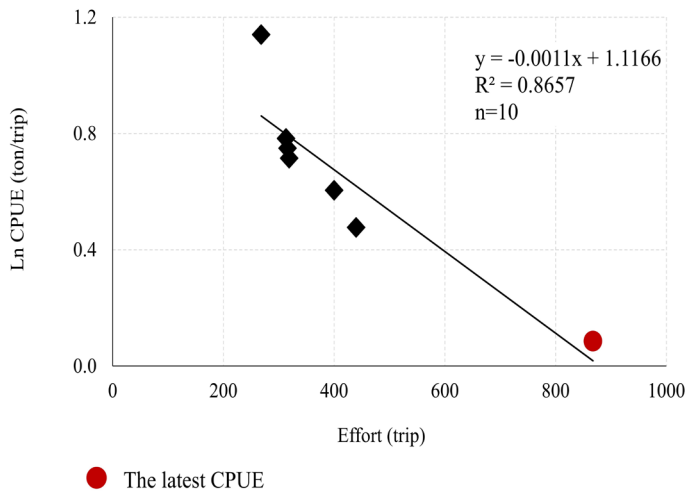


Figure 5. Linear regression of Ln CPUE and effort

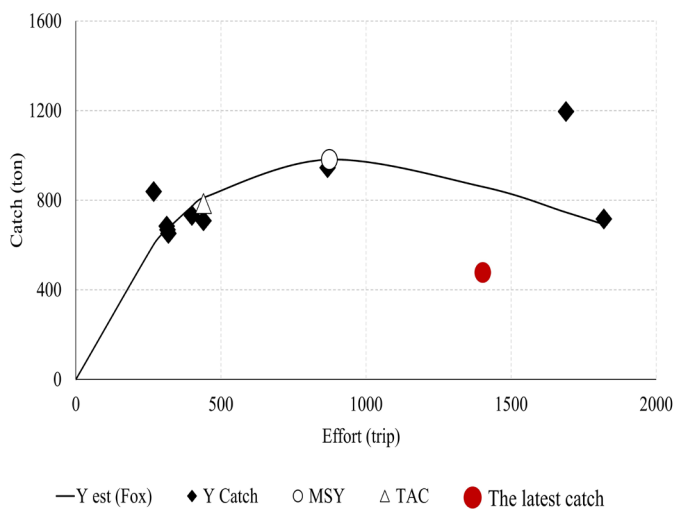


Figure 6. The relationship between catch and effort of scads fishery in Fox model

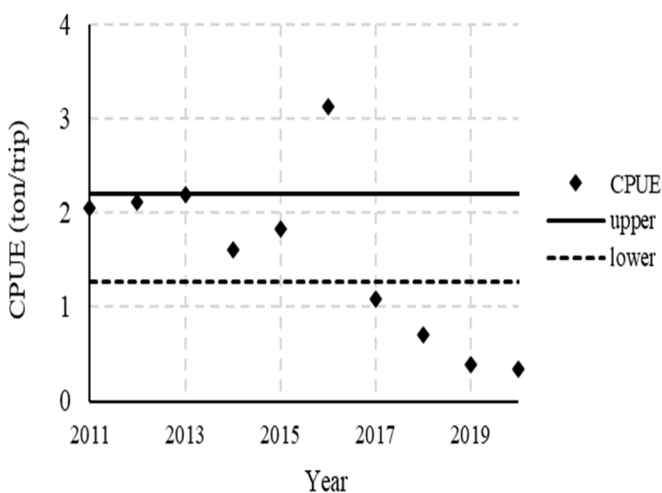


Figure 7. The stock abundance index (CPUE) of scads fishery in Blitar Regency in 2011 – 2020 with the upper and lower limits for determining stock status level in feedback HCR

Regarding data-poor fisheries management in some tropical countries that is struggling with fish stock assessment (Harlyan *et al.*, 2021), the feedback HCR offers practical information with flexibility in data requirements compared to the conventional single-species surplus production models (Chumchuen *et al.*, 2016; Harlyan *et al.*, 2019; Kvamsdal *et al.*, 2016; Makino, 2011a). Generally, Indonesian fisheries management apply a conventional single-species approach for some important species, including scads, tuna and mackerel (Chumchuen and Chumchuen, 2019; Harlyan *et al.*, 2019, 2020).

