Analysis of growth parameters and exploitation level of rabbitfish (*Siganus virgatus*) in Karimunjawa Islands

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Abstract. This study was performed to examine the population parameters of rabbitfish (*Siganus virgatus*) in Karimunjawa waters as the basis of determining the sustainable management strategies. Sampling was conducted over a two-month period (between February and March 2025) at the main fish trading centers on Karimunjawa and Kemujan Islands. A total of 660 fish samples were measured for total length (TL, cm) and body weight (W, g) to estimate growth parameters, exploitation rates, and recruitment patterns. The results showed a negative allometric length-weight relationship. Length at first capture (Lc50%) was 16.7 cm TL, the growth coefficient (K) was 1.88 per year, and the exploitation rate (E) was 0.34, still below the optimal limit (E = 0.5), indicating normal exploitation status. The fish recruitment analysis revealed a continuous pattern throughout the year, occurred throughout the year, with peak recruitment in August and November. The results showed that the *S. virgatus* population in the Karimunjawa Islands was not over-exploited.
Key Words: exploitation rate, Karimunjawa Islands, Lc50%, length-weight relationship, *Siganus virgatus*.

Introduction. *Siganus virgatus* is an herbivorous fish from the Siganidae family found abundantly in Indo-Pacific coral reef ecosystems in shallow waters with coral and algal substrates, such as in Karimunjawa Islands, Indonesia. *S. virgatus* are generally diurnal, living in pairs or small groups around reefs to find food and protection. *S. virgatus* is regarded a mixed herbivore that feeds on macroalgae, turf algae, and epilithic algal matrix. Its diet exhibits high levels of dietary that adjust to food availability within a biogeographical scale (Zarco-Perello et al 2024). In reef ecosystems, the species controls macroalgal growth through intensive browsing activity. In some locations with low herbivore biomass, *S. virgatus* contributes up to > 90% of algal grazing pressure. Besides maintaining coral dominance, it also prevents the shift to the macroalgal phase (Müller et al 2021; Evensen et al 2021). The variety of algae indicates food sharing and coexistence with other Siganidae species in the same habitat (Nanami 2018). In systems with low functional redundancy, *S. virgatus* helps enhance coral reef resilience as it balances the coral-algae competition (Müller et al 2021; Zarco-Perello et al 2024).

Herbivorous reef fish, including *S. virgatus* has been widely exploited to meet the increasing demand for seafood, including in the Indo-Pacific region. Fishing in unprotected areas reduces herbivore biomass and inhibits algal grazing pressure, potentially triggering a phase shift in reefs toward macroalgal dominance (Müller et al 2021). In Indonesia, the Siganide family is a commodity with high economic value, with production still dominated by capture fisheries (Sarjito et al 2025). The signs of overexploitation in some waters increase the risk of population decline in the wild (Umar et al 2020). Catching of broodstock fish and its juveniles in seagrass habitats also inhibits natural recruitment (Rauf et al 2024). The reduction in herbivory due to artisanal fisheries has altered the structure of reef fish communities and benthic cover (Campbell & Pardede 2006; Hoey et al 2013). In regards to this condition, it is considered necessary to examine the stock of *S. virgatus* in the Karimunjawa Islands.

Material and Method

Research location and time. The research was conducted in the Karimunjawa Islands during the active fishing season from February 2025 to March 2025 (Figure 1). Data of the fish were collected from Karimunjawa and Kemujan Islands, the two largest islands and main economic and fish trading centers in the area. These islands are the center of the local fisheries activities, where the fish landing sites allow for systematic data collection in this study.

