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Growth and mortality model of *Caesio cuning* in Karimunjawa National Park, Indonesia

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Abstract. *Putra PCP, Wahyudi ST, Sambah AB, Sartimbul A. 2024. Growth and mortality model of* Caesio cuning *in Karimunjawa National Park, Indonesia. Biodiversitas 25: 4215-4222.* Global climate change causes an increase in sea surface temperatures and changes in current patterns, which implies the occurrence of marine deoxidation, which has an impact on fish reproduction and growth and coupled with high levels of exploitation, which causes a decrease in fisheries productivity in the Karimunjawa National Park Area, one of which is yellowtail (*Caesio cuning* (Bloch, 1791)). This study aims to analyze yellowtail growth and mortality model with a biology approach. Samples were collected from as many as 900 individuals during the Northwest and Southeast monsoon season. Data were analyzed using the von Bertalanffy growth model with FAO-ICLARM Stock Assessment Tools II. The results show a significant relationship between the Northwest and Southeast monsoon seasons where growth is negative allometric because $b<3$ with r^2 values in each season of 0.85 and 0.89, the growth model obtained ($Lt = 389.6[1 - e^{0.22\text{-}(t0+0.37)}]$) with total mortality of 2.02, where fishing mortality (F) 1.69 and natural mortality (M) 0.33 and produces an exploitation level (E) of 0.84 which indicates that yellowtail has been fully exploited as indicated by the value of E>0.5. The highest recruitment pattern occurs in the Southeast monsoon season (July), amounting to 19.46%. This means that sustainable management is needed to maintain the stock of yellowtail resources in the Karimunjawa National Park Area.

Keywords: *Caesio cuning*, growth, mortality, von Bertalanffy

INTRODUCTION

Marine ecosystem degradation is a pressing global issue, and it's largely a result of human activities. These activities are threatening biodiversity and the balance of marine ecosystems (Ward et al. 2022). Marine ecosystems such as coral reefs, mangrove forests, and seagrass beds face significant pressure from human activities, including unsustainable fishing practices (Crespo and Duun 2017; Alava et al. 2023). Overfishing and destructive fishing practices threaten fish populations and destroy important habitats supporting marine life. These problems are exacerbated by the increasing human population and climate change, as seen from phenomena such as increasing sea surface temperatures (Checkley et al. 2017; Wang 2019), rising sea levels (Novita et al. 2021), decreasing pH (Hoegh-Guldberg et al. 2017), and the occurrence of the Indian Ocean Dipole (IOD) and El Niño Southern Oscillation (ENSO) phenomena (Sartimbul et al. 2018, 2023a; Sambah et al. 2021). These changes imply that marine deoxygenation can limit the growth and reproduction of fish resources through disruption of their metabolic functions (Roman et al. 2019; Borges et al. 2022), and when combined with global warming, can reduce the length and weight of fish (Pauly and Cheung 2018; Watson and Stewart 2020). One such area under threat is the Karimunjawa National Park Area.

Karimunjawa is one of the reliable fisheries centers in Central Jawa, Indonesia. It is home to a majority of the population (60.25%) who work as fishermen, with fisheries resources being their main source of income (Hapsari et al. 2023). Karimunjawa located in the North of Java Island (Muskananfola et al. 2021) which is located at coordinates 5°40'39" to 5°55'00"S and 110°05'57" to 110°31'15"E (Azzahra et al. 2023) and was designated as one of the National Park Areas through the Decree of the Minister of Forestry No. 78/KPTS-II/1999. As one of the conservation areas in Indonesia, Karimunjawa boasts important biodiversity and habitat for several species (Rahmandhana et al. 2022; Halim et al. 2023), including the economically significant yellowtail (*Caesio cuning* (Bloch, 1791)). Yellowtail is the main fish caught in Karimunjawa and holds a relatively high economic value (Yuliana et al. 2016).

