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Morphometrics and Growth Patterns of Squids in the North and South Coasts of Java, Indonesia

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Abstract

Squids play vital ecological and economic functions as keystone species in marine food webs and integral components of global capture fisheries. However, a comprehensive understanding of their diversity and life history characteristics in Indonesian waters is still poorly understood. This study aimed to identify squids that inhabited Java's northern and southern coasts and examine their growth pattern through morphometric analysis. Six hundred eighteen squid samples were collected fishers caught from May to September 2022 in Blanakan and Palabuhanratu Bay, representing two areas of interest. The body size and the shape of sucker rings of squids were observed using morphometric method. Kruskall-Wallis test, Principal Component Analysis, and Spearman's correlation were performed to investigate morphometric variation and relationships. The length-weight relationships were estimated for each species.. This study reported three species of squid on the north and south coasts of Java, namely the mitre squid (*Uroteuthis chinensis*), the Indian squid (*Uroteuthis duvaucelii*), and the purpleback flying squid (*Sthenoteuthis oualaniensis*). There were significant differences observed in ten morphometric variables among the three species of squid ($p < 0.05$), with fin width, fin length, and sucker ring teeth identified as the key distinguishing feature for the squids. Spearman's correlation indicated stronger associations between mantle and fin variables ($\rho = 0.666\text{-}0.967$, $p < 0.05$) than those between mantle and head variables ($\rho = 0.380\text{-}0.864$, $p < 0.05$). Mantle length-weight relationships revealed a hypoallometric growth pattern for *U. chinensis* and *U. duvaucelii*, while *S. oualaniensis* exhibited an isometric growth pattern. The finding of this study provides valuable insights concerning the growth of squids that reflect variation in ontogenic development, trophic ecology, and environmental conditions in Indonesian waters.

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1. Introduction

Cephalopods play important ecological and economic roles as a keystone species in marine food webs and a crucial component of global capture fisheries (Coll *et al*., 2013; Doubleday *et al*., 2016; Rosa *et al*., 2019). Over the past decade, the global production of cephalopods (squids, cuttlefishes, and octopuses) has quadrupled compared to the production levels before 1970, rising from one million tons in the 1970s to an average of four million tons in the period from 2013-2019 (Jereb and Roper, 2010; FAO, 2021). Indonesia is the world's third-largest cephalopod producer, following China and Peru. In 2022, its total production reached 226.4 thousand tons, valued at USD 667.4 million (KKP, 2022). The global demand for cephalopods is increasing rapidly, yet some fisheries exhibited signs of overexploitation (Doubleday *et al*., 2016; Sabrah *et al*., 2015).

There are approximately 290 species of squids worldwide, which comprise two families: Loliginidae (inshore squids) and Ommastrephidae (oceanic squids) (Arkhipkin *et al*., 2015). The Indo-Pacific region, encompassing the Java Sea, Sulawesi Seas, Palawan, and Malacca Strait, was identified as a hotspot for inshore squid species richness (Rosa *et al*., 2019). Some species might have wide distribution ranges, while others are more localized. The oceanographic environment greatly influences squid distribution and life cycle, including temperature, coastal currents, habitat conditions, and primary productivity (Zhao *et al*., 2020). Squids are recognized as ecological opportunities owing to their life history plasticity, like short lifespans, fast growth, and opportunistic dietary preferences (Rodhouse *et al*., 2014). This ecological versatility enables squids to adapt quickly to changing environmental conditions. Nevertheless, the ever-growing seafood industry might lead to the depletion of squid stocks (Doubleday *et al*., 2016). Adequate knowledge of species diversity, distribution, life history traits, and population dynamics is crucial for developing strategies to sustain cephalopod fisheries.

The species diversity and life history characteristics of squids in Indonesian waters are poorly understood. Numerous regional studies have reported squids identified with the scientific name *Loligo* sp. Some species of squids have been reported to exhibit polymorphism and species complexes due to their wide distributional range, which can sometimes lead to species misidentification (Carpenter and Niem, 1998; Jereb and Roper, 2010; Sin *et al*., 2009). Previous studies documented the presence of three economically important squids in the Indo-Pacific Region: the mitre squid (*Uroteuthis chinensis*), the Indian squid (*Uroteuthis duvaucelii*), and the purpleback flying squid (*Sthenoteuthis oualaniensis*). The mitre squid *U. chinensis* was observed in the South China Sea, Hongkong, Taiwan, North Queensland, Sabah-Malaysia, and Rembang-Indonesia) (Yan *et al*., 2013; Sin *et al*., 2009; Chang *et al*., 2014; Siddique *et al*., 2014; Triharyuni and Puspasari, 2012). Other significant squid resources in the seafood industry, the Indian squid were reported in many areas including India, Bangladesh, Thailand, South China Sea, and Indonesia (Jakarta, Cirebon, Rembang) (Anusha and Fleming, 2015; Siddique *et al*., 2016; Jin *et al*., 2017; Puspasari and Triharyuni, 2016; Afiati *et al*., 2017; Wagiyo *et al*., 2020). Furthermore, the purpleback flying squid was found to be abundant in the South China Seas (Fan *et al*., 2022; Zhao *et al*., 2020) and has also been observed in Manado Bay, North Sulawesi (Pratasik *et al*., 2022). Given the crucial role of biodiversity in sustaining ecosystems, species identification forms the foundation of ecological studies, conservation, and sustainable fisheries management (Afiati *et al*., 2022).

Morphometric studies are recognized as efficient and powerful methods for identifying species and estimating growth patterns, ontogeny, and population variations of aquatic organisms. These methods have been widely applied to squids for many years. Morphological features have been handy in identifying several squid species (Sin *et al*., 2009; Muchlisin *et al*., 2014; Jin *et al*., 2017). For squids, the fin and arm sucker rings have been identified as the most valuable features for differentiation (Carpenter and Niem, 1998). While some studies combine genetic analyses with advanced morphometric techniques using squid hard tissues, for example, beaks, statoliths, and gladius, to overcome the limitations of morphometric measurements (Sin *et al*., 2009; Jin *et al*., 2017), such approaches are often impractical and costly to apply in the field. Additionally, length-weight relationships analysis is commonly used to assess squid stocks' growth characteristics and conditions. However, few studies have been undertaken on *U. chinensis*, *U. duvaucelii*, and *S. oualaniensis* in Indonesian waters.

The north and south coasts of Java, Indonesia, are particularly interesting in this study. They exhibit distinct oceanographic characteristics, such as tides, currents, and waves (Setyawan and Pamungkas, 2017). The north coast of Java faces waters with low wave energy conditions from the Java Sea, while the south coast of Java experiences strong wave energy due to swells originating from the Indian Ocean. The difference in oceanographic conditions may significantly affect the distribution and characteristics of various marine organisms, including squid. Therefore, this study aimed to identify squids caught in Java's north and south coasts and examine their growth pattern through morphometric analysis.

2. Materials and Methods

2.1 Materials

The tools and materials used in the study include the samples of squid, calipers with the accuracy of 1 mm, digital scale with the accuracy of 0.1 g, ziplock sample bag, labels, and markers. The total sample of squid used in the study accounted to 618 individuals. The sample size taken each month ranged from 100 to 150 individuals.

