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Fishing Pattern and Harvest Control Rules of the Octopus (*Octopus cyanea*) Fishery in Flores Sea, Indonesia

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ABSTRACT

The octopus (*Octopus cyanea*) fishery in the Flores Sea, Indonesia, supports local livelihoods and supplies not only domestic, but also international markets which require ecolabel certification. Nevertheless, insufficient data on fishing patterns and harvest strategies has impeded the fishery's eligibility for Marine Stewardship Council (MSC) ecolabel certification, highlighting a significant research gap. Validated data collection methods regarding catch and effort were acquired from octopus landings in Nangahale village, Sikka Regency, from 2020 to 2023. The analysis of catch per unit effort (CPUE) indicated stable stock abundance, with peak fishing seasons occurring between April–July and October–December. Two harvest control rule (HCR) models were assessed: the Schaefer surplus production model and the feedback HCR. Results demonstrated that the feedback HCR provided more adaptive and precise management recommendations, setting an allowable biological catch (ABC) of 7,880kg and an allowable biological effort (ABE) of 5,131 trips for 2024. The Schaefer model, typically applied in single-species fisheries, proved less effective in this small-scale, multi-gear, and data-limited context, as shown by a positive correlation between CPUE and fishing effort. These findings highlight the utility of feedback HCRs for managing small-scale, data-limited fisheries by enabling dynamic adjustments based on real-time stock assessments. While current fishing pressures in the Flores Sea have not resulted in overexploitation, continued adaptive management is essential to ensure sustainability. Future research should consider environmental variables and socio-economic factors to enhance HCR applications, thereby underlining the fishery's applicability to comparable cephalopod fisheries worldwide. These strategies are critical for maintaining long-term sustainability and aligning the fishery with international standards for MSC certification.

INTRODUCTION

The octopus fishery in the Flores Sea is a small-scale, traditional fishery characterized by limited data recording. Nevertheless, this fishery serves as a primary supplier to the food industry, fulfilling both domestic needs and international market demands, including that of PT. Agrita Best Seafood, Tbk. To access global markets, PT.

Agrita Best Seafood, Tbk requires Marine Stewardship Council (MSC) certification for the octopus in the Flores Sea. Achieving this certification will ensure the sustainability of fishery stocks, minimize the fishery's impact on the surrounding ecosystem, and promote effective management **(Southall *et al.* 2016)**. The certification process is technically supported by PT. Sahabat Laut Lestari. Consequently, since 2019, the local government of East Nusa Tenggara Province, in collaboration with PT. Agrita Best Seafood, Tbk as the industry actor, has applied for MSC certification for the octopus fishery in the Flores Sea **(Fishery Networks, 2021)**.

Octopus cyanea represents the predominant catch within the Flores Sea, primarily harvested utilizing fishing methods such as pocong, siput, and spears. Pocong is the most prevalent in the octopus fishery of Flores Sea **(Fishery Networks, 2021)**. It involves a fishing line modified with an attractor that mimics octopus tentacles **(Bunbun *et al.*, 2019, Minggo *et al.*, 2023)**. The siput employs a modified handline with an artificial lure shaped like a snail **(Minggo *et al.*, 2023)**, while the spear is an active fishing tool designed for close-range targeting of prey **(Ministry of Fisheries and Marine Affairs, 2023)**. In the context of the octopus fishery improvement program aimed at achieving MSC certification, the evaluation encompasses octopuses captured using these three types of fishing gear **(Fishery Networks, 2021)**.

The Marine Stewardship Council (MSC) certification is a benchmark for ensuring that fisheries adhere to the highest international standards for sustainable fishing practices. The evaluation process for MSC certification is grounded in three fundamental principles: the sustainability of fish stocks, the minimization of environmental impacts from fishing activities, and the assurance of effective fisheries management **(Southall *et al.*, 2016, Le Manach *et al.*, 2020, Harlyan *et al.*, 2023, 2025)**. Fisheries seeking certification must undergo a series of rigorous stages, including pre-assessment, the development of an action plan, and the implementation of that plan, all of which constitute the fisheries improvement program (FIP) **(Fishery Networks, 2021)**.