Yellowtails, a key species in coral reefs (Suyasa et al. 2023), are facing a significant decline. The yellowtail stock in Karimunjawa National Park has experienced a significant decline, primarily attributed to overfishing activities, particularly through the use of spear and handline fishing gear. These unsustainable practices have led to a significant decrease in annual production (PPP Karimunjawa 2023). The continuous pressure exerted on the yellowtail population not only threatens its sustainability but also poses a broader ecological risk to the coral reef ecosystems in which these fish inhabit. Coral reefs, known for their biodiversity and ecological importance, rely on the balance of predator-prey relationships to maintain their health. The depletion of yellowtail disrupts these dynamics, potentially leading to cascading effects that impair reef resilience, biodiversity, and overall ecosystem function. This environmental degradation underscores the urgent need for effective fisheries management and conservation strategies. It also highlights the interconnectedness of the ecosystem, where the decline of one species can have far-reaching implications for the entire ecosystem. Immediate action is needed to ensure the long-term sustainability of both the yellowtail population and the coral reef ecosystems they support.

Previous studies were conducted by Yuliana et al. (2016). However, this is limited to data samples taken from transition season 1, making it difficult to manage the process well. In addition, Prihatiningsih et al. (2024) conducted a study in Kendari Waters, Banda Sea, Indonesia. So, for management, comprehensive research is required in the Karimunjawa. This is based on indicators of fish reproductive biology data. Therefore, this study examines the relationship between length and weight, growth models, mortality, and recruitment patterns of yellowtail based on the catches of fishermen landed in Karimunjawa. The results of this research can become the basis for decision-making and policies for adaptive and sustainable fisheries management in the Karimunjawa conservation area and contribute to global efforts to address the challenges of climate change and its impacts on marine ecosystems.

MATERIALS AND METHODS

Study area

The research location was chosen based on areas with high capture fisheries ground of *C. cuning* in the Karimunjawa National Park, Jepara District, Central Java Province, Indonesia 5°52'43.34"S to 110°25'56.17"E. The research location area is illustrated in (Figure 1).

Procedure

The methodology used in this study is quantitative descriptive, namely describing variables as they are supported by data in the form of numbers generated from the actual situation (Jarausch and Hardy 2016). The method of sampling yellowtail is random sampling. Sampling was carried out randomly from the catch of fishermen landed at fish collectors in Karimunjawa Village by determining 450 individuals representatives of the Northwest monsoon season (January 2024) and Southeast monsoon season (July 2024). Sampling was carried out randomly because the population of yellowtail is not known for sure or is biased, so the conclusions made are not biased and can be accounted for (McGarvey et al. 2016).

