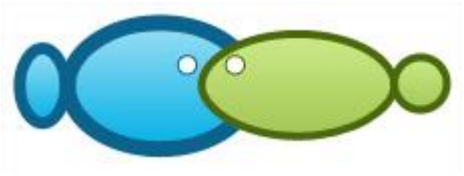


Potential decrease of *Octopus cyanea* population based on size distribution and gonad maturity stages in Kaur waters, Bengkulu, Indonesia

[1,2]Daniel J. Tarigan, [3]Domu Simbolon, [3]Am A. Taurusman, [3]Mohammad Imron, [4]Tegoeh Noegroho

[1] Study Program of Marine Fisheries Technology, Graduated Program, IPB University, Bogor, Indonesia; [2] Marine and Fisheries Education Study Program, Universitas Pendidikan Indonesia, Bandung, Indonesia; [3] Department of Fishery Resources Utilization, Faculty of Fisheries and Marine Science, IPB University, Bogor, Indonesia; [4] Research Center For Fishery, National Research and Innovation Agency, Bogor, Indonesia. Corresponding author: D. Simbolon, domu@apps.ipb.ac.id

Abstract. The big blue octopus (*Octopus cyanea*) has high economic value, making it vulnerable to overexploitation. On the other hand, this species belongs to a group of fisheries resources with a short, single-generation life cycle. As a result, octopus are highly susceptible to degradation if exploitation levels are high and catches are dominated by individuals that are not biologically mature. The implementation of open-closed fishing areas for octopus in the waters of Kaur indicates a decline or degradation of octopus stocks, highlighting the need to examine size distribution through mantle length and gonadal maturity. The objective of this study was to assess the size distribution of octopus resources in Kaur based on mantle length and gonadal maturity stages. Samples were collected using purposive sampling, with a total of 2,691 individuals measured for mantle length. For gonadal maturity analysis, 330 individuals were randomly selected. The results showed that gonadal maturity stages of male octopuses were dominated by stage II (79%), while females were dominated by stage II (58%). Mature male octopus were captured at a mantle length of 12 cm, while mature females were captured at 14 cm. Males reached gonadal maturity earlier than females, with body weights of 510 g and 730 g, respectively. To ensure the sustainability of *O. cyanea* stocks, the local government and other stakeholders need to regulate the capture of juveniles and mature octopus during spawning.
Key Words: degradation, juveniles, mature, octopus biology, regulation.

Introduction. *Octopus cyanea*, commonly known as the big blue octopus, is a high-value Indonesian fishery commodity with a wide distribution in the waters around Sulawesi, Maluku, Papua, Lombok, and Sumatra. This species is typically caught using handlines with artificial bait resembling crabs (Farikha et al 2014; Nurdiansyah et al 2015; Tarigan et al 2019; Rahmatang et al 2023). This octopus commodity is also a leading product in Indonesia, as it is generally exported to China, Japan, Korea, the United States, and Hong Kong (Listiani 2013), and has significantly increased the profits and welfare of fishers (Tarigan et al 2020).

The high interest and demand in the export market for octopus has the potential to lead to overexploitation, which in turn can reduce stock levels in the waters and decrease catch yields (Simbolon et al 2020). An indicator of declining octopus stocks can be observed from the decreasing size composition of the catch. If the trend of catching predominantly small-sized octopuses continues, it will threaten the sustainability of octopus resources. This indication underscores the urgent need for studies that provide detailed biological information on octopus to support sustainable fisheries management practices.

The practice of opening and closing octopus fishing grounds in several regions of Indonesia has shown that octopus stocks are declining. Resource degradation can result in reduced catch productivity. Such degradation can occur due to various factors,

including the use of less environmentally friendly fishing technologies, overfishing, and harvesting undersized octopus. This will impact various aspects of fisheries resources, particularly biological aspects (Simbolon 2019). This study focuses on two biological parameters: gonad maturity level and size distribution.

