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Length – Weight Relationship of *Octopus cyanea* (Gray, 1849) in Zanzibar: Informing Sustainable Management Practices in Zanzibar Fisheries

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Abstract: *This study explored the length-weight relationship in octopus populations at Unguja Ukuu and Uroa, Zanzibar, by analysing data from 8,127 octopuses collected throughout 2020. We aimed to understand growth patterns and their implications for sustainable fisheries management. The analysis involved quantifying weight frequency distributions, assessing the correlation between length and weight, identifying key weight classes, and observing seasonal growth fluctuations. Our findings reveal a robust positive correlation between length and weight, with Coefficient of determination values between 0.5831 and 0.8037, suggesting reliable growth models for these populations. Notably, male octopuses consistently recorded higher mean weights than females, with the highest weight peaks in June and October, highlighting significant seasonal and sex-specific growth variations that may be linked to reproductive and metabolic differences. The study also detected negative allometric growth at both sites, implying that environmental factors like food availability and habitat conditions may drive these octopuses to increase in length more than weight. These results emphasise the need for integrating biological and ecological data into management strategies, advocating for adaptive measures such as size-specific harvesting regulations and seasonal habitat protections. This approach is crucial for maintaining the sustainability of octopus populations in Zanzibar, thereby supporting the region's marine biodiversity and the economic stability of its fisheries.*

Keywords: Length-weight, Relationship, Octopus, Zanzibar

1. Introduction

Octopus fishery is one of the crucial fisheries that support the livelihood of coastal communities of Zanzibar through economy and food. Economically, octopus fishery contributes significantly to about 10-15% of the total value of Zanzibar's marine fisheries sector, which as a whole approximately accounts around 4-6% of the GDP of Zanzibar **(**Thyresson *et al.*, 2013). Octopuses have complex life histories, including rapid growth, short lifespans, and high fecundity (Van Heukelem, 1983; Guard and Mgaya, 2003; Pliego-Cárdenas *et al.*, 2016; Halton, 2024).

Zanzibar's coastal waters, enriched by the Indian Ocean's diverse marine habitats, host a variety of octopus species, dominated by *Octopus cyanea* Gray (1849) by 99.9% (Gurad & Mgaya, 2003; Rocliffe & Harris, 2016) whose populations are subject to both natural and anthropogenic pressures (Forsythe JW, Hanlon RT. 1997; Guard, 2009,). Overfishing, habitat degradation, and climate change alter marine landscapes, thus impacting the growth and sustainability of octopus populations (Guard, 2009; Rosa *et al.*, 2012). In this context, studies on length-weight relationships can provide essential insights into the current state of octopus populations and help predict their responses to environmental changes.

The length-weight relationship is a fundamental parameter in fisheries biology, providing crucial insights into a species' growth, health, and overall population dynamics (Miranda *et al.*, 2024). The parameter predicts the average weight of an octopus of known length using a mathematical equation relating to the two factors (Alam *et al.*, 2024). By examining the length-weight relationship of octopuses in Zanzibar, we aimed to shed light on the species-specific variations in growth patterns and size distribution. This relationship is a key indicator of the ecological balance within an ecosystem (Magloo *et al.*, 2024) and will aid in formulating sustainable management practices.

Like in many other tropical coastal regions, the exploitation rates of Octopus in Zanzibar are a matter of concern due to their potential impact on the local marine ecosystems and the livelihoods of communities dependent on fisheries. However, unsustainable fishing practices, overharvesting, and inadequate management measures remain critical concerns that can lead to the depletion of octopus populations, jeopardising the long-term sustainability of the fishery. The investigation into the length-weight dynamics of octopuses offers broader ecological insights. It measures the population's reproductive health and overall vitality, factors directly influenced by the physical and biological environment (Boyle & Rodhouse, 2005). This study aimed to assess the stock of octopus fisheries, which is essential to bridge the current knowledge gap concerning octopus fishery management in Zanzibar by assessing the length-weight relationship and size (weight) frequency distribution to contribute to the sustainable use and long-term viability of octopus resources in Zanzibar, ensuring that these marine resources can continue to support the economic stability and biodiversity of the region.