2.1.1 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

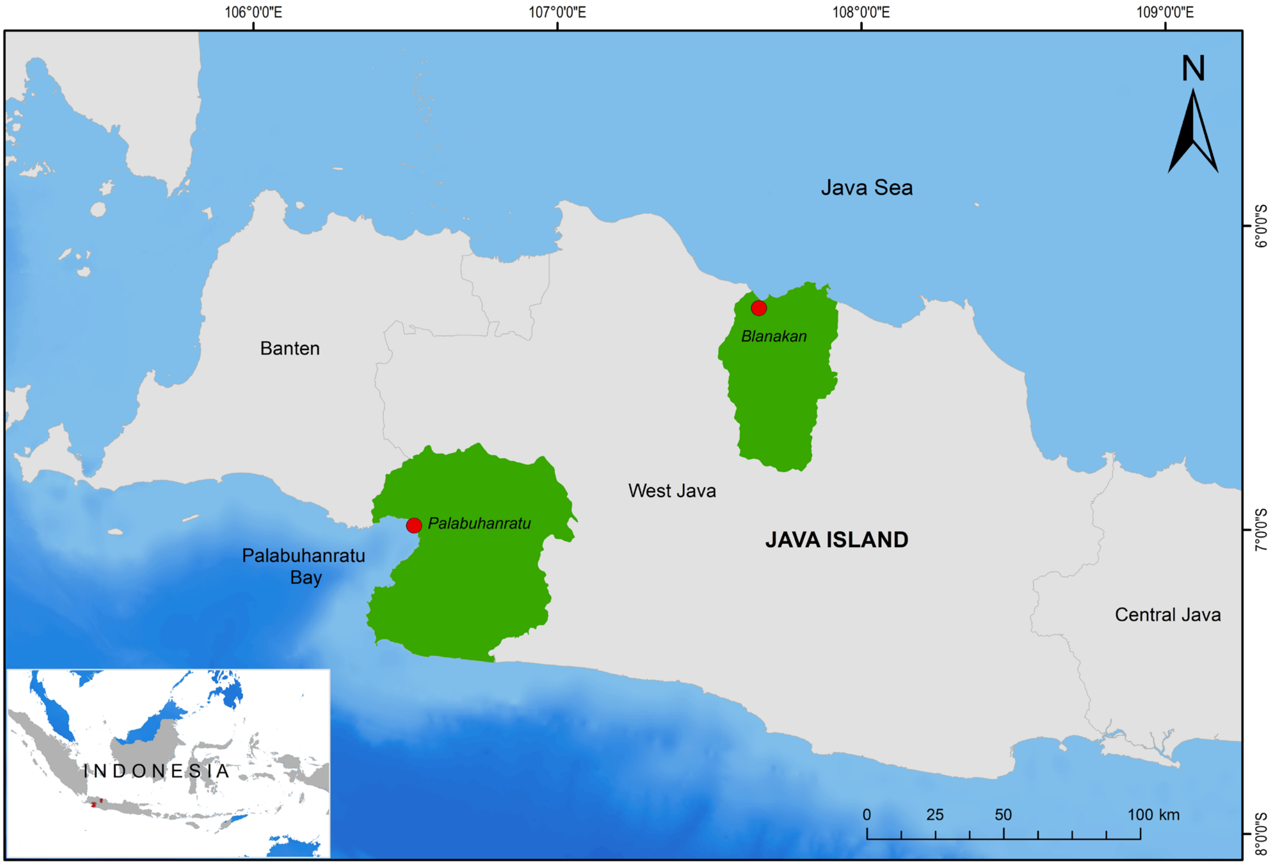

Figure 1. Map of sampling locations in Blanakan (north of Java) and Palabuhanratu Bay (south of Java), Indonesia. The red dots denote the sampling locations

2.2 Study Area

This research was conducted monthly from May to September 2022 in Blanakan and Palabuhanratu Bay, representing Java's northern and southern coasts, respectively (Figure 1). Sample analysis was performed at the Macro Biology Laboratory, Department of Aquatic Resource Management, Faculty of Fisheries and Marine Science, IPB University. Squid samples from Blanakan were collected from fishermen employing two types of fishing gear: purse seine and trolling line, within the Java Sea fishing area. On the other hand, squid samples from Palabuhanratu Bay were collected from fishers who used fixed lift nets placed along the bay. Squid catches was predominantly obtained during the dark moon (new moon phase).

2.3 Morphological Identification and Measurement

The study encompassed a total of 618 individual squid samples. Morphological identification of the squid was based on the identification book Cephalopods of the World (Jereb and Roper, 2010). Morphometric characters measured to the nearest 1.0 mm included mantle length (ML), total length (TL), mantle width (MW), fin length (FL), fin width (FW), head length (ED), and tentacle length (TC), using a ruler (Figure 2). Squid weight was measured using a digital scale with an accuracy of 0.1 g. Microanatomy observations focused on the sucker ring of the arm III and on the tentacular club of the squid (Carpenter and Niem, 1998). Sucker rings were carefully removed and examined under a light stereo microscope (Figure 2B).

2.4 Data Analysis

2.4.1 Morphometric differences

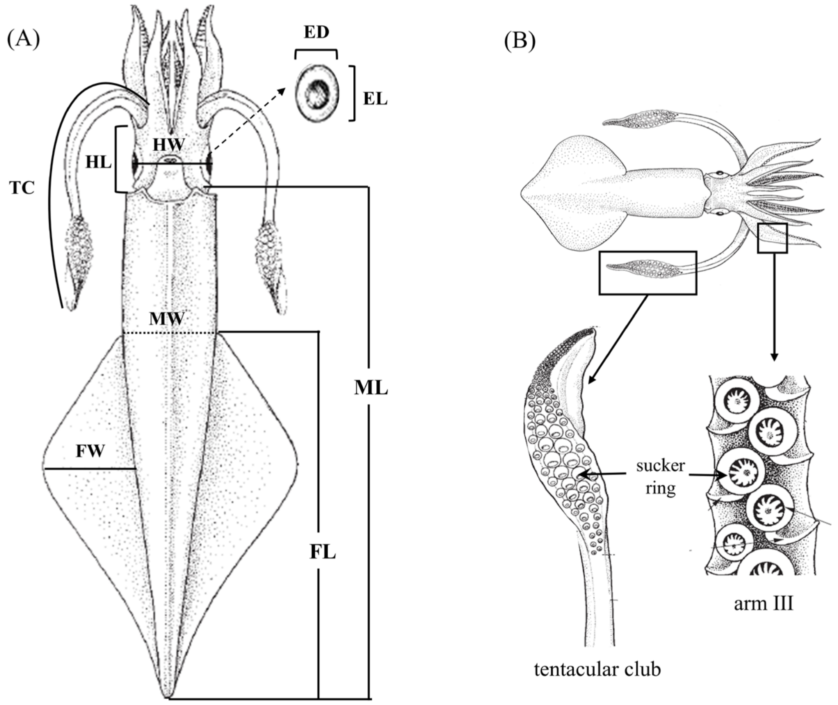

Figure 2. Morphological characters of squid (A) and sucker rings of arm III and tentacular club (B). ML is mantle length, MW is mantle width, FL is fin length, FW is fin width, HL is head length, HW is head width, EL is eye length, ED is eye diameter, and TC is tentacle length.

