E-ISSN: 2073-3720
https://doi.org/10.33997/j.afs.2025.38.2.005

Stock Performance of Leopard Coral Grouper (*Plectropomus leopardus*) and Orange-Spotted Grouper (*Epinephelus coioides*) in Saleh Bay, West Nusa Tenggara, Indonesia

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Abstract

The Saleh Bay grouper fishery is under high fishing pressure, and some species are overexploited such as the leopard coral grouper (*Plectropomus leopardus*) and the orange-spotted grouper (*Epinephelus coioides*). These species are targeted because of their high value. This study aimed to determine the stock performance of these two grouper species in Saleh Bay and identify the factors that influence their stock performance using generalised linear models (GLMs). The results showed that both the leopard coral grouper and the orange-spotted grouper have a long lifespan with 11.02 years and 8.47 years, respectively. In addition, both species show relatively slow growth with k values of 0.26 and 0.34, asymptotic lengths of 74.00 cm and 107.80 cm, and lengths at first maturity (L_m) of 39.83 cm and 55.83 cm. It is important to note that for both species, at least 50 % of the catches are smaller than the size at first maturity (L_m). The ratios of fishing mortality to natural mortality (F/M) were 0.53 and 1.11, and exploitation rates (E) were 0.35 and 0.525. Both species' catch per unit effort (CPUE) fluctuated from 2016 to 2020. The standardised CPUE models showed that types of fishing gear (speargun and hand line), the engine power of fishing vessels, and fishing ground in the utilisation zone are factors that influence these resources. Therefore, for future management, monitoring, and enforcement of size limits, environmentally friendly fishing gear, and improving marine protected areas with 'no take' zones in Saleh Bay are recommended.

Keywords: biological parameter, catch per unit effort, exploitation rate, generalised linear models, fisheries management

Introduction

Stock performance in fisheries is crucial and must be thoroughly evaluated to maintain sustainability fisheries. The catch per unit effort (CPUE) is a significant indicator used to analyse stock performance in fisheries (Okamura et al., 2017). Standardised CPUE is especially important since it offers a reliable indication of stock status, which helps inform management choices and assess the success of management measures (Owiredu, 2024). The standardisation of CPUE is required to account for causes of variation other than stock abundance and ensure that the data properly represents the stock's state (Novianto et al., 2019). By standardising CPUE data, factors impacting catch rates, such as environmental variables and fishing effort, may be accurately adjusted to offer a relative abundance index for monitoring population status (Pulver, 2017).

Standardised catch per unit effort (CPUE) is a critical component of fisheries stock assessment (Okamura et al., 2017). Catchability in multi-gear fisheries may vary according to the gear utilized. Standardised CPUE is a technique that considers the dynamics of the fishing boat by analysing the historical distribution of effort and fish capture in a multi-gear fishery. Standardised catch per unit effort was calculated by taking into account the interactions of fishing effort, gears (Forrestal et al., 2019), fish catch, crew, time (year, quarter), engine vessel size, and fishing ground (i.e., conservation or non-conservation zone).

Incorporating life-history factors into stock evaluations is critical for understanding stock dynamics and forecasting future patterns. Adult mortality, growth rates, and sexual maturity are important factors in determining a stock's productivity (Thorson, 2019). Changes in these life-history factors may significantly influence stock status interpretation, emphasizing the need to incorporate them into fisheries management strategies (Lee et al., 2014). Furthermore, including harvesters' knowledge of abundance indices may improve the accuracy of stock assessments by offering valuable insights into the population susceptible to fishing pressure (Hansell et al., 2020).

Standardising CPUE using advanced statistical models, such as generalised linear models (GLMs), can provide more accurate assessments of stock abundance and account for variance heterogeneity and asymmetric, non-normal behaviour by providing a variety of distributional types that include at least the most common mean-variance relationships in fisheries datasets (Venables and Dichmont, 2004). Previously studied, these models consider both the anticipated CPUE of unfished regions and the actual CPUE of fished areas, providing a complete method for calculating stock abundance indices (Cao et al., 2011). Technological improvements and environmental factors may also affect CPUE trends and stock estimates. Influences such as technological creep in fisheries may disguise losses in stock abundance, highlighting the significance of CPUE standardisation to adjust for external influences impacting catch rates (Kleiven et al., 2022). Environmental factors, such as decadal climatic variability, might influence the spatiotemporal distribution of fish populations, requiring the standardisation of CPUE data to account for these fluctuations (Wu et al., 2022).

