# Harvest control rules of pelagic fisheries in the Bali Strait, Indonesia

**LEDHYANE IKA HARLYAN[1,2,♥], LAILATUL BADRIYAH[1], MUHAMMAD ARIF RAHMAN[1,2],**
**DARMAWAN OCKTO SUTJIPTO[1], WAHIDA KARTIKA SARI[1]**

[1]Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran No.16, Malang 65145, East Java, Indonesia.
Tel.: +62-341-553512, Fax.: +62-341-557837, ♥email: ledhyane@ub.ac.id
[2]MEXMA Research Group, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. Jl. Veteran No.16, Malang 65145, East Java, Indonesia

**Abstract.** *Harlyan LI, Badriyah L, Rahman MA, Sutjipto DO, Sari WK. 2022. Harvest control rules of pelagic fisheries in the Bali Strait, Indonesia. Biodiversitas 23: 947-953.* Multispecies pelagic fisheries have contributed as the main fishery production for the Bali Strait fisheries. To maintain the sustainability of the fish stock, sets of harvest control rules (HCRs) have been introduced in terms of fishery management. Conventional single-species surplus production models have been used extensively to determine the future annual allowable biological catch (ABC). However, they may not technically apply to multispecies fishery management. The feedback harvest control rule HCR has been validated and applied to maintain the catch variability of the multispecies fishery. This study aims to technically compare the use of the surplus production model and the feedback HCR in the ABC estimation. The catch and effort data series of the three dominant species from 2010-2019, collected from Pengambengan and Muncar fishing port, were analyzed by two HCRs, the Schaefer surplus production model and the feedback HCR to obtain the ABC. As a result, the Schaefer model showed a higher estimation of ABC than the feedback HCR because the feedback HCR may reflect the recent historical catch consistent with precautionary principles. The feedback HCR showed an initial step toward sustainably managing multispecies fisheries while dealing with unavailability in species-specific data conditions.

**Keywords:** Allowable biological catch, feedback HCR, mixed-species data, multispecies fishery, Schaefer model

## INTRODUCTION

The Indonesian fisheries management area (WPP-NRI) 573, which encompasses the Indian Ocean from South Java to the South Nusa Tenggara, the Sawu Sea, and the western part of the Timor Sea, is enriched with several valuable species (Department of Fisheries and Marine Affairs Indonesia 2014). Under WPP NRI 573, the Bali Strait has contributed to significant pelagic fisheries production in Indonesia (Himelda et al. 2011). Pelagic fisheries are widely distributed in the Bali Strait and are landed in Muncar fishing port, Banyuwangi, and Pengambengan fishing port, Bali. In most fishing activities, purse seine is used as the main fishing gear since the gear can effectively catch pelagic schooling fish (Nugraha et al. 2018).

*Sardinella* and some tuna species are the dominant species in the Bali Strait, contributing 14.23% of the total Indonesian fisheries export (Department of Fisheries and Marine Affairs Indonesia 2020a). The exploitation rate, the potential estimation, and the total allowable catch of pelagic fisheries resources have been fully implemented in some WPP-NRI (Nugraha et al. 2018). In this situation, the fisheries can continue to be exploited under strict monitoring. The exploitation ratio has increased from a moderate status by 50% while applying a precautionary approach for sustainable fishery management (Department of Fisheries and Marine Affairs Indonesia 2016). The population dynamics of the Bali Strait pelagic fishery is relatively high as various oceanography phenomenon (Sambah et al. 2016), which may affect catch variability for some group species such as *Sardinella* spp., *Euthynnus* spp., and *Decapterus* spp.

Over the past decade, several studies have documented the management of the Bali Strait fishery using conventional single-species surplus production models to address a high risk of over-exploitation of some dominant species (Himelda et al. 2011). These single-species models have been used to estimate fish stock in most tropical fisheries that are characterized as multispecies fishery (Hilborn and Ovando 2014; Newman et al. 2018; Harlyan et al. 2019, 2020). The models require biologically species-specific for each species (Costello et al. 2012; Cadrin and Dickey-Collas 2015; Kvamsdal et al. 2016). Therefore, technically conventional surplus production models may not apply practically to multispecies fishery or fishery without species-specific data (Shertzer et al. 2008; Harlyan et al. 2019, 2020).

In tropical multispecies fishery, adopting a single-species assumption may not be practical as multi-gear exploits various groups of species (Harlyan et al. 2021). However, fishery management still applied the single-species approach used in sub-tropical regions. Therefore, in this situation, the approaches only prioritize estimating some key species or dominant species even though many species exist in the tropical multispecies fishery. In addition, tropical regions might deal with species separation problems, limiting capability in providing species-specific data as required by the single-species approach (Yuniarta et al. 2017).