Table 1. Descriptive statistics for morphometric variables of three species of squid observed in Blanakan (north coast of Java) and Palabuhanratu Bay (south coast of Java), Indonesia

Parameter		***U. chinensis*** **(Blanakan) n=124 ind.**	***U. duvaucelii*** **(Blanakan) n=206 ind.**	***U. duvaucelii*** **(Palabuhanratu Bay) n=160 ind.**	***S. oualaniensis*** **(Palabuhanratu Bay) n=128 ind.**
Mantle Length (mm)	range	79–292	50–131	48–103	51–165
	mean±sd	162±45.3	73.3±14.5	68.2±11.5	91.9±20.0
Mantle Width (mm)	range	20–100	10–35	10–31	12–60
	mean±sd	42.6±10.3	22.8±3.8	17.7±4.4	25.1±8.0
Fin Length (mm)	range	28–220	18–72	10–63	18–70
	mean±sd	101.7±33.0	35.9±9.3	32.8±7.1	35.8±8.8
Fin Width (mm)	range	12–50	6–30	4–22	12–57
	mean±sd	28.0±9.1	12.3±3.9	11.4±2.9	28.2±8.1
Head Length (mm)	range	13–43	9–20	9–19	10–46
	mean±sd	25.8±4.7	13.2±1.8	11.6±1.8	15.6±4.6
Head Width (mm)	range	11–34	10–21	7–22	8–25
	mean±sd	22.8±5.0	13.1±2.3	11.8±2.5	13.3±3.1
Eye Length (mm)	range	10–30	9–21	7–15	7–15
	mean±sd	16.3±3.6	11±1.4	10.1±1.1	10.1±1.6
Eye Diameter (mm)	range	9–19	6–16	4–12	5–13
	mean±sd	22±2.2	9±1.4	7.7±1.1	8.4±1.6
Tentacle Length (mm)	range	83–374	65–195	30-123	50–190
	mean±sd	210.9±71.9	113±26.2	69.1±14.9	91.8±24.3
Total Length (mm)	range	202–674	143–332	112–228	141–368
	mean±sd	399.3±108.7	204.2±40.2	154±22.6	202.1±42.4
Weight (g)	range	32.1–408.6	9.8–101.3	6.4-77.5	11.4–232.9
	mean±sd	142.2±78.4	26.5±13.3	19.2±8.6	40.4±38.9

The morphometric data were transformed as ratios to mantle length to account for the size effect. The normality and homogeneity of data were checked using the Kolmogorov-Smirnov test and Levene's test. The Kruskal-Wallis test was applied to test for differences in the means of each morphometric character across three squid species with a significant level of 0.05. The specific difference between two species group were tested with the Mann-Whitney U Test. Principal Component Analysis (PCA) was conducted to determine the morphometric characteristics contributing significantly to the differences in the squid species. PCA could reduce data dimensionality to two principal components. Eigenvalues, variance, and factor loadings of these principal components were evaluated. The PCA analysis was performed using the R programming language, with the assistance of the 'factoextra' package (Kassambara and Mundt, 2020).

2.4.2 Morphometric relationship

The relationships between mantle length (ML) and other morphometric variables (e.g., MW, FL, FW, HL, HW, EL, ED, and TC) were visualized using scatter plots. Spearman's rank correlation coefficients (ρ) were calculated to measure the strength and direction of relationships for each pair of morphometric variables.

2.4.3 Growth pattern

Mantle length-weight relationships were determined with the equation . W is the weight in g, ML is the mantle length in cm, a and b correspond to the intercept and slope of the regression, respectively, along with 95% confidence interval. A t-test was performed on the b value to evaluate its significance. The isometric growth pattern is typically inferred for squids when the b value is equal to 3. Deviating from 3, the squid's growth pattern can be classified as either hypoallometric (b<3) or hyperallometric (b>3) (Ricker, 1973).

3. Results and Discussion

3.1 Species Diversity

Based on morphological characteristics, squids from Blanakan were identified as *Uroteuthis chinensis* (Gray, 1849) and *Uroteuthis duvaucelii* (d'Orbigny, 1835). Meanwhile, squids from Palabuhanratu Bay were identified as *U. duvaucelii* (d'Orbigny, 1835) and *Sthenoteuthis oualaniensis* (Lesson, 1830) (Figure 1).

The Loliginidae family exhibits greater diversity compared to the Ommastrephidae. Loliginids inhabit shelf waters near the coast and do not display extensive migratory behavior like ommastrephids (Jereb and Roper, 2010). Furthermore, Loliginidae are less reliant on large-scale current systems compared to Ommastrephidae. According to Apriansyah *et al.* (2023), the Java Sea comprises shallow shelf waters with an average depth of approximately 40 m, receiving great runoff from many big rivers in Sumatra, Java, and Kalimantan. Bird and Ongkosongo (1980) stated the south coast of Java experiences strong wave energy due to swells originating from the Indian Ocean. The distribution patterns of squid are influenced by the marine environmental conditions. Factors such as temperature, coastal currents, habitat conditions, and primary productivity have a substantial impact (Wang *et al.,* 2021). Several studies reported the presence of *Uroteuthis chinensis* in South China Seas, Hong Kong, Taiwan, Philippines, Indonesia (Yan *et al.,* 2013; Wang *et al.,* 2021; Xu *et al.,* 2020), *U. duvaucelii* were found in Indonesia, Andaman Sea, Bay of Bengal, Arabian Sea, Persian Gulf (Sajikumar *et al.*, 2022). Deep sea squids, *S. oualaniensis*, occur in diverse environments, including the Pacific Ocean, the South China Sea, the Indian, and Australia Ocean (Zhao *et al.,* 2020). The species can inhabit water columns from the surface to more than 600 m depth, allowing for the occurrence of this species in Palabuhanratu Bay.

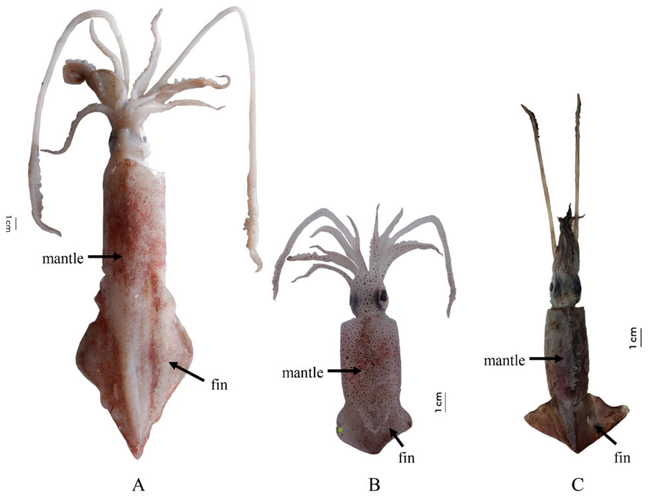

Figure 3. Morphology of mitre squid (*Uroteuthis chinensis*) (A), indian squid (*Uroteuthis duvaucelii*) (B), and purpleback flying squid (*Sthenoteuthis oualaniensis*) (C) observed in north and south coasts of Java, Indonesia.

3.2 Morphometric Differences

We obtained morphometric data of three species of squids from Blanakan and Palabuhanratu Bay (*U. chinensis*, n=124; U. duvaucelii, n=366; and S. oualaniensis, n=128) (Table 1). The mitre squid (*U. chinensis*) had the mantle length of 79-292 mm and a body weight of 32.1-408.6 g whereas the Indian squid (*U. duvaucelii*) had the mantle length ranges of 48-131 mm and body weight of 6.4-101.3

g. The range of mantle length for purpleback flying squid (*S. oualaniensis*) was from 51 to 165 mm, while the weight range from 11.4 to 232.9 g. The Mann Whitney U test showed the mantle length and body weight of *U. chinensis* are statistically greater than those of the other two species ($p < 0.05$). (Sin *et al.,* 2009; Islam *et al.,* 2017; Wang *et al.*, 2021; Siddique *et al.,* 2014).