The effectiveness of GLMs in fisheries research lies in their ability to handle multiple predictor variables simultaneously. GLMs enable researchers to explore the complex interactions between fishing practices and biological, environmental, and anthropogenic variables that affect fish populations. Therefore, GLMs substantially contribute to our knowledge of the underlying processes that regulate fisheries dynamics. Saleh Bay is a marine area with multi-gear and multi-species fisheries. Furthermore, there has been excessive fishing pressure in Saleh Bay, which has led to overfishing, particularly in the grouper fishery (Agustina et al., 2019). Some species that have been overexploited include *Epinephelus coioides*, *Plectropomus leopardus*, *P. maculatus*, and *Variola albimarginata* (Efendi et al., 2020; Halim et al., 2020). According to Agustina et al. (2017), the grouper species *P. leopardus* and *E. coioides* are extensively exploited by fishers. The high utilisation of these two species leads to overexploitation, which may threaten their sustainability. Therefore, it is necessary to identify the factors that affect the condition of grouper fishery stocks in Saleh Bay. This study aims to determine the stock performances (such as growth parameters, the length at first capture (L_c), asymptotic length ($L\infty$), length at first maturity (L_m), and length optimum (L_{opt}), and other factors that influence the stock dynamics of grouper fisheries) of leopard coral grouper (*P. leopardus*) and orange-spotted grouper (*E. coioides*) in Saleh Bay.

Materials and Methods

Ethical approval

No live animals were used in this study. Therefore, no Institutional Animal Care and Use Committee (IACUC) approval was required.

Study sites and sample collection

The study was conducted in Saleh Bay, West Nusa Tenggara. *P. leopardus* (locally called 'sunu halus') and *E. coioides* (locally called 'kerapu tutul') were sampled 14 days every month from 2016 to 2020. The data were obtained from the Scientific Forum for Sustainable Fisheries Management of West Nusa Tenggara (FIP2B-WNT). The following data were collected: total catch, individual length (total length and total weight), length of vessel, vessel power engine, crew, type of fishing gear, fishing effort (trip), and fishing ground (conservation or utilisation zone). Fishing activities were conducted in Saleh Bay, and fish landed at Labuhan Sumbawa, Labuhan Kuris, Labuhan Sangoro, Labuhan Jambu, and Soro. Figure 1 shows the fish landing locations and grouper fishing grounds.

Data analysis

Growth constant (k) and asymptotic length ($L\infty$) were obtained through analysis of length data using FISAT II software (FAO-ICLARM Stock Assessment Tools) with the ELEFAN I method (Pauly and David, 1981). For the calculation of length at first maturity (L_m), and optimum length (L_{opt}), we used the method developed by Froese and Binohlan (2000). The calculation formula is as follows:

$$\log L_m = 0.8979 * \log L\infty - 0.0782$$

$$\log L_{opt} = 1.0421 * \log(L\infty) - 0.2742$$

The length at first capture (L_c); the length at which 50 % of the fish species captured, also known as the "selection range" defined by Sparre and Venema (1998). We estimated natural mortality (M) and age (t_0) following Pauly (1983) and the longevity or lifespan (t_{max}) following Pauly (1980) with formulation:

$$\log M = -0.0066 - 0.279 \log L\infty + 0.6543 \log K + 0.4634 \log T$$

$$\log(-t_0) = -0.3922 - 0.2752 \log(L\infty) - 1.038 \log K$$

$$t_{max} = 3/K$$

Where, T = temperature (°C)