The feedback harvest control rule (HCR) is an implemented HCR for the Japanese fisheries (Tanaka 1980; Ohshimo and Naya 2014; Ichinokawa et al. 2015, 2017). It was introduced in 1997 as one of the fishery management tools that does not require biomass estimation to determine the amount of allowable catch (Matsuda et al. 2010; Makino 2011). The application can provide scientific recommendations for estimating the future annual allowable biological catch (ABC) by considering previous stock abundances. In the feedback strategy, fish stock is assumed as a control system for catch quota as an outcome and the previous stock abundance as an input. They work as a loop system as the catch quota is controlled and adapted to the previous fish stock abundance (Magnusson 1992; Goethel et al. 2019). Using the feedback HCR might provide balance in stock size and sustainable fisheries (Hoshino et al. 2012; Ohshimo and Naya 2014; Harlyan et al. 2019, 2020), as is the policy for catch quota (Makino 2011; Ichinokawa et al. 2017) without having species separation as needed in the conventional single-species model (Harlyan et al. 2020). Therefore, considering the concept of the feedback HCR and the species separation problems in the multispecies tropical regions, it is important to assess the use of these applications in tropical regions such as Indonesia.

The Indonesian government has committed itself to conduct fisheries management through catch quota in the Strategic Plan of the Ministry of Fisheries and Marine Affairs from 2015-2024 (Department of Fisheries and Marine Affairs Indonesia 2020b). Therefore, it is important to establish an appropriate harvest control rule to support the multispecies catch quota policy. From 2010-2019, three dominant groups of species contributed to the multispecies pelagic fishery of the Bali Strait. They are Bali Sardinella (*Sardinella lemuru)*, cads (*Decapterus* spp), and Bullet tuna (*Auxis* spp). This study was aimed to conduct a technical comparison between the applied HCR based on the surplus production Schaefer model and the validated feedback HCR in providing the annual ABC and allowable biological effort (ABE) of three dominant species caught in the Bali Strait for sustainable fisheries management.

## MATERIALS AND METHODS

### Study area
The Bali Strait catches were landed in two fishing ports. The catch and effort data series were collected from Muncar fishing port, Banyuwangi, East Java, and Pengembengan fishing port, Jembrana, Bali, Indonesia. The study was conducted in April-May 2021 (Figure 1).

### Materials
The source data was time-series of catch-effort data collected from the annual reports of the fisheries statistics data from 2011 to 2020 collected from a fishing port in Muncar and Pengambengan. The catch data were the three dominant species landing data, while the effort data was the fishing trips conducted for catching three dominant species in the Bali Strait. The annual fishing trips per year were calculated from all fishing gears with which three dominant species were caught. Four gears were documented in Muncar and Pengambengan fishing ports. Purse seine and gillnet existed in both areas, while hand-line was merely documented in Pengambengan fishing port, and payang was documented only in Muncar fishing port.
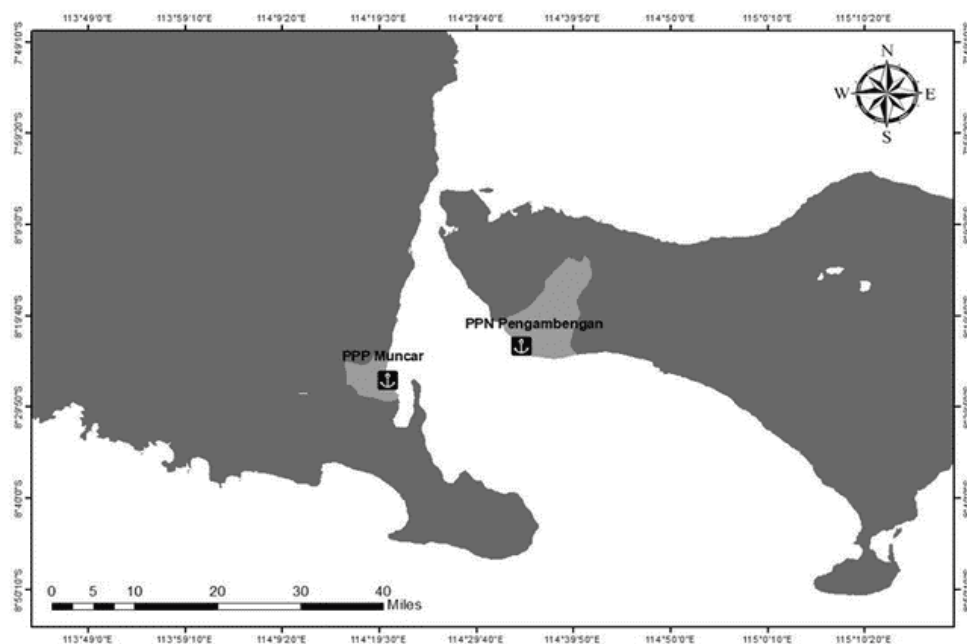


**Figure 1.** Location of data collection in Muncar fishing port (PPP Muncar, Banyuwangi) and Pengambengan fishing port (PPN Pengambengan, Bali)