2. Methodology

2.1 Study area

This study was conducted in the Zanzibar Archipelago in the Indian Ocean, 25–50 kilometres off the coast of the mainland (Fig. 1). Interchanging monsoons influence the Zanzibar Archipelago; The North East Monsoon (NEM) occurs between October to March, and the South East Monsoon (SEM) occurs between March and October (Semba *et al.*, 2019). The shift in monsoon seasons significantly influences rainfall patterns and sea surface temperature (SST) within the site and, in turn, influences the catches of major marine fish, including Octopus (McClanahan & Cinner, 2012). This study used two sites, Unguja Ukuu and Uroa. Fishing was the main economic activity in both villages, with octopus fishery being one of the main targets. Unguja Ukuu is located on the western side of the archipelago, characterised by patchy reefs that nourish under the filtration support of the mangrove vegetation. The orientation of the Unguja Ukuu site exposes it to SEM. Uroa is located on the eastern side of the archipelago and is characterised by a fringing reef that partly nourishes under the support of the filtration of mangrove vegetation along Chwaka Bay. The orientation of Uroa exposes it to NEM.

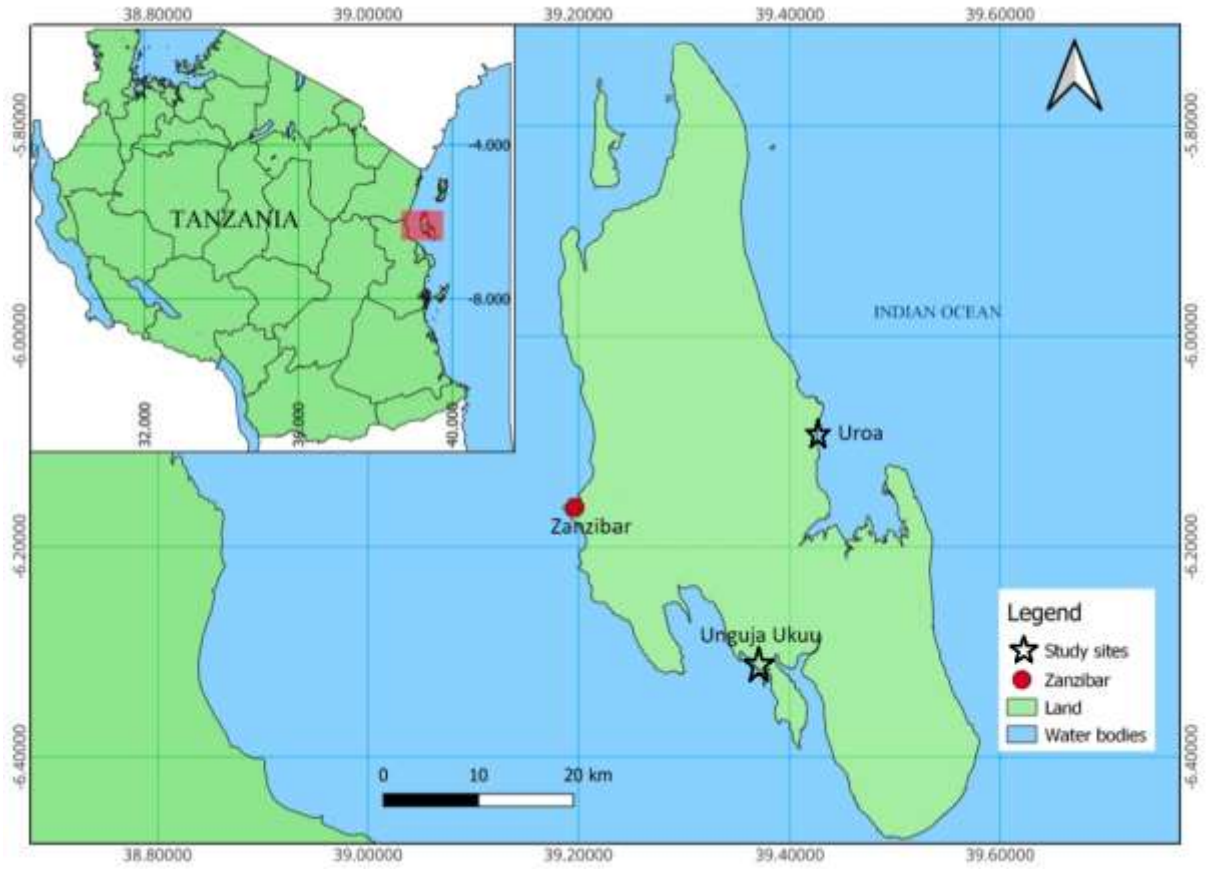

Figure 1: Map of Zanzibar showing the location of Unguja Ukuu and Uroa.