The gonad maturity stage can provide insight into the condition of octopus, indicating whether they fall into the juvenile or adult category. Understanding the gonad maturity level provides information on whether an individual is suitable for harvest or should not be caught. The condition of the gonad maturity level also reflects the potential occurrence of octopus resource degradation. One indication of octopus resource degradation is the presence of recruitment overfishing and growth overfishing (Simbolon 2019). Recruitment overfishing refers to excessive harvesting of octopus, which reduces overall catch yields, while growth overfishing means that many small-sized octopuses are caught, leading to a decline in the octopus population.

Degradation of octopus resources is indicated by a marked decline in the biological condition of the species, accompanied by a reduction in the size of individuals caught and a decrease in overall catch yields. Mantle length and body weight are critical parameters for determining harvestable size and growth rates. This study integrates both aspects - mantle length and body weight - in order to provide a more precise basis for the biological management of octopus fisheries. Despite this, information on the biological condition of octopus in Kaur remains limited. Such a lack of biological data poses a risk to the sustainability of the resource. Effective management of octopus resources therefore requires accurate biological assessments, supported by strict monitoring to ensure the continuity of reproduction. These considerations also form the foundation for establishing regulatory frameworks, including seasonal closures and openings of the fishery. Accordingly, an investigation into the size distribution of *O. cyanea*, based on mantle length, body weight, and gonad maturity stages in the waters of Kaur, is essential. The findings will provide important guidance for developing management measures relating to minimum size limits and seasonal fishing closures.

Material and Method

Study area and time research. The octopus sampling was conducted in Linau village, Kaur Regency, Bengkulu Province, from July to December 2024. The research location is shown in Figure 1.

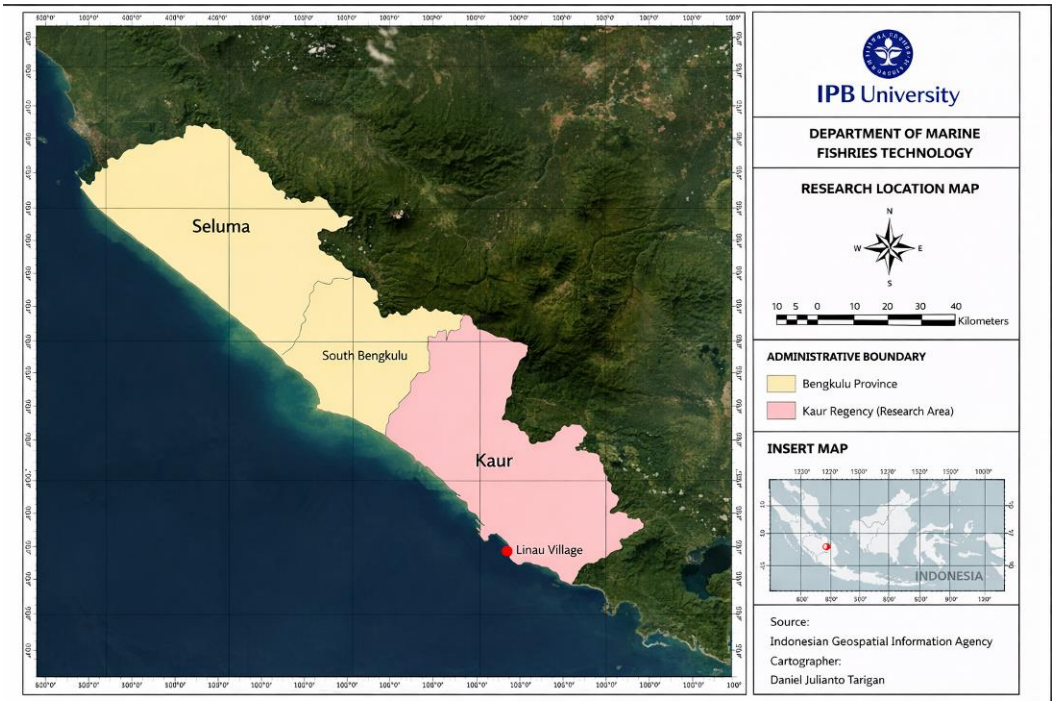


Figure 1. Research locations in Kaur waters.