Table 2 shows the mean morphometric variable of each squid species. Mean variations of ten morphometric variables (ML, TL, MW, FL, FW, HL, HW, EL, ED, and TC) showed significant differences

Table 2. Comparison of the mean morphometric variables after transformation for each species

No	Morphometric variable	Species (mean±sd)			Chi-Square	p*
		U. chinensis	*U. duvaucelii*	*S. oualaniensis*		
1	TL	2.48±0.27	2.51±0.38	2.22±0.25	68.96	1.06×10^{-15}
2	MW	0.27±0.05	0.28±0.05	0.27±0.04	13.27	0.0013
3	FL	0.62±0.06	0.48±0.05	0.39±0.04	417.85	2.2×10^{-16}
4	FW	0.17±0.03	0.16±0.03	0.30±0.04	282.22	2.2×10^{-16}
5	HL	0.16±0.03	0.18±0.03	0.17±0.03	18.24	0.0001
6	HW	0.14±0.03	0.15±0.03	0.18±0.03	159.24	2.2×10^{-16}
7	EL	0.10±0.02	0.15±0.23	0.11±0.20	302.78	2.2×10^{-16}
8	ED	0.08±0.02	0.12±0.02	0.09±0.02	282.63	2.2×10^{-16}
9	TC	1.29±0.24	1.26±0.36	1.01±0.19	76.86	2.2×10^{-16}

Note: Data were transformed relative to mantle length. TL=total length, MW=mantle width, FL=fin length, FW=fin width, HL=head length, HW=head width, EL=eye length, ED=eye diameter, TC=tentacle length. *significance value from Kruskal-Wallis test. The mean difference is significant at the 0.05 level.

The above results were within the range reported by other previous studies. *U. chinensis* in the Beibu Gulf of the South China Sea had a mantle length range of 42-438 mm (Yan *et al.,* 2013), while *U. chinensis* from Hongkong, Taiwan, and Australia had a mantle length of about 70-260 mm and 54-441 mm, 40-180 mm, respectively (Sin *et al.,* 2009; Chang *et al.,* 2014; Jackson, 1995). Previous studies on *U. duvaucelii* reported variations in mantle length, such as 84 mm in Rembang (Puspasari *et al.,* 2013), 80 mm in Cirebon (Afiati et al., 2017), 85-90 mm in Jakarta Bay (Wagiyo *et al.,* 2020), 55-128 mm in South China Sea (Jin *et al.,* 2017), 32-160 mm in Gulf of Thailand and 20-309 mm in India (Anusha and Fleming, 2015). The mantle length of purpleback flying squid (*S. oualaniensis*) in Palabuhanratu Bay was in the range of 51-165 mm, relatively small compared to the results of other studies. Fan *et al.* (2022) stated that the mantle length of *S. oualaniensis* in the South China Sea, Indian Ocean, and Pacific Ocean was 82-189 mm, 560 mm, and 140-240 mm, respectively. The mantle length was comparable with *S. oualaniensis* caught in the Sulawesi Sea, range between 68 mm to 119 mm (Pratasik *et al.,* 2022). The size range of purbleback flying squid caught in Palabuhanratu Bay belongs to the dwarf form, the smallest form of *S. oualaniensis* groups. The morphological characteristics of squids may vary in response to genetics, maturity stages, geographic locations, environmental factors, and food availability ($p < 0.05$) in the three species of squid. Multivariate tests showed significant differences among three squid species across ten dependent morphometric variables ($p < 0.05$) (Table 1). The most significant variables distinguishing squid were the ratios of fin length and fin width to mantle length ($p < 0.001$). The fin lengths of *U. chinensis*, *U. duvaucelii*, and *S. oualaniensis* were 0.62, 0.48, and 0.39 of their respective mantle lengths. The fin widths of *U. chinensis*, *U. duvaucelii*, and *S. oualaniensis* were 0.17, 0.16, and 0.30 of their respective mantle lengths.

The findings of the present study are consistent with observations made by Jereb and Roper (2010), who reported that the fin length of *U. chinensis* was roughly two-thirds of the mantle length, while the fin length of *U. duvaucelii* was approximately half of the mantle length. The present study also agrees with Pratasik *et al.* (2022), who found *S. oualaniensis* from the Sulawesi Sea had a fin length of 0.4 ML and a fin width of 0.3 ML. Squids have soft bodies that are easily damaged after being captured, which often affects the morphometric study (Jin *et al.,* 2017). Furthermore, polymorphism and species complexes have been reported within the genus Uroteuthis, which can result in species misidentification (Carpenter and Niem, 1998; Sin *et al.,* 2009; Jereb and Roper, 2010).

Based on the microanatomy observations, the shapes of the sucker rings and tentacle teeth were

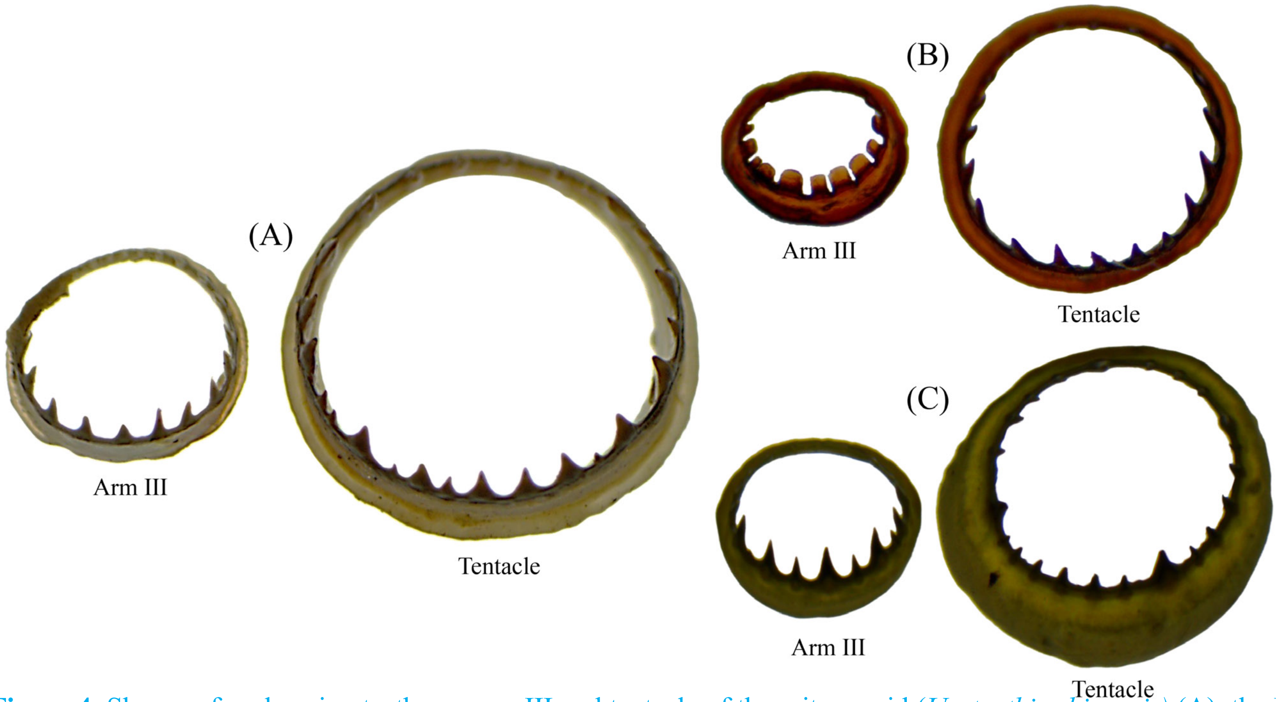

Figure 4. Shapes of sucker ring teeth on arms III and tentacle of the mitre squid (*Uroteuthis chinensis)* (A), the Indian squid (*Uroteuthis duvaucelii*) (B), and the purpleback flying squid (*Sthenoteuthis oualaniensis*) (C).