2.2 Sampling procedure and data collection

Octopus morphometric data were systematically collected monthly for a year, using prepared data sheets, from January to December 2020 in their respective sites, Unguja Ukuu and Uroa. Each site was sampled for ten days a month during a spring tide (full moon (five days) and new moon (five days), considering that the fishing habitats become exposed during these days of the respective months. The morphometric data were collected from the catches of at least 20 fishers from each site. Fishers were registered for consistent reporting of their catch. Morphometric data collection was done from a daily minimum of 25 individual octopuses randomly selected during catch data collection, making at least 200 monthly samples per site. Each sampled Octopus was identified at a species level. The gathered morphometric information was the dorsal mantle length (DML) and total length (TL) of each individual, which were measured to the nearest centimetres using a 100 cm measuring board. The total weight of individuals was measured using a 50 kg weighing scale to the nearest 0.1 kg. Once all the forms were filled, the morphometric information was entered into an Excel sheet for processing.

2.3 Data processing and analysis

We analysed the length and weight relationships of the *Octopus cyanea* using the power curve equation $W = qL^b$, where "W" was the total wet weight of the Octopus (g), "q" was the intercept on the Y-axis that defined the rate of change of weight with length, "L" was the dorsal mantle length (cm) and "b" was the slope of the regression line ((also known as the allometry coefficient), which defined the weight at unit length. Estimating the parameters "a" and "b" involved the log transformation of the equation. The parameter "b" at a 95 % confidence level was used to determine the growth pattern of the Octopus. When "b" was equal to three (3), it was concluded that an isometric pattern of growth occurred, but when "b" was not equal to 3, it was concluded that an allometric pattern of growth occurred, which could be positive if >3 or negative if <3. The t-test was used to evaluate whether the observed slope (Coefficient of the independent variable in the regression model) was significantly different from zero. Likewise, a two-sample t-test was used to compare mean weights between sexes within sites, and one-way ANOVA was used to compare mean weights among months within sites.

3. Results

3.1 Weight frequency distribution

We measured the length and weight of 8,127 individual Octopus for one year for the two sites. Of 8,127, 4,414 were from Unguja Ukuu, and 4,013 were from Uroa (Table 1). Generally, for Unguja Ukuu, the weights ranged broadly from 100g to 22000g, with the most dominant weight class being 300-450g and the second most abundant weight class being 600-750g (Fig. 2a). The peak occurrences for the 300-450g weight class in Unguja Ukuu for both sexes were in August (Fig3a), with significant numbers also in April and February for males and notable numbers in March and April for females. The largest average size class of octopuses occurred in June and October for both sexes within sites (Fig.3). Males generally exhibited significantly higher mean weights than females across most months ($p < 0.0001$), with notable differences observed during March, April, May, July and August. For Uroa, a wide weight range of Octopus was recorded, from 80 to 11,100 grams. The most dominant weight class ranged from 200 to 400 grams, with the peak frequency reaching 1,039 samples, followed by the 400-600g range for both sexes (Fig. 2b). On average, male octopuses had significantly higher mean weight than female octopuses ($p < 0.0001$). The monthly mean weights revealed significant fluctuations throughout the year, with the highest peaks in June and October - November and a general decline towards the year's end, with males consistently maintaining higher mean weights than females, having both sexes peaked in June (Fig.4). Conspicuously, males consistently displayed significantly higher average weights compared to females throughout the year ($p < 0.001$), except for May and October (Fig. 4).

Table 1: Morphometric characteristics of the length-weight parameters of both sexes and overall for the Octopus cyanea species within sites. ML = Mantle length, cm = centimetre, TL = Total length, W = Weight, g = gram, SE = Standard Error, N = Sample size.

Site	Sex	Range ML (cm)	Mean ML (cm)	SE (ML)	Mean TL (cm)	SE TL	Range W (g)	Mean W(g)	SE(W)	N
Unguja Ukuu	All	38.50	4.02	0.03	30.36	0.14	21,900	840.85	14.74	4,114
	Male	38.20	4.21	0.05	31.62	0.22	7,900	909.97	17.77	1,736
	Female	31.50	3.89	0.03	29.45	0.19	21,900	790.41	21.89	2,379
Uroa	All	46.00	3.92	0.03	28.34	0.15	11,020	720.65	10.18	4,013
	Male	45.00	4.23	0.05	30.29	0.23	11,010	848.38	17.77	1,662
	Female	46.00	3.70	0.03	26.96	0.19	4,220	630.36	11.65	2,351