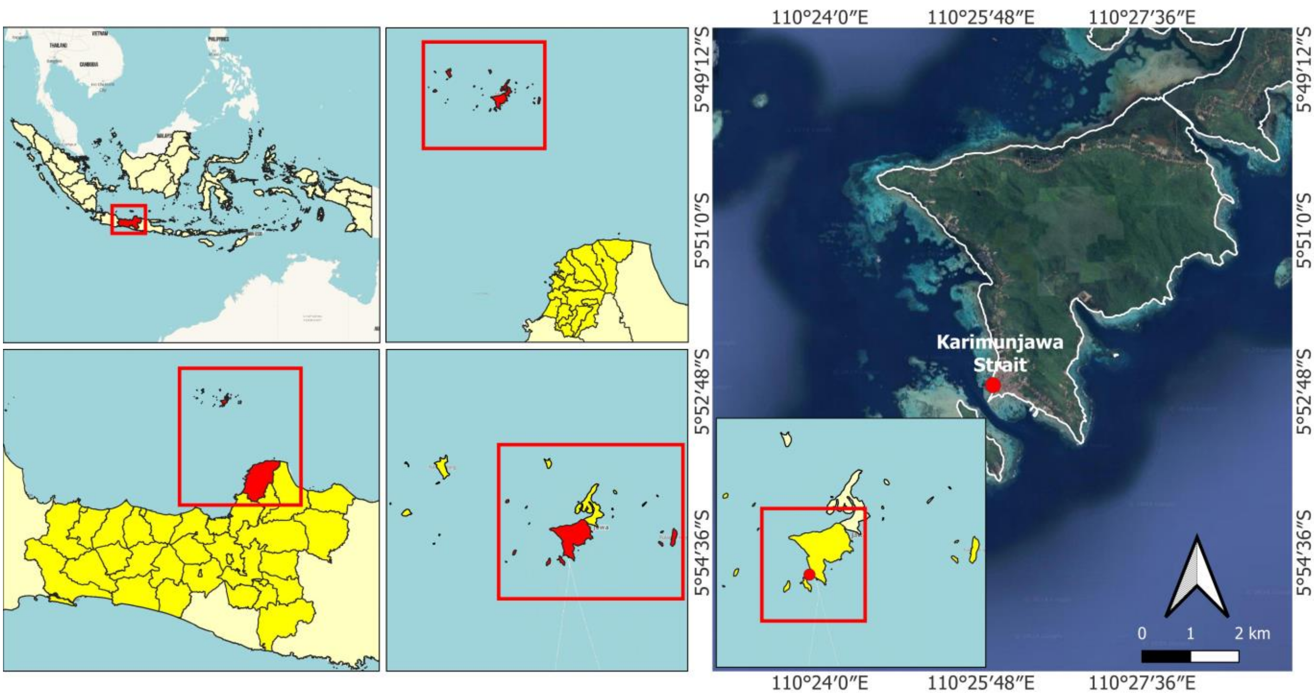

Figure 1. Research location: West area of Karimunjawa Strait, Jepara, Indonesia (Location of sampling from fishermen's catches)

Data analysis

Length-weight relationship

Analysis of the relationship between length and weight can be determined by the equation (Bintoro et al. 2021a,b) as follows:

$$W = aL^b$$

Where:
W : Weight (gram)
L : Length (mm)
a : Intercept
b : Slope

Equation (1) is then transformed into a linear equation so that it becomes an equation (Bintoro et al. 2021b) as follows:

$$LnW = aLnL^b$$

To test the value of b = 3 or b 3, a t-test (partial test) was carried out (Bintoro et al. 2021c). With the hypothesis:

H0: $b = 3$, the growth pattern is isometric, which means that the length and weight relationship is balanced.

H1: $b \neq 3$, the growth pattern is allometric, meaning the length and weight relationship is not balanced.

There are two types of allometrics, as follows:

Positive allometric if the value of b>3 (weight growth is faster than length growth).

Negative allometric if the value of b<3 (length growth is faster than weight growth).

Growth model

The Von Bertalanffy growth model can meet the criteria as a good model because it only requires three parameters (L_∞, K, and $t0$) (Kühleitner et al. 2019; Lee et al. 2020). Estimation of growth parameters can be calculated using the ELEFAN 1 method with FiSAT II and formulated with the Von Bertalanffy with an estimated fish age of 10 years, equation as follows (Sparre and Venema 1999):

$$L_t = L_\infty (1- e^{K(t-t0)})$$

Where:
L_t : Total length of fish at time t years (mm)
L_∞ : Asymptotic length of fish (mm)
K : Coefficient of growth rate
t : Age of fish
$t0$: Age of fish when the length of the fish is 0 (year)

The value of L_∞ and K are obtained using the ELEFAN 1 program in FAO-ICLARM Stock Assessment Tools II (FiSAT II), and the value of $t0$ is obtained through the equation proposed by Hikmawansyah et al. (2019):

$$\text{Log} (-t0) = 0.3922 - 0.2752 (\log L_\infty) - 1.0338 (\log K)$$

Mortality rate

The total mortality (Z) can be estimated by projecting the production curve using the slope (b) and Ln N/t with relative age based on the equation proposed by Pauly (1984):

$$\text{Ln} \frac{N}{t} = a - Zt$$

Where:
N : Total fish at time i
t : Amount of time to grow one length class
a : Conversion of catch to length

Exploitation rate

The estimation of natural mortality rate (M) is calculated using the formula proposed by Pauly (1984) as follows:

$$\text{Log } M = 0.0066 - 0.279 \log L_\infty + 0.6543 \text{ Log } K + 0.6543 \text{ Log } T$$

Where:
M : Natural mortality rate
L_∞ : Maximum total length (mm)
T : Sea surface temperature (°C)

According to the Minister of Marine Affairs and Fisheries Law No. 19 of 2022, fish resource utilization is categorized as follows: (i) Exploited: Catch exceeds the sustainable potential more significantly than 1; (ii) Fully exploited: Catch is within 0.5 to 1 of the sustainable potential; and (iii) Moderate: Catch is less than 0.5 of the sustainable potential.