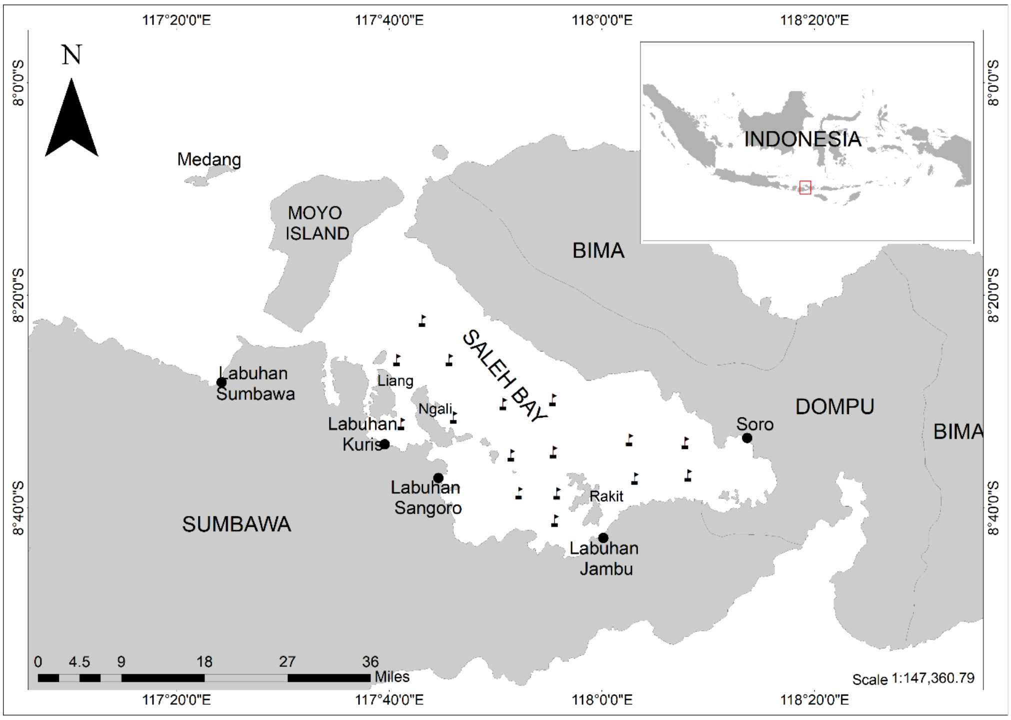


Fig. 1. Fish landing location (dot) and grouper fishing ground (flag).

Estimated total mortality (Z) values were obtained through length-converted catch curve analysis using FISAT II software. Then, the instantaneous rate of fishing mortality (F) was estimated from the relation: F = Z - M (Pauly, 1980). The stock status of *P. leopardus* and *E. coioides* is assessed by calculating the exploitation rate (E) using the formula E = F / Z. This provides an estimate of whether the stock is overfished (Pauly, 1983). The optimal value of E is reported to be approximately 0.5, assuming that efficiency is optimised when F is approximately equal to M (Sossoukpe et al., 2022).

The generalised linear models (GLMs) approach was used to calculate standardised catch per unit effort (CPUE). The inputs used to calculate the standardised CPUE values include the annual catch data, the quarter, the weight of the grouper catch, the crew, the gear and the fishing ground (conservation or non-conservation). The calculation was performed using the 'glm2' packages (Marschner and Donoghoe, 2022), 'emmeans' packages (Lenth et al., 2018), and visualisation using 'ggplot2' packages (Wickham, 2016) in R Studio. The standardised CPUE model is presented below:

CPUE ~ Year + Quarter + PK + L + Crew + Gears + Zone

The data information on variables used as input parameters in generalised linear models (GLMs)is presented in Table 1.

Results

The sample size for *P. leopardus* was 3934 fish, with a range of lengths from 19.86 cm to 70.39 cm and a mean length of 40.12 cm. The sample size for *E. coioides* was 2331 fish, with a range of lengths from 23.97 cm to 107.46 cm and a mean length of 56.27 cm. The estimation of fishery parameters on leopard coral grouper (*P. leopardus*) and orange-spotted grouper (*E. coioides*) are presented in Table 2.

Based on fishery parameters (Table 2) revealed that *E. coioides* has a higher asymptotic length than those of *P. leopardus*. Both species have large body sizes, slow growth and long lifespans. *P. leopardus* showed growth constant (K) of 0.26 per year with a t_0 = -0.502 year and K in *E. coioides* was 0.34 per year with t_0 = -0.343 year. The exploitation rate of leopard coral grouper (*P. leopardus*) was 0.35, while the exploitation rate of orange-spotted grouper (*E. coioides*) was reached 0.525. Compared to the optimum utilization point of 0.5, only the exploitation rate of orange-spotted grouper has exceeded the optimum limit. However, it is crucial to note that at least 50 % of the catches of both species are smaller than the size at first maturity (L_m). Therefore, it is essential to pay close attention to fishing activities conducted by fishers (Fig. 2).

The standardised catch per unit effort (CPUE) of leopard coral grouper (*P. leopardus*) and orange-spotted grouper (*E. coioides*) has shown a fluctuated from 2016 to 2020, as seen in Figure 3. From 2016 to 2019, the CPUE value of *P. leopardus* decreased, but increased again in 2020. Meanwhile, the CPUE of *E. coioides* decreased from 2016 to 2018, then increased again in 2019 to 2020.