Data collection. Octopus fishery samples were determined using purposive sampling based on the following considerations: (1) the octopuses landed were caught in the waters around Kaur, (2) the fishing fleet used octopus handlines as the fishing gear, and (3) weekly catch data of octopus were available for six months. Biological sampling included 2,691 individuals for measuring mantle length and body weight, while 330 samples were taken to assess gonadal maturity. Octopus samples for gonadal maturity were collected using a random sampling method. Samples for gonadal maturity assessment were collected from octopus landed catches in the study area. Mantle length was measured following the FAO (2016) criteria, as illustrated in Figure 2. Mantle length was defined as the dorsal mantle length, measured as the straight line distance from the posterior tip of the mantle to the midpoint between the eyes at the anterior margin of the mantle.

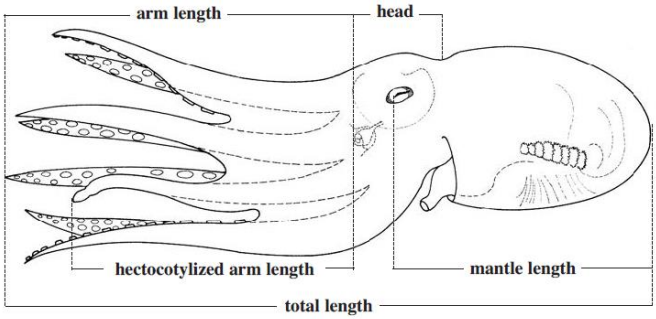


Figure 2. The measurement of mantle length.

Data analysis. Mantle length and body weight of octopus were statistically analyzed using Microsoft Excel software to examine size structure and weight distribution of the catch. The results of the mantle length and body weight analyses were presented descriptively. The length at first gonadal maturity (Lm) was determined based on the distribution of mantle length and gonadal maturity stages (GMS). The Lm value was defined as the mantle length at which 50% or more of individuals had reached gonadal maturity (GMS III). Furthermore, the results of this study were compared with references from previous studies by Mulyani et al (2025) and Noegroho et al (2025). The Lm value represents the mantle length of octopus considered suitable for capture and can be used as an indicator to assess whether the target octopus are biologically appropriate in size.

The GMS of octopus refers to the classification of gonad development stages based on changes occurring in the gonads. The observation of gonad maturity levels follows Mangold (1983), and Guard & Mgaya (2002), as presented in Table 1. The categories are differentiated by sex. Male octopus are classified into three categories: immature, pre-mature, and mature. Female octopus are classified into five categories, ranging from immature to post laying stages.

Table 1

Gonad maturity stage for male and female *O. cyanea*

Maturity stage	*Identification*	
	Gonad mass	*Gonad appearance*
Male		
I. Immature	< 2 g	< 8 spermatophores in Needhams complex
II. Pre-maturation	2-5 g	Spermatophores are disordered and number 8-208
III. Mature	> 5-47 g	Spermatophores arranged in parallel and number 18-687
Female		
I. Immature	< 3 g	Ovary white
II. Incipient maturity	3-7 g	Ovary white/pale yellow
III. Mature	8-80 g	Ovary pale yellow/yellow
IV. Fully mature	> 80 g	Ovary yellow/dark yellow
V. Post laying	4-16 g	Distended empty ovary