Table 3. Eigenvalues, variance, and cumulative variance for principal component analysis in the squid species

Factor	Eigenvalues	Variance (%)	Cumulative Variance (%)
PC1	3,223	40,297	40,297
PC2	1,554	19,428	59,726
PC3	0.985	12,311	72,037
PC4	0.734	9,181	81,219
PC5	0.618	7,736	88,955
PC6	0.437	5,469	94,425
PC7	0.306	3,822	98,246
PC8	0.140	1,753	100

distinctive for each species, as illustrated in Figure 4. The sucker rings teeth on the arms III of *U. chinensis* were sharp, conical, separate, and evenly sized, whereas *U. duvaucelii* featured broadly blunt teeth, and *S. oualaniensis* had sharp teeth and unevenly sized. The shapes of sucker ring teeth on tentacles were almost similar among the three species, characterized by sharp teeth with slight differences in their structure. For example, *U. chinensis* showed large and uneven conical teeth around the ring (Figure 4A), whereas *S. oualaniensis* showed tetraserial teeth, with one large tooth in each quadrant and small teeth in between (Figure 4C).

Distinct morphological differences in the shape of sucker rings among squid species are consistent with findings from previous studies (Carpenter and Niem, 1998; Sin *et al.,* 2009; Jereb and Roper, 2010). Suckers are an important feature for capturing prey and locomotion of cephalopods, so the sucker morphology is diversified among species, depending on their ecological niche (Kimbara *et al.,* 2020). Sucker ring teeth are made of a protein called suckerin that offers potential for a range of biomedical and engineering applications (Ding *et al.,* 2014). These findings emphasize the importance of comprehensive analyses that consider multiple characteristics, including the morphology of sucker rings, for accurate species identification.

PCA of morphometric variables resulted in eight principal components explaining100% of variance (40.3% for PC1, 19.4% for PC2, 12.3% for PC3, 9.2% for PC4, 7.7% for PC5, 5.5% for PC6, 3.8% for PC7, and 1.7% for PC8) (Table 3). PC1 and PC2 were identified with eigenvalues > 1 and cumulative variance of 59.7%. Table 4 presented factor loading scores for each morphometric variable from PC1 and PC2. TC/ML, FL/ML, and FW/ML had higher factor loadings in PC1 and PC2. Jin *et al.* (2018) suggested that variables with higher contributions to variance from PC1 and PC2 could be used for further study due to their representation of morphometric characteristics.

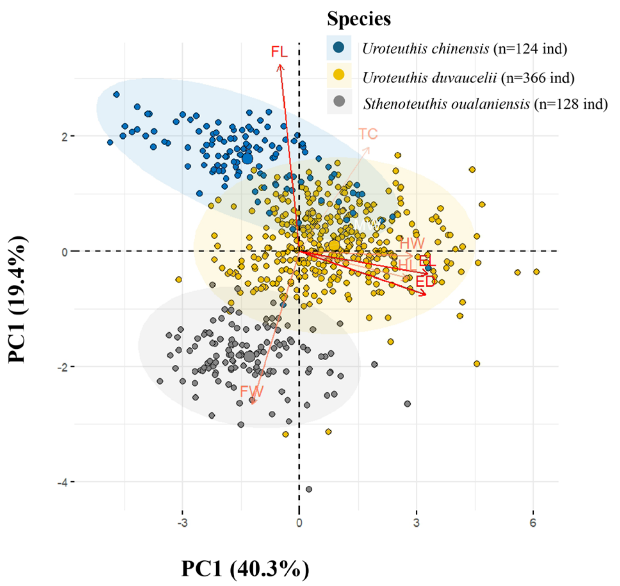

Figure 5. Scatter plot of the two principal components based on morphometric variables for the three squid species in north and south of Java, Indonesia.

The first two components of the PCA are represented in Figure 5. PCA biplot showed that differences in centroid distribution characterize the three species group of squid. The scatter plot of *U. chinensis* showed closer proximity to those of *U. duvaucelii*, which is reasonable because both species in the same genus Uroteuthis and family Loliginidae. Meanwhile, *S. oualaniensis* exhibited a distinct clustering as it belongs to family Ommastrephidae. Another study observed similar pattern, where the distance between clusters in PCA was related to taxonomic classification (Muchlisin *et al.,* 2014).

3.3 Morphometric Relationships

Regression analysis showed a relationship of varying strength between each species' mantle length and other characteristics (Figure 6). All pairs of morphometric variables were positively correlated, with Spearman's correlation coefficients (ρ) ranges from 0.283 to 1.000 ($p < 0.05$) (Table 5). Mantle length showed strong correlations with fin length, fin width, and mantle width ($\rho > 0.8$ $p < 0.05$). Other morphometric parameters representing the head of squid (i.e., HL, HW, EL, and ED) showed weaker correlations with mantle length.

Table 4. Factor loadings of principal components based on morphometric variables in three species of squids

Variables	Factor Loading	
	PC1	PC2
MW/ML	0.049	0.112
FL/ML	0.072	-0.902
FW/ML	-0.049	0.376
HL/ML	0.031	0.082
HW/ML	0.019	0.051
EL/ML	0.026	0.081
ED/ML	0.024	0.101
TC/ML	0.993	0.070

Note: ML=mantle length, MW=mantle width, FL=fin length, FW=fin width, HL=head length, HW=head width, EL=eye length, ED=eye diameter, TC=tentacle length. Factor loading greater than 0.30 is considered significant, 0.40 is considered more significant, and 0.50 or above is considered very significant.

This study suggests that the growth of mantle length was more closely associated with fin length and width growth in the posterior part than in the anterior part (e.g., head length, head width, eye length, and eye diameter). This indicates that head growth was slower than mantle and fin growth. Study by Moltschaniwskyj (1995) revealed that the head and eyes of squid grow predominantly during early stages of development. As the squid matures, energy is allocated for the growth of other important structures such as arms and tentacles, mantle muscle, gametic tissue, and gonad. These results align with the findings of Afiati *et al.* (2017) who reported similar patterns of fin growth occurring at a comparable rate to mantle length, while the head and eye exhibited slower growth compared to the overall body. This was possibly related to the squid's behavior in performing vertical and horizontal migrations. Most squids have to swim up to the surface at night for feeding. Squid's eyes considerably took up large portion of the head area. Large eyes are likely adaptations to low-light environments so that squid can spot the movement of prey and predators at the depths of the ocean (Nilsson *et al.,* 2012).

3.4 Growth Pattern

The relationship between mantle length and body weight is useful in studying the growth rate of cephalopods. Parameter b indicates the growth status and type of the species, which are mainly affected by the growth environment of species and food availability. The relationships between mantle length and total weight were highly significant for three species of squid ($p < 0.05$ with $r^2 > 0.85$) (Table 6 and Figure 7). The estimated b values were 1.906 for *U. chinensis*,

