Original Article

Reproductive characteristics of the big blue octopus, *Octopus cyanea* (Gray 1849) in Zanzibar coastal waters, Tanzania

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Abstract

The big blue octopus, *Octopus cyanea* (Gray 1849) is heavily fished in Zanzibar coastal waters, yet several aspects of its biology remain unstudied in the area. The reproductive biology of *O. cyanea* (Gray 1849) was investigated, including sex ratios, length-weight relationships, size at maturity, and seasonal variation in maturity and spawning activity. Sampling of specimens caught by local fishers was conducted monthly at four sites. Octopus size and weight were measured and the sex determined, whereafter their gonads were extracted and staged. Female octopuses dominated the sex ratio across most size classes and seasons. Males reached sexual maturity at a smaller size than females and mature individuals of both sexes were present throughout the year, suggesting continuous spawning activity. Based on the gonadosomatic index (GSI), peak spawning periods were in June and October. The new insights into the reproductive dynamics of *O. cyanea* are important for fisheries management efforts and effective conservation of the species.

Keywords: *Octopus cyanea*, sex ratio, size at maturity, spawning

Introduction

Currently, the global octopus species count is over 200, although only 30 species are commonly subjected to fishing for commercial, subsistence, or recreational purposes (Sauer *et al.*, 2011; Herwig *et al.*, 2012; Rocliffe and Harris, 2016). In the Western Indian Ocean (WIO) region, the predominant species harvested is the big blue octopus *(Octopus cyanea,* Gray 1849) (Rocliffe and Harris, 2016). The big blue octopus exhibits a cosmopolitan distribution, inhabiting mainly the shallow reefs in tropical and subtropical oceans (Herwig *et al.*, 2012; Borges *et al.*, 2022). It shares features such as rapid growth rates, short life spans, and opportunistic feeding behaviour with other cephalopods (Guard and Mgaya, 2002; Doubleday *et al.*, 2016).

All octopuses exhibit sexual dimorphism, and it is essential to take the male-to-female sex ratio into account when assessing their population dynamics (Engen *et al.*, 2003). In *O. cyanea,* the sex ratio varies with area, with some studies documenting male dominance (Guard and Mgaya, 2002; Nair *et al.*, 2018), while others report female dominance (Herwig *et al.*, 2012). These discrepancies show the complexity of the octopus population and suggest that there are various environmental and biological factors controlling the sex ratio. In general, the sex ratio in octopuses is not static, with periodic fluctuations with time and location (Nair *et al.*, 2018). Factors such as breeding cycles, environmental conditions, and food availability contribute to these changes (Guard and Mgaya, 2002;

Sauer *et al*., 2021). Given this variability, this study set out to investigate how monthly and seasonal patterns affect the sex ratio of *O. cyanea* in Zanzibar.

The size at first maturity is a critical biological aspect that defines the size at which half of the population (50 %) is sexually mature (Mawa *et al*., 2021). For *O. cyanea,* the size varies across different geographical areas, seasons and sexes (Guard and Mgaya, 2002; Raberinary and Benbow, 2012). Currently, the size at maturity of *O. cyanea* remains unknown in Zanzibar, which presents a significant gap in knowledge of the species. Since Zanzibar experiences two monsoon seasons: the southeast monsoon (SEM) and the northeast monsoon (NEM), it is important to investigate how these seasonal changes may influence the onset of maturity in this species. Identifying specific seasons during which *O. cyanea* reaches larger body sizes and becomes sexually mature is important since this has a direct relationship with spawning and the overall life cycle, thereby aiding in the effective management of this species.

The big blue octopus exhibits year-round spawning activity, although the timing of its spawning peak varies geographically (Guard and Mgaya, 2002). This continuous spawning cycle facilitates the species' existence in fulfilling its ecological functions within marine ecosystems and supporting livelihood activities in coastal communities (Armendáriz-Villegas *et al.*, 2014).

Currently, research on the reproductive biology of *O. cyanea* in Zanzibar is lacking despite its valuable contribution to the coastal communities. Therefore, this study addresses this gap by investigating the sex ratio dynamics, length-weight relationship, size at maturity, seasonal variation in maturity stages, and timing of spawning events of this species. These findings are crucial for enhancing understanding and developing effective management plans to sustain and conserve the population of *O. cyanea* in Zanzibar, Tanzania, and the greater WIO region.