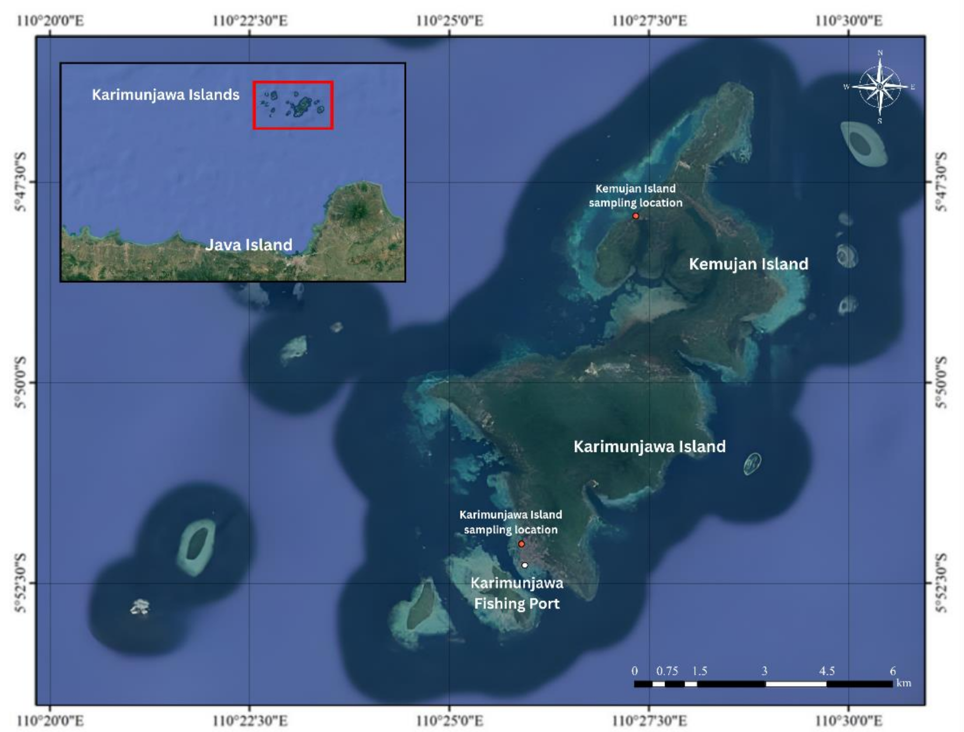

Figure 1. Karimunjawa Islands (research locations).

Research material. Morphometric data for *S. virgatus* were obtained by measuring total length (TL, cm) and body weight (W, g) from 660 fish samples collected from different fish trading locations. The sampling was conducted over 2 months, from February 2025 to March 2025, with an intensity of seven days per month. A representative number of fish samples was selected randomly from daily catches at the trading sites. Fish total length was measured using a measuring board to the nearest 0.1 cm, while body weight was recorded using a digital scale with an accuracy of 0.01 g. All measurements were conducted immediately after landing to minimize potential bias due to post-harvest handling and weight loss.

Analysis method. Data analysis was performed using Microsoft Excel and FiSAT II software. Fish growth parameters that included asymptotic length ($L\infty$) and growth coefficient (K) were measured using the ELEFAN I (Electronic Length Frequency Analysis) based on Von Bertalanffy's growth model. Gulland's formula was employed to calculate t_0, while total mortality (Z) was calculated on FiSAT II. Natural mortality (M) was calculated using Pauly's empirical formula, including the average water temperature factor. The length at first capture (Lc50%) and length at first maturity (Lm) were also analyzed to determine the length-weight relationship using the following formulas:

$$W = a L^b \quad (1)$$
$$Ln W = Ln a + b Ln L \quad (2)$$
$$Lt = L\infty (1-e^{-k(t-t0)}) \quad (3)$$
$$Log(-t0) = -0.3922 - 0.2752 Log L\infty - 1.038 Log K \quad (4)$$

$$Log (M) = -0.0066 - 0.279 Log L\infty + 0.6543 Log K + 0.4634 Log T \quad ... \quad (5)$$
$$F = Z - M \quad ... \quad (6)$$
$$E = F/Z \quad ... \quad (7)$$
$$E_{MSY} = 0.5 \quad ... \quad (8)$$

where: W = fish weight (g);
L = total length (cm);
a and b = length-weight relationship constants;
$L\infty$ = asymptotic length (cm);
K = growth coefficient (per year);
t = fish age (years);
t_0 = theoretical age at which length equals zero (years);
T = water temperature (assumed 28°C);
Z = total mortality;
M = natural mortality;
F = fishing mortality;
E = exploitation rate.

The theoretical basis and formulas used in this analysis refer to Sparre & Venema (1998), Gayanilo et al (2005), Dutta (2023), and Wijayanto et al (2025).

Results and Discussion. *S. virgatus* is a local fish commodity with strong demand and high economic value. This herbivorous fish inhabits shallow waters with coral reefs, seagrass beds, and coastal areas. Rabbitfish move in large classes within limited migration patterns around their habitat. Their sedentary nature and dependence on coastal ecosystems such as seagrass beds and coral reefs make them vulnerable to environmental changes. Damages to their habitat, including degradation of coral reefs and seagrass beds due to human activities, directly impact its population and sustainability.