In this study, three HCRs were performed, Schaefer and Fox models as conventional surplus production models and the feedback HCR to estimate the annual TAC along with the annual TAE. The results of all HCRs provided the annual TAC that is biologically safe since those applied precautionary approaches to avoid overfishing (Ichinokawa *et al.*, 2015). Based on the calculation of the feedback HCR, the annual TAC was set a half lower than the ones that set by the Schaefer and Fox model. Technically, the different of basic calculation on the annual TAC of the three HCRs is in the two conventional surplus production models, the abundance index estimation (i.e., the b-value, regression coefficient) was considered for all years, however, in the feedback HCR, only the recent four years was considered to be calculated. In this study, the b-values were influenced by the high CPUEs during 2011-2016 and the low CPUEs during 2017-2020.

The historical catch shown in the stock levels has an important role to determine upcoming policy and fishing strategies (Harlyan *et al.*, 2019; Magnusson, 1992). If a fishery has a low stock level (Kleisner *et al.*, 2013), this fishery must be recovered by applying lower catch quotas (Carruthers *et al.*, 2014; Dowling *et al.*, 2015; Harlyan *et al.*, 2019). While, on the other hand, the conventional surplus production models were based on the MSY estimation, which might contain uncertainties and bias due to impractical single-species approaches to be applied in the multispecies fishery (Shertzer and Williams, 2008). Regarding the comparison of the annual TAE estimations, the feedback HCR allowed the scads fishery to have more fishing trips compared to the other two HCRs to adapt a lower stock abundance index in the recent years. Nevertheless, the TAE estimations provided by three HCRs are still relatively safer than the actual fishing effort in the recent years.

Table 2. Catch and effort data of scad fishery in 2011 – 2020

Year	Effort (trip)	Catch (ton)	CPUE (ton/trip)
2011	319	651,7	2,04
2012	316	668,2	2,12
2013	313	684,7	2,19
2014	440	708,4	1,61
2015	400	732,1	1,83
2016	268	838,6	3,13
2017	868	945,1	1,09
2018	1689	1196,1	0,71
2019	1819	716,8	0,39
2020	1402	477,1	0,34

Description: Effort indicating the number of trips operated per year (trip), catch indicating the amount of catch landed in Tambakrejo fishing port (ton), and CPUE (catch per unit effort) indicating the stock abundance index (ton/trip)

Table 3. The annual TAC and TAE comparison among HCRs

No Parameters	The Schaefer model	The Fox model	The feedback HCR
1 TAC ₂₀₂₁ (tons)	1012	785,38	300,6
2 TAE ₂₀₂₁ (trips)	550	440	763

Description: TAC₂₀₂₁ is the estimation of total allowable catch (tons) in 2021 and TAE₂₀₂₁ is the estimation of total allowable effort (trips) in 2021

The impracticality of single-species surplus production models occurred due to the requirement of the species-specific data that multispecies fishery might hardly provide (Cadriin and Dickey-Collas, 2015; Hilborn and Walters, 1992). Meanwhile, the feedback HCR can estimate TAC without having species-specific data since the species can be grouped based on their growth rate with special monitoring for slow-growing minor species (Harlyan et al., 2019). The other impracticality of single-species surplus production models is their assumptions which may limit the use of these models for all types of fisheries. It was stated that the relationship between catch per unit effort and effort must be a negative correlation, which indicates the models could not work in a “healthy” fishery where an increase of effort still can increase catch per unit effort (Sartimbul et al., 2016).

The scads fishery in Blitar is a multispecies fishery that comprises of four scads species. Commonly, the multispecies fishery might raise an avoidable species aggregation problem (Harlyan et al., 2019). This problem might lead to high uncertainty in fisheries data collection and fish stock assessment (Yuniarta et al., 2017). Therefore, the feedback HCR for multispecies scads fishery in Blitar can answer the species aggregation problems, since it does not require species segregation as required by most conventional single-species approaches.

4. Conclusion

Compared to the HCRs of the conventional surplus production models, the application of the feedback HCR can be closer and more adaptable to the historical stock abundance, which is biologically safer to scads multispecies fishery. This research also suggested that the feedback HCR is appropriate for multispecies fisheries management where only mixed-species data are available. Therefore, the implementation of the feedback HCR in the actual multispecies fishery needs to be documented to validate the use of the feedback HCR as a preliminary management for sustainable multispecies fisheries while dealing with data-limited conditions.

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Authors' Contributions

All authors contributed to the final manuscript. The contribution of each author as follow, L.I.H.; devised the main conceptual ideas and drafted the manuscript. S.A.N.; collected data and designed the figures. D.S.; provided critical revision of the articles. M.A.N.; formulated discussion and designed the figures. S.P.; formulated the critical discussion. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests of conducting this research.

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