Results and Discussion. The mantle length of octopuses caught in the study area showed considerable variation, reflecting differences in size and growth stages among individuals (Figure 3). The mantle length of male octopuses ranged from 3 to 20 cm, with an average size of 11 cm. The dominant mantle length class of male octopuses caught was 14.9-16.5 cm, with a total of 230 individuals or 24.7%. This was followed by mantle lengths of 13.2-14.8 cm with 151 individuals (16.2%), 9.8-11.4 cm with 143 individuals (15.4%), 8.1-9.7 cm with 143 individuals (15.4%), 11.5-13.1 with 78 individuals (8.4%), 16.6-18.2 cm with 74 individuals (8%), 6.4-8 cm with 46 individuals (4.9%), 4.7-6.3 cm with 41 individuals (4.4%), 18.3-19.9 cm with 21 individuals (2.3%), 20.1-21.6 cm with 1 individual (0.1%). The smallest mantle lengths were 3-4.6 cm with 1 individual (0.1%) and the largest was 20 cm with 1 individual (0.1%).

The mantle length of female octopuses caught during the study ranged from 3 to 23.3 cm, with an average of 9.8 cm. The size distribution of female mantle length was dominated by the 9.8-11.4 cm class with 498 individuals (28%), followed by the 8.1-9.7 cm class with 453 individuals (26%), the 6.4-8 cm class with 322 individuals (18%), the 11.5-13.1 cm class with 253 individuals (14%), 13.2-14.8 cm with 86 individuals (5%), 4.7-6.3 cm with 86 individuals (5%), 14.9-16.5 cm with 35 individuals (2%), 16.6-18.2 cm with 11 individuals (1%), 18.3-19.9 cm with 7 individuals (0.4%), 20-21.6 cm with 2 individuals (0.1%). The smallest size class (3-4.6 cm) was represented by only 5 individuals (0.3%), while the largest size class (21.7-23.3 cm) was represented by 3 individuals (0.2%).

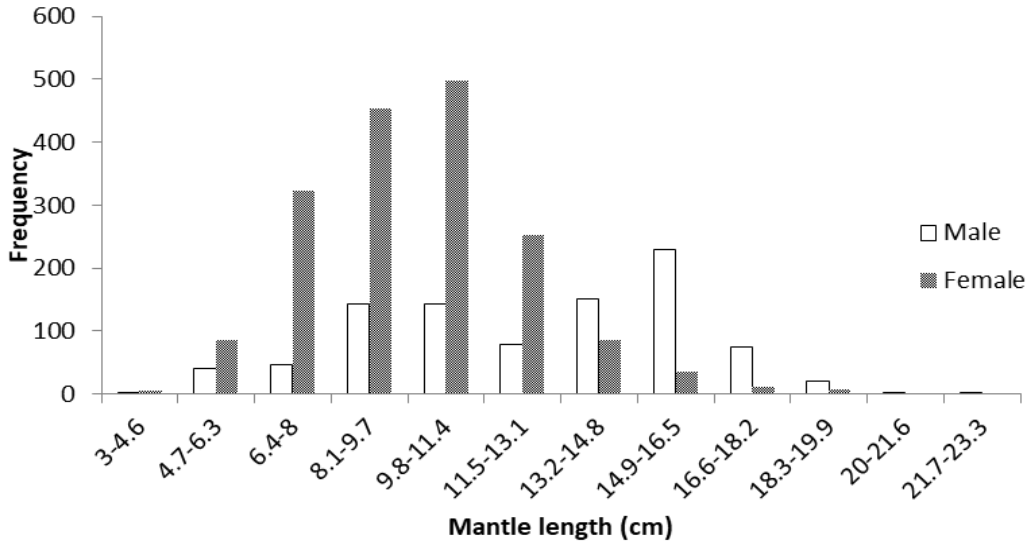


Figure 3. Mantle length of captured octopus.

These results indicate that female octopuses tend to have a larger mantle length compared to males. This condition is consistent with previous studies which reported that female *O. cyanea* generally grow to larger sizes than males (Guard & Mgaya 2002; Herwig et al 2012; Omar et al 2020). This finding is also in line with Leporati et al (2009), who explained that growth patterns in cephalopods often show a tendency for females to reach larger body sizes due to reproductive strategies that require greater energy reserves for gonad development.