The octopus FIP in Flores Sea has undergone a pre-assessment by Fishery Networks, which concluded that the fishery generally requires additional information on existing octopus fishery management. Octopus fishing is conducted year-round, with a high degree of uncertainty about octopus availability. There is a lack of specific information on octopus seasonal fishing patterns to guide fishing operations. Moreover, no specific harvest strategy nor harvest control rule (HCR) in place to manage the octopus fishery effectively **(Fishery Networks, 2021)**. This situation highlights a significant research gap, as prior studies have insufficiently examined how data-limited octopus fisheries can systematically implement targeted harvest strategies to comply with fishery certification requirements, hence leaving management without a clear guidance on sustainable exploitation levels. HCRs have emerged as a crucial component in fisheries management. Their adoption is becoming more widespread as they offer a consistent approach to management practices, address uncertainties and ecosystem-related factors

(Kvamsdal *et al.*, 2016, Harlyan *et al.*, 2019). The absence of harvest control rules (HCRs) in fishery could lead to a lack of control over resource exploitation, potentially resulting in overexploitation **(Harlyan *et al.*, 2019, 2022a, b, 2023)**.

Various HCRs are implemented in fisheries management. In tropical fisheries, the single-species approach, commonly utilized in sub-tropical fisheries, is frequently adopted **(Harlyan *et al.*, 2022c)**. This conventional surplus production model generally emphasizes the estimation of a select number of key or dominant species **(Yuniarta *et al.*, 2017)**. On the other hand, there is an implemented HCR for Japanese fisheries which can provide the feedback strategy to estimate catch quota from the previous stock abundances **(Tanaka, 1980, Ohshimo & Naya, 2014, Ichinokawa *et al.*, 2015, 2017)**, named feedback HCR. The feedback HCR enables the estimation of allowable catch levels without the necessity of conducting biomass assessment beforehand **(Matsuda *et al.*, 2010, Makino, 2011)**. Consequently, it is critical to formulate an appropriate HCR by systematic assessment several HCRs to ensure an effective catch quota strategy **(Harlyan *et al.*, 2022a)**. Similar data-limited octopus fisheries in other areas face comparable uncertainty, demonstrating the global importance of investigating adaptive HCR models to address sustainability issues **(Jurado-Molina *et al.*, 2021; Wiryawan *et al.*, 2022)**.

The aims of this study were to (1) identify seasonal trends in octopus fishing in the Flores Sea to enhance fishing efficiency, and (2) estimate the allowable biological catch for the octopus fishery by a comparative assessment of Harvest Control Rules (HCRs). This study provides critical insights for enhancing octopus fishery strategies in accordance with MSC certification requirements by addressing the knowledge gap about seasonal changes and determining biologically sustainable catch.

MATERIALS AND METHODS

Study area

The research was conducted at the octopus landing site in Nangahale Village, Sikka Regency, East Nusa Tenggara Province which is located between Fisheries Management Area (FMA)-713 and FMA-573 (Fig. 1). The fishing areas are spread across the waters of Flores Island from 2020 to 2023, with preliminary site verification conducted to confirm the consistency of observed fishing activities. The data collection period was aligned with the octopus fishing season. Fig. (1) shows the map of the research sites:

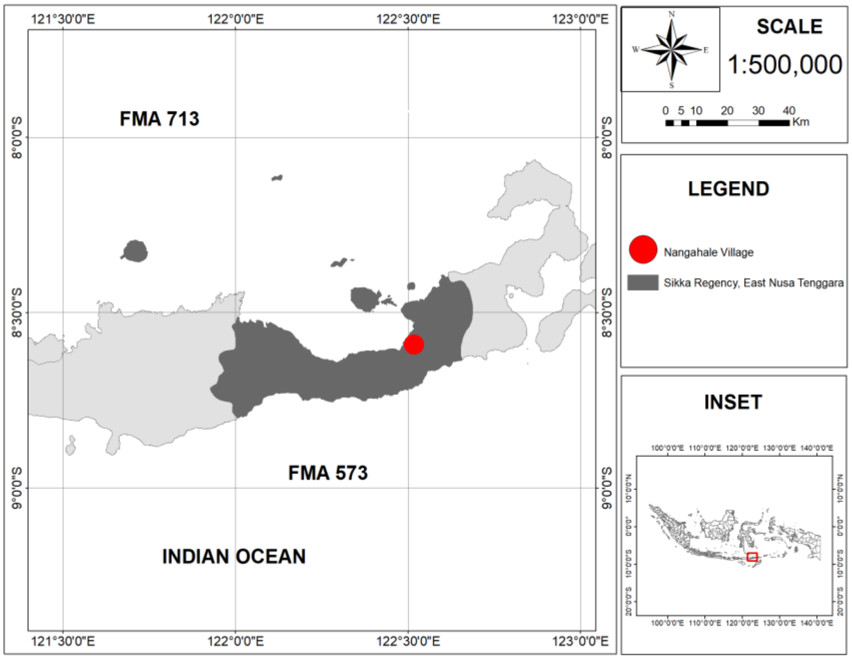

Fig. 1. Location of octopus landing site

Data collection

A field survey was conducted to collect data on octopus catch, fishing effort from landings and fishing ground data in Nangahale village, Sikka Regency, East Nusa Tenggara. The catch data were obtained from the use of spears or harpoons, while the effort data referred to the fishing trips undertaken for catching octopus (*Octopus cyanea*) in the Flores Sea. Harpoons or spears are used to catch octopuses and are equipped with an attractant that resembles an octopus. This attractant, known as "pocong," is made of wood and cement and is covered with frayed cloth (Fig. 2).