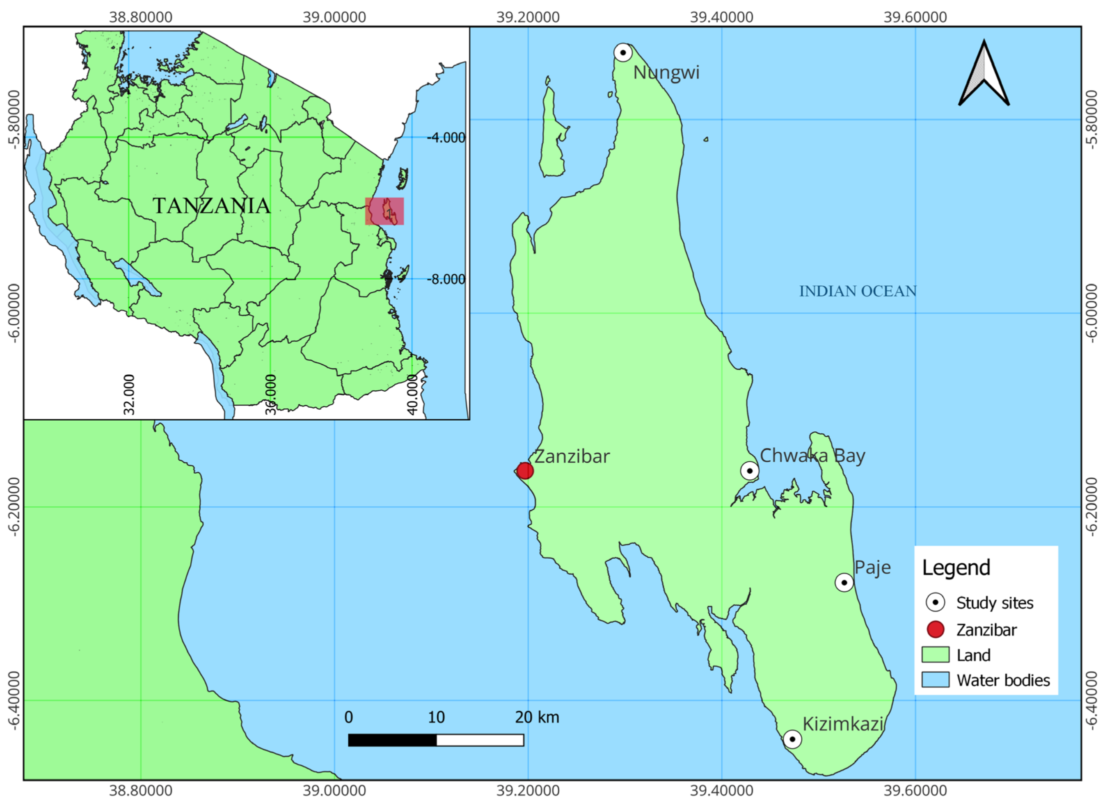

Figure 1. Map of Unguja Island (Zanzibar) showing the four study sites.

Materials and methods

Description of the study area

This study was conducted in Unguja, one of the two sister islands forming the Zanzibar archipelago (Fig. 1). The study covered four important fishing sites of the island where octopus are extensively harvested:

Kizimkazi and Paje (Southern district); Nungwi (Northern district); and Chwaka Bay (Central district). In close collaboration with octopus fishers, all octopuses landed at these sites were recorded.

Biological sampling

The samples of *O. cyanea* were collected monthly over two days of the spring tides in close collaboration with fishers at each site. All octopuses harvested during sampling days were used in this study. Some samples were purchased directly from fishers and taken to the laboratory for analysis, where their DML, sex and gonad maturity stages were determined. For the samples that were not purchased, gonads were extracted at the landing sites, placed in ethanol in separate sample bottles along with their information on DML, TW and sex, then put in a cool box for transport to the laboratory for analysis of the maturity stages. DML was measured with a measuring tape to the nearest 0.5 cm, while TW was measured using an electronic digital balance to the nearest 0.5 g. The sex of each octopus was determined by observing the presence of spermatophoric grooves (a whitish-grey line on the ventral surface) on the third right arm of males, which are absent in females (Herwig *et al.*, 2012).

Determination of maturity stages

The gonadal development of male octopuses was classified into three (3) maturity stages: stage I (immature); stages II (maturing); and stage III (mature), while females were classified into five (5) maturity stages: stage I (immature); stage II (maturing); stage III (mature); stage IV (spawning); and stage V (spent). This classification was used as per Guard and Mgaya (2002) with minimal modification. In males at stage III, spermatids and spermatozoa are abundant, and there are no empty spaces between cells. Females at stage IV show a significant increase in oocyte size, deeper infoldings of the follicular epithelium, and increased yolk production. At stage V, female oocytes have been discharged. All octopuses at stages III, IV, and V were classified as mature, and those with maturity stages I and II were categorized as immature.