Recruitment pattern

The recruitment pattern is used to reconstruct it over time using total length frequency data to estimate the recruitment quantity per unit of time and the percentage of that recruitment (Thorson et al. 2014). The parameters needed to calculate the recruitment pattern are L_∞, K, and t0. The analysis is conducted with the assistance of the "Assess" menu and the "Recruitment Pattern" subprogram.

RESULTS AND DISCUSSION

Size distribution and length-weight relationship

The results of the study, in Figures 2 and 3, explain the distribution of length and weight. The average fish caught in the Northwest monsoon season was in the interval of 199-215 mm (30.44%) and weighed 81-108 grams (38.22%), while in the Southeast monsoon season in the interval of 210-224 mm (30.44%) with a weight of 95-129 grams (36.67%), so it can be concluded that in the east season, the length of the weight of fish caught was more significant than in the west season. Length and weight relationship contained in Table 1 and Figure 4 show that the analysis of the length-weight relationship of yellowtail in Karimunjawa waters throughout the Northwest monsoon season (December, January, February) and Southeast monsoon season (June, July, and August) shows a negative allometric growth pattern because (b<3). In the Northwest monsoon season, the model equation obtained is $W = -182.69{*}L^{1.442}$ with an r^2 value of 0.85 p-value <0.01 and a t-count of 54.4, more significant than the t-critical of 1.888. In the Southeast monsoon season, the model equation obtained is $W = -294.85{*}L^{2.010}$ with an r^2 value of 0.89, a p-value <0.01, and a t-count of 30.27, more significant than the t-critical of 1.888. Overall, these results indicate that a negative allometric growth pattern occurred consistently in the two fishing seasons studied, indicating that yellowtail in Karimunjawa Waters experienced more increase in length than weight.

Growth model

Based on data analysis and yellowtail growth model found in Figure 5, the asymptotic length (L_∞) for yellowtail caught by fishermen in the Karimunjawa Area was estimated at 389.6 mm, where the maximum size of fish caught is 300 mm for the Northwest monsoon season and 310 mm for the Southeast monsoon season. This value indicates the maximum length that fish can reach at ten years. The resulting growth rate coefficient (K) was 0.22, indicating a relatively slow fish growth rate, while the $t0$ value was estimated at -0.37 mm. By using these parameters, the growth model of yellowtail in Karimunjawa Waters can be explained through the von Bertalanffy model equation $Lt = 389.6(1 - e^{0.22\text{-}(t0+0.37)})$. This equation describes the growth of fish over time, with the results indicating that yellowtail in this area grows gradually towards maximum size throughout their life cycle. These results provide important insights into the population dynamics of yellowtail in the Karimunjawa conservation waters, which can be the basis for sustainable fisheries management in the future.

Mortality and exploitation rate

Data on mortality rates and exploitation levels can be seen in Table 2 and Figure 6. In the table and figure based on measurements with an average water temperature of 29°C, the natural mortality (M) value was obtained at 0.33 per year, while mortality due to fishing (F) reached 1.69 per year. Thus, the total mortality rate (Z) is 2.02 per year. The exploitation level (E) of yellowtail in Karimunjawa waters is 0.84, far exceeding the optimum exploitation level. This high exploitation level indicates a state of overfishing, where the level of fishing exceeds the sustainable threshold needed to maintain its population. Overfishing can lead to declining fish stocks, disrupt the ecological balance, and potentially have economic and environmental consequences. Effective management strategies and regulatory measures are essential to address this overfishing problem and ensure the long-term sustainability of the yellowtail population in this area.