The results of the study showed that the mantle length of male octopuses was largely distributed within the range of 6.4-8 cm to 14.9-16.5 cm, while female octopus were mostly distributed within the range of 6.4-8 cm to 13.2-14.8 cm. Thus, the mantle length distribution of both male and female octopus generally fell within the range of 6-16.5 cm. This size range is relatively small compared to the potential maximum size of *O. cyanea,* which can exceed 20 cm in mantle length (Guard & Mgaya 2002). This condition indicates the limited availability of large-sized octopus in the study area.

The decline in the proportion of large-sized individuals can be presumed to result from continuous fishing pressure, which has led to the degradation of fishing grounds.

This is consistent with findings from other octopus fisheries in the Indo-Pacific, where overexploitation has caused a reduction in the average catch size and a decrease in reproductive biomass (Oliver et al 2015). Based on interviews with fishers, current octopus catches are declining, and fishers must travel farther to obtain their catch. This finding aligns with the study of Guard & Mgaya (2002), which noted that increasing fishing distances is one indicator of stock depletion.

On the other hand, management efforts through an open-closed fishing area system for octopus have been implemented. However, based on field observations, the application of this system is still not optimal, as some fishers are still found fishing in areas that should be closed. This situation is consistent with the findings of Benbow et al (2014) in Madagascar, where the effectiveness of open-closed systems was highly dependent on the level of fisher compliance and local monitoring. Therefore, the open-closed strategy needs to be strengthened by increasing fisher awareness and implementing community-based monitoring in order to ensure the long-term sustainability of octopus stocks.

Total of 2.691 octopus were caught during the study. The number of male octopuses was 930 individuals, while the number of female octopuses was 1.761 individuals (Figure 4). The number of male octopus caught was lower than that of females. The body weight of male octopus caught during the study ranged from 102 to 2.530 grams. Thus, the smallest recorded weight was 102 grams, and the largest was 2.530 grams. The male octopus catch was dominated by the weight class of 998-1.221 grams with 230 individuals, followed by 326-549 grams with 189 individuals, and 550-773 grams with 139 individuals. The average body weight of male octopus caught in Kaur waters during the study was 823.6 grams.

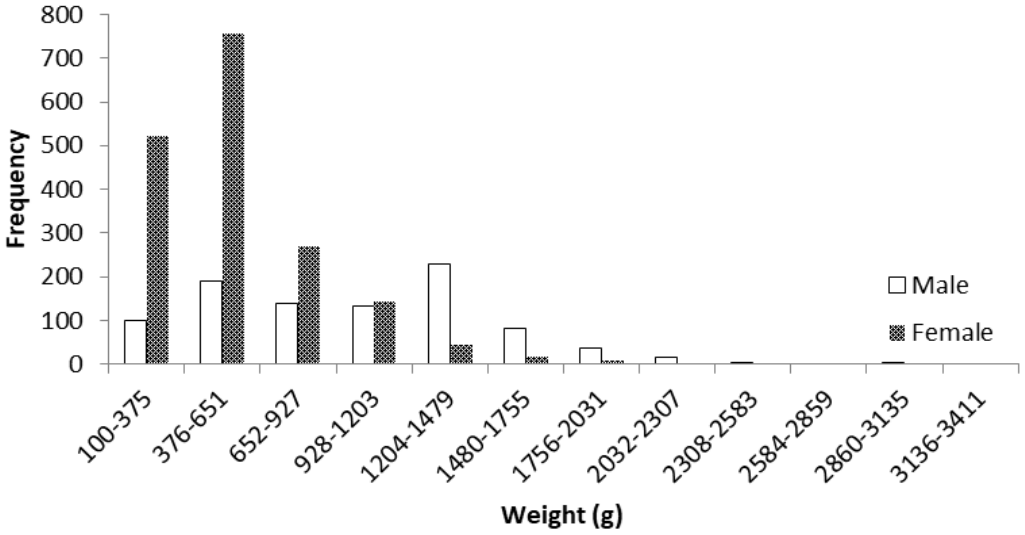


Figure 4. Weight of captured octopus.