## Procedures

Several forms of data analyses were carried out to estimate the ABC of the year. Two HCRs were technically compared, the common HCR with conventional surplus production model approach and the feedback HCR. The Schaefer model represented the common HCR. The catch per unit effort ratio was applied to express the stock abundance index for three dominant species, Bali Sardinella, scads and bullet tuna, the catch per unit effort ratio was applied. The details of formulas are shown as follows:

### Catch per unit effort

Catch per unit effort (*CPUE*) specifies the stock abundance index of each species or group species that calculated by the following formula:

$$CPUE = \frac{c}{f} \qquad [1]$$

Where, *c* and *f* indicate catch (kg) and effort (fishing trips), respectively (Sparre and Venema 1992). In the Bali Strait pelagic fisheries, the trip length is one-day fishing for all gears.

### Effort standardization

Before HCR analyses, the data treatment was performed to determine the fishing effort standard for various fishing gears. Effort standardization was applied since various fishing gears differ from each other employed to exploit the dominant species in the Bali Strait. In practice, the method is applied to obtain the standard gear that generates the highest fishing effort in all fishing gears. The productivity of all gears is compared by calculating the fishing power index (FPI) of each gear. The FPI of standard gear is equal to 1 (Sparre and Venema 1992).

$$FPI = \frac{CPUE \text{ of gear}}{CPUE \text{ of standard gear}} \qquad [2]$$

The standardized effort is calculated by the following formula:

The standardized effort = $FPI \times$ effort $\qquad$ [3]

## Data analyses

The annual ABC was assessed by applying two HCRs to the catch and effort data series year 2010-2019 of three dominant group species in the Bali Strait.

### The feedback HCR

The results of calculation feedback HCR were the annual ABC. The ABC was recommended based on the overfishing limit for scientific uncertainty. However, the total allowable catch (TAC) can be set, which cannot exceed the recommended ABC in an actual situation.

The feedback HCR applied was calculated using the following formulas $ABC_y$:

$$ABC_y = \delta \times C_{y-2} \times \gamma \qquad [4]$$

$$\gamma = 1 + k\frac{b}{I} \qquad [5]$$

The weighting coefficient is set as 1, 1, and 0.8 for stock levels high, medium, and low, respectively. The stock levels are estimated from the trend of the stock abundance index of three dominant species in the Bali Strait from 2010-2019. In this study, *CPUE* was applied as the stock abundance level index. The stock level was determined by calculating the upper and the lower limit of the stock abundance index obtained from the minimum and maximum value differences towards its interval. The high stock level is defined if the recent CPUE value is higher than the upper limit, while the medium is between the upper and lower limit. The low stock level is defined if the recent *CPUE* is lower than the lower limit. The indicated the catch of y-2 (kg), the *k* is the feedback factor (which is set to 1), while indicating the trend of *CPUE* during the study period. The symbols *b* and *I* are defined as regression coefficients and the average of *CPUE* in the y-4 to y-2 (kg/fishing day).

The feedback HCR can simply be applied to all species in the multispecies fishery if the species has a fast and/or moderate growth rate. However, in the case of slow-growing species, in particular, special monitoring and evaluation must be conducted to assure its stock size and status (Harlyan et al. 2019).

### Schaefer surplus production model

In this study, the Schaefer model was used to represent the conventional single-species surplus production model to estimate the annual ABC. The basic concept of surplus production models is used to determine the maximum sustainable yield (MSY) as the condition where the stock can be exploited with no impact on future stock production. Therefore, it is assumed that CPUE and effort have a linear negative relationship using the following formula:

$$\frac{c}{f} = a - b.f \qquad [6]$$

$$f_{MSY} = -\frac{a}{2b} \qquad [7]$$

$$C_{MSY} = -\frac{a^2}{4b} \qquad [8]$$

The a and b are the regression coefficient indicating the intercept and slope, respectively. The *fMSY* denotes the effort that is consistent with achieving *MSY*, while the *CMSY* specifies the largest average catch that can continuously be obtained from a stock under existing environmental conditions. The total allowable catch (TAC) is 80% of the *CMSY* (Harlyan et al. 2020).

## RESULTS AND DISCUSSION

### The feedback HCR

Since the three dominant species have a relatively similar growth rate, the feedback HCR was conducted simultaneously for those species from 2010-2019 as shown in Table 1. As a result, the stock abundance index of Bali Sardinella, Scads and bullet tuna fisheries in the Bali Strait fluctuated during the last 10 years.

From the calculation of stock level ($\delta$) (Eq. 4-5), the stock level ($\delta$) showed a low level of 0.8, as can be seen from the CPUE trend in 2010-2019 (Figure 2).

The catch of pelagic fishery resources in the Bali Strait in the two years prior to the estimated year (Cy-2) was 35,236,844 kg (Table 1). The regression coefficient from 2016-2019 was 3.64, while the average value of CPUE was 158.23 kg/fishing day. Based on the results of the calculations, the value of ABC was 23,201,383 kg, which can also be separated for each species (Table 2).

