

The exploitation level of squid (*Loligo* sp.) in the waters of Karimunjawa Islands, Indonesia

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Abstract. Squid (*Loligo* sp.) is an economically important fishery resource in the Karimunjawa Islands, Central Java, Indonesia, yet information on its length-weight relationship and population dynamics were limited. This study analyzed the length-frequency distribution, length-weight relationship, growth, mortality, and exploitation rate of squid catch in Karimunjawa Island. A total of 431 squid individuals were sampled from fish-trading sites over seven days each month from December 2024 to January 2025. Mantle length and body weight were measured, and growth parameters were estimated using the ELEFAN I method in FISAT II based on the von Bertalanffy growth model. Mantle length ranged from 22.9 to 48.3 cm, with the 25.1-28.0 cm size class accounting for 35% of the sample. The length-weight relationship was $W = 1.38L^{1.6937}$ ($R^2 = 0.6041$), with a growth coefficient (b) of 1.6937, indicating negative allometric growth. The estimated asymptotic length (L_{∞}) was 49.8 cm, with a growth coefficient (K) of 0.58 year^{-1} . Natural mortality (M), total mortality (Z), and fishing mortality (F) were 1.12, 1.17, and 0.05 year^{-1} , respectively, resulting in a low exploitation rate (E) of 0.04, well below the optimum level of 0.5. These findings indicate that the squid resource in Karimunjawa waters was not overexploited during the study period. Continued monitoring and precautionary management, including control of fishing effort and minimum catch-size regulations, are recommended to support sustainable utilisation.

Keywords: exploitation rate, growth parameters, Karimunjawa Islands, length-weight relationship, squid.

Introduction. Squid (*Loligo* sp.) is a soft-bodied marine invertebrate within the class Cephalopoda with distinctive arms and tentacles. Squid have specialised adaptations for predatory feeding, using jet propulsion for rapid movement, and are highly nutritious, making them an economically important fishery commodity (Arkhipkin et al., 2015). In waters with high biodiversity, various marine organisms thrive, including squid. Karimunjawa National Park is an area in Central Java, Indonesia, that is home to more than 500 fish species and approximately 300 coral species. The area is designated as a marine conservation area to protect its high biodiversity and marine ecosystems (Wibowo et al., 2022; Satyawan, 2025).

Indonesia is an archipelagic nation with extensive tropical waters, coral reefs and mangroves serving as the habitat for numerous marine organisms (Ariyani & Kismartini, 2018), including squids. The sustainability of squid in fisheries requires an integrated resource management that balances ecological conservation with community resource use (Niagara et al., 2021). However, squid has relatively short life cycle, rapid growth, and reproductive function that are significantly influenced by environmental conditions and high fishing pressure. To determine a sustainable resource management for squid, it is necessary to gain extensive information on the biological aspects, growth, and population dynamics of squid (Froese, 2004).

In fisheries, length-weight relationship analysis evaluates the biological condition and growth characteristics of aquatic organisms through the growth coefficient (b), which indicates either isometric or allometric growth. It also provides information on physiological condition, nutritional status, environmental adaptation, and responses to fishing pressure. Length-frequency distribution complements this analysis by describing population size structure, recruitment, age-group dominance, and resource utilisation. Both parameters are important in fisheries biology and stock management (Fauziyah et al., 2020; Hamdan et al., 2026).

The Karimunjawa Islands have substantial fishery potential and support fishing activities that contribute to local fishers' livelihoods. Local fishers use traditional gears, with catches fluctuating seasonally due to environmental factors. The high market demand often causes increased fishing pressure which may lead to fish stock depletion (FAO, 2024). In Jepara, Fishing Season Index (FSI) occurs between May–July and October–December (Dewi et al., 2026b).

Literature discussing the length-weight relationships and population dynamics of squid in Karimunjawa was still limited, while such information is essential for sustainable marine and fisheries. To address this gap, this study analysed length-frequency distribution, length-weight relationships, and growth, mortality, and exploitation parameters. The findings are expected to provide scientific information on stock condition and utilisation status and support sustainable squid fisheries management.