Fig. 2. Various forms of Pocong as tool for supporting octopus fishing

To mitigate biases and validate the catch-effort statistics, daily logbook entries from fishermen were compared with on-site landing inspections. Differences were addressed by standardizing data through a review of conflicting entries via direct interviews and an average of consistent records. In addition, an initial count was performed monthly to verify the accuracy of documented catch weight and effort units.

Fishing trips in Nangahale Village generally begin early in the morning. Fishers depart in small boats targeting fishing ground within 4km of the shore. Each trip lasts about 4-6 hours. The trip concludes when the catch is landed back at the village by midday for unloading and recording.

Data analysis

Several forms of data analyses were conducted to estimate fishing pattern and allowable biological catch (ABC) of octopus.

1. Catch per unit effort

Catch per unit effort (CPUE) serves as an index of stock abundance for octopus. Catch Per Unit Effort (CPUE) was calculated as the total number of standardized one-day fishing trips, each typically lasting 4-6 hours. In Nangahale Village, the fishing methods primarily involve hand lines, spears, or harpoons with attractants. This method aligns with similar studies in other tropical fisheries, where one-day trips serve as a standard unit of effort measurement. It is calculated using the following formula:

$$CPUE = \frac{c_i}{f_i} \quad (1)$$

The c and f assumed as catch (kg) and effort (fishing trips), respectively **(Sparre & Venema, 1992)**. In the Flores Sea octopus fishery, the trip is one-day fishing.

2. The fishing season index

The fishing season was determined through a moving average approach and calculating an fishing season index (*FSI*) for each month **(Nurani *et al.*, 2021)**. This analysis was conducted in accordance with the procedural steps. The CPUE was denoted as U, while the monthly CPUE was denoted as U_i and the monthly average CPUE in a year denoted as $\bar{U}$. The m value is denoted as 12, indicating 12 months of fishing operation. It formulated by following formula:

$$\bar{U} = \frac{1}{m} + \sum_{i=1}^{m} U_i \quad (2)$$

To calculate the ratio of U_i to $\bar{U}$, it was applied by following formula:

$$U_p = \frac{U_i}{\bar{U}} \times 100\% \quad (3)$$

To estimate the season index (SI_i), it was considered t as number of years data by following formula:

$$SI_i = \frac{1}{t} + \sum_{i=1}^{t} U_p \qquad (4)$$

The value SI_i should be equal to 1200. However, several factors can cause the this value to deviate from 1200. Therefore, it needs to be corrected using following formula:

$$FSI_i = \frac{1200}{\sum_{i=1}^{m} SI_i} \times FS_i \qquad (5)$$

Where, FSI_i is fishing season index to i. Months where FSI exceeded 100% were considered peak fishing seasons, while values between 50–100% indicated moderate fishing seasons.

3. Justification of models

Two HCR models were selected based on their suitability for data-limited and small-scale fisheries contexts. They are the Schaefer surplus production model **(Schaefer 1957)** and the feedback HCR **(Tanaka, 1980; Makino, 2011; Harlyan *et al.*, 2019)**.

a. Feedback HCR

This was chosen for its adaptability in real-time and ability to estimate allowable catch without fully relying on biomass assessments **(Matsuda *et al.*, 2010; Harlyan *et al.*, 2019)**. This model is particularly relevant when dealing with multiple fishing gears and variable species behavior, as in the Flores Sea.

b. Schaefer model

This model frequently used in single-species fisheries, it assumes a linear inverse relationship between CPUE and fishing effort. Despite this simplicity, it can provide a reference point (MSY) for management decisions if data cover a sufficient range of effort.