### The surplus production model (Schaefer model)

Since the Schaefer model is a single-species approach, three dominant species must be estimated for each species.

### Bali Sardinella (Sardinella lemuru)

The linear regression relationship between effort (fishing day) and CPUE (kg/fishing day) showed a negative slope in the Schaefer model (Figure 3a). This indicated that an increase in fishing days decreased in the amount of CPUE by 0.0003 kg. Since the regression relationship showed a negative slope, it met the Schaefer model assumption. The model indicates that the value of CPUE depends on the fishing day about 88.47%, while 11.53% was affected by other factors.

The Schaefer curve (Figure 3b) was parabolically fitted with the catch of Bali Sardinella during 2010-2019. The optimum catch was estimated at about 25,430,214 kg, and the TAC was 20,344,171 kg, while the optimum fishing effort was estimated at 220,285 fishing days. According to the model, the historical catch of Bali Sardinella has exceeded as the impact of an increase in the number of fishing days operated by three fishing gears for exploiting this species.

### Scads (Decapterus spp.)

The scads fishery comprises two species, however, there was species segregation in documenting four species, *Decapterus russelli*, *D. macarellus*, *D. kurroides,* and *D. macrosoma* as *Decapterus* spp. As Bali Sardinella results, the linear regression of CPUE and effort of scads showed a negative relationship with the regression model y = 63.81-0.0002x (Figure 4a). An increase of fishing days will decrease the amount of CPUE by 0.0002 kg/day. As the R2 was 0.87 indicated that 87% of CPUE variation was explained by the number of fishing days. The parabolic Schaefer curve (Figure 4b) was performed at 5,933,228 kg, and the TAC was 4,746,582 kg, while the was about 185,966 fishing days. It showed that the catch and effort of scads exceeded the and the, respectively.

### Bullet tuna (Auxis spp.).

There were two species of bullet tuna, *Auxis thazard* and *A. rochei*, however, it was simply documented as *Auxis* spp. in the fisheries statistics data due to species aggregation in data collection. The linear regression of CPUE and effort was performed negatively as Schaefer model assumption (Figure 5a). An increase in fishing days will result in a reduced CPUE at 0.0001 kg. The model indicated that the variability of CPUE was affected by an increase of fishing days at 81.28% while the rest was affected by other factors. Under the Schaefer curve (Figure 5b), the bullet tuna was 5,945,703 kg, and the TAC was 4,756,562 kg, while the was obtained at 207,311 days at sea. As the other two groups of species, the bullet tuna fishery also exceeded the and the during 2010-2019.

### Technical comparison among HCRs

Technical comparison among HCRs was conducted to analyze the precautionary approach of each HCR to provide the annual TAC (Table 2). It compared the amount of the TAC or ABC generated by the feedback HCR and the Schaefer model.

**Table 1.** Catch and effort data of the dominant species in the period of 2010-2019

| Year | Catch/ $C$ (kg) | Effort/$f$ (fishing days) | CPUE |
|------|-----------------|---------------------------|------|
| 2010 | 35,407,737 | 172,358 | 205.43 |
| 2011 | 36,280,472 | 175,548 | 206.67 |
| 2012 | 37,050,608 | 167,359 | 221.38 |
| 2013 | 38,268,300 | 188,063 | 203.49 |
| 2014 | 37,542,345 | 210,690 | 178.19 |
| 2015 | 38,387,870 | 209,833 | 182.95 |
| 2016 | 35,845,032 | 223,923 | 160.08 |
| 2017 | 36,411,330 | 239,105 | 152.28 |
| 2018 | 36,579,900 | 224,638 | 162.84 |
| 2019 | 35,236,844 | 220,814 | 159.58 |

Collected and verified from the fishery logbook of Pengambengan and Muncar fishing port.
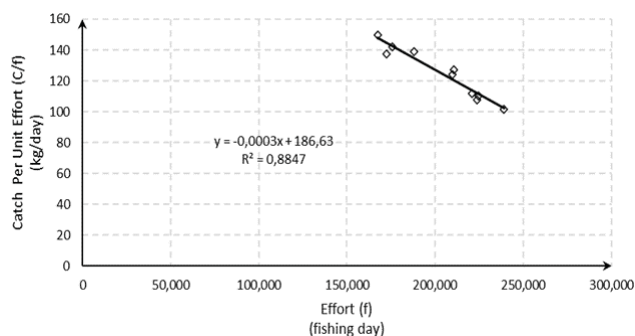