Determination of the sex ratio

This study estimated the sex ratio on both a monthly and seasonal bases. This methodology provides a comprehensive understanding of the trends and patterns in the sex ratio of this species throughout both monthly and seasonal periods. The monthly sex ratios were calculated based on all octopuses collected each month over 12 months. Meanwhile, the seasonal sex ratios were determined for the southeast monsoon (SEM) and northeast monsoon (NEM) periods. However, the sex ratio estimation by season was conducted based on two groups of octopuses: immature and mature individuals of both sexes. In each case, any deviation from the expected 1:1 ratio (M: F) was compared using the Chi-square (χ^2).

Determination of length-weight relationship

In this study length-weight (L/W) relationship was determined based on the dorsal mantle length (DML) of octopuses against their total weight (TW). The length-weight relationship was then modeled using a power curve expression $W = aL^b$ following the method outlined by Guard and Mgaya (2002). In this equation, 'W' represents total body weight (g), 'L' is dorsal mantle length (cm), '*a*' is the intercept, and '*b*' is the regression slope. The calculated coefficient value of *b* was evaluated according to the general assumption that when $b = 3$, the octopus undergoes isometric growth, but when $b > 3$, growth is positive allometric, while if $b < 3$, the growth of the octopus is negative allometric.

Estimation of size (length and weight) at maturity

This study used both lengths and weights to estimate the size at maturity of *O. cyanea*. The length at maturity was calculated using DML while the weight at maturity was assessed by using TW. Both $DML_{50\%}$ (length at which 50 % of individuals are mature) and $TW_{50\%}$ (weight at which individuals mature) were determined for males and females to assess sexual differences. To estimate size at maturity, DML and TW were fitted to a logistic regression curve by using the Bayesian approach logistic model (Sileesh *et al.*, 2020):

$$P(x) = \left(\frac{e\,(b0 + b1x}{1 + e\,b0 + b1x} \right) 100$$

Where: P(x) is the probability that an octopus of a given length x is mature, b0 and b1 are parameters for determining the shape and location of the sigmoid curve.

From the above, the proportion corresponding to $TL_{50\%}$, $DML_{50\%}$, and $TW_{50\%}$ of the model was computed by:

$$X = \left(In \ \frac{p}{1 - p} \right) - b0$$

A paired sample t-test was used to compare the size at maturity between the sexes.

Determination of the timing of spawning

The spawning time of *O. cyanea* was calculated using the gonadosomatic index (GSI). The monthly calculation of GSI was done for both male and female individuals. GSI was calculated as:

$$GSI = \left(\frac{W_o}{TW - W_o}\right) 100$$

Where 'Wo' is the weight of the ovary and 'TW' is the total wet weight of the octopus (Guard and Mgaya, 2002). The comparison in GSI between male and female octopuses across months was done by using one-way ANOVA and considered significant at $p < 0.05$

Statistical analysis

A Chi-square (χ^2) test was used to determine whether there were significant variations in the proportion of male to female sex ratios. The paired sample t-test was used to compare male and female size at maturity. The one-way analysis of variance (ANOVA) was employed to compare monthly changes in GSI between sexes. All comparisons were considered significant at $p < 0.05$.

Results

Sex ratio

The total number of females was significantly higher than the males (t - value = 3.67, $df.$ = 22, p = 0.001). The overall M: F sex ratio was 0.69:1 and the Chi-square test showed a significant difference from the expected ratio of 1:1 (χ^2 = 34.2, $df.$ = 22, $p < 0.0001$). The female *O. cyanea* dominated the population in all months except in May, where the sex ratio of 1.11:1, indicates that males are similar to females (Table 1). On a seasonal basis, the number of immature females was significantly higher than immature males in both SEM (χ^2 = 2.11, p < 0.0001) and NEM (χ^2 = 17.5, p < 0.0001). The number of mature females were significantly higher than males only during SEM (χ^2 =10.93, p = 0.0009) but not during NEM (χ^2 = 1.73, p = 0.18) (Table 2).

Length-weight relationships

Based on the DML, the L/W relationship of *O. cyanea* was described by the equation: W = 1.6286 $DML^{2.4177}$, R^2 = 0.87 for males and W = 0.9346 $DML^{2.5951}$, R^2 = 0.83 for females. The relative value of constant b was less than 3 (b < 3) in both sexes (Fig. 2).