4. Harvest control rules

a. The feedback HCR

The feedback HCR calculations yielded the annual Allowable Biological Catch (ABC). This ABC was recommended with consideration for the overfishing limit and accounted for scientific uncertainty. However, in practice, the Total Allowable Catch (TAC) can be established, ensuring it does not surpass the recommended ABC. The feedback Harvest Control Rule (HCR) was performed using the following formulas:

$$ABC_y = \delta \times C_{y-2} \times \gamma \qquad (6)$$

$$\gamma = 1 + k\frac{b}{I} \qquad (7)$$

The weighting coefficients for stock levels were assigned as follows: 1 for high, 1 for medium, and 0.8 for low stock levels. These stock levels were estimated based on the trends observed in the stock abundance index of octopus from 2020 to 2023. In this analysis, CPUE was utilized as the index for stock abundance. The determination of stock levels involved calculating both the upper and lower limits of the stock abundance index by assessing the differences between the minimum and maximum values within the defined intervals. A high stock level is designated when the current CPUE value exceeds the upper limit, while a medium stock level is indicated if the CPUE falls between the upper and lower limits. A low stock level is defined if the recent CPUE is below the lower limit. The variable C_{y-2} represents the catch in kilograms, k denotes the feedback factor (set to 1), and the trend in CPUE during the study period is indicated. The symbols b and I refer to the regression coefficients and the average CPUE from $y-4$ to $y-2$ (kg/fishing day), respectively **(Goethel *et al.*, 2019a, Harlyan *et al.*, 2019)**.

b. The Schaefer model (1957)

In this study, the Schaefer surplus production model was employed to represent the conventional single-species approach for estimating the annual ABC. The fundamental principle behind surplus production models is used to estimate the maximum sustainable yield (MSY), which represents the level of exploitation that ensures the stock's future productivity remains unaffected. This model operates under the assumption of a linear inverse relationship between CPUE and fishing effort, as described by the following formula:

$$\frac{c}{f} = a - b.f \quad (8)$$

$$f_{MSY} = -\frac{a}{2b} \quad (9)$$

$$C_{MSY} = -\frac{a^2}{4b} \quad (10)$$

In this model, a and b represent the regression coefficients, where a indicates the intercept and b the slope of the linear relationship. The variable f_{MSY} denotes the fishing effort level that corresponds to achieving the maximum sustainable yield (MSY), while C_{MSY} specifies the largest average catch that can be consistently harvested from a stock under current environmental conditions. For practical management purposes, the total allowable catch (TAC) is set at 80% of the C_{MSY} to account for uncertainties and ensure sustainability **(Harlyan *et al.*, 2020)**.

RESULTS

Habitat and distribution of octopus in East Nusa Tenggara

The octopus is predominantly found in benthic environments characterized by a variety of substrates including rocky areas, sandy beds, remnants of mollusk shells, and other debris on the seafloor. According to **Roper *et al.* (1984)**, this species thrives in marine habitats such as coral reefs, seagrass meadows, and substrates composed of sand, mud, and rocky formations. These habitat preferences indicate that the coastal waters of Sikka Regency in East Nusa Tenggara possess significant potential for octopus' fisheries.

The spatial distribution of octopus catches, as depicted in Fig. (3), highlights substantial resource potential within these regions. The presence of local fisheries targeting octopus in the coastal zones of Sikka Regency—encompassing areas such as Wolomarang, Bola, Woloterang, Namangkewa, Kojadoi, Nangahale, Wairbleler, Talibura, Paga, Parumaan, Pemana, Pruda, Samparong, Watudiran, Talibura, Darat Pantai, and Wuring—supports this assessment. Additionally, fishing activities extend to Ende Regency (Maurole Village) and Flores Timur Regency (including Watowara, Larantuka, Kawalelo, Nobo, Ojan Detun, and Oa Beach).