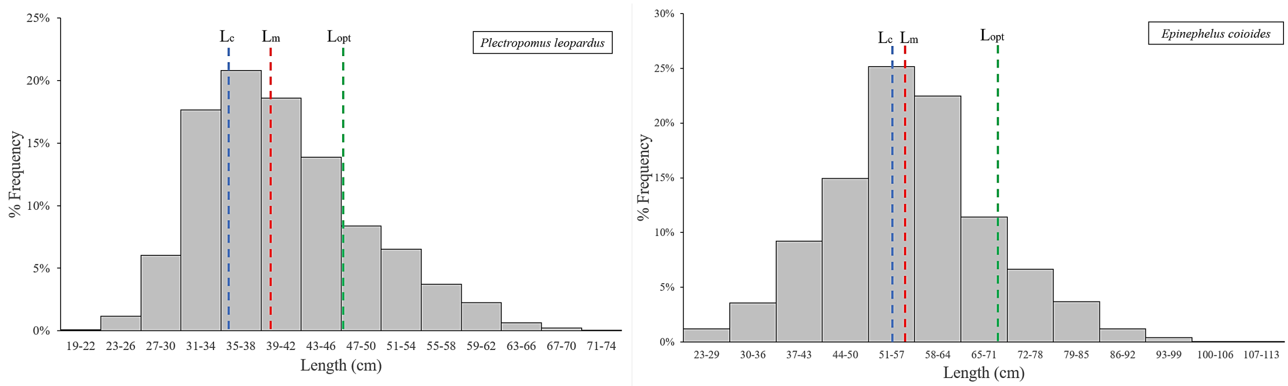
The findings from the generalised linear models (GLMs) provide an overview of the parameters influencing the catch per unit effort (CPUE) for both leopard coral grouper (*P. leopardus*) and orange-spotted grouper (*E. coioides*) fishing in Saleh Bay (Table 3; Fig. 4).

Table 1. Data information on variables used as input parameters in generalised linear models (GLMs).

Variables	Information
CPUE	Catch per unit effort (ind/trip)
Year	Fish landing data from 2016 to 2020
Quarter	Q1 = Jan-March, Q2 = Apr-Jun, Q3 = Jul-Sept, Q4 = Oct-Dec
PK	Fishing boat engine in horsepower
L	Length over all of fishing boat
Crew	Total crew each fishing boat (1, 2, 3... etc.)
Gear	Fishing gear used to catch grouper fish (hand line, troll line, bottom longline, speargun, drop line)
Zone	Fishing ground (conservation zone or utilisation zone)

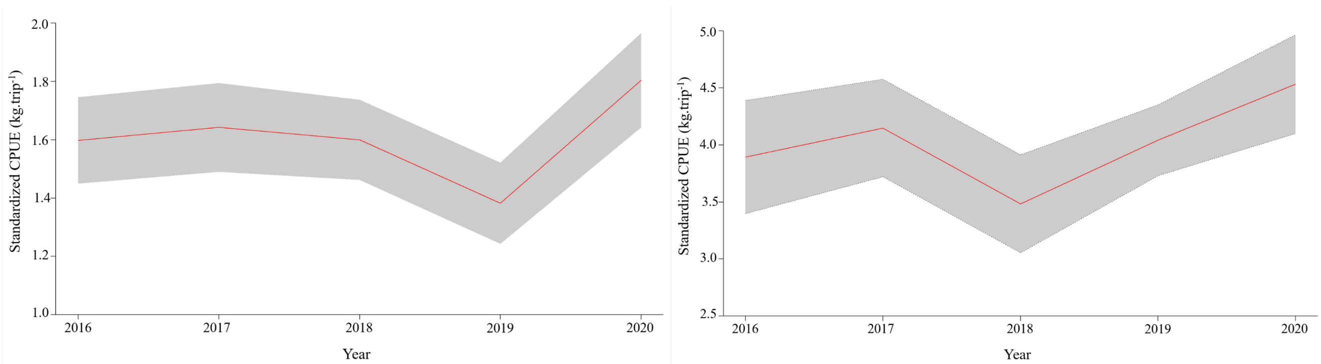
Table 2. Fishery parameters of leopard coral grouper (*Plectropomus leopardus*) and orange-spotted grouper (*Epinephelus coioides*).