Size at first maturity

The smallest mature individuals recorded in this study were 7.4 cm DML and 360 g TW for males, and 8.1 cm DML and 610 g TW for females. Both $DML_{50\%}$, and $TW_{50\%}$ significantly varied ($DML_{50\%}$, t = 16.29, p = 0.01; $TW_{50\%}$, t = 54.96, p = 0.005) between the sexes. Seasonally, as shown in Table 3, during the SEM season the $DML_{50\%}$ was 9.03 cm for the males and 10.5 cm for the females while the $TW_{50\%}$ was 641.9 g for males and 1019.6 g for females. But during the NEM season, the $DML_{50\%}$ was 8.9 cm for males and 10.2 cm for females, whereas the $TW_{50\%}$ was 638.4 g for males and 1006.6 g for females. These results show that males mature at substantially smaller body sizes and hence are lighter than females in all seasons. However, all *O. cyanea* mature at slightly larger body sizes and are thus heavier during SEM than NEM.

Monthly variation in maturity stages

The stages of maturity of *O. cyanea* were found to fluctuate during the year. Despite such quantitative

Table 1. Annual sex ratio of *O. cyanea* from June to May. Statistically significant difference deviating from 1:1 is indicated by * while no significant differnce is abbreviated by 'ns' through the Chi-square (χ^2) test. ♂ represents male and ♀ represents female octopuses. The value in parentheses represents the percentage of males and females in a particular month.

Months	Males (%)	Females (%)	Sex ratio (♂:♀)	χ^2 (Sig.)
June	362 (43.92)	462 (56.07)	0.78:1	*
July	818 (36.52)	1422 (63.48)	0.58:1	*
August	816 (41.46)	1152 (58.54)	0.71:1	*
September	954 (48.48)	1014 (51.52)	0.94:1	ns
October	290 (35.45)	528 (64.55)	0.55:1	*
November	570 (36.54)	990 (63.46)	0.58:1	*
December	1196 (49.50)	1202 (50.50)	0.99:1	ns
January	1404 (49.61)	1670 (50.39)	0.84:1	ns
February	1098 (49.02)	1142 (50.98)	0.96:1	ns
March	840 (45.60)	1002 (54.40)	0.84:1	ns
April	422 (40.42)	622 (59.58)	0.68:1	*
May	484 (52.5)	438 (47.5)	1.1:1	*
Total	**8444 (40.97)**	**12,202 (59.03)**	**0.69:1**	*

Table 2. Sex ratio of male and female *O. cyanea* by seasons. SEM = means southeast monsoon and NEM = northeast monsoon. Individuals are separated as mature and immature individuals of both sexes per season. * indicates a significant difference while 'ns' shows no significant difference.

	Immature				Mature			
	♂	♀	Sex ratio	χ^2 (Sig)	♂	♀	Sex ratio	χ^2 (Sig)
SEM	2321	4013	0.58:1	*	1603	2011	0.79:1	*
NEM	2937	4565	0.64:1	*	1580	1616	0.98:1	ns

fluctuations, all maturity stages appeared in all months in both sexes except that stage V females did not appear in December and February (Fig. 3). Immature individuals dominated the catch of both male and female octopuses. The proportion of mature individuals peaked in June and October, corresponding to the spawning periods of this octopus species as indicated by GSI in Figure 4. In general, there was a minimal proportion of individuals that were ready to spawn or were spent.

Spawning time

Analysis of the gonadosomatic index indicated a significant difference between male and female individuals (ANOVA, $F_{(22)} = 5.72$, $p = 0.02$). The actual value of GSI showed a pattern of spawning fluctuation in male and female *O. cyanea*. Although mature individuals occur throughout the year, their proportion varies between the months and seasons. *O. cyanea* showed two peaks in spawning periods in both sexes (June and October) based on the GSI values. These peaks were followed by a decline in the subsequent months, in which the June peak season was followed by a sharp decline in August and September while in October the peak season was followed by a rapid decline from November to March (Fig. 4). The females showed an increased value of GSI from April to May while males showed the opposite trend.