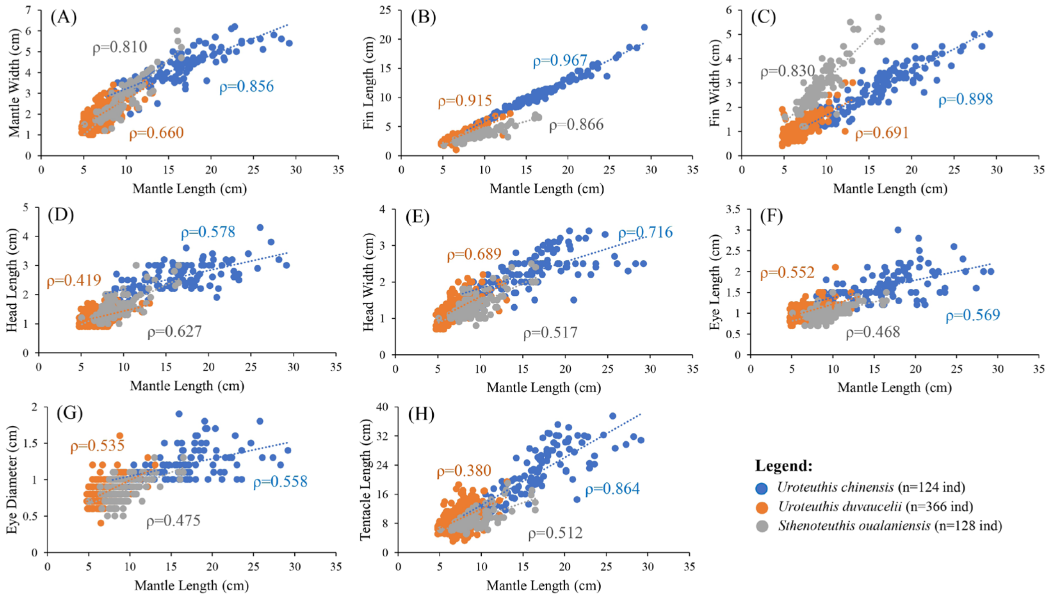

Figure 6. Linear morphometric relationships of three species of squid *U. chinensis*, *U. duvaucelii,* and *S. oualaniensis*, (A) ML vs MW, (B) ML vs FL, (C) ML vs FW, (D) ML vs HL, (E) ML vs HW, (F), ML vs EL, (G) ML vs ED, and (H) ML vs TC. The ρ values are Spearman correlation coefficient at significance level 0.05.

Table 5. Spearman correlation coefficient (ρ) for all pairs of morphometric variables of U. chinensis (n=124), *U. duvaucelii* (n=366), and *S. oualaniensis* (n=128). All relationships are statistically significant at the 0.05 level.

Species	Parameter	ML	MW	FL	FW	HL	HW	EL	ED	TC
	ML	1,000								
	MW	0.856	1,000							
	FL	0.967	0.809	1,000						
	FW	0.898	0.748	0.900	1,000					
Uroteuthis chinensis	HL	0.578	0.424	0.579	0.622	1,000				
	HW	0.716	0.635	0.697	0.733	0.613	1,000			
	EL	0.569	0.486	0.558	0.620	0.643	0.699	1,000		
	ED	0.558	0.575	0.558	0.603	0.601	0.678	0.788	1,000	
	TC	0.864	0.778	0.824	0.880	0.616	0.846	0.706	0.656	1,000
	ML	1,000								
	MW	0.660	1,000							
	FL	0.915	0.639	1,000						
	FW	0.691	0.426	0.742	1,000					
Uroteuthis duvaucelii	HL	0.419	0.603	0.469	0.358	1,000				
	HW	0.689	0.533	0.592	0.390	0.491	1,000			
	EL	0.552	0.542	0.567	0.488	0.572	0.429	1,000		
	ED	0.535	0.555	0.560	0.485	0.569	0.411	0.683	1,000	
	TC	0.380	0.652	0.393	0.294	0.560	0.283	0.457	0.567	1,000
	ML	1,000								
	MW	0.810	1,000							
	FL	0.866	0.730	1,000						
	FW	0.830	0.746	0.806	1,000					
Sthenoteuthis oualaniensis	HL	0.627	0.551	0.641	0.579	1,000				
	HW	0.517	0.435	0.567	0.476	0.723	1,000			
	EL	0.468	0.486	0.493	0.485	0.601	0.461	1,000		
	ED	0.475	0.504	0.471	0.472	0.594	0.451	0.807	1,000	
	TC	0.512	0.344	0.509	0.405	0.471	0.489	0.423	0.388	1,000

Note: ML=mantle length, MW=mantle width, FL=fin length, FW=fin width, HL=head length, HW=head width, EL=eye length, ED=eye diameter, TC=tentacle length.

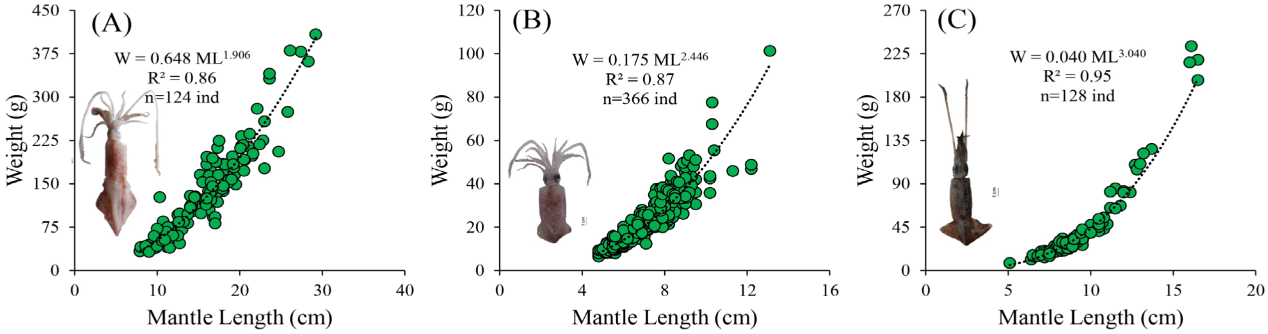

Figure 7. Mantle length-weight relationship of three species of *U. chinensis* (A), *U. duvaucelii* (B), and *S. oualaniensis* (C)

Table 6. Regression parameters of mantle length-weight relationships and growth pattern of *U. chinensis, U. duvaucelii*, and *S. oualaniensis*

Species	Common name	n	Regression parameter a (95% CI)	Regression parameter b (95% CI)	r^2	Growth Pattern
Uroteuthis chinensis (Gray, 1849)	Mitre squid	124	0.648 (0.442–0.950)	1,906 (1.767–2.044)	0.86	Hypoallometric
Uroteuthis duvaucelii (d'Orbigny, 1835)	Indian squid	366	0.175 (0.145–0.212)	2,446 (2.348–2.545)	0.87	Hypoallometric
Sthenoteuthis oualaniensis (Lesson, 1830)	Purpleback flying squid	128	0.040 (0.031–0.052)	3,040 (2.918–3.162)	0.95	Isometric

2.446 for *U. duvaucelii*, and 3.040 for *S. oualaniensis*. Two species of Uroteuthis were found to have hypoallometric growth, while *S. oualaniensis* has an isometric growth pattern.

The present study estimated the growth parameter b of *U. chinensis* in the Java Sea was 1.91. The growth parameter of *U. chinensis* from different locations have been reported, where the b value was 2.35 in the South China Seas (Jin *et al.,* 2019), 1.46 in Banyuasin Coastal Water (Fauziyah *et al.,* 2020), 2.58 in Sabah Malaysia and 2.23 in the Beibu Gulf (Siddique *et al.,* 2014). The present study supports evidence in previous studies that suggest hypoallometric growth in *U.chinensis*, where the growth rate of body weight was faster than that of mantle length. Hypoallometric growth was also observed for Indian squid (*U. duvaucelii*). The present study showed that the b value for this species in the Java Sea and Palabuhanratu Bay (Indian Ocean) was 2.45, which was consistent with the b value of 2.37 in the Gulf of Thailand, 2.42 in the Indian waters (Tehseen *et al.,* 2019). A lower b value was recorded from Goa, west coast of India (Mishra *et al.,* 2012), and 1.38 from the Bay of Bengal, Bangladesh (Siddique *et al.,* 2016). Subsequently, purpleback flying squid in Palabuhanratu Bay, Indian Ocean, exhibit isometric growth, with b value of 3.04, which is in agreement with the b value of 2.98 for dwarf squid form of this species in the southern South China Sea (Wang *et al.,* 2017). Other studies showed different growth type of *S. oualaniensis* in South China Sea with with b value was greater than 3, indicating a positive allometric growth (Lu *et al.,* 2018; Fan *et al.,* 2022; Zhao *et al.,* 2020). Different growth types of squids may be caused by various internal factors (e.g., sex, gonad maturity, intraspecific diversity, life stages) and external factors (e.g., seasonal changes, food availability, habitat, environmental condition, primary productivity, etc.).