Karimunjawa Islands is a National Park located in the Java Sea, with small islands, interconnected coral reefs, seagrass beds, and mangroves as their primary ecosystems. The waters is vital habitat for reef fish, herbivorous biota, and nursery grounds for various economically important species (Campbell et al 2014). The connectivity between habitats maintains the life cycle of fish by providing spawning, growth, and feeding areas (Nagelkerken et al 2015).

S. virgatus is a fish species that balances the macroalgae growth through grazing and browsing. It maintains the dominance of hard corals and prevents the shift toward an algae-dominated ecosystem. The presence of herbivores in sufficient biomass has been shown to increase the resilience of coral reefs to disturbances, including global warming and anthropogenic pressures (Hoey & Bellwood 2011). On the other hand, rabbitfish has been a favorite source of protein among society. Small-scale fishermen catch the fish and gain significant economic benefits. Therefore, maintaining rabbitfish populations is parallel to maintaining ecosystem balance and the sustainability of fisheries in Karimunjawa.

Total length (TL) composition. The data obtained in this study are presented in Table 1. The length frequency distribution shows a dominance of fish in the interval class 13.5-17.9 cm (53.6%), while sizes over 24 cm are very small (less than 5%), indicating a population dominated by young individuals and a low proportion of large fish. This pattern reflects a combination of high recruitment, ongoing growth, and greater mortality or fishing pressure at large sizes (Guy & Brown 2007). Decreasing frequency followed with increasing length shows a stable size structure, yet the rarity of large classes is often associated with exploitation or gear selectivity (Robinson et al 2017). Length-frequency analysis also estimates the growth and cohort parameters when the data include multiple size classes (Zhou et al 2022). In addition, body size also indicates trophic dynamics and vulnerability to fisheries in reef fish (Bonar 2002).

Table 1

Size composition of *Siganus virgatus*

Interval of TL (cm)	*Middle value*	*Frequency*	*Percentage (%)*	*Cumulative percentage (%)*
13.5-15.9	15.0	158	23.9	23.9
16.0-17.9	17.0	196	29.7	53.6
18.0-19.9	19.0	106	16.0	69.6
20.0-21.9	21.0	56	8.5	78.1
22.0-23.9	23.0	82	12.4	90.5
24.0-25.9	25.0	36	5.5	96.0
26.0-27.9	27.0	7	1.1	97.1
28.0-29.9	29.0	6	0.9	98.0
30.0-31.9	31.0	4	0.6	98.6
32.0-33.9	33.0	2	0.3	98.9
34.0-35.9	35.0	2	0.3	99.2
36.0-39.5	37.0	5	0.8	100

The mature gonad length in this study was set at 13.5 cm as proposed by Syadli et al (2022). Patanda & Rahmani (2018) emphasized the importance of length selection for fish to ensure that immature individuals have the opportunity to reproduce. Data on fish size structure were obtained by measuring the length and weight of 660 fish samples. Information on this size structure provides an important basis for analyzing other growth parameters. The frequency distribution of the length of *S. virgatus* landed in Karimunjawa waters shows a dominance of fish size within the 13.5-17.9 cm range. All sampled fish caught were found to have exceeded the length at first maturity (Lm = 13.5 cm), indicating that the catch consists entirely of legally harvestable sizes (Figure 2). This length-frequency distribution pattern provides the foundation for the further analysis.