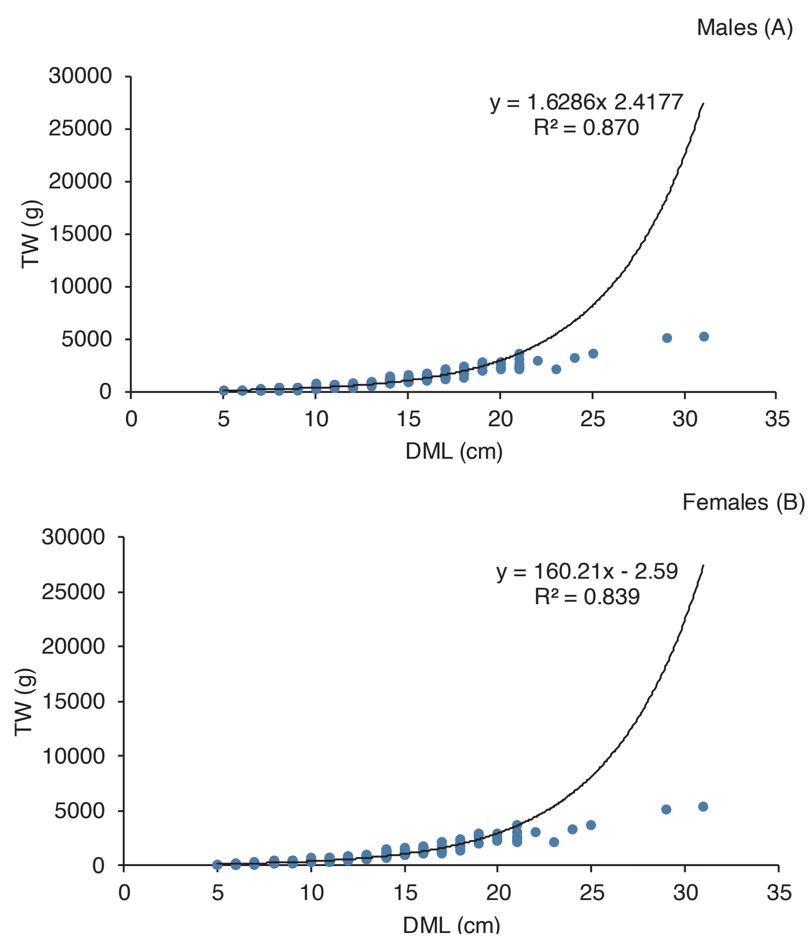

Figure 2. Length-weight relationship of male (A) and female (B) *O. cyanea* caught in Zanzibar coastal waters.

Table 3. Size at maturity in *O. cyanea* population. Each season (southeast monsoon, SEM and northeast monsoon, NEM) the size at maturity was determined based on total length (TL), dorsal mantle length (DML), and total weight (TW).

	SEM		NEM		PULLED	
Size at maturity	**DML (cm)**	**TW (g)**	**DML (cm)**	**TW (g)**	**DML (cm)**	**TW (g)**
Male	9.0	641.9	8.9	638.4	8.9	640.2
Female	10.5	1019.6	10.2	1006.6	10.4	1013.1

Discussion

Cephalopod resource management has received much attention over the past few decades, boosted by global market expansion (Ospina-Alvarez *et al*., 2022). Effective biological resource management relies on understanding the key life history data such as growth patterns, mortality rates and reproductive behaviours to enable informed decision-making crucial for sustainable conservation (Herwig *et al*., 2012; González-Gómez *et al*., 2020). In particular, the timing of reproductive activities has been important in implementing management strategies like seasonal closure, which is the most prevalent management technique for artisanal fisheries in the majority of WIO states (Humber *et al*., 2006; Rocliffe and Harris, 2016; Silas *et al*., 2022). This paper focuses on the aspects of reproductive biology - specifically the sex ratio, spawning cycle, size at maturity and length-weight relationship of *O. cyanea* - as a foundation for addressing management challenges in Zanzibar, Tanzania.