**Figure 2.** The stock level of three dominant pelagic species in the Bali Strait, Indonesia
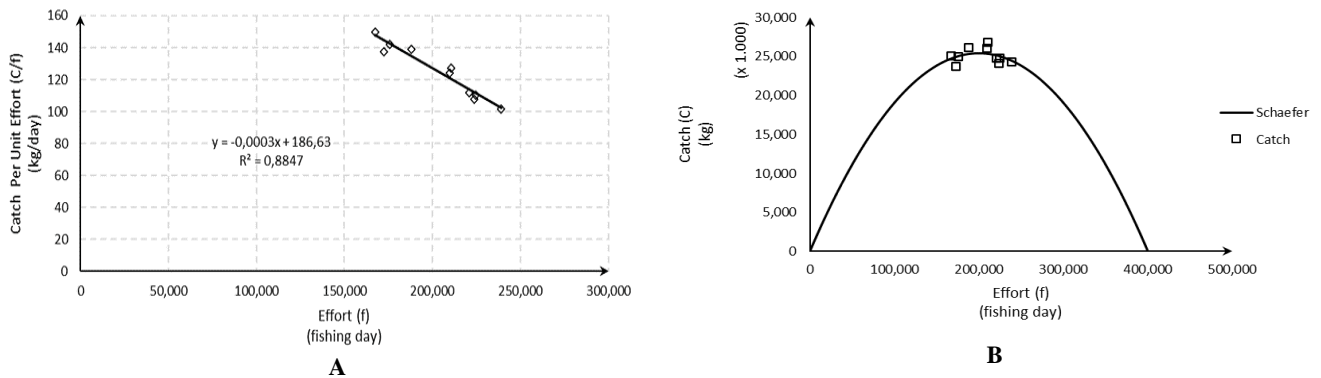
**Figure 3.** Linear regression relationship between CPUE and effort (A) and Schaefer curve (B) of Bali Sardinella in Bali Strait, Indonesia
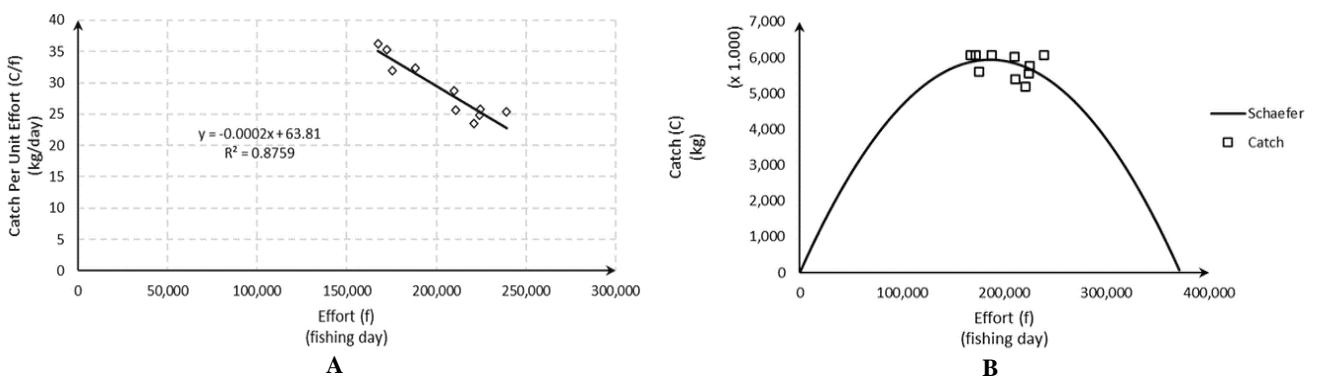


**Figure 4.** Linear regression relationship between CPUE and effort (A) and Schaefer curve (B) of scads in Bali Strait, Indonesia
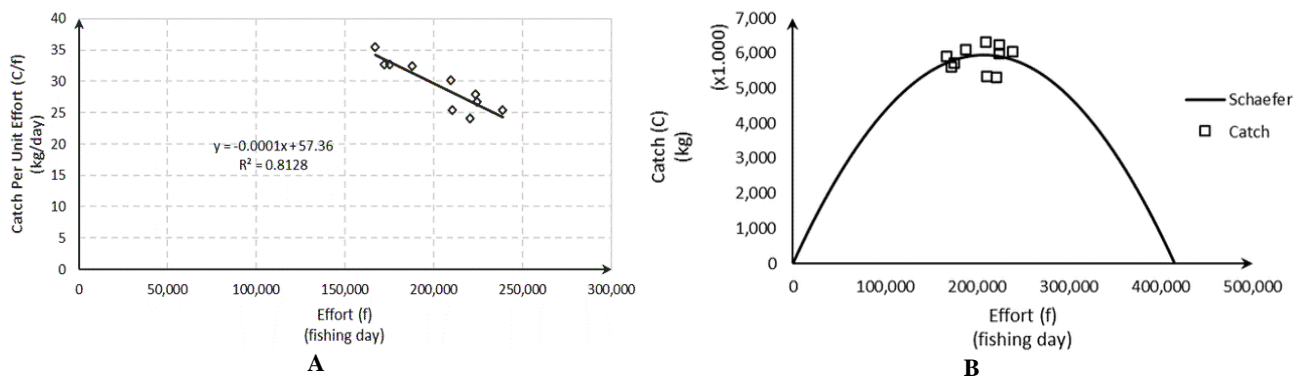