Material and Method

Time and location of the study. This study was conducted in Karimunjawa Islands during December 2024 and January 2025. Data were collected from Karimunjawa Island and Kemojan Island, which are the centre of economic activity, fishery production, and catch trading in the area. Those islands hold strategic importance to local fishing activities, significant fishery contributions, accessibility, and concentration of fish-landing sites, allowing for systematic data collection. The study period coincided with the peak fishing season, allowing the collection of representative and consistent catch data that reflected local fishery conditions (Anggreni et al., 2026; Riza et al., 2026).

Data collection. Squid data were obtained by measuring the mantle length (ML, cm) and body weight (W, g) of 431 squid samples collected from various fish-trading sites. Sampling was carried out over two months, from December 2024 to January 2025, with a sampling intensity of seven days per month. Squid samples were randomly selected from the daily catches landed at the trading sites until at least 30 individuals per sampling day had been measured. This threshold was adopted as the minimum sample size per sampling day, following the conventional minimum of 30 observations for a reliable estimate of a sample distribution; in total, 431 individuals were measured across the 14 sampling days. Mantle length was measured using a measuring board with a precision of 0.1 cm, while body weight was measured using a digital scale with a precision of 0.01 g. All measurements were carried out immediately after landing to minimise potential bias from post-harvest handling and weight loss during storage.

Data analysis. Data analysis was performed using Microsoft Excel and FiSAT II software. Growth parameters, including asymptotic length (L_{∞}) and the growth coefficient (K), were estimated using the ELEFAN I (Electronic Length Frequency Analysis) method based on the von Bertalanffy growth model. The t_0 value was calculated using the empirical formula of Pauly (1979), while total mortality (Z) was estimated using the FiSAT II software. Natural mortality (M) was calculated using the empirical formula of Pauly (1980), which incorporates mean water temperature. Fishing mortality (F) and the exploitation rate (E) were then derived from Z and M, and E was compared with the optimum exploitation rate at maximum sustainable yield ($EMS_Y = 0.5$; Gulland, 1971). Length at first capture ($L_{c50\%}$) and length at first gonadal maturity (L_m) were also analysed. The length-weight relationship was analysed using the following equations:

$$\begin{aligned} W &= aL^b \\ \ln W &= \ln a + b \ln L \\ L_t &= L_{\infty} (1 - e^{-k(t-t_0)}) \\ \text{Log}(-t_0) &= -0.3922 - 0.2752 \text{ Log } L_{\infty} - 1.038 \text{ Log } K \\ \text{Log}(M) &= -0.0066 - 0.279 \text{ Log } L_{\infty} + 0.6543 \text{ Log } K + 0.4634 \text{ Log } T \\ F &= Z - M \\ E &= F/Z \\ EMS_Y &= 0.5 \end{aligned}$$

where: W = body weight (g);
 L = mantle length (cm);
 a and b = constants of the length-weight relationship;
 L_{∞} = asymptotic length (cm);
 K = growth coefficient (per year);
 t = age (years);
 t_0 = theoretical age at zero length (years);
 T = water temperature (assumed at 28°C);
 Z = total mortality;
 M = natural mortality;
 F = fishing mortality;
 E = exploitation rate;
 E_{MSY} = optimum exploitation rate.

Results and Discussion. Squid is a high-value fishery resource in Indonesia, with strong market demand. As an active nektonic organism, squid inhabits coastal to offshore waters. Squid is sensitive to environmental conditions and fishing pressure, in which overexploitation may rapidly reduce squid stocks. Therefore, it is necessary to examine the size distribution and length-weight relationships for sustainable management of squid stocks (Oktariza et al., 2015; Fauziyah et al., 2020).

Karimunjawa Islands have interconnected coral reefs, seagrass beds, mangroves, and pelagic waters that are suitable habitats for squid (Fitri et al 2015). Squid have rapid growth and a short lifespan of one to two years, resulting in populations dominated by young and early-adult individuals (Jereb & Roper, 2010). As opportunistic predators, squid also contribute to ecosystem balance, while their sensitivity to environmental changes and fishing pressure requires sustainable management based on size at capture, reproductive periods, and stock regeneration capacity (Arkhipkin et al., 2015). Additionally, intensive fishing before maturity may inhibit population regeneration.

Length composition of squid. The data of this study were collected from 431 squid individuals with a mantle length ranging between 22.9 and 48.3 cm. The length-frequency distribution showed that the 25.1-28.0 cm size class dominated, with a frequency of 153 individuals (35%), followed by the 28.1-31.0 cm size class with 81 individuals (19%). Meanwhile, individuals with a mantle length above 43 cm were found in relatively small numbers of approximately 6% of the total sample (Table 1).