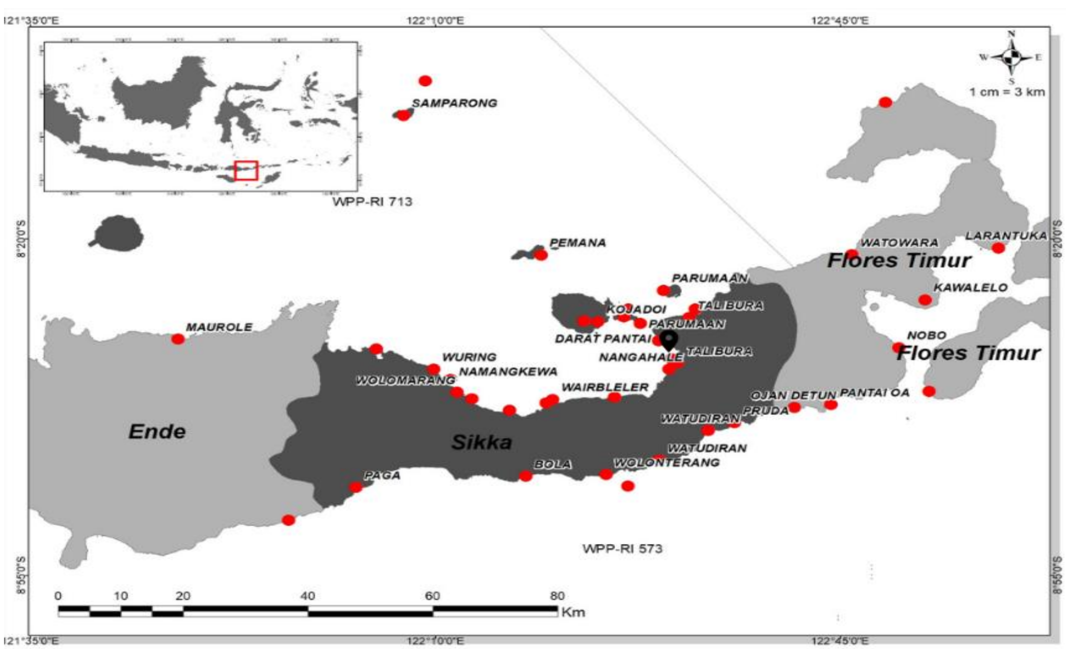

Fig. 3. Distribution of octopus fishery in Flores Sea

Nangahale Village in Sikka Regency serves as the primary aggregation point for octopus landings. The findings indicate that the fishery mainly operates within a 4km radius from the coastline, consistent with its small-scale characteristics.

Trends of CPUE

Based on the catch and fishing effort data for the octopus fishery landed in Nangahale Village, Sikka Regency, from 2020 to 2023, there were no significant differences in CPUE from January to June across the years observed. However, from July to December in all observed years, there was a decline in CPUE from July through August and September, followed by an increase in CPUE from September to December in specific pattern (Fig. 4).

Based on the annual trend, from July to December, there has been an overall increase in CPUE from 2020 to 2023, following a specific pattern. These fluctuations indicate that although CPUE remains comparatively stable in the first half of the year, a mid-year decline is consistently observed, potentially indicating decreased octopus availability or decreased fishing activity during this period. The subsequent increase from September to December shows either a stock recovery or increased fishing activities.

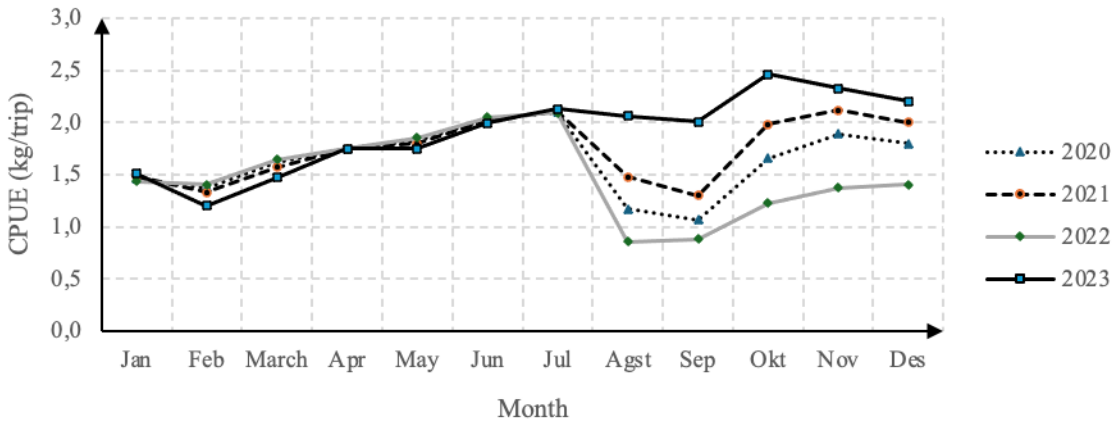

Fig. 4. The monthly CPUE trend of Octopus fishery in Flores Sea

The fishing season index

The seasonal fishing pattern for octopus, as determined by the calculation of the Fishing Season Index (FSI_i) and illustrated in Fig. (5) reveals that the peak fishing season for octopus landings in Sikka Regency occurs from April to July, and again from October to December, with FSI_i values exceeding 100%. The highest IMP value is observed in July at 132%. A secondary, moderate fishing season is indicated from January to March and from August to September, with FSI_i values exceeding 50%, the lowest being recorded at 67%.