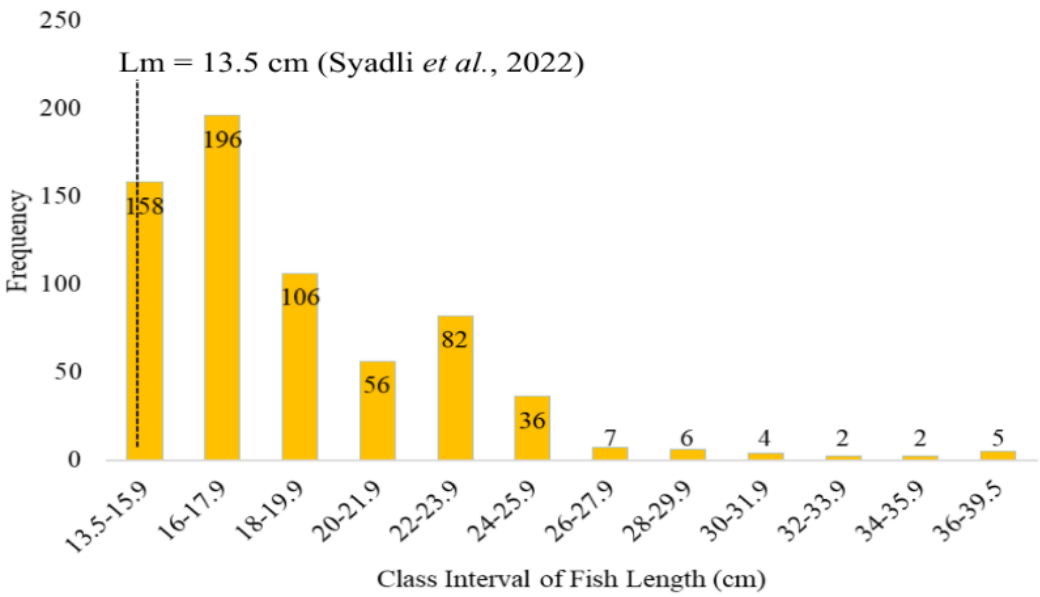

Figure 2. Frequency distribution of the length of *Siganus virgatus*.

The weight frequency distribution of *S. virgatus* in Karimunjawa waters is highly concentrated within the 50-107 gram range, peaking at the 79-107 gram class with 263 individuals (Figure 3). This weight composition indicates that the majority of the landed catch consists of smaller to medium-sized individuals. These weight variations, in relation to the previously discussed fish lengths, provide the basis for the length-weight relationship analysis.

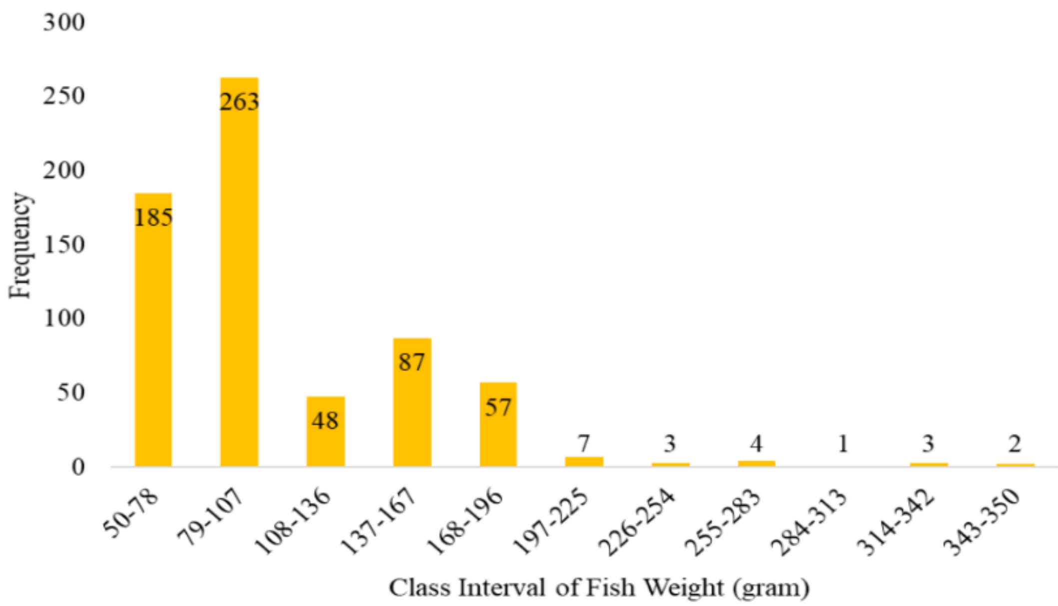

Figure 3. Frequency distribution of *Siganus virgatus* weight.

Length-weight relationship. As presented in Figure 4, the length-weight relationship shows a negative allometric growth pattern ($W = 0.59L^{1.76}$; $b < 3$), which indicates a faster increase in length compared to weight. The R^2 value = 0.93 indicates a very strong correlation and a high model fit to describe weight variations based on length.