Fishery parameters	*P. leopardus*	*E. coioides*
Asymptotic length L_∞ (cm)	74.00	107.80
Von Bertalanffy K parameter (year^{-1})	0.26	0.34
Von Bertalanffy t_0 parameter (year^{-1})	-0.502	-0.343
Lifespan (year)	11.02	8.47
Length at first capture L_c (cm)	35.20	53.73
Length at first maturity L_m (cm)	39.83	55.83
Length optimum L_{opt} (cm)	47.18	69.82
Fishing mortality (F)	0.28	0.63
Natural mortality (M)	0.53	0.57
Relative fishing mortality (F/M)	0.53	1.11
Total mortality (Z)	0.81	0.40
Exploitation rate (E)	0.35	0.525



(a) (b)

Fig. 2. Percentage frequency distribution of (a) leopard coral grouper (*Plectropomus leopardus*) and (b) orange-spotted grouper (*Epinephelus coioides*) caught in Saleh Bay, West Nusa Tenggara, Indonesia.



(a) (b)

Fig. 3. Catch per unit effort (CPUE) of (a) leopard coral grouper (*Plectropomus leopardus*) and (b) orange-spotted grouper (*Epinephelus coioides*) from 2016 to 2020 in Saleh Bay, West Nusa Tenggara, Indonesia.

Table 3. Summary of generalised linear models (GLMs) of *Plectropomus leopardus* and *Epinephelus coioides*.

	Estimate		Std. Error		t value		Pr(>|t|)	
	P. leopardus	*E. coioides*	*P. leopardus*	*E. coioides*	*P. leopardus*	*E. coioides*	*P. leopardus*	*E. coioides*
(Intercept)	135.734	112.7062	46.88247	38.20928	2.895	2.95	0.00385**	0.003245**
Year	-0.06693	-0.05526	0.023218	0.018913	-2.883	-2.922	0.00401**	0.003548**
Quarter	-0.04135	-0.04222	0.02485	0.021828	-1.664	-1.934	0.09631	0.053313.
Length over all	0.032368	0.009416	0.026995	0.014512	1.199	0.649	0.23072	0.516547
Crew	-0.00768	0.001749	0.026294	0.026679	-0.292	0.066	0.77042	0.947751
Drop line	0.158938	-0.10563	0.104745	0.228350	1.517	-0.463	0.12941	0.643753
Hand line	0.031339	-0.38572	0.111037	0.102615	0.282	-3.759	0.77781	0.000179***
Speargun	0.523894	0.055644	0.110202	0.095173	4.754	0.585	2.21E-06***	0.558889
Troll line	0.088103	-0.31373	0.120251	0.220284	0.733	-1.424	0.46389	0.154655
Utilisation zone	0.327975	0.216208	0.071978	0.056448	4.557	3.83	5.67E-06***	0.000135***
Horsepower	0.012319	0.005479	0.006132	0.004470	2.009	1.226	0.04474*	0.220569

Significance codes: 0 ***, 0.001 **, 0.01 *, 0.05 '.', 0.1 ' ' 1

Generalised linear models (GLMs) helped determine the factors that influence the catch per unit effort (CPUE) of *P. leopardus* and *E. coioides*. This methodology made it clear that several variables significantly impacted CPUE. Firstly, fish landing data (year) provided information on temporal changes in *P. leopardus* and *E. coioides* populations. Furthermore, choosing fishing gear, especially using a speargun and a handline, was identified as a critical factor influencing CPUE fluctuation. Furthermore, the fishing ground in utilisation zones significantly affected the catch per unit effort of *P. leopardus* and *E. coioides*.

Discussion

Both grouper species are protogynous hermaphrodites, meaning they start as females and can later change into males (Ferreira, 1995; Andamari et al., 2007), with *E. coioides* remaining male throughout its life span (Chen et al., 2019). This study showed that both grouper species were mainly caught before reaching the length at first maturity, making them more highly vulnerable to fishing-induced reductions in recruitment (Carter et al., 2015). In addition, these two grouper species have long lifespans with slow growth, making them susceptible to being overexploited.