Recruitment pattern

The results revealed pronounced recruitment activity between July and September (Figure 7), with a notable peak in July, where it constituted 17.14% of the total annual recruitment. A detailed breakdown of monthly recruitment percentages further illustrates this trend in Figure 6, as demonstrated in the following data: January (10.77%), February (3.29%), March (6.69%), April (13.23%), May (3.52%), June (13.61%), July (17.14%), August (10.29%), September (10.09%), October (7.37%), November (4%), and December (0%). The data indicate that the recruitment pattern is characterized by a significant influx of new individuals during mid-year, aligning with environmental and biological factors that may enhance reproductive success in that period. These seasonal recruitment patterns underscore the importance of effective management strategies to ensure the sustainability of yellowtail stocks, particularly during peak recruitment months when juvenile populations are most vulnerable to fishing pressures. Moreover, recognizing these dynamics is crucial for developing targeted conservation measures that not only protect the yellowtail population but also contribute to the overall health of the marine ecosystem within the Karimunjawa National Park. Consequently, the findings from this study advocate for the implementation of adaptive management practices that account for temporal fluctuations in recruitment to maintain the resilience and sustainability of yellowtail in the region.

Table 1. Length-weight relationship of yellowtail (*Caesio cuning*)

Season	Average length of fish caught		Length-weight relationship			Test-$_{t0.05}$		Growth pattern
	Length (mm)±SD	Weight (gr)±SD	Model equation	p-value	r^2	$t_{calculate}$	$t_{critical}$	
Northwest monsoon season	202 ± 26.44	108 ± 41.36	$W = -182.69*L^{1.442}$	p<0.01	0.85	54.4	1.888	*b*<3 (Negative Allometric)
Southeast monsoon season	216 ± 27.23	138 ± 57.92	$W = -294.85*L^{2.010}$	p<0.01	0.89	30.27	1.888	*b*<3 (Negative Allometric)

Note: *SD: Standard Deviation

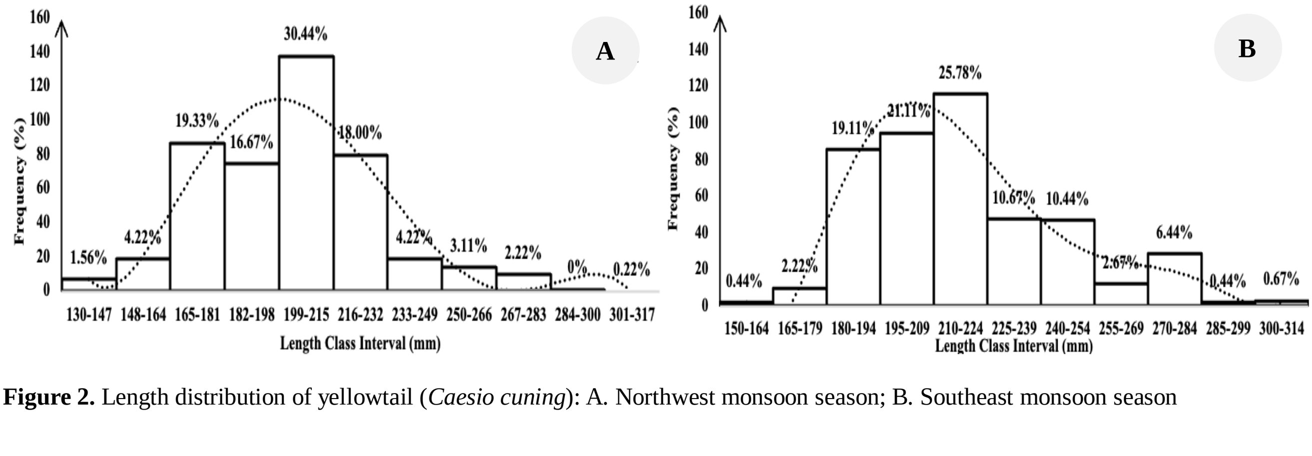

Figure 2. Length distribution of yellowtail (*Caesio cuning*): A. Northwest monsoon season; B. Southeast monsoon season