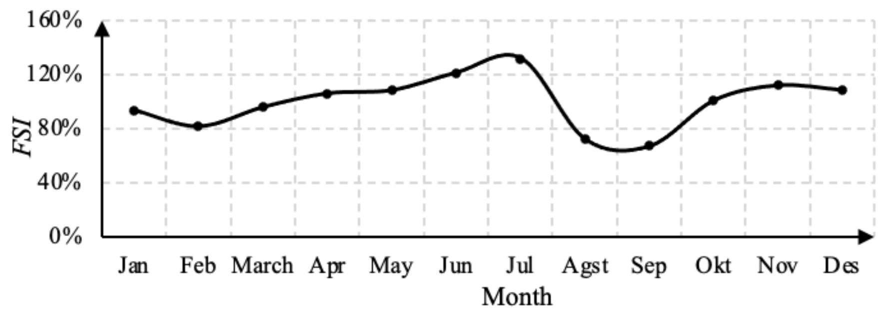

Fig. 5. The fishing season index of octopus fishery in Flores Sea

The peak seasons correspond with the recorded CPUE trends, confirming that months with increased FSI also correlated with increased catch rates, which is important when designing targeted fishing operations and monitoring activities.

Harvest control rules

There were two HCRs that are technically compared to generate the estimation of annual ABC.

a. The feedback HCR

The feedback HCR was conducted for octopus landed in Nangahale Village, Sikka Regency from 2020 – 2023, as shown in Table (1).

Table 1. Catch and effort data of octopus in the Flores Sea in the period of 2020-2023

Year	Catch/C (kg)	Effort (trip)	CPUE (kg/trip)
2020	8268.5575	4987	1.66
2021	9103.23	5134	1.77
2022	7433.885	4841	1.54
2023	10772.575	5427	1.98

The stock abundance index for octopus has remained relatively stable over the past four years. From the estimation of stock level (δ) (Eq. 6-7), the stock is assumed to be at a high level, with a value of 1, as indicated by the CPUE trend from 2020 to 2023 (Fig. 6).

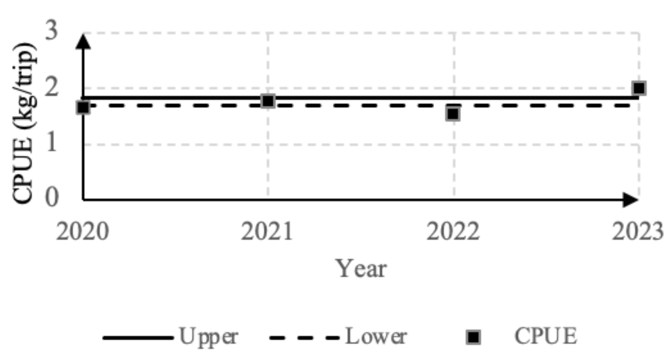

Fig. 6. The stock level of octopus fishery based on the trend of CPUE

The octopus catch for the two years preceding the estimation ($\boldsymbol{C_{y-2}}$) totaled 7433.885 kg (Table 1). The regression coefficient (*b*) for the CPUE trend during the 2021–2023 period was 0.10, while the average CPUE trend (I) over the same period was 1.76kg/ trip. Based on these results, the allowable biological catch (ABC) was estimated at 7,880kg, while the allowable biological effort (ABE) was calculated at 5,131 trips. Consequently, both catch volume and fishing effort must be reduced to allign with these recommendations. These estimates highlight the adaptive characteristics of the feedback HCR, which modifies catch limits in response to real-time stock indicators, thus minimizing the risks of overexploitation.

b. ***The Schaefer model***

This study investigated the relationship between CPUE and fishing effort for octopus fishery in Flores Sea. A linear regression model was employed to analyze the data, resulting in the equation $y = 0.0008\,x - 2.154$ (Fig. 7). This equation shows a positive correlation, indicating that higher fishing effort was generally associated with the increased CPUE over the period of study.