The relationship between F/M and E values from both species may provide a more thorough understanding of fishing intensity. High F/M ratios and exploitation rates (E) are indicative of overexploitation, and as seen in the size distribution of catches (Fig. 3), have a direct impact on resource stocks. Overfishing reduces the number of mature fish available for reproduction in nature. Therefore, it has far-reaching implications that can reduce the fishery's overall productivity as fewer adults contribute to the next generation. The loss of mature individuals can disrupt the balance of the ecosystem, impacting other species that depend on them for food or as part of the food web. As carnivorous predators, leopard coral grouper and orange-spotted grouper feed on various reef-associated organisms, including small fish, crustaceans, and cephalopods. Their feeding habits play a crucial role in maintaining the ecological balance of coral reef ecosystems (Frisch et al., 2016).

The present study found that the mortality (M) of *P. leopardus* was 0.53. In comparison, the mortality values (M) of *P. leopardus* in Cendrawasih Bay National Park, Kwandang Bay, and Karimunjawa were 0.75, 1.16, and 0.13, respectively (Bawole et al., 2017; Agustina et al., 2018; Achmad et al., 2022). The present study's mortality (M) of *E. coioides* was 0.57. The mortality (M) of *E. coioides* in Kwandang Bay and Southern Arabian Gulf waters is 0.69 and 0.19, respectively (Grandcourt et al., 2005; Achmad et al., 2022). The mortality rates of both species in Saleh Bay, as observed in the present study, are still within the range of mortality values reported from other waters.

Based on the present study (Table 2), the exploitation rate (E) was estimated to be 0.35 for *P. leopardus* and 0.525 for *E. coioides*. The exploitation rate (E) for *E. coioides* in this study exceeds the optimum exploitation rate (E_{opt}) of 0.5, indicating overfishing (Pauly, 1987). According to Efendi et al. (2020), *P. leopardus* and *E. coioides* had exploitation rates of 0.57 and 0.60, respectively. Similarly, Achmad et al. (2022), reported exploitation rates of 0.56 for both *P. leopardus* and *E. coioides*. Compared to these previous studies, the current research shows lower exploitation rates for *P. leopardus* and *E. coioides* in Saleh Bay. Consequently, improvements to grouper fisheries management in Saleh Bay are being implemented to ensure sustainability.