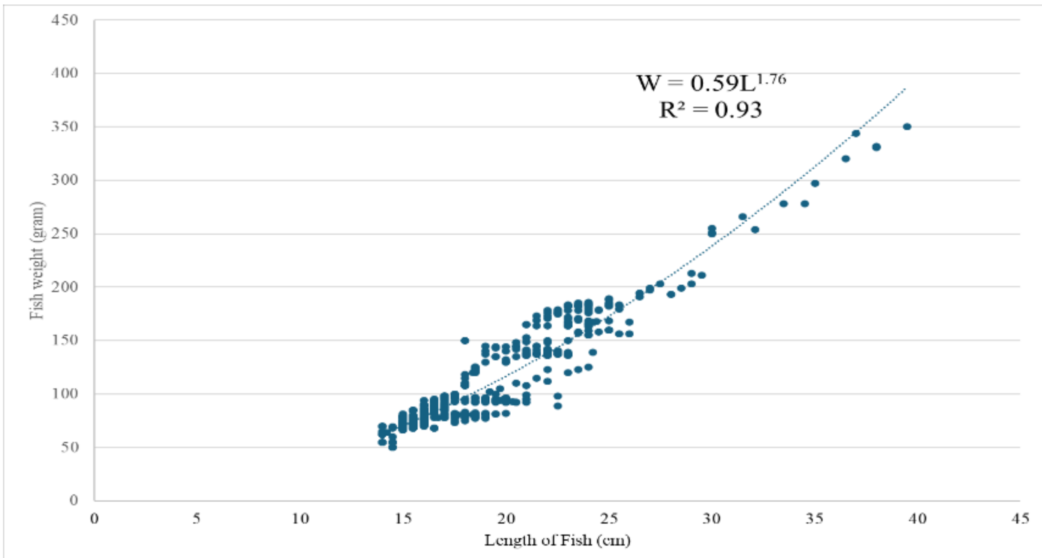

Figure 4. Length-weight relationship of *Siganus virgatus*.

This pattern is common in habitats with strong food competition or fishing pressure (Froese 2006). The low b value reflects a dominant juvenile phase and seasonal and reproductive factors. The length-weight relationship is an important indicator of population condition, growth strategy, and response to exploitation and habitat quality (Froese et al 2011).

Based on Figure 5, the Lc50% value or the first size caught from 660 *S. virgatus* is 16.7 cm. This value was obtained through the calculation stages of the Lc50% analysis method through data compilation, logistic curve calculation and the determination of the intersection point between the cumulative percentage and the mean value in the length distribution. The Lc50% size is greater than the Lm size, implying that most of the fish samples exceeded the Lm size. Lc50% value that is higher than Lm indicates that most of the fish were caught after reaching gonadal maturity and a lower likelihood of overfishing.

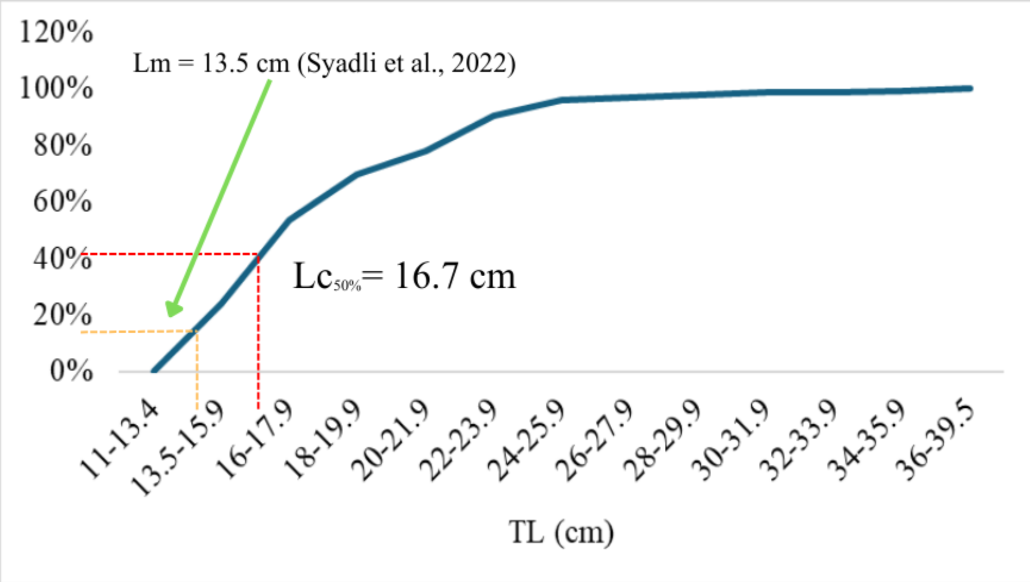

Figure 5. Lc50% analysis of *Siganus virgatus*.