**Figure 5.** Linear regression relationship between CPUE and effort (a) and Schaefer curve (b) of bullet tuna in Bali Strait, Indonesia

**Table 2.** Technical comparison of ABC/TAC estimation

| Species | The ABC estimation of Feedback HCR (kg) | The TAC estimation of the Schaefer model (kg) |
|---|---|---|
| Bali sardinella (*Sardinella lemuru*) | 15,839,626 | 20,344,171 |
| Bullet tuna (*Auxis* sp.) | 3,706,370 | 4,756,562 |
| Scads (*Decapterus* sp.) | 3,655,387 | 4,746,582 |

Overall values showed that the feedback HCR provided the lower estimation of ABC than that of the Schaefer model for all dominant groups of species. For Bali Sardinella, the feedback HCR generated a higher difference estimation of TAC than the Schaefer model, while for the other two species, two models showed less difference TAC estimation.

**Discussion**

As with other tropical fishery managements, multi-species fisheries management in Indonesia has largely

applied conventional single-species stock assessment for years (Newman et al. 2018; Chumchuen and Chumchuen 2019). The Schaefer model, one of the surplus production models, provides estimation on the annual ABC by fitting the historical catch and effort data on the parabolic relationship (Hilborn et al. 2015). A single-species approach requires data of each species individually, which is impractical to be conducted in a mixed or multispecies fishery (Cadrin and Dickey-Collas 2015).

On the other hand, the feedback HCR is a practical application validated to be conducted in a multispecies fishery where only mixed-species data are available (Harlyan et al. 2019). This HCR can determine the annual ABC without estimating species-specific stock biomass (Makino 2011; Ohshimo and Naya 2014; Ichinokawa et al. 2017). In principle, the feedback HCR can manage catch variability by considering the recent historical stock abundance index for the following catch quota (Harlyan et al. 2019, 2020). Most cases in Japan, in the fishery where there are unvalidated effort data, catch data might be applied as stock abundance index (Hurtado-Ferro et al. 2010; Ohshimo and Naya 2014; Harlyan et al. 2019). The feedback HCR may provide practical information with flexibility in data requirement compared to the conventional approach provided by the surplus production model (Makino 2011; Chumchuen and Chumchuen 2019; Harlyan et al. 2019).

Setting up a catch quota system with a single-species approach requires single-species catch data (Yuniarta et al. 2017). However, uncertainties of attaining single-species data caused a delay in catch quota implementation (Harlyan et al. 2021). Therefore, implementing the quota system might need a precautionary approach to comply with the unavailability of single-species specific data such as the feedback HCR.

Due to the lack of study about the use of harvest control rules, therefore in this study, two HCRs were compared in estimating the annual ABC. The technical difference in using two HCRs was caused by the time series of stock abundance index considered in the models. The feedback HCR provides catch recommendation by considering the trend of the recent historical stock abundance index of the two-to-four-year prior estimated year calculated from the stock level, the average I, and the regression slope *b*. While the surplus production model determined the annual ABC by calculating half of carrying capacity as the optimum stock condition to be exploited, which is based on the whole period of historical catch and effort data series. Under these conditions, the feedback HCR is more capable of maintaining catch variability than the HCR generated from the Schaefer surplus production model.

Generally, both HCRs provided a precautionary approach in determining the following catch quota (Harlyan et al. 2020; Harlyan et al. 2022). Fishery management might have sets of precautionary approaches to reduce the effect of high harvest levels, which may assure fishery sustainability (Asche et al. 2018). The approaches are efficacious to maintain fishery sustainability, considering decreased trends in population that occurred for all group species in the Bali Strait.

Technically, the recommendation of the annual ABC provided by the feedback HCR was lower than that of the Schaefer model, which is biology safer to be applied in the multispecies fishery. The determination of the ABC, which later can be assumed as catch quota, was based on the recent historical catch data. To determine upcoming policy and harvest strategy, it is recommended to carefully consider about the historical stock abundance shown at the stock level (Magnusson 1992; Harlyan et al. 2019). The feedback HCR offered capacious fishing effort more than the surplus production model, and it still maintains the catch variability. While, on the other hand, the single-species Schaefer model was based on the MSY estimation, which might contain uncertainties and bias due to the incapability of the multispecies fishery in providing single-species specific data (Shertzer et al. 2008; Cadrin and Dickey-Collas 2015).