Table 1
 Length structure composition of squid (*Loligo* sp.) in the waters of Karimunjawa Island

Mantle length interval (cm)	Midpoint (cm)	Frequency (ind.)	Percentage (%)	Cumulative percentage (%)
22.1-25.0	23.5	39	9	9
25.1-28.0	26.5	153	35	45
28.1-31.0	29.5	81	19	63
31.1-34.0	32.5	18	4	68
34.1-37.0	35.5	40	9	77
37.1-40.0	38.5	40	9	86
40.1-43.0	41.5	32	7	94
43.1-46.0	44.5	18	4	98
46.1-49.0	47.5	10	2	100

The dominance of the medium size group indicates that the catches consist mainly of squid in the active growth phase. With rapid growth rate and a relatively short life cycle with rapid recruitment, the population structure of squid is generally dominated by young to early-adult individuals (Vidal & Shea, 2023). This size distribution also indicates that population recruitment occurs continuously, whereas the low proportion of large individuals may be influenced by natural mortality and high fishing pressure on adult individuals (Puspitasari & Fahrudin, 2019a).

Length-frequency distribution analysis is important in analyzing population dynamics, since it describes size structure, recruitment patterns, and the utilisation status of a fishery resource (Haddon, 2011). Information on squid size structure is essential for developing sustainable fisheries management strategies, particularly for establishing a minimum legal catch size that allows individuals to reproduce before capture.

Length-weight relationship. Figure 1 presents the length-weight relationship curve of squid that follows the ln-transformed equation $\ln W = 0.3243 + 1.6937 \ln L$, which is equivalent to $W = 1.38L^{1.6937}$ ($a = e^{0.3243} = 1.38$), with a growth coefficient (b) of 1.6937. A b-value below 3 indicates a negatively allometric pattern, where increases in mantle length occur faster than the increase in body weight.

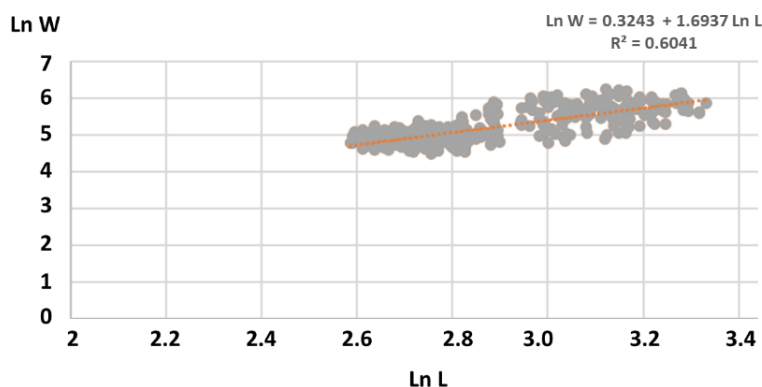


Figure 1. The length-weight relationship.

The coefficient of determination (R^2) of 0.6041 indicates that about 60.41% of the variation in body weight can be explained by mantle length growth, while the remainder is influenced by biological and environmental factors such as age, sex, and gonadal maturity stage (Nasyrah et al., 2024). The negative allometric growth pattern is the outcome of the biological conditions and characteristics of squid, in which weight is influenced by the development of reproductive organs, activity level, and water conditions (Anderson & Neumann, 1996).

Growth parameters and exploitation rate. Growth, age, and maximum size are biological characteristics that can vary between species and between populations. These differences are influenced by the interaction between genetic factors and environmental conditions, such as food availability, water temperature, habitat, and oceanographic conditions. Hence, each squid species or population has distinct characteristics of growth rate, longevity, and maximum size, requiring a species- or population-specific approach in biological studies and management (Moreno et al., 2007; Keyl et al., 2011). Information on age and growth describes the population dynamics and can be used to estimate the resource capacity. The results of the analysis using the ELEFAN I method in the FiSAT II software showed that squid had an asymptotic length (L_∞) of 49.8 cm with a growth coefficient (K) of 0.58 year⁻¹ (Table 2). Therefore, squid in Karimunjawa waters can reach a theoretical maximum length of about 49.8 cm, with a relatively fast growth rate. Rapid growth is an adaptive strategy of cephalopods to reach adult size and reproduce before experiencing high natural mortality (Arkhipkin et al., 2015; Vidal & Shea, 2023).