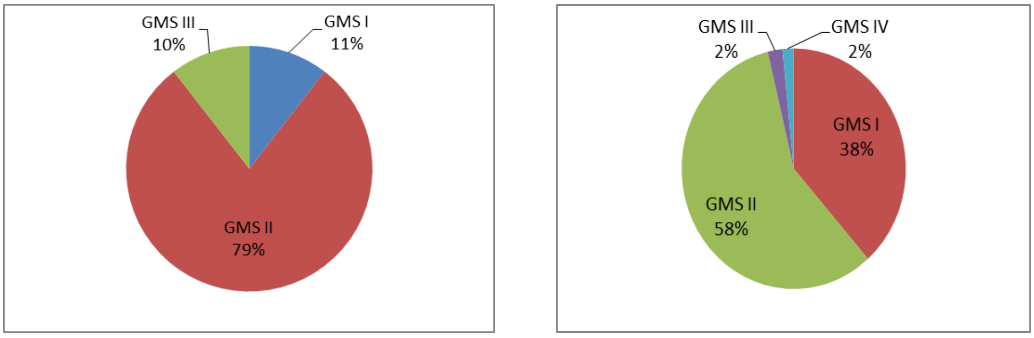
The body weight of female octopus caught during the study ranged from 100 to 3.350 grams. The largest female octopus weighed 3.350 grams, while the smallest weighed 100 grams. The study showed that the dominant catch consisted of individuals weighing 376-651 grams, totaling 756 octopus, followed by the 100-375 gram class with 521 individuals. The average body weight of female octopus caught in Kaur waters was 567 grams. The results indicate that female octopus generally have a higher body weight than males. The catch during the study was dominated by smaller-sized octopuses, which warrants serious attention. Continuous harvesting of small-sized octopuses will lead to the degradation of octopus resources, making it increasingly difficult and requiring longer distances to catch octopus in the future.

Octopus fishers in Kaur waters typically catch octopus in the late afternoon along the coastal areas, which serve as octopus habitats. On the other hand, children and women are involved in exploiting the octopus catch along the shore, where juvenile

octopus reside, but large-sized octopus are rarely found. This is likely because adult octopus are spawning in deeper habitats, particularly in coral reef areas, making them difficult to locate (Guard & Mgaya 2002; Benbow et al 2014). This practice occurs because fishers seldom venture to more distant fishing grounds, and fishing is limited by the availability of fishing vessels. As they constitute the majority of octopus fishers, their practices can lead to overexploitation of nearshore areas (Cosgrove 1987; Tanzania Fisheries Research Institute 2021). Ultimately, octopuses have insufficient time to reach larger sizes, resulting in smaller individuals predominating in nearshore coral reef habitats, whereas larger individuals are more prevalent in less frequently exploited reef areas (Silas et al 2021).

Although numerous studies on octopus body weight have been conducted in Indonesia, regulations regarding minimum catch size for sale or export have not yet been established, highlighting the need for policy development. This is particularly important as octopus is currently a highly valued commodity in Indonesia. For example, in Venezuela, the minimum allowable catch size for octopuses is 400 g (GO 2008). Without immediate and proper management and utilization, the sustainability of octopus resources may be seriously threatened in the future.

The gonadal maturity stages of male and female *O. cyanea* are shown in Figure 5. Among *O. cyanea* male, 11% were in maturity stage I (GMS I), 79% in stage II (GMS II), and 10% in stage III (GMS III). The results indicate that male octopus in study area were predominantly in GMS II. According to Guard & Mgaya (2002), GMS II is still considered a pre-mature stage, suggesting that male octopus in Kaur are still very early for harvesting. This stage is estimated to require more time to allow male octopus to develop fully and reach GMS III, which is the adult stage.