Growth parameters and exploitation status. The data of the growth parameters of *S. virgatus* are presented in Table 2. The population dynamics parameters show an L∞ value of 23.7 cm and a K of 1.88 yr^{-1}, indicating a fast growth rate with a relatively small asymptotic size. This pattern is common among short-lived herbivorous reef fish. Such fish often employ an opportunistic life strategy by maximizing early growth to reduce the risk of predation and high natural mortality. The natural mortality value (M = 2.98 yr^{-1}) is greater than the fishing mortality (F = 1.54 yr^{-1}), indicating that population mortality is rather influenced by environmental, predation, and physiological factors than fishing pressure. Since the exploitation level (E = 0.34) is still below the optimum value (Eopt ≈ 0.5), the rabbitfish in this area is not over-exploited (Gulland 1971; Pauly 1980). The Z-value of 4.52 yr^{-1} reflects the high population turnover typical of small- to medium-sized reef fish. Herbivorous species, such as *S. virgatus*, have high natural mortality due to predation pressure and habitat dynamics. However, its rapid growth allows faster population recovery when the fishing pressure is not excessive (Hoey et al 2013). Smaller asymptotic sizes may indicate resource limitations, high population densities, or differences in habitat quality, while high K values reflect good aquatic productivity and abundant algal food availability (Müller et al 2021).

Table 2

Growth, mortality, and exploitation parameters

Location	*L_∞ (cm)*	*K*	*M*	*Z*	*F*	*E*	*Notes*	*References*
Karimunjawa	23.7	1.88	2.98	4.52	1.54	0.34	Not over-exploited	This research
Luwu Regency	28.1	0.61	2.34	2.34	1.08	0.5	Optimal	Jalil et al (2003)

In terms of management, the combination of M > F and E < 0.5 indicates that the current level of utilization is regarded as sustainable and has not disrupted the population structure. However, the high growth rate and dominance of small individuals also might pose a risk to its sustainability. Therefore, it is necessary to set the minimum catch size and protect the seagrass and coral reef habitats as rearing areas (Froese 2004; Robinson et al 2017).

Recruitment patterns. Recruitment pattern calculations were performed using FiSAT II software through the Recruitment Pattern subprogram based on the L∞, K, and t_0 values. The results of the recruitment pattern analysis show that the monthly distribution of recruitment percentages allows for estimation of the time (month) of fish spawning.

According to Saputra et al (2021), the entry of new individuals into exploited fish stocks originates from the reproductive results of fish that have reached gonad maturity. Table 3 shows quantitative data on *S. virgatus* recruitment over a one-year period, which are illustrated in Figure 6. The recruitment process or the entry of new individuals into the *S. virgatus* population occurs throughout the year, with percentages varying from low to high. The peak recruitment occurs four months in August, September, October, and November with peak recruitment rates exceeding 10%.

Table 3

Percentage (%) of *Siganus virgatus* recruitment patterns

Months	*Percentage (%)*
January	0.41
February	0.55
March	0.68
April	0.82
May	2.99
June	5.53
July	6.76
August	18.52
September	21.27
October	28.4
November	14.07
December	0