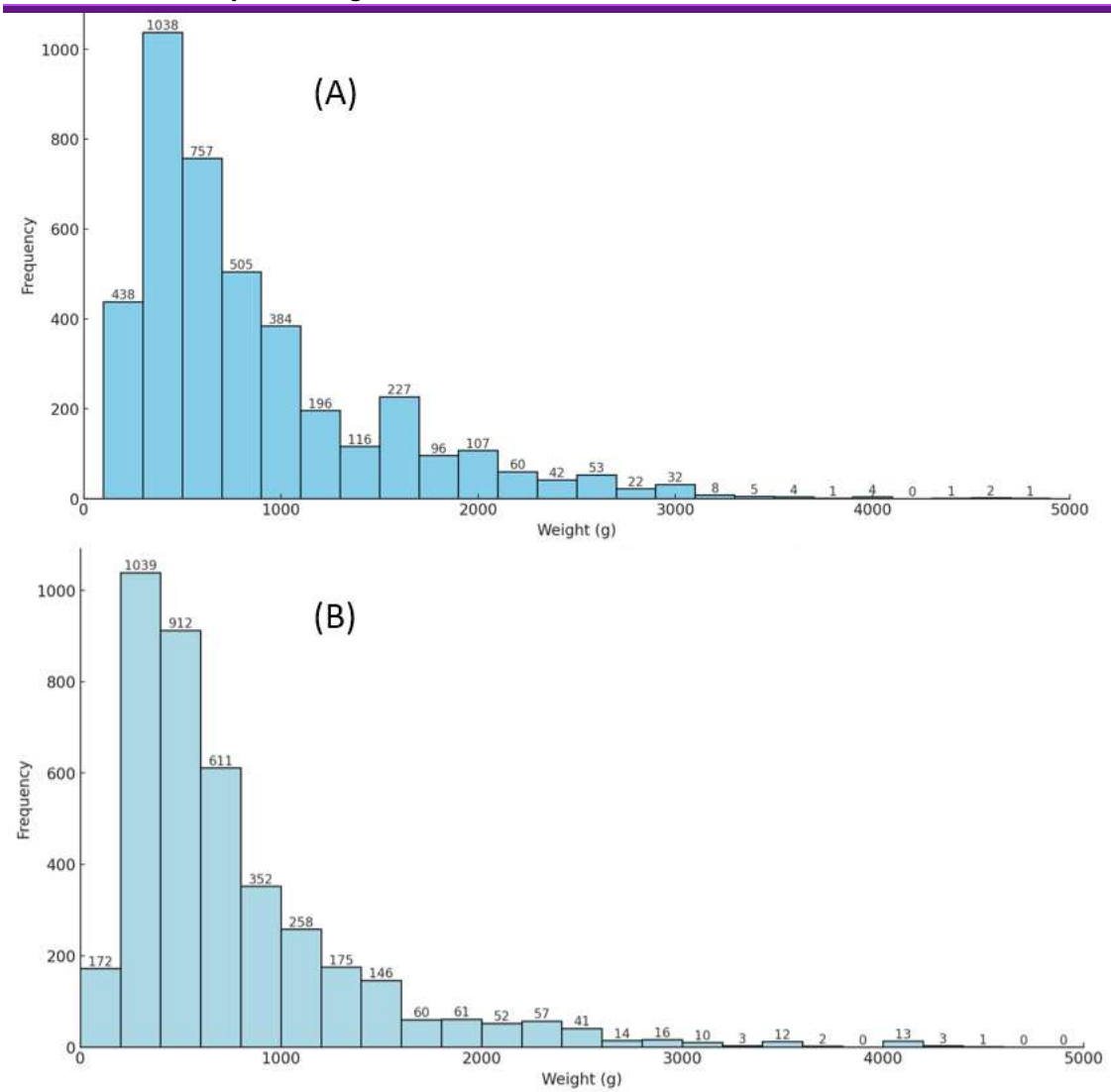

Figure 2: Weight frequency distribution of Octopus cyanea among size classes of size interval of 200g for Unguja Ukuu (A) and Uroa (B). The numbers above the bars denote sample sizes.