Male Female

Figure 5. Gonadal maturity stages of octopus in Kaur waters.

The gonadal maturity stages of female octopus were 38% in stage I (GMS I), 58% in stage II (GMS II), 2% in stage III (GMS III), and 2% in stage IV (GMS IV). The results show that female octopus in the waters around Kaur were mostly in GMS II (58%), followed by GMS I (38%). Gonadal maturity stages I and II are considered immature or newly developing, indicating that the gonads of female octopus in Kaur are predominantly not yet mature. Combined, GMS I and GMS II account for 96% of the population. This situation is highly concerning for the future, even though 4% of females were found to be fully mature and spawning. The study indicates that this reflects degradation of octopus resources based on gonadal maturity. Although mature female octopuses can produce 150,000 to 700,000 eggs, and *O. cyanea* is reported to spawn year-round (Guard & Mgaya 2002), the current condition is alarming for the sustainability of octopus resources in Kaur waters. Awareness of gonadal maturity stages needs to be disseminated to local fishers. Immature gonads are usually small and whitish, while mature gonads are larger and show a color change toward yellowish or brownish tones associated with the development of eggs or sperm (Raberinary & Benbow 2012). Additionally, regulations on the size of octopus that can be harvested need to be established to ensure the conservation of octopus resources.

O. cyanea have a single reproductive cycle and die after laying or hatching eggs (Guard & Mgaya 2002), which necessitates careful management. The vulnerability of this

species to fishing pressure, especially on adults, must be taken seriously. Protecting female octopus before they lay eggs allows them time to reproduce, which is crucial for maintaining the sustainability of octopus resources. Since female octopus do not reproduce again after spawning, their removal reduces the population available for subsequent regeneration.

Raberinary & Benbow (2012) reported that female octopus reach gonadal maturity at a body weight of 2,246 g and males at 643 g, whereas a study in Tanzania found lower gonadal maturity weights, with females at 600 g and males at 320 g. In Kaur waters, female octopus reached gonadal maturity at around 730 g and males at around 510 g. The Kaur study shows higher weights compared to octopus in Tanzania but lower than those reported in Madagascar. Differences in gonadal maturity information are influenced by geographic location, sample size, and the timing of the study. Furthermore, the rate of gonadal maturation is affected by environmental factors such as water temperature and food availability (Humber et al 2006; Herwig et al 2012). The study also indicates that male *O. cyanea* tend to reach sexual maturity at a younger age and smaller size compared to females. Differences in timing and size at maturity have implications for population dynamics and fishing pressure (Adibrata et al 2018).

Observations of gonad development in *O. cyanea* showed differences in maturity stages between males and females (Table 2). Male octopus reached gonadal maturity at relatively smaller mantle lengths, ranging from 9 to 20 cm with an average of 12 cm, body weights ranging from 510 to 2.530 g with an average of 931 g, and an average gonad weight of 11.6 g at stage III. In contrast, female octopus reached gonadal stage III (mature) at mantle lengths of 12-17 cm with an average of 14 cm, body weights ranging from 730 to 1.340 g with an average of 950 g, and an average gonad weight of 11.3 g. Gonad development progressed more gradually in females, with a significant increase at stage IV (fully mature), when mantle lengths reached 19-23 cm with an average of 20.3 cm and an average gonad weight of 119 g. The sharp increase in gonad biomass at this stage reflects the biological strategy of females to allocate a large amount of energy to egg production, consistent with the semelparous characteristic of octopus, which reproduce only once before dying (Guard & Mgaya 2002). The absence of data for stage V (post-laying) aligns with this biological phenomenon, as females generally die after spawning and guarding their eggs until hatching is complete.