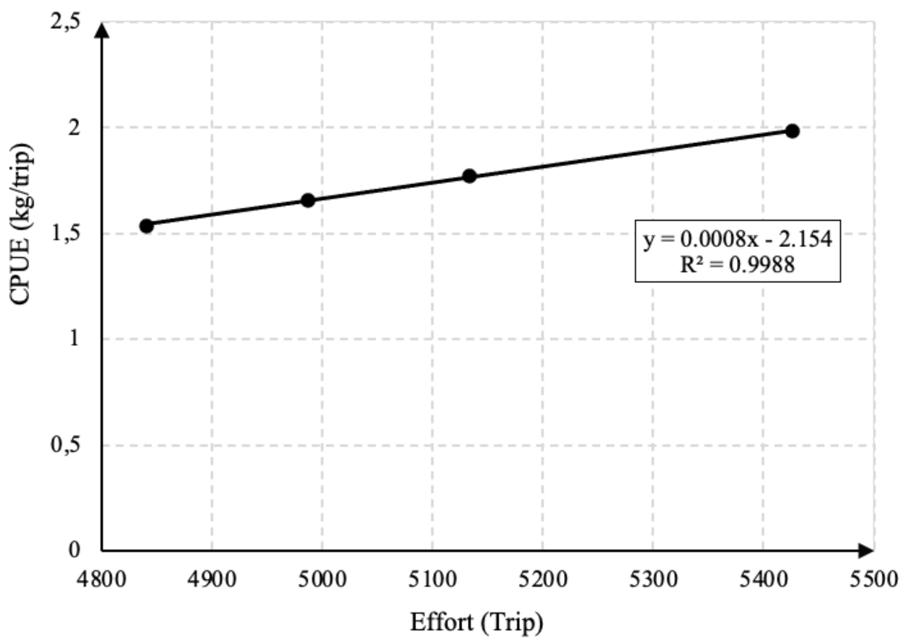

Fig. 7. Linear regression relationship between CPUE and effort of octopus in Flores Sea, Indonesia

This finding contradicts the Schaefer model assumption of a negative correlation between CPUE and fishing effort. Despite the high R^2 value, this positive slope suggests that the fishery has not reached a point where increased effort leads to overfishing and a subsequent decline in CPUE. However, it does raise questions about applying the conventional surplus production model in this context.

DISCUSSION

This study provides a comprehensive assessment of the fishing patterns and stock dynamics of *Octopus cyanea* in the Flores Sea, emphasizing the utility of Harvest Control Rules (HCRs) in managing small-scale, data-limited fisheries. The comparison between the feedback HCR and the conventional Schaefer surplus production model offers new insights into the suitability of these approaches for sustainable fisheries management, particularly in multispecies tropical ecosystems.

Regarding the stock abundance and the CPUE trend, the analysis of catch per unit effort (CPUE) trends from 2020 to 2023 revealed a relatively stable stock abundance for *Octopus cyanea* suggesting that the current levels of exploitation have not yet led to significant depletion. This stability aligns with findings in other tropical cephalopod fisheries, which indicate that octopus species exhibit a degree of resilience under moderate fishing pressure, provided that management interventions are in place **(Semmens *et al.*, 2020, Pierce *et al.*, 2022)**. However, it is critical to underline that, while stable CPUE trends reflect present resource availability, they do not preclude the risk of overexploitation in the absence of robust, precautionary management measures **(FAO, 2020)**.

The positive linear relationship between CPUE and fishing effort, as captured by the regression equation suggests that fishing effort has not yet reached the level at which overexploitation is evident. This finding challenges the conventional assumption of a negative correlation between CPUE and effort typically observed in overfished stocks **(Hilborn *et al.*, 2020, Shelton *et al.*, 2021)**. The high coefficient of determination, indicating that almost all CPUE variability can be explained by fishing effort, further strengthens the argument that the stock is currently resilient to the fishing pressures applied. However, this positive correlation should be interpreted cautiously, as it underlines the need for continued monitoring and adaptive management to prevent the onset of overfishing, a risk documented in other small-scale fisheries **(Cinner *et al.*, 2016, Froese *et al.*, 2020)**.

Regarding the effectiveness of feedback HCRs compared to the Schaefer model, the feedback HCR applied in this study demonstrated its utility in estimating biologically allowable catch (ABC) and effort (ABE). This adaptive approach, which adjusts fishing limits based on real-time stock assessments, proved especially valuable in the data-limited context of the Flores Sea fisheries. The flexibility of feedback HCRs allows for more accurate management decisions, thereby reducing the risk of overexploitation while simultaneously balancing ecological sustainability with the livelihoods of fishing communities **(Punt *et al.*, 2015, Goethel *et al.*, 2019b)**. In contrast, the Schaefer surplus production model, while traditionally employed in single-species fisheries, exhibited limitations when applied to a multispecies, multi-gear fishery such as this one. The assumption that CPUE decreases as fishing effort increases was not supported by the data, where a positive correlation was observed instead. This inconsistency highlights the need for more context-specific models that account for the complexities of tropical multispecies fisheries, where species interactions and ecosystem dynamics play a crucial role in stock behavior **(Martell & Froese, 2017)**. The feedback HCR, which includes real-time data and adjusts accordingly, presents a more suitable framework for fisheries management in such contexts **(Froese *et al.*, 2020)**.

Despite these benefits, the feedback HCR has the constraints requiring consideration. Biases in stock assessments may occur due to inconsistent data collection or misreporting of catches by fishers **(Harlyan *et al.*, 2019)**. The approach requires continuous monitoring to rapidly increase catch and effort limits, which depends on stakeholder involvement and institutional capacity **(Goethel *et al.*, 2019b; Harlyan *et al.*, 2022a; 2022b)**, disregarding these constraints may result in inaccurate stock status estimates and, subsequently, incorrect management decisions **(Harlyan *et al.*, 2022b)**.