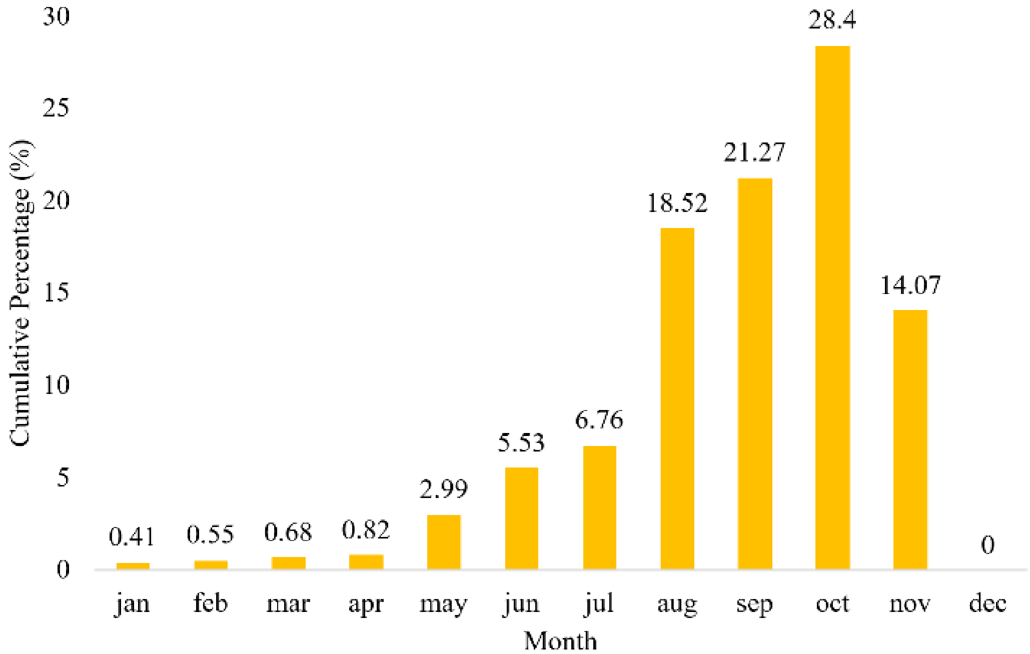

Figure 6. *Siganus virgatus* recruitment patterns.

Table 3 presents data on the recruitment percentage of *S. virgatus* in Karimunjawa waters over the course of one year. The peak recruitment occurred in October, with a peak percentage of 28.40%. High recruitment rates (more than 10%) were also found in August (18.52%), September (21.27%), and November (14.07%). December showed a recruitment rate of 0% in the FiSAT II analysis, which could be attributed to the failure of detecting new fish size groups entering the captured population during that month, thus preventing the model from identifying a recruitment peak. Low fishing activity or sample size in December might be due to seasonal factors such as bad weather. The variation reflects a recurring spawning cycle that is likely influenced by environmental conditions such as temperature and availability.

Stock management policy. The low exploitation rate of *S. virgatus* in Karimunjawa (E = 0.34) still requires a precautionary management approach. Fishing mortality (F) should be maintained lower than the natural mortality (M) by limiting the types of fishing gears, regulating fishing seasons, and implementing a minimum catch size above the first gonadal maturity size to ensure sustainable recruitment (Froese 2004). These measures are effective in maintaining the size structure of reef fish populations and preventing growth overfishing (Prince et al 2015).

The habitats of the fish also need protection, since *S. virgatus* relies heavily on coral reef ecosystems and seagrass beds for feeding and rearing. Establishing core zones (no-take zones) and strengthening marine conservation areas can increase herbivore biomass and improve ecosystem function by controlling macroalgal growth (Mumby & Harborne 2010). In addition, habitat connectivity needs to be maintained to support population dynamics and natural recruitment processes (Nagelkerken et al 2015). A community-based approach (co-management) is also important to apply in small-scale fisheries in Indonesia, since fishermen are involved in recording fish catches, environment monitoring, and compliance to the local regulations (Cinner et al 2012). Monitoring several basic indicators such as changes in average size, proportion of mature fish, and values of catch per unit effort, is important for periodic evaluation of the stock status (Froese et al 2011). The combination of catch size regulation, fishing effort restrictions, habitat protection, and participatory management will keep exploitation levels below the threshold and maintain the ecological role of *S. virgatus* to the resilience of coral reef ecosystems.

Conclusions. The length-weight relationship of *Siganus virgatus* shows a negative allometric growth pattern (b < 3), indicating that the length increases faster than weight. The pattern shows the dominance of small to medium-sized individuals in the population and the influence of environmental factors, food availability, and physiological dynamics on fish body condition. The high coefficient of determination indicates that the model is capable of explaining the weight variations based on length in the population dynamics analysis. The growth parameters showed a high K value with a relatively small L_∞, showing a life strategy of fast growth, short life, and a high population turnover rate that are common characteristics of herbivorous reef fish in tropical waters. The fish recruitment occurs annually, with a peak in 4 months between August and November, where the recruitment rates exceeded 10%. The high natural mortality compared to fishing mortality indicates that fishing pressure is not yet a major factor influencing population structure. The exploitation rate value (E = 0.34) below the optimum value (E = 0.5) shows that over-exploitation does not occur. However, the dominance of small fish requires careful management through minimum catch size regulation and controlled fishing to ensure the long-term population balance and ecological role of *S. virgatus* in coral reef ecosystems.

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Authors contributions. Data collection: BDB; Research framework and data analysis: BDB, DW; Writing: BDM, DW, SMW.

Conflict of interest. The authors declare that there is no conflict of interest.

Data availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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