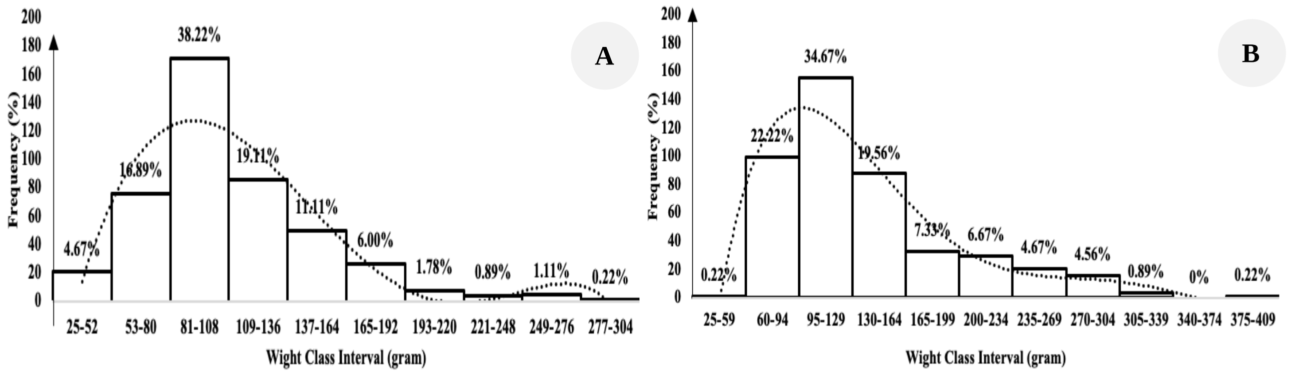

Figure 3. Wight distribution of yellowtail (*Caesio cuning*): A. Northwest monsoon season; B. Southeast monsoon season

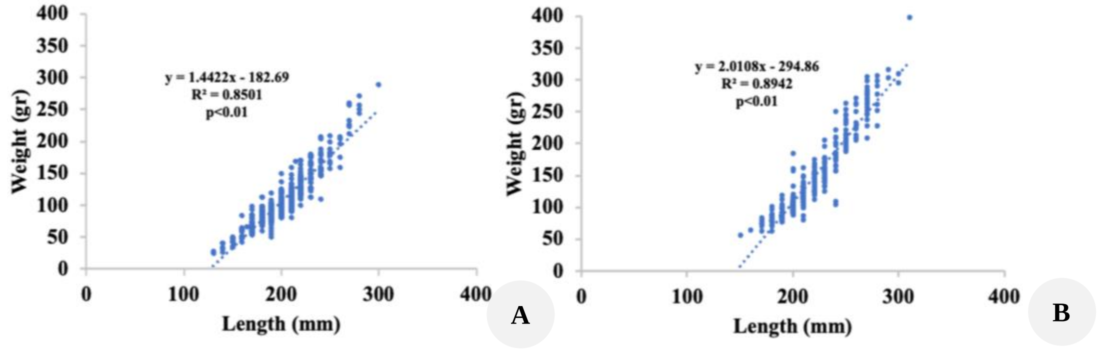

Figure 4. Relationship between length and weight of yellowtail (*Caesio cuning*): A. Northwest monsoon season; B. Southeast monsoon season

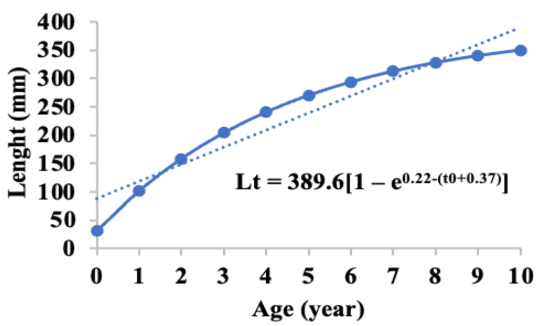

Figure 5. Model growth of yellowtail (*Caesio cuning*)

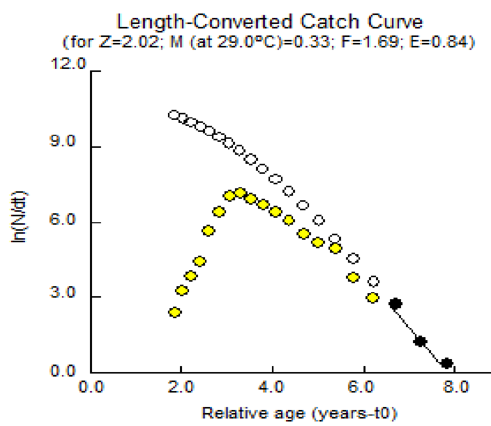

Figure 6. Mortality rate of yellowtail (*Caesio cuning*)