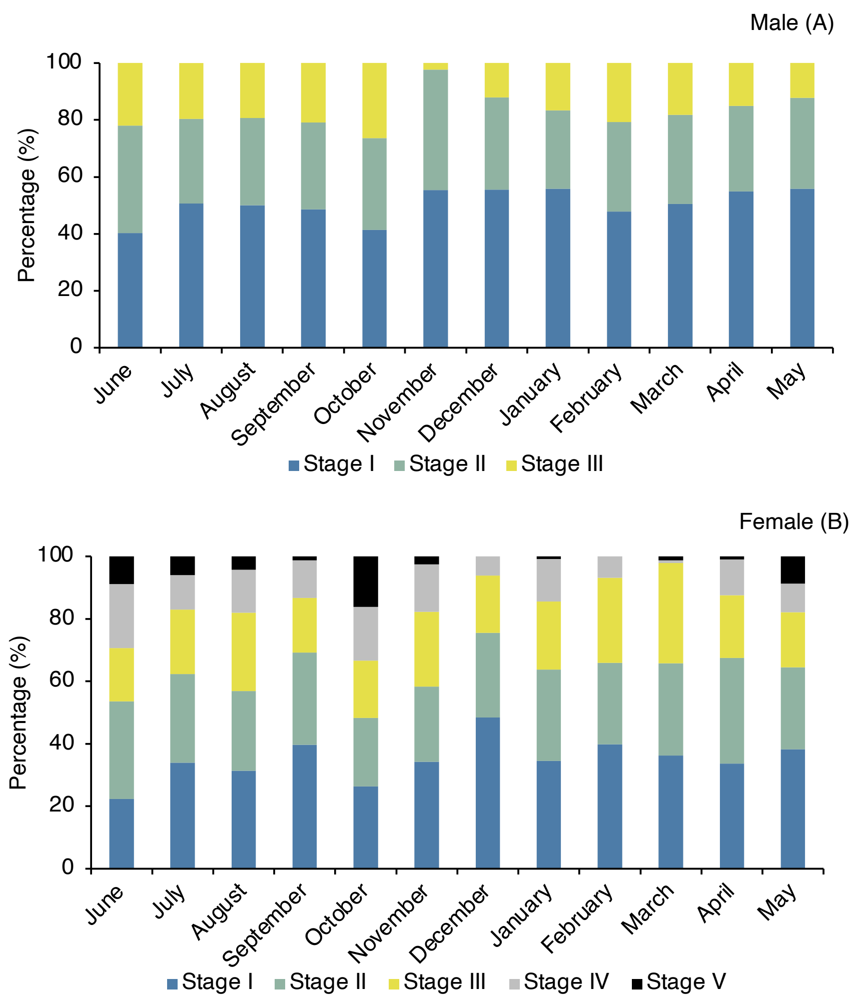

Figure 3. Monthly variation in the different stages of maturity of males (A) and females (B) *Octopus cyanea*. Stage I = immature, stage II = maturing, stage III = mature, stage IV = spawning, and stage V = post-spawning or spent. Stages I, II, and III are common to both males and females while stages IV and V are only found in female *O. cyanea*.

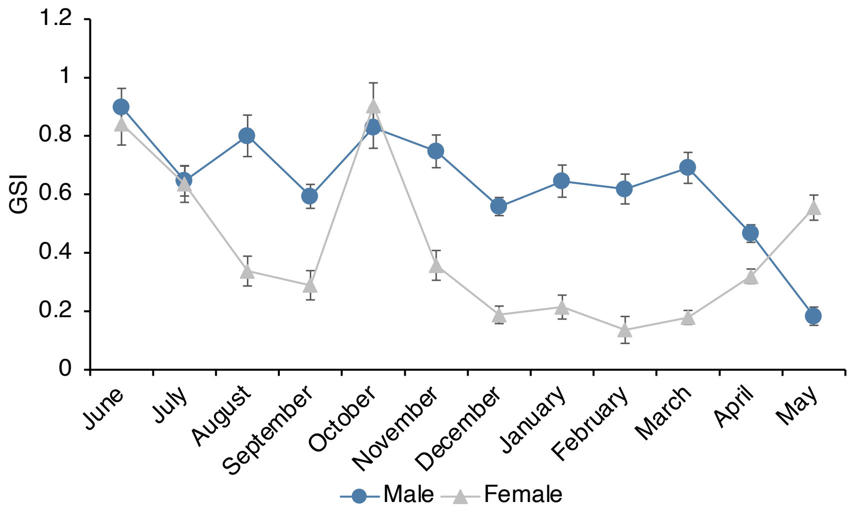

Figure 4. Monthly variation in the gonadosomatic index (GSI) of male and female *O. cyanea* from Zanzibar coastal waters.