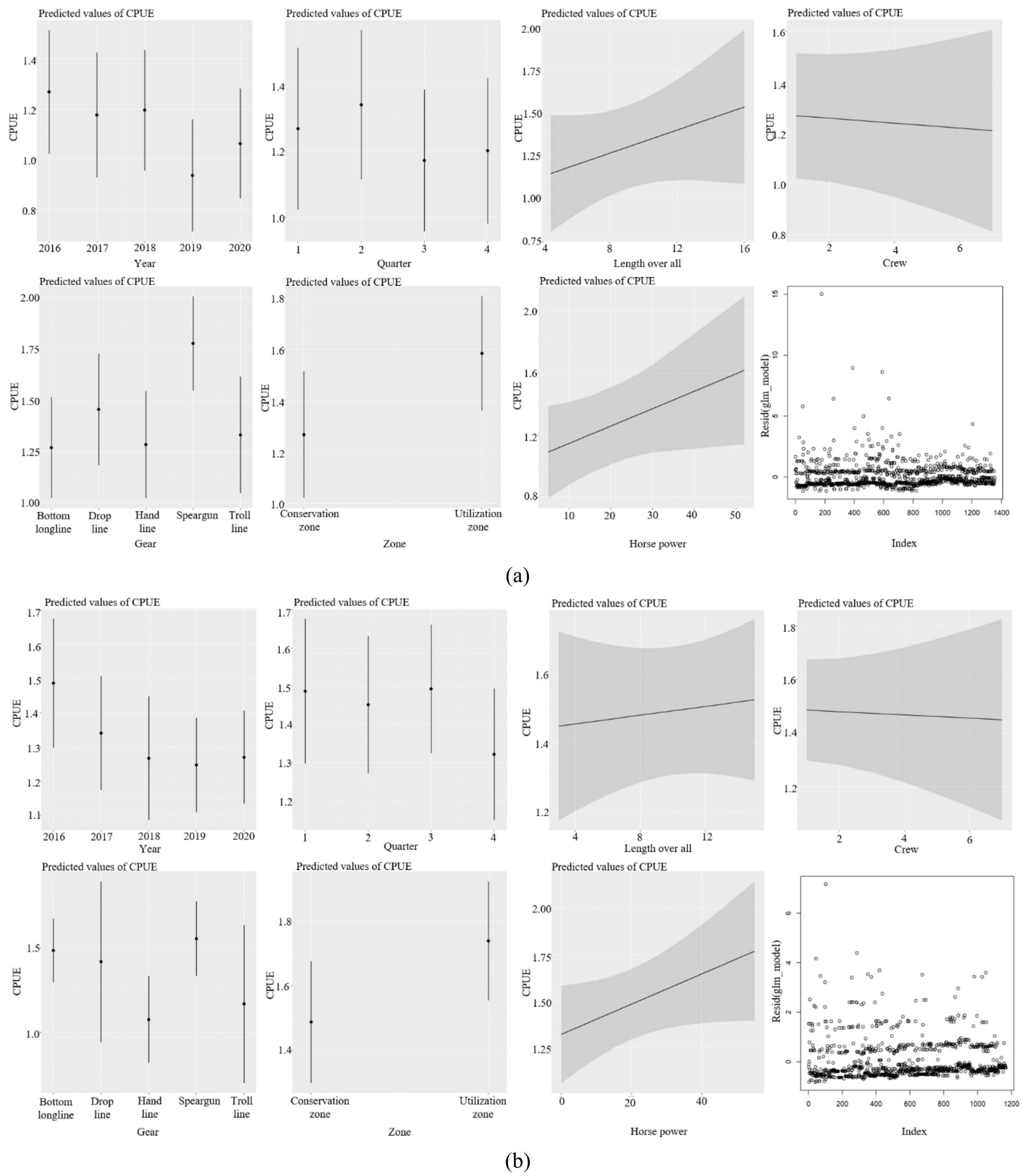


Fig. 4. Prediction values of CPUE and residual GLMs for (a) *Plectropomus leopardus* and (b) *Epinephelus coioides.*

Based on standardised CPUE models, the pattern of CPUE dynamics is influenced by several factors, including fishing gears (specifically, spearguns and hand line), the fishing grounds (particularly those utilization zones), and the size engine of the fishing vessel. Seasonal and annual production data provided information on temporal changes. Acknowledging and accounting for temporal variability is essential in capturing fluctuations in CPUE that may be attributed to external factors influencing fish abundance or behaviour. Also, by acknowledging and accounting for this temporal variability, the model enhances its capacity to depict the complex interplay of factors affecting CPUE standardisation accurately.

Furthermore, the variables of fishing gear, fishing ground, and engine size of fishing vessels illustrate the human, environmental, and technological elements that influence CPUE. The most influential predictor variable is fishing gear, specifically spearguns and hand line. These gears are commonly used in grouper fishing operations in Saleh Bay. Speargun operations occur in coral reef-rich environments, usually at depths ranging from 3 to 15 meters. Spearguns can capture various reef fish of different sizes, and their operation may be customised to target specific fish.

However, the unregulated usage of spearguns can damage fish populations. To avoid this, standards for exploiting fish resources must be established (Agustina et al., 2019; Humphries et al., 2019).

The hand line significantly influences fishing gear, which has excellent selectivity and involves modifying the hook size to target various fish sizes. Hook size influences catch size because bigger hooks increase the length at first capture (Lc), resulting in more excellent maximum selectivity. In Saleh Bay, handline operations are usually carried out at water depths ranging from 40 to 60 meters, using a hook size 7 to catch larger fish. Using bigger hooks reduces the chances of capturing smaller fish, giving them enough time to reach sexual maturity and spawn before being captured (Yulianto et al., 2023).

Grouper fishing operations in utilisation zones may enable groupers to recruit in conservation zones with spawning and nursery grounds. Conservation zones are mostly coastal ecosystems and small islands, focusing on coral reefs, mangroves, seagrasses, and threatened and endemic marine biota. Reef fish communities living at nearshore sites, which serve as a representative for fisheries best-practices conditions, showed substantial changes in community biomass and life-history characteristics compared to offshore sites. It is vital to emphasise that these discrepancies are probably the result of human influences (McClanahan et al., 2022).