Table 2

Stages of maturity in the categories of mantle length, weight and gonad weight

Maturity stage		*Mantle length (cm)*		*Gonad weight (g)*		*Weight (g)*	
		Range	*Average*	*Range*	*Average*	*Range*	*Average*
	Male						
I	Immature	4.6-5	4.8	1.1-1.8	1.5	110-180	152
II	Pre-maturation	5-9	7.6	2-5.2	3.3	200-500	338.5
III	Mature	9-20	12	5.1-35	11.6	510-2530	931
	Female						
I	Immature	4.5-7.5	6.6	1-2.7	2	100-270	204.7
II	Incipient maturity	8-11.5	9.1	3-6.7	4.2	300-670	425.4
III	Mature	12-17	14	7.5-20.4	11.3	730-1340	950
IV	Fully mature	19-23	20.3	93-159	119	1900-3350	2450
V	Post laying	-	-	-	-	-	-

The Lm values of *O. cyanea* obtained from this study were 11 cm for males and 14 cm for females, with corresponding body weights of 510 g and 730 g. These findings differ from those for female *O. cyanea* in Alas Strait, West Nusa Tenggara, where the mantle length at first gonadal maturity was reported to be around 11.8 cm for males and 11.65 cm for females, with body weights of 995.26 g and 1,514.4 g, respectively (Mulyani et al 2025). In the Uno-Una waters, the mantle length at first gonadal maturity was approximately 10-11 cm for males and 11-12 cm for females, with body weights of 605 g

and 1,086 g, respectively (Noegroho et al 2025). The differences in mantle length at first gonadal maturity between studies in Bengkulu, Alas Strait, and Uno-Una indicate spatial variation likely influenced by environmental factors and fishing pressure. Furthermore, Raberinary & Benbow (2012) in Madagascar reported that the relationship between body weight and gonad weight progresses faster in males than in females. This indicates that males tend to reach reproductive maturity more quickly, while females require greater energy allocation to support substantial gonad development in the final maturity stage.

Conclusions. This study provides an overview of the condition of *Octopus cyanea* resources based on gonadal maturity stages, mantle length distribution, and body weight in the waters around Kaur, Bengkulu. Male *Octopus cyanea* were dominated by maturity stage II at 79%, while females were dominated by maturity stage II at 58%. Gonadal maturity in males (510 g) occurred earlier than in females (730 g). The length at first gonadal maturity (Lm) for males was recorded at 11 cm, while for females it was 14 cm. Male octopus reached gonadal maturity earlier than females. The local government and other stakeholders need to regulate the capture of *Octopus cyanea* by avoiding the harvest of juveniles and mature individuals during spawning in order to prevent overfishing of this fishery resource.

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

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Authors:
Daniel Julianto Tarigan, Study Program of Marine Fisheries Technology, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Agatis Street, No. 1, 16680 Dramaga District, Bogor, West Java, Indonesia; Marine and Fisheries Education Study Program, Universitas Pendidikan Indonesia, Dr. Setiabudhi Street, No. 229, 40154 Bandung, West Java, Indonesia, e-mail: danieljulianto@upi.edu
Domu Simbolon, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Agatis Street, No. 1, 16680 Dramaga District, Bogor, West Java, Indonesia, e-mail: domu@apps.ipb.ac.id
Am Azbas Taurusman, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Agatis Street, No. 1, 16680 Dramaga District, Bogor, West Java, Indonesia, e-mail: azbas@apps.ipb.ac.id
Mohammad Imron, Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Agatis Street, No. 1, 16680 Dramaga District, Bogor, West Java, Indonesia, e-mail: mohammadim@apps.ipb.ac.id
Tegoeh Noegroho, Research Center for Fishery, National Research and Innovation Agency, Raya Jakarta-Bogor Street No. 32, 16915, Cibinong District, Bogor, West Java, Indonesia, e-mail: tego001@brin.go.id.

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