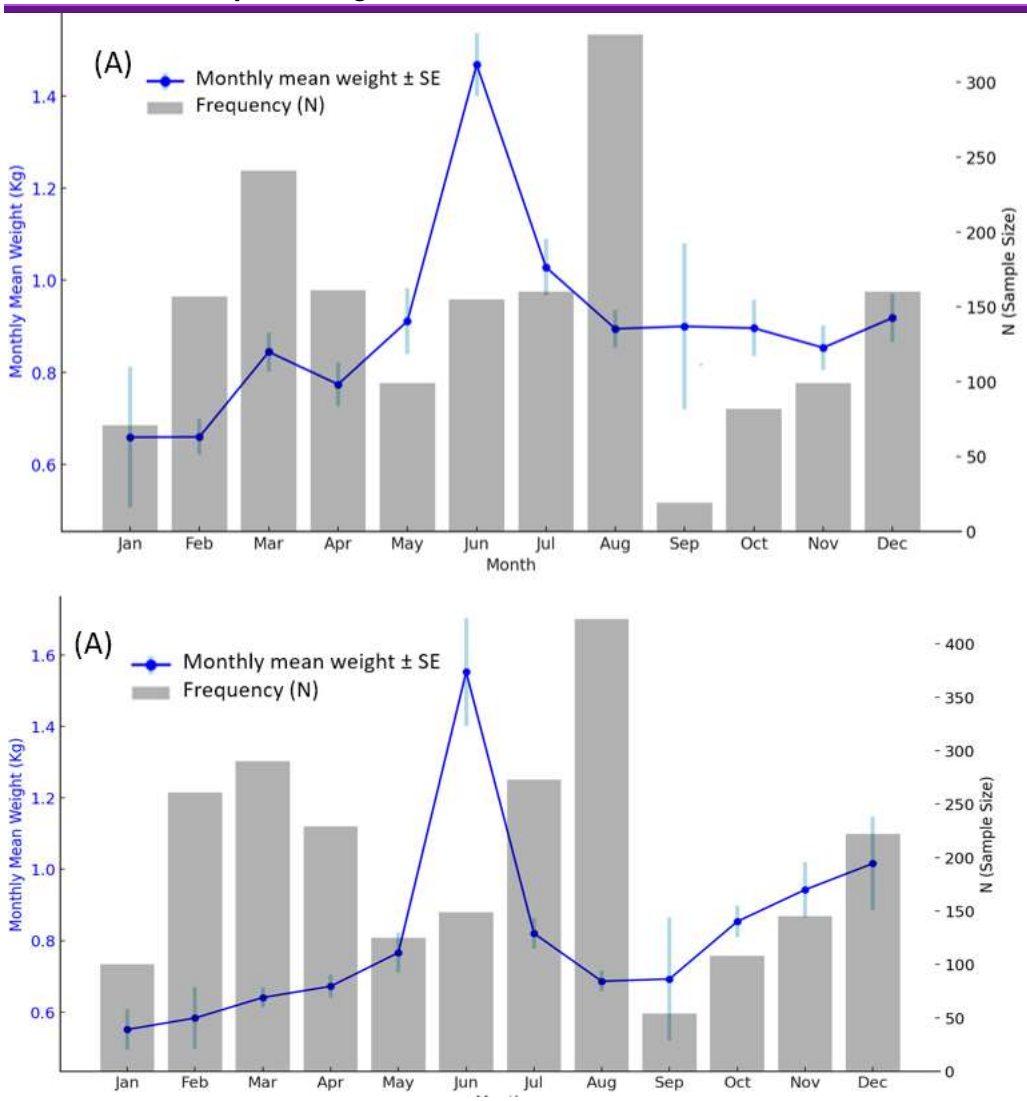

Figure 3: Monthly mean weight (± Standard Error) distribution of Octopus cyanea at Unguja (A) Ukuu and Uroa (B). Error = SE. Bars denote the frequency of observations (Sample size) as guided by the secondary Y-axis.