In the feedback HCR, the species can be grouped based on their growth rate with special monitoring for slow-growing minor species (Harlyan et al. 2019), which will be applicable for the segregation-species data as occurred in this study. This study comprised two aggregated species, *Auxis* spp. and *Decapterus* spp., which were documented as the dominant group of species. There was no necessity to document all species separately, furthermore, there might be a lack of technical data enumeration in providing species identification. This might lead to failure to provide species-specific biological data as required by surplus production models (Yuniarta et al. 2017; Harlyan et al. 2021). This condition reveals the possibility of uncertainty in the whole annual fisheries statistics data since the inaccuracies in species separation will lead to misreporting and unreliable stock estimations (Yuniarta et al. 2017). Therefore, the use of the feedback HCR for multispecies pelagic fisheries in Bali Strait can be an answer to the unavailability of fisheries in species separation problems which commonly occur in mixed-species and/or multispecies fishery.

Compared to the conventional surplus production model, the feedback HCR is more adjustable to the historical abundance, which is biologically safe to be applied for the Bali Strait pelagic fisheries. This study also suggested that the feedback HCR is applicable for multiple species fisheries management, like the Bali Strait pelagic fisheries, where only mixed-species data are available. Therefore, it is necessary to document the implementation of the feedback HCR in the actual multispecies fishery in order to verify the use of the feedback HCR as provisional management of sustainable multispecies fisheries under data-limited conditions.

# REFERENCES

Asche F, Garlock TM, Anderson JL, Bush SR, Smith MD, Anderson CM, Chu J, Garrett KA, Lem A, Lorenzen K, Oglend A, Tveterasc S, Vannuccini S. 2018. Three pillars of sustainability in fisheries. Proc Natl Acad Sci 115 (44): 11221-11225. DOI: 10.1073/pnas.1807677115.

Cadrin SX, Dickey-Collas M. 2015. Stock assessment methods for sustainable fisheries. ICES J Mar Sci 72 (1): 1-6. DOI: 10.1093/icesjms/fsu228.

Chumchuen W, Chumchuen SV. 2019. Development of albacore tuna fishery and estimation of allowable biological catch for resource management in the Indian Ocean. Fish People 17: 34-40.

Costello C, Ovando D, Hilborn R, Gaines SD, Deschenes O, Lester SE. 2012. Status and solutions for the world's unassessed fisheries. Science 338 (6106): 517-520. DOI: 10.1126/science.1223389.

Department of Fisheries and Marine Affairs Indonesia. 2014. Ministry of Fisheries and Marine Affairs Regulation No. 18 about Indonesian Fisheries Management Areas. Ministery of Fisheries and Marine Affairs, Jakarta. [Indonesian]

Department of Fisheries and Marine Affairs Indonesia. 2016. Ministry of Fisheries and Marine Affairs Regulation No 71/Permen-Kp/2016 about Regarding Fishing Routes and Placement of Fishing Equipment in the Fisheries Management Area of the Republic of Indonesia. Ministery of Fisheries and Marine Affairs, Jakarta. [Indonesian]

Department of Fisheries and Marine Affairs Indonesia. 2020a. 1st Quartely of 2020, Export Values Reach USD 1.24 Billion. Press Release. [Indonesian]

Department of Fisheries and Marine Affairs Indonesia. 2020b. Regulation of Ministry of Fisheries and Marine Affairs The Republic of Indonesia No 17/PERMEN-KP/2020. Ministry of Fisheries and Marine Affairs, Jakarta. [Indonesian]

Goethel DR, Lucey SM, Berger AM, Gaichas SA, Karp MA, Lynch PD, Walter JF. 2019. Recent advances in management strategy evaluation: Introduction to the special issue "Under pressure: Addressing fisheries challenges with management strategy evaluation." Can J Fish Aquat Sci 76 (10): 1-8. DOI: 10.1139/cjfas-2019-0084.

Harlyan LI, Matsuishi TF, Md Saleh MF. 2021. Feasibility of a single-species quota system for management of the Malaysian multispecies purse-seine fishery. Fish Manag Ecol 28 (2): 126-137. DOI: 10.1111/fme.12470.

Harlyan LI, Sari WK, Rahma FM, Fuad, Rahman MA. 2020. Fishery management of Skip jack tuna landed in Prigi Fishing Port, Trenggalek: Feedback harvest control rule application. Mar Fish 11 (1): 111-120. DOI: 10.29244/jmf.v11i1.34866. [Indonesia]

Harlyan LI, Nabilah SA, Setyohadi D, Rahman MA, Pattarapongpan P. 2022. Harvest control rules of multispecies Scads (*Decapterus* Spp.) fishery in Blitar Waters, East Java. Sci J Fish Mar 14 (1). In press. DOI: 10.20473/jipk.v14i1.30688.

Harlyan LI, Wu D, Kinashi R, Kaewnern M, Matsuishi T. 2019. Validation of a feedback harvest control rule in data-limited conditions for managing multispecies fisheries. Can J Fish Aquat Sci 76 (10): 1885-1893. DOI: 10.1139/cjfas-2018-0318.

Hilborn R, Fulton EA, Green BS, Hartmann K, Tracey SR, Watson RA. 2015. When is a fishery sustainable? Can J Fish Aquat Sci 72 (9): 1433-1441. DOI: 10.1139/cjfas-2015-0062.