The total mortality (Z) of 1.17 year⁻¹ (Table 2) indicates a moderate rate of individual loss in the squid population. In cephalopods, total mortality reflects both natural mortality, including predation, oceanographic variability, and their short life cycle, and fishing mortality. Squid have high population turnover, allowing substantial changes in abundance over relatively short periods compared with demersal or reef fishes (Arkhipkin et al., 2015). The relatively high asymptotic length (L_∞) suggests that Karimunjawa waters can support squid growth to a substantial maximum size, while the growth coefficient (K) of 0.58 year⁻¹ indicates relatively rapid growth. Variations in the growth parameters of squid across regions may result from variations in temperature, food availability, population density, and oceanographic conditions (Pech & Jackson, 2008; Jereb & Roper, 2010).

Table 2

Growth, mortality, and exploitation parameters of squid (*Loligo* sp.) in the waters of Karimunjawa Island, compared with other locations

Location	L_{∞} (cm)	K	M	Z	F	E	Notes	Reference
Karimunjawa	49.8	0.58	1.12	1.17	0.05	0.04	Not over-exploited	This study
Banten Bay (female)	30.3	1.92	0.24	1.20	0.97	0.80	Over-exploited	(Puspitasari & Fahrudin, 2019a)
Banten Bay (male)	41.2	0.72	0.11	0.74	0.63	0.85	Over-exploited	(Puspitasari & Fahrudin, 2019a)
Jepara (Ujung Batu)	25.2	1.5	-	-	-	-	Recruitment overfishing (L_c 70.8 mm < L_m)	(Dewi et al., 2026a)

However, *Loligo* spp. landed at the Ujungbatu Fish Auction Place in Jepara Regency showed different characteristics. Among the 1,029 individuals, mantle length ranged from 20.0 to 230.0 mm, with a mean of 81.5 mm. The length at first capture (L_c) was 70.8 mm, which was below the reported length at first maturity (L_m), indicating potential recruitment overfishing (Dewi et al., 2026a). The population also exhibited markedly different growth parameters (L_{∞} = 25.2 cm; K = 1.5 year⁻¹), possibly due to differences in fishing gear and the life stages targeted. These differences demonstrate that exploitation status can vary substantially within the same regency, highlighting the need for area- and gear-specific management.

Natural mortality (M) in Karimunjawa was higher than fishing mortality (F), while exploitation rate (E) remained below the optimum threshold of 0.5, indicating that the squid stock was not overexploited (Table 2). A similar pattern was reported for *Uroteuthis duvaucelii*, with M = 0.853 year⁻¹, F = 0.287 year⁻¹, and E = 0.251 (Soomro et al., 2015). On the other hand, E > 0.5 of squid in Banten Bay indicates high fishing pressure and potential over-exploitation. If the exploitation rate (E) in Karimunjawa exceeds 0.5, management measures should include controls on fishing intensity and effort, along with minimum size-at-capture regulations (Puspitasari & Fahrudin, 2019a).

Sustainable fishery management requires science-based regulations, regular stock monitoring, and a total allowable catch (TAC) to keep exploitation rate within the safe biological limits. Economic and social considerations should also be integrated to protect coastal livelihoods (Liu et al., 2014; Aguilera, 2018; Lim & Jung, 2025). The Ecosystem Approach to Fisheries Management (EAFM) can strengthen management by taking into account the interactions among organisms, habitats, and environmental conditions (Koniyo et al., 2025). Reproductive escapement is particularly important because adult squid that avoid capture need to remain available for reproduction due to their short lifespan and rapid life cycle (Iwata et al., 2010).

High catch per unit effort (CPUE) value reflects optimal stocks, while lower CPUE might be a sign of overfishing (Koniyo et al., 2025). Species-specific catch and population-dynamics data are essential for appropriate management policies (Kamaruzzaman et al., 2026). Because squid populations respond strongly to environmental change, adaptive management that adjusts policies to changing stock and environmental conditions is essential for long-term sustainability (Pech & Jackson, 2008). In addition, migratory or high-seas squid stocks often require international cooperation to prevent over-exploitation (Arkhipkin et al., 2023; Chemshirova et al., 2023; Urrutia et al., 2025).