The impact of ship engine size on fishing vessels is significant in supporting fishing operations. The vessel's capacity to reach farther areas and its time efficiency in fishing operations are crucial factors in the success of fishing. The various technologies employed in vessel engines can reduce fuel consumption and exhaust emissions in fishing (Gabiña et al., 2016), to be effective in fishing operation time. In addition, each fishing vessel's engine power and gross tonnage can be classified into fishing capacity as characteristics of a fishery (Pascoe and Gréboval, 2003; Eigaard et al., 2011). The size of fishing vessels in Saleh Bay has been categorised as small-scale fisheries (Darmawan et al., 2023; Herdiana et al., 2023). Incorporating fishing vessel engine power as a predictor further emphasizes the technological aspect of shaping catch dynamics. These predictors provide a comprehensive framework for understanding and standardising CPUE, contributing to a more nuanced and accurate representation of the intricate relationships between various factors and the abundance of fish populations (Hinton and Maunder, 2004).

Based on Wiryawan et al. (2020), other factors can influence CPUE, as in the case of yellow-fin tuna, including the amount of fishing effort, days at sea, vessel size, total weight and total individual of catch, sea surface temperature, and chlorophyll-a concentration. Also, catch per unit effort (CPUE) can be influenced based on stock density, physical and financial productivity, and an indicator of the efficiency of a fishing operation, such as fishing technology (Ghosh and Biswas, 2017).

The government has taken many steps to ensure the sustainability of grouper fisheries, including limiting the permitted size for capturing and selling, fishing gear, and fishing time. The Fishery Improvement Project (FIP) may also address stock rebuilding strategies, harvest control regulations, and partial habitat/ecosystem management to assure sustainability and market value (FIP, 2023). Using total allowed catch (TAC) and seasonal closures may help reduce existing fishing pressure (Herdiana et al., 2023). Continuous monitoring of fish landing data is necessary to ascertain the condition of stocks. Other measures that contribute to sustainability of grouper fisheries include effective information dissemination, and the introduction of 'no take' zones (marine protected areas) and grouper size limits.

According to Darmawan et al. (2022), the conservation zone had the highest spatial CPUE for grouper fishing in Saleh Bay. However, according to GLMs (present study), fishing in the utilization zone is a key contributor to enhancing the CPUE. As a result, the recommendation for future management is spatial closures in utilisation zones with high fishing pressure, which are critical for the long-term sustainability of fish species and marine ecosystem health. Spatial closures may be utilised for various purposes, including protecting sensitive ecosystems, conserving vulnerable species, and reducing fishing mortality on overexploited fisheries. Area closures are often employed to address sustainability issues in fisheries management because they effectively safeguard critical habitats and facilitate fish population recovery (Davies et al., 2017).

Conclusion

The leopard coral grouper and the orange-spotted grouper have a relatively long lifespans of 11.02 and 8.47 years, respectively. In addition, both species show relatively slow growth with k value 0.26 and 0.34, with asymptotic lengths of 74.00 cm and 107.80 cm, and lengths at first maturity (L_m) of 39.83 cm and 55.83 cm. It is important to note that for both species, at least 50 % of the catches are smaller than the size at first maturity (L_m). The ratios of fishing mortality to natural mortality (F/M) were 0.53 and 1.11, and exploitation rates (E) were 0.35 and 0.525. The trend CPUE of both species were fluctuated from 2016 to 2020. The standardised CPUE models showed that types of fishing gear (speargun and hand line), engine power of fishing vessels, and fishing ground in the utilisation zone are factors that influence these resources. Therefore, for future management, monitoring and enforcement of size limits, environmentally friendly fishing gear, and improving marine protected areas with 'no take' zones in Saleh Bay are recommended.

Acknowledgements

We would like to thank the Ministry of Education, Culture, Research, and Technology for providing research funding in the scholarship program "Program Magister menuju Doktor untuk Sarjana Unggul". Grant No.: 001/E5/PG.02.00PT/2022 and 3675/IT3.L1/PT.01.03/P/B/2022. We express our gratitude to the local governments in West Nusa Tenggara province, Scientific Forum for Sustainable Fisheries Management of West Nusa Tenggara Province (FIP2B-NTB), Wildlife Conservation Society (Field staff WCS-West Nusa Tenggara: Abdul Muis), Rekam Nusantara Foundation, and local fishers for their information.

Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Regi Darmawan: Conceptualisation, methodology, data curation, formal analysis, investigation, writing – original draft, writing – review and editing, visualisation. Budy Wiryawan: Conceptualisation, methodology, investigation, writing – original draft, writing – review and editing, validation, supervision. Ari Purbayanto: Writing – review and editing, validation, supervision. Irfan Yulianto: Methodology, validation, formal analysis, writing – review and editing, visualisation, supervision. Sonja Kleinertz: Writing – review and editing, validation, supervision.

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