Being sexually dimorphic, the sex ratio of *O. cyanea* in this study skews towards the female sex. Similar patterns were observed in the *O. vulgaris* population across the WIO (Raberinary and Benbow, 2012; Kivengea *et al.*, 2014), Mediterranean (Herwig *et al.*, 2012), and Northeast Atlantic (Otero *et al.*, 2007) regions. Other species like *O. insularis* (González-Gómez *et al.*, 2020), *O. maya* (Avila-Poveda *et al.*, 2016), and *O. mimus* (Cortez *et al.*, 1995), exhibit male dominance. In India however, *O. cyanea* population has been shown to be dominated by male individuals (Aditi and Deepak 2013; Nair *et al.*, 2018). The variation in sex ratio in cephalopods has been connected to several factors. For example, Cortez *et al.* (1995) and López-Uriarte and Ríos-Jara (2009) noted the variations in sex ratio across individual sizes and sexual maturity stages; however, *O. cyanea* rarely displayed these attributes in the current study. Instead, female octopuses outnumbered males throughout the year, maturity stages and season (Table 1 and 2). Differences in sampling methods used in this study could explain the female dominance. The current study includes octopuses sampled from combined deep water free diving and shallow water on-foot collection methods to avoid bias of catching octopuses in the habitats preferred by certain sex, size or stages of maturity. This is because male and juvenile octopuses prefer shallow water areas as a refuge and feeding ground, whereas adult and spawning females migrate to deep water habitats primarily for reproductive purposes (Silas *et al.*, 2023). In this sense, a sampling strategy that focuses solely on intertidal areas might favour males and juveniles while most spawners and brooders occur in deeper habitats (Avila-Poveda *et al.*, 2016). As a result, combining intertidal and deep-water sampling methods aids in the inclusion of a broad range of individuals.

The sex ratio was not significantly skewed in September, December, January, February and March (Table 1). However, if it is assumed that June and October are the top spawning and breeding months, and the subsequent months of September (for the June peak) and December, January, February and March (for the October peak) could be recruitment periods, which was characterized by a high proportion of immature and juveniles. Because juvenile *O. cyanea* of both sexes forage in similar habitats (Archer *et al.*, 2022), the likelihood of catching both sexes is higher, reducing sex ratio differences.

Furthermore, the sex ratio in this study exhibits seasonal fluctuations, with immature and mature females outnumbering males, particularly during the SEM compared to the NEM (Table 2). The SEM is characterized by heavy rains and strong southeast winds which promote nutrient-upwelling and bring cool, nutrient-rich waters into the ecosystem, resulting in an abundance of prey species (Hallegraeff, 2010). The food availability attracts octopuses of both sexes to feed and invest energy for reproductive purposes (Morse *et al.*, 2019). However, immature females become more prevalent in foraging grounds due to their higher digestion and metabolic rates which are specialized for long-term energy investment compared to males (Hamad and Muhando, 2023). In contrast, the NEM fosters warmer, less turbulent waters which facilitate maturation and reproductive success, resulting in a balanced maturation rate among males and females, as seen in the results from this study (Table 3). Alternatively, a non-significant change in the sex ratio of mature individuals during the NEM suggests that either more males undergo maturation or more females undergo post-spawning death, both of which minimize sex ratio differences (Silas *et al.*, 2021).

For a precise comparison, the length-weight (L/W) relationship of *O. cyanea* in this study was estimated by using dorsal mantle length (DML) for each sex and strong correlations were obtained. Additionally, the correlation coefficient (R^2) value is almost similar (R^2 = 0.87 for males and 0.83 for females) when calculated by TW/DML. The correlation coefficient (R^2) of *O. cyanea* from Mafia, Tanzania is lower than the current findings, although their estimation does not consider the sex of octopuses (Silas *et al.*, 2022). However, Silas *et al.* (2021) showed that this species exhibits an allometric growth pattern, in which octopuses increase more in length than weight. Moreover, from DML, b = 2.59 of females is larger than 2.41 of males (Fig. 2), which suggests that female *O. cyanea* are heavier than males. The larger body weights of females might be attributed to the mass of the gonads and other accessory reproductive organs which constitute a greater proportion of the female body weights, making the female *O. cyanea* heavier than males of a given size (Gabr and Rafik, 2008). These findings have been supported by Guard (2009); Benbow *et al.* (2014), Raberinary and Benbow (2012) and Nair *et al.* (2018) who reported that female *O. cyanea* are significantly larger than males. A sex-based study on the L/W relationship conducted in Madagascar by Raberinary and Benbow (2012) also reported a b-value corresponding to the current findings.