The implications of these findings for fisheries management are significant. The feedback HCR model offers a practical solution for fisheries in data-limited environments, providing a scientifically rigorous framework for setting biologically sustainable catch and effort limits. The stable CPUE trends observed over the study period suggest that the octopus fishery in the Flores Sea is currently being exploited at sustainable levels. However, it is critical that management measures be put in place to ensure this stability is maintained, particularly as fishing pressures increase. Similar management interventions have proven effective in small-scale tropical fisheries, reinforcing the importance of adaptive management strategies **(Cochrane & Garcia, 2021, Shelton *et al.*, 2021)**.

Moreover, the seasonal variations in CPUE, with peak periods from April to July and October to December, provide valuable insights for optimizing fishing strategies. During these peak months, targeted monitoring and enforcement of catch limits are essential to prevent overfishing. The moderate fishing seasons between January and March, and August and September, offer opportunities to reduce fishing effort, allowing for stock recovery. The incorporation of such temporal fishing patterns into management strategies aligns with global best practices for sustainable fisheries and can improve both ecological and economic outcomes **(Rodhouse *et al.*, 2014, Hartmann *et al.*, 2021)**.

As in terms of policy, increasing the application of the Feedback HCR requires the establishment of explicit guidelines regarding allowable effort, the improvement of logbook systems, and the implementation of capacity-building initiatives for local fishers to increase compliance **(Mildenberger *et al.*, 2021)**. Fisheries authorities may conduct stakeholder workshops that explain the rationale and mechanics of adaptive catch limits, while also implementing regular on-site inspections to ensure accurate reporting **(Barclay *et al.*, 2023)**. Putting these measures into local regulations and collaborating with community leaders will assist in addressing potential enforcement challenges, as well as ensuring that the proposed catch limits correspond with socio-economic realities **(Free *et al.*, 2022)**.

While the feedback HCR has proven effective in this context, future research should focus on refining the model to account for broader environmental variables, such as sea surface temperature, ocean currents, and habitat changes, which are known to influence cephalopod abundance **(Pecl *et al.*, 2020)**. Incorporating these factors into future models would allow for more accurate predictions of stock fluctuations and would support the development of more resilient management strategies. Additionally, the socio-economic impacts of implementing stricter catch and effort limits must be carefully evaluated. As with many small-scale fisheries, the livelihoods of coastal communities are closely tied to fishery resources, and any changes in management policies must balance ecological sustainability with social and economic considerations **(Cinner *et al.*, 2021)**.

Furthermore, an ecosystem-based management (EBM) approach should be prioritized, focusing not only on the target species but also on the broader marine environment. The integration of multi-species assessments, habitat protection measures, and broader ecosystem dynamics into management plans is critical for ensuring long-term sustainability **(Hilborn *et al.*, 2020, Garcia *et al.*, 2021)**. This approach would help maintain the resilience of marine ecosystems while safeguarding the economic well-being of the fishing communities that depend on them.

This study highlights the efficacy of feedback HCRs in managing the *Octopus cyanea* fishery in the Flores Sea, particularly in data-limited contexts. The strong correlation between CPUE and fishing effort provides a robust basis for implementing adaptive management strategies that align ecological sustainability with socio-economic realities. The identification of distinct seasonal patterns and the calculation of biologically allowable catch and effort limits offer actionable insights for fisheries managers. Moving forward, the integration of feedback HCRs with ecosystem-based management approaches will be essential for ensuring the long-term sustainability and resilience of small-scale fisheries in the region.

CONCLUSION

This study assesses fishing patterns and harvest control rules (HCRs) for the Octopus cyanea fishery in the Flores Sea, Indonesia, highlighting sustainable management strategies. CPUE analysis from 2020–2023 indicates a stable stock, with peak fishing observed from April–July and October–December. The feedback HCR emerges as the most effective strategy for data-limited fisheries, enabling real-time adaptive management based on stock conditions. This study recommends an ABC of 7,880kg and an ABE of 5,131 trips for 2024. The Schaefer model, assuming an inverse CPUE-effort relationship, proved unsuitable due to a positive CPUE-effort correlation. Continuous monitoring and adaptive management are key to sustainability. Future models should incorporate environmental variables (e.g., ocean temperature, currents) and socio-economic factors to balance conservation with community livelihoods. Achieving MSC certification requires strengthening fisheries governance, transparent data reporting, and active stakeholder engagement. Future research should focus on ecosystem-based management, integrating multi-species assessments and habitat conservation to enhance marine resilience and long-term fishery sustainability.

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