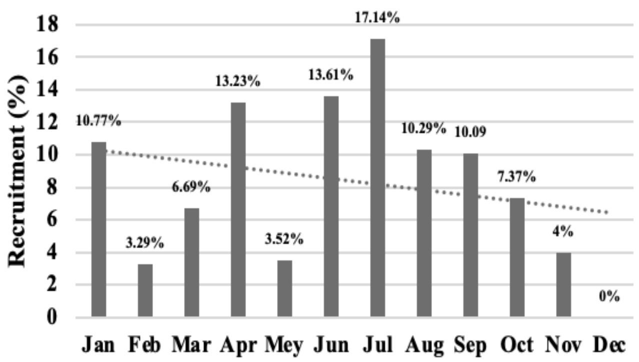

Figure 7. Recruitment pattern of yellowtail (*Caesio cuning*)

Table 2. Mortality and exploitation rate of yellowtail *Caesio cuning*)

Variable	Value
Natural mortality (M)	0.33
Fishing mortality (F)	1.69
Total mortality	2.02
Exploitation level of fishing (E)	0.84 (Fully exploited)*

Note: *The optimum exploitation rate is 0.5 (E = 0.5), the exploitation rate is less than 0.5 (E<0.5), and the exploitation rate is over if the estimate is above 0.5 (E>0.5)

Discussion

The study of the distribution and relationship between the length and weight of yellowtail is a fascinating area of research, but it also raises many questions that require further investigation to provide insight into the distribution and growth patterns that occur during southeast monsoon (J,J,A stand for June, July, and August, respectively) and northwest monsoon (D,J,F: December, January, and February) according of seasons by Sartimbul et al. (2010, 2023b) and Wijaya et al. (2020). The results show a negative allometric growth pattern, indicating that this fish tends to grow faster in length than in weight. This could be due to several environmental factors, such as the availability of food that supports body length growth or water conditions that may not support significant body mass accumulation (Jonsson and Jonsson 2014). High interspecies competition can cause fish to focus more on length growth to increase mobility and foraging ability rather than increasing body mass (Černý et al. 2019). In several studies related to the growth of yellowtail in other waters, the length and weight of fish show similar growth patterns, where fish tend to grow longer than they do in weight (Yang et al. 2016). In some areas with more abundant food availability and stable environmental conditions, fish tend to show isometric or even positive allometric growth patterns, where fish grow evenly or faster in terms of weight (Phillips et al. 2018; Seamone et al. 2023). This underscores the importance of local environmental factors in influencing fish growth patterns and provides insight that fisheries management strategies in Karimunjawa must consider ecosystem conditions that support fish growth in length as a priority while ensuring a balance that supports body mass accumulation for the sustainability of fish stocks in the future.

Estimating yellowtail growth parameters in Karimunjawa Waters using the ELEFAN I method through the FISAT II program provides essential information regarding the dynamics of the growth of the fish population. The asymptotic length value (L_∞) of 389.6 mm indicates that yellowtail can reach this maximum length during their lifetime under optimal conditions. The higher the growth rate, the faster the fish reach their asymptotic length and end up dying sooner (Ørgensen et al. 2014). The analysis results explain that the yellowtail caught is around half the asymptotic length that can be achieved. Meanwhile, the growth rate coefficient (K) of 0.22 indicates that fish growth towards asymptotic length is relatively slow. A small K value indicates that fishery resources have a slow growth pattern (Maunder and Piner 2015). This means that yellowtail takes a long time to reach full adult size. The $t0$ value of -0.37, estimated using Pauly's empirical equation, indicates that at birth (t = 0), the yellowtail theoretically hash as a length close to zero, consistent with the von Bertalanffy growth model. The resulting growth equation $Lt = 389.6(1 - e^{0.22-(t0+0.37)})$ provides predictions of fish length at various ages, indicating that yellowtail reaches a length of 213 mm at around one to two years of age. This means that most fish caught in these waters have not yet reached full adult size, which could have implications for potential stock declines if fishing is not well regulated.