4. Conclusion

Squids observed on the north and south coasts of Java were distinct. Specifically, the mitre squid (*Uroteuthis chinensis*) was populated in the northern region (Java Sea), while the purpleback flying squid (*Sthenoteuthis oualaniensis*) inhabited the southern region (Indian Ocean). Meanwhile, the Indian squid (*Uroteuthis duvaucelii*) was observed in both areas. Three squid species display high morphological differences, with the most significant variation observed in fin width, fin length, and shape of sucker rings. The morphometric character correlations differ between the anterior and posterior body parts. The growth coefficient for *Uroteuthis* and *Sthenoteuthis* suggested hypoallometric and isometric growth, respectively. This study's findings contribute insights regarding identifying important economic squid resources in Indonesian waters. Information on the growth pattern of squids becomes the basis for understanding their life history and fishery assessment. The small coverage of the study area and a short period of research are essential limitations in the present study. This could have led to the underestimated richness of species of squids in the Java Sea and Indian Ocean. Future research would be worthwhile by conducting molecular assessment on genetic diversity of the species. Additionally, conducting large-scale studies on ecological aspect such as feeding habits, trophic level, and reproduction strategy would be interesting as efforts towards sustainable fisheries management.

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Authors' Contributions

All authors have contributed to the final manuscript. Each author's contribution is as follows: AE: designed the research project, collected the sample, analyzed the data, drafted the manuscript, and designed the figures. CPHS, SS, DYW, and ZZ: designed the research project, collected the sample, and critically revised the article. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests. We certify that the submission is original work and is not under review at any other publication.

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References

Afiati, N., Nusari, D. M., & Subagiyo, S. (2017). Allometric study of *Urotheutis* (Photololigo) duvauceli (d'Orbigny 1835) from Northern Coast of Java, Indonesia. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, 54(1):21-37.

Afiati, N., Subagiyo, Handayani, C. R., Hartati, R., Kholilah, N. (2022) DNA barcoding on Indian Ocean squid, *Uroteuthis duvaucelii* (D'Orbigny, 1835) (Cephalopoda: Loliginidae) from the Java Sea, Indonesia. *Jurnal Ilmiah Perikanan dan Kelautan*, 14(2):231-245.

Anusha, J. R., & Fleming, A. T. (2015). Cephalopod: Squid biology, ecology and fisheries in Indian waters. *International Journal of Fisheries and Aquatic Studies*, 1(4):41-50.

Apriansyah, Atmadipoera, A. S., Nugroho, D., Jaya, I., & Akhir, M. F. (2023). Simulated seasonal oceanographic changes and their implication for the small pelagic fisheries in the Java Sea, Indonesia. *Marine Environmental Research,* 188(1):1-15.

Arkhipkin, A. I., Rodhouse, P. G. K., Pierce, G. J., Sauer, W., Sakai, M., Allcock, L., Arguelles, J., Bower, J. R., Castillo, G., Ceriola, L., Chen, C.-S., Chen, X., Diaz-Santana, M., Downey, N., González, A. F., Granados Amores, J., Green, C. P., Guerra, A., Hendrickson, L. C., … Zeidberg, L. D. (2015). World squid fisheries. *Reviews in Fisheries Science & Aquaculture,* 23(2):92-252.

Bird, E. C. F., & Ongkosongo, O. S. R. (1980). Environmental changes on the coasts of Indonesia. Tokyo: United Nations University.

Carpenter, K. E., & Niem, V. H. (1998). FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 2. Cephalopods, crustaceans, holothurians and sharks. Rome: FAO.

Chang, K. Y., Liao, C. H., Huang, H. T., Wu, C. L., & Wang, K. Y. (2014). Age and growth of *Uroteuthis* (Photololigo) *chinensis*, *U.* (P.) *duvauceli* and *U.* (P.) *edulis* from the waters around Taiwan. *Journal of Taiwan Fisheries Research*, 22(1):1-13.

Coll, M., Navarro, J., Olson, R. J., & Christensen, V. (2013). Assessing the trophic position and ecological role of squids in marine ecosystems by means of food-web models. *Deep Sea Research Part II: Topical Studies in Oceanography,* 95(1):21-36.

Ding, D., Guerette, P. A., Hoon, S., Kong, K. W., Cornvik, T., Nilsson, M., Kumar, A., Lescar, J., & Miserez, A. (2014). Biomimetic production of silk-like recombinant squid sucker ring teeth proteins. *Biomacromolecules,* 15(9):3278-3289.

Doubleday, Z. A., Prowse, T. A. A., Arkhipkin, A., Pierce, G. J., Semmens, J., Steer, M., Leporati, S. C., Lourenço, S., Quetglas, A., Sauer, W., & Gillanders, B. M. (2016). Global proliferation of cephalopods. *Current Biology*, 26(10):PR406-R407.

Fan, J., Fang, Z., Ma, S., Zhang, P., & Chen, Z. (2022). Age, growth, and population characteristics of Sthenoteuthis oualaniensis in the South China Sea. *Regional Studies in Marine Science,* 55(1):1-11.

FAO. (2021). FAO yearbook. Fishery and aquaculture statistics 2019. Rome: FAO.

Fauziyah, Purwiyanto, A. I. S., Agustriani, F., & Putri, W. A. E. (2020). Growth aspect of squid (Loligo chinensis) from the Banyuasin Coastal Waters, South Sumatra, Indonesia. *Ecologica Montenegrina*, 27(1):1-10.

Islam, R., Pradir, S., Hajisamae, S., Perngmak, P., Paul, M., Naim, J., & Fazrul, H. (2017). Abundance and distribution pattern of two common Loliginid squids, *Uroteuthis* (Photololigo) *chinensis* (Gray 1849) and *Uroteuthis* (Photololigo) *duvaucelii* (d'Orbigny 1835), in the Gulf of Thailand. *Asian Fisheries Science*, 30(4):262-273.

Jackson, G. D. (1995). Seasonal influences on statolith growth in the tropical nearshore loliginid squid *Loligo chinensis* (Cephalopoda: Loliginidae) off Townsville, North Queensland, Australia. *Fishery Bulletin,* 93(4):749-752.

Jereb, P., & Roper, C. F. E. (2010). Cephalopods of the world. An annotated and illustrated catalogue of cephalopod species known to date. Volume 2. Myopsid and oegopsid squids. FAO species catalogue for fishery purposes. Rome: FAO.

Jin, Y., Li, N., Chen, X., Liu, B., & Li, J. (2019). Comparative age and growth of *Uroteuthis chinensis* and *Uroteuthis edulis* from China Seas based on statolith. *Aquaculture and Fisheries*, 4(4):166-172.

Jin, Y., Liu, B., Li, J., & Chen, X. (2017). Identification of three common Loliginidae squid species in the South China Sea by analyzing hard tissues with geometric outline method. *Journal of Ocean University of China,* 16(5):840-846.

Jin, Y., Liu, B., Chen, X., & Staples, K. (2018) Morphological beak differences of loliginid squid, *Uroteuthis chinensis* and *Uroteuthis edulis*, in the northern South China Sea. *Journal of Oceanology and Limnology,* 36(1):559–571.