The size at maturity of male *O. cyanea* in this study was significantly smaller than females. For the females, the size at maturity was 10.4 cm DML, 1013 g TW while for males it was 9.0 cm DML, 640 g TW. These results coincide with those of Markaida *et al.* (2017) who reported that the size at maturity in *O. maya* ranges from 11.7 to 13.3 cm DML and 931 to 1238 g TW for females, while it ranges from 7.7 to 10.0 cm DML and 331 to 613 g TW in males in Mexico. On the Kenyan coast, male and female *O. vulgaris* attain the size at maturity at 10.5 cm and 10.8 cm, respectively (Kivengea *et al.*, 2014), agreeing with *O. cyanea* in the present study. However, in Madagascar, the size at first maturity of male *O. cyanea* of 550 g concurs with the males from the current study but not for the females of 2200 g (Raberinary and Benbow, 2012). Similarly, in Spain, *O. vulgaris* reach sexual maturity at a larger body size of 903 g and 1788 g for males and females, respectively (Otero *et al.*, 2007). Food availability, type and season of sampling as well as environmental plasticity caused by geographical differences, have been reported to alter the size at maturity in cephalopod species (Mangold and Boletzky, 1973; Leporati *et al.*, 2008; Markaida *et al.*, 2017). Nevertheless, *O. cyanea* in this study mature at a larger body size during the SEM as compared to the NEM (Table 2). This is because the SEM season in Zanzibar coastal waters is rainy and is associated with upwelling activity that brings nutrient-rich water to the octopus habitats (Barlow *et al.*, 2011; Semba *et al.*, 2019), enriching the food web, thus making octopuses grow and mature at larger body sizes due to food availability.

All the maturity stages of *O. cyanea* are found throughout the year except for December and February, where spent females were not captured. In both sexes, immature individuals are more numerous than individuals of any stage of maturity; a similar situation has been reported for *O. vulgaris* in South Africa (Smith and Griffiths, 2002). For females, only immature and maturing individuals follow a consistent trend but individuals of other stages fluctuate greatly with months (Fig. 4). Unlike females, mature males of this species show less monthly fluctuation compared to females probably because the maturity of many male octopuses are determined by size (Smith and Griffiths, 2002). Such male uniformity across the months is used as a strategy by most cephalopod species to ensure the continuous presence of mature males available for mating with mature females (Wang *et al.*, 2008). In contrast, the inconsistency of mature females is because the maturation of female octopuses depends on various factors such as genetics (Politis *et al.*, 2014), water temperature (Juárez *et al.*, 2015), and food availability (Quintana *et al.*, 2015). Spent individuals exhibit post-spawning mortality (Smith *et al.*, 2006), hence were not present in the December and February catch.

After maturation, *O. cyanea* undergoes spawning, laying eggs, hatching of eggs, and subsequently dies; all of these physiological activities occur at the end of its life cycle, defining it as a semelparous and simultaneous terminal spawner (Rocha *et al.*, 2001; Anderson *et al.*, 2002). The semelparity and terminal spawning strategies have been adopted by other species like *O. hubbsorum*, *O. vulgaris*, and *O. mimus* (Van Heukelem, 1973; Cortez *et al*., 1995; López-Uriarte and Ríos-Jara, 2009). The peak spawning and brooding activities in octopuses differ with geographical locations (e.g. Otero *et al*., 2007; Herwig *et al*., 2012; Avila-Poveda *et al*., 2016; González-Gómez *et al*., 2020). In Zanzibar, distinct spawning patterns have been observed for *O. cyanea*, with two primary spawning periods identified: one from April to July, peaking in June, and another from September to November, peaking in October. The timing of these spawning periods suggests a close relationship between the reproductive cycle of *O. cyanea* and the availability of food resources in the environment. For example, the peak spawning period of June might be attributed by the accumulation of high energy reserves gained from the increased food consumption in May (Hamad and Muhando, 2023). This food consumption increases the overall health and reproductive success of the octopus during spawning time (Anderson *et al*., 2002). Similarly, the peak spawning period of October could be linked to the greater energy reserve accumulated by more food consumption in August (Hamad and Muhando, 2023).

The findings indicate that the spawning cycle of *O. cyanea* is closely linked to the abundance of food resources, suggesting that the timing of spawning periods is influenced by prior food consumption. This relationship implies that adequate food availability is crucial for overall health and reproductive success, though other environmental factors also play a role. Based on the results, maintaining a stable and abundant food supply in these sites is essential for ensuring spawning onset and hence sustainable reproductive success.

Conclusions

This study revealed that *O. cyanea* behaves similarly to those studied in other geographical areas in terms of growth pattern, sex-based size, and maturity stages, except for the timing of spawning, which usually varies with geographical locations. Overall, this research enhances current understanding of the reproductive dynamics of *O. cyanea*, crucial for implementing effective conservation and management measures. Based on these findings, management efforts might consider the interplay between spawning peaks and food supply so as to ensure successful and effective management outcomes. However, the research suggests the need for further studies on the ecological factors influencing reproductive behaviours and life history traits of *O. cyanea* to improve predictive models for management purposes.

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