Management policy. The squid stock in Karimunjawa waters shows a low exploitation rate (E = 0.04), with natural mortality (M = 1.12 year⁻¹) substantially higher than fishing mortality (F = 0.05 year⁻¹). Therefore, the mortality rate is mainly affected by natural factors rather than fishing. However, with rapid growth, short lifespans, and short life cycles, squid are responsive to changes in fishing intensity. Therefore, a precautionary management approach is needed to maintain sustainable exploitation (Arkhipkin et al., 2015; FAO 2022).

Fishing activities should be controlled by regulating the number of fishing fleets and gears, controlling light-fishing intensity, and adjusting fishing seasons to avoid spawning periods. A minimum catch size above the length at first maturity should also be implemented in order to allow individuals to reproduce before capture (Pierce & Guerra, 1994; FAO, 2022). Evidence from Ujungbatu, within the same regency, shows recruitment overfishing associated with non-selective bottom-set gear, supporting mesh-size regulations or spatial closures to allow reproduction before capture (Dewi et al., 2026a). In addition, fishing activities should be scheduled according to the Fishing Season Index, with greater effort during the peak seasons of June-July and November-December and reduced effort during the less productive periods of January-April and August-September (Dewi et al., 2026b).

Habitat protection is another essential component. With coral reefs, seagrass beds, and coastal ecosystems for squid, the habitat quality of Karimunjawa waters should be maintained through seabed protection, pollution control, and strengthened marine conservation. Habitat degradation needs to be prevented, as it negatively affects squid distribution, growth, and reproductive success (Pech & Jackson, 2008; Jereb & Roper, 2010). Since squid fishers are predominantly small-scale, community-based management (co-management) should be encouraged, where fishers participate in catch recording, individual size measurements, and fishing-season monitoring to gain valid biological information. Regular monitoring of length-frequency distribution, length-weight relationships, growth, mortality, exploitation rate, and CPUE is also essential for detecting changes in stock condition and enabling adaptive management (Arkhipkin et al., 2015; FAO, 2022).

Bioeconomic modelling further complements biological assessment by integrating stock productivity with economic performance. In Batang Regency, a Gordon-Schaefer model for the purple-spotted bigeye (*Priacanthus tayenus*) estimated a maximum sustainable yield (MSY) of 2,473.16 tons year⁻¹ at 2,075 trips year⁻¹ and a maximum economic yield (MEY) of 2,184.03 tons year⁻¹ at 1,366 trips year⁻¹ below the threshold, indicating that the fishing activity is within normal intensity (Dewi et al., 2022). Comprehensive data also support the determination of a TAC that is both economically and biologically appropriate.

Complementary evidence from Banten Bay illustrates the value of multiple assessment methods. A Fox surplus-production model estimated MSY at 361.91 tons year⁻¹ and optimal effort at 1,083 trips year⁻¹, with utilisation at 76% of MSY (moderate exploitation) (Puspitasari & Fahrudin, 2019b). However, a length-based assessment classified the same stock as over-exploited based on $E = 0.80\text{--}0.85$ (Puspitasari & Fahrudin, 2019a). The difference shows that biological and catch-based approaches may produce different assessments, thereby the use of complementary methods is needed.

In general, the exploitation of squid in Karimunjawa waters can be maintained within normal level by regulating fishing activities, applying minimum catch sizes, protecting critical habitats, strengthening co-management, and integrating biological and bioeconomic assessments. Eventually, the squid stocks, fisheries production, and coastal livelihoods remain sustainable for a long-term (Arkhipkin et al., 2015; FAO 2022).

Conclusions. Based on the results of this study, the squid population in Karimunjawa waters was dominated by medium-sized individuals in an active growth phase and showed a negative allometric growth pattern. The estimated asymptotic length (L_{∞}) was 49.8 cm, with a growth coefficient (K) of 0.58 year⁻¹, indicating relatively rapid growth and a short life cycle. Natural mortality ($M = 1.12$ year⁻¹) was substantially higher than fishing mortality ($F = 0.05$ year⁻¹), indicating that population losses were primarily associated with natural factors. The low exploitation rate ($E = 0.04$) indicates that the stock was not overexploited and remained lightly exploited during the study period. Nevertheless, regular monitoring of size structure, growth, mortality, exploitation, and CPUE is needed. Management measures should include controlling fishing effort and catch size and protecting important habitats to maintain stock condition and support sustainable squid utilisation.

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