Kassambara, A., & Mundt, F. (2020). factoextra: Extract and visualize the results of multivariate data analyses.

Kimbara, R., Nakamura, M., Oguchi, K., Kohtsuka, H., & Miura, T. (2020). Pattern of sucker development in cuttlefishes. *Frontiers in Zoology,* 17(1):1-13.

KKP. (2022). Statistik KKP. Available at: https://statistik.kkp.go.id/home.php

Lu, H., Tong, Y., Liu, W., Liu, K., Dong, Z., Cheng, X., & Chen, X. (2018). Fisheries biological characteristics of Sthenoteuthis oualaniensis in the spring season in the El Nino year of 2016 in the Zhongsha Islands waters of South China Sea. *Journal of Fisheries of China*, 42(6):912-921.

Mishra, A. S., Nautiyal, P., & Somvanshi, V. (2012). Length-weight relationship, condition factor and sex ratio of *Uroteuthis* (Photololigo) *duvaucelii* (d'Orbigny, 1848) from Goa, west coast of India. *Journal of the Marine Biological Association of India,* 54(2):65-68

Moltschaniwskyj, N. A. (1995) Changes in shape associated with growth in the loliginid squid *Photololigo* sp.: a morphometric approach. *Canadian Journal of Zoology*, 73(1): 1335–1343.

Muchlisin, Z. A., Zulkarnaini, B., Purnawan, S., Muhadjier, A., Fadli, N., & Cheng, S. H. (2014). Morphometric variations of three species of harvested cephalopods found in northern sea of Aceh Province, Indonesia. *Biodiversitas Journal of Biological Diversity*, 15(2):142-146.

Nilsson, D. E., Warrant, E. J., Johnsen, S., Hanlon, R., Shashar, N. (2012) A unique advantage for giant eyes in giant squid. *Current Biology*, 22(8):683-688.

Pratasik, S. B., Lalamentik, L. T. X., Manoppo, L., & Budiman, J. (2022). Deep sea squid in Sulawesi Sea, North Sulawesi Province, Indonesia. Biodiversitas *Journal of Biological Diversity,* 23(4):1774-1779.

Puspasari, R., & Triharyuni, S. (2016). Karakteristik biologi cumi-cumi di Perairan Laut Jawa.

BAWAL Widya Riset Perikanan Tangkap, 5(2):103-111.

Ricker, W. E. (1973). Linear regressions in fishery research. *Journal of the Fisheries Research Board of Canada*, 30(3):409-434.

Rodhouse, P. G. K., Pierce, G. J., Nichols, O. C., Sauer, W. H. H., Arkhipkin, A. I., Laptikhovsky, V. V., Lipiński, M. R., Ramos, J. E., Gras, M., Kidokoro, H., Sadayasu, K., Pereira, J., Lefkaditou, E., Pita, C., Gasalla, M., Haimovici, M., Sakai, M., & Downey, N. (2014). Environmental effects on cephalopod population dynamics. *Advances in Marine Biology,* 67(1):99-233.

Rosa, R., Pissarra, V., Borges, F. O., Xavier, J., Gleadall, I. G., Golikov, A., Bello, G., Morais, L., Lishchenko, F., Roura, Á., Judkins, H., Ibáñez, C. M., Piatkowski, U., Vecchione, M., & Villanueva, R. (2019). Global patterns of species richness in coastal cephalopods. *Frontiers in Marine Science*, 6(1):1-16.

Sabrah, M. M., El-Sayed, A. Y., & El-Ganiny, A. A. (2015). Fishery and population characteristics of the Indian squids *Loligo duvauceli* Orbigny, 1848 from trawl survey along the North-West Red Sea. *The Egyptian Journal of Aquatic Research*, 41(3):279-285.

Sajikumar, K. K., Sasikumar, G., Jayasankar, J., Bharti, V., Venkatesan, V., Joy, K. M. J., Alloycious, P. S., & Mohamed, K. S. (2022). Dynamics of growth and spawning in the Indian squid *Uroteuthis duvaucelii* (Cephalopoda: Loliginidae) from the tropical Arabian Sea. *Regional Studies in Marine Science,* 52(1):1-16.

Setyawan, W. B., & Pamungkas, A. (2017). Perbandingan karakteristik oseanografi Pesisir Utara dan Selatan Pulau Jawa: Pasang-surut, arus, dan gelombang. *Prosiding Seminar Nasional Kelautan Dan Perikanan III*, 191-202.

Siddique, M. A. M., Arshad, A., & Nurul Amin, S. M. (2014). Length–weight relationships of the tropical cephalopod *Uroteuthis chinensis* (Gray, 1849) from Sabah, Malaysia. *Zoology and Ecology*, 24(3):215-218.

Siddique, M. A. M., Khan, Md. S. K., Habib, A., Bhuiyan, Md. K. A., & Aftabuddin, S. (2016). Size frequency and length–weight relationships of three semi-tropical cephalopods, Indian squid Photololigo duvaucelii, needle cuttlefish *Sepia aculeata*, and spineless cuttlefish *Sepiella inermis* from the coastal waters of Bangladesh, Bay of Bengal. *Zoology and Ecology,* 26(3):176-180.

Sin, Y. W., Yau, C., & Chu, K. H. (2009). Morphological and genetic differentiation of two loliginid squids, *Uroteuthis* (Photololigo) *chinensis* and *Uroteuthis* (Photololigo) *edulis* (Cephalopoda: Loliginidae), in Asia. *Journal of Experimental Marine Biology and Ecology,* 369(1):22-30.

Tehseen, P., Desai, A. Y., Saroj, J., & Arti, J. (2019). Feeding biology and length-weight relationship of Indian squid (*Uroteuthis duvauceli*) in coastal waters of Gujarat. *Journal of Experimental Zoology India*, 22(1):609-613.

Triharyuni, S., & Puspasari, R. (2012). Production and fishing season of squids (*Loligo* spp.) in Rembang Waters (Central Java). *Jurnal Penelitian Perikanan Indonesia,* 18(2):77-83.

Wagiyo, K., Tirtadanu, & Fauzi, M. (2020). Dinamika populasi dan tingkat pemanfaatam cumi-cumi jamak (*Photololigo duvaucelii* Orbigny, 1848) di Teluk Jakarta. *Jurnal Penelitian Perikanan Indonesia,* 26(4):233-246.

Wang, D., Yao, L., Yu, J., & Chen, P. (2021). The Role of environmental factors on the fishery catch of the squid *Uroteuthis chinensis* in the Pearl River Estuary, China. *Journal of Marine Science and Engineering*, 9(1):1-15.

Wang, X., Qiu, Y., Zhang, P., & Du, F. (2017). Natural mortality estimation and rational exploitation of purpleback flying squid *Sthenoteuthis oua*laniensis in the southern South China Sea. *Chinese Journal of Oceanology and Limnology,* 35(4):902-911.

Xu, L., Wang, X., & Du, F. (2020). The complete mitochondrial genome of loliginid squid (*Uroteuthis chinensis*) from Minnan–Taiwan bank fishing ground. *Mitochondrial DNA Part B*, 5(1):428-429.

Yan, Y., Li, Y., Yang, S., Wu, G., Tao, Y., Feng, Q., & Lu, H. (2013). Biological characteristics and spatial—temporal distribution of mitre squid, *Uroteuthis chinensis*, in the Beibu Gulf, South China Sea. *Journal of Shellfish Research*, 32(3):835-844.

Zhao, C., Shen, C., Bakun, A., Yan, Y., & Kang, B. (2020). Purpleback flying squid *Sthenoteuthis oualaniensis* in the South China Sea: growth, resources and association with the environment. *Water,* 13(1):1-17.