Hilborn R, Ovando D. 2014. Reflections on the success of traditional fisheries management. ICES J Mar Sci 71 (5): 1040-1046. DOI: 10.1093/icesjms/fsu034.

Himelda, Wiyono ES, Purbayanto A, Mustaruddin. 2011. Analysis of the sardine oil (*Sardinella lemuru* Bleeker 1853) resources in Bali Strait [Indonesian]. Mar Fish 2 (2): 165-176. DOI: 10.29244/jmf.2.2.165-176.

Hoshino E, Milner-Gulland EJ, Hillary RM. 2012. Bioeconomic adaptive management procedures for short-lived species: A case study of Pacific saury (*Cololabis saira*) and Japanese common squid (*Todarodes pacificus*). Fish Res 121-122: 17-30. DOI: 10.1016/j.fishres.2012.01.007.

Hurtado-Ferro F, Hiramatsu K, Shirakihara K. 2010. Allowing for environmental effects in a management strategy evaluation for Japanese sardine. ICES J Mar Sci 67 (9): 2012-2017. DOI: 10.1093/icesjms/fsq126.

Ichinokawa M, Okamura H, Kurota H. 2017. The status of Japanese fisheries relative to fisheries around the world. ICES J Mar Sci 74 (5): 1277-1287. DOI: 10.1093/icesjms/fsx002.

Ichinokawa M, Okamura H, Kurota H, Yukami R, Tanaka H, Shibata Y, Ohshimo S. 2015. Searching for optimum management procedures by quantifying management objectives for Japanese domestic fishery stocks without stock biomass estimation. Nippon Suisan Gakkaishi 81 (2): 206-218. DOI: 10.2331/suisan.81.206. [Japanese]

Kvamsdal SF, Eide A, Ekerhovd N-A, Enberg K, Gudmundsdottir A, Hoel AH, Mills KE, Mueter FJ, Ravn-Jonsen L, Sandal LK, Stiansen JE, Vestergaard N. 2016. Harvest control rules in modern fisheries management. Elem Sci Anth 4: 000114. DOI: 10.12952/journal.elementa.000114.

Magnusson KG. 1992. A feedback and probing strategy to regulate harvesting from a renewable resource. Math Med Biol 9 (1): 43-65. DOI: 10.1093/imammb/9.1.43.

Makino M. 2011. Fisheries Management in Japan: A Brief Institutional History of Japanese Fisheries Management. Springer, Netherlands.

Matsuda H, Makino M, Tomiyama M, Gelcich S, Castilla JC. 2010. Fishery management in Japan. Ecol Res 25 (5): 899-907. DOI: 10.1007/s11284-010-0748-5.

Newman SJ, Brown JI, Fairclough DV, Wise BS, Bellchambers LM, Molony BW, Lenanton RCJ, Jackson G, Smith KA, Gaughan DJ, Fletcher WRJ, McAuley RB, Wakefield CB. 2018. A risk assessment and prioritisation approach to the selection of indicator species for the assessment of multi-species, multi-gear, multi-sector fishery resources. Mar Policy 88: 11-12. DOI: 10.1016/j.marpol.2017.10.028.

Nugraha SW, Ghofar A, Saputra SW. 2018. Monitoring of Bali Sardinella in Bali Strait. Manag Aquat Resour J 7 (1): 130-140. DOI: 10.14710/marj.v7i1.22533. [Indonesian]

Ohshimo S, Naya M. 2014. Management strategy evaluation of fisheries resources in data-poor situations using an operating model based on a production model. Japan Agric Res Q JARQ 48 (2): 237-244. DOI: 10.6090/jarq.48.237.

Sambah AB, Iranawati F, Sari SHJ, Pranoto D, Harlyan LI, Ghafiky AF. 2016. The spatial analysis in tuna habitat related to the ocean variability in the Indian ocean BT. Proceeding of lst International Conference on Geography and Education (ICGE 2016). Universitas Negeri Malang, Indonesia, 29 October 2016.

Shertzer KW, Prager MH, Vaughan DS, Williams EH. 2008. Fishery models. In: Jørgensen SE, Fath BDBT-E of E (eds). Handbook of Fish Biology and Fisheries. Academic Press, Oxford.

Sparre P, Venema SC. 1992. Introduction to Tropical Fish Stock Assessment. Part 1: Manual. FAO, Rome.

Tanaka S. 1980. A theoretical consideration on the management of a stock-fishery system by catch quota and on its dynamical properties. Nippon Suisan Gakkaishi 46 (12): 1477-1482. DOI: 10.2331/suisan.46.1477.

Yuniarta S, van Zwieten PAM, Groeneveld RA, Wisudo SH, van Ierland EC. 2017. Uncertainty in catch and effort data of small- and medium-scale tuna fisheries in Indonesia: Sources, operational causes and magnitude. Fish Res 193: 173-183. DOI: 10.1016/j.fishres.2017.04.009.