Mortality parameters from this study were based on yellowtail fish data first published in the Karimunjawa Water Area, underscoring the need for sustainable management. The mortality rate due to yellowtail fishing is significantly higher than the natural mortality rate (F>M), highlighting the importance of responsible practices. The high fishing mortality rate compared to the natural mortality rate indicates that fishing is the main factor affecting the survival rate of the yellowtail population in this area. The total mortality rate (Z), the sum of the natural and fishing mortality rates, was obtained at 2.02 per year. The mortality value provides an overall picture of the mortality rate of yellowtail in the Karimunjawa conservation area. According to Dienye et al. (2023), the exploitation rate ranges from 0 to 1. The optimum exploitation rate is 0.5 (E = 0.5), the exploitation rate is less than 0.5 (E<0.5), and the overexploitation rate is if the estimate is above 0.5 (E>0.5). The exploitation rate (E) of yellowtail of 0.84 is higher than the optimum exploitation rate (E>0.5). This value indicates the proportion of mortality caused by fishing relative to total mortality. A high exploitation rate indicates that more than 84% of yellowtail mortality is caused by fishing. This exceeds the optimal exploitation value usually recommended for sustainable fisheries management. The optimal exploitation value generally falls around 0.5, meaning that at least half of the total mortality must come from natural sources to maintain the balance of the fish population. High exploitation rates indicate that fish are being overexploited (Watson and Stewart 2020), which can lead to a drastic decline in fish populations in the long term (Denechaud et al. 2020). If this condition continues, fish stocks will decline, and the coral reef ecosystem, which is their habitat, will also be damaged due to the loss of essential components in the food chain.

Critical parameters used to analyze recruitment patterns include asymptotic length (L_∞), growth rate coefficient (K), and theoretical age at zero length ($t0$). Research previously by Yuliana et al. (2016) estimated these parameters with an L_∞ value of 332 mm, K of 0.42 per year, and $t0$ of -0.01. The analysis showed that yellowtail recruitment mainly occurred from July to September, with the peak recruitment occurring in July, where the recruitment percentage reached 19.8%. This pattern indicates a solid and concentrated recruitment season in the middle of the year. A complex interplay of environmental factors such as water temperature, food availability, and habitat conditions likely influences this phenomenon. Understanding these recruitment patterns is crucial for effective fisheries management. By understanding the peak recruitment time, fisheries managers can design more appropriate strategies to protect young fish that have just joined the population. One strategy that could be implemented is establishing stricter fishing periods or even fishing moratoriums during peak recruitment months to ensure that sufficient numbers of fish can reach maturity and contribute to population reproduction. Salim et al. (2020) added that the number of fish in each size class at any given time is determined by the annual recruitment rate, with many species declining in population due to human exploitation or other natural factors.

Understanding fish growth rates allows fisheries managers to regulate fishing seasons, set minimum catch sizes, and set appropriate catch quotas to avoid overexploitation that can endanger fish populations and coral reef ecosystems. Therefore, information on stock size conditions and exploitation will be important in the coming years from an ecological perspective (Daban et al. 2023). This can be done for sustainable management, which is vital for yellowtail. Information on growth and mortality patterns is essential for fisheries' resource management and sustainable development (Indarjo et al. 2020).

The conclusion of this study shows that the allometric growth of yellowtail fish is significantly negative in Karimunjawa waters, evidenced by growth coefficients (*b*) less than 3 with the maximum growth at 10 years of age with a length of 389.6 mm. Indicates a total mortality rate of 2.02 and exploitation level (E) calculated at 0.8 suggests that the yellowtail population is fully exploited. Additionally, the highest recruitment rate, observed in July during the Southeast monsoon season at 19.46%, further emphasizes the vulnerability of this species. Based on these findings, implementing sustainable management practices is essential to ensure the long-term viability of yellowtail stocks within the Karimunjawa National Park. Such measures are essential not only for the preservation of the yellowtail population but also for maintaining the ecological balance of the marine environment, thereby safeguarding the overall health and resilience of the coral reef ecosystems that support diverse marine life. Therefore, a proactive approach to fisheries management, including regulation of fishing practices and habitat conservation, is crucial for achieving sustainability in this region.

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