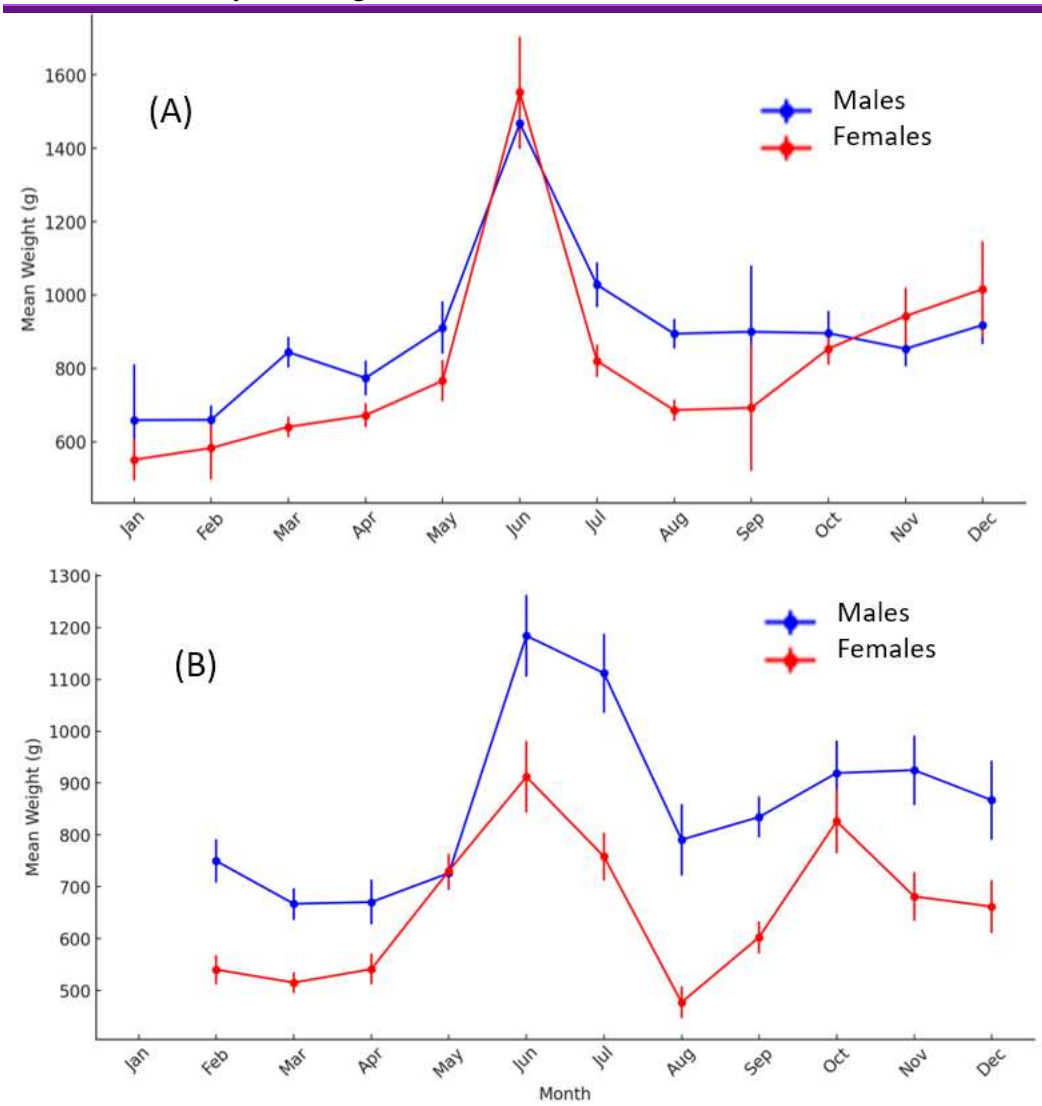

Figure 4: Monthly mean weight (± Standard Error) distribution of Octopus cyanea between sexes at Unguja (A) Ukuu and Uroa (B).

3.2 Length-weight relationships

In this study, the male Octopus recorded a higher mean mantle length (ML), mean total length (TL) and mean weight (W) in both sites assessed (Table 2). There was a significant difference in mean mantle length, mean total length and mean weight between male and female octopuses in all sites ($p < 0.0001$). Table 3 presents the length-weight parameters for octopus species sexes for both sites. The length-weight relationship of the Octopus was significantly positive for both sexes in both sites ($p < 0.001$, Fig.5). Correspondingly, there was a strong length-weight relationship in octopus species for both sites, indicative of good fitted data, with the Coefficient of determination (r^2) and the correlation coefficient (r) ranging from 0.5831 to 0.8037 (Fig.5, Table 2). The exponent b values indicated a negative allometric growth in both sexes, ranging from 1.7175 to 1.9218 between sexes and from 1.8036 and 1.8969 overall between sites (Table 2).

*Table 2: Summary of the length-weight relationship parameters of both sexes and overall for the Octopus cyanea species within sites. * = There is a significant relationship; a = Rate of change of weight with length (intercept), b = weight at unit length (slope), r = Correlation co-efficient, r^2 = Coefficient of determination and p = probability value at 95% confidence level.*

Site	Sex	a	b	r	r^2	p
Unguja Ukuu	All	48.71	1.8969	0.7684	0.5904	0.001*
	Male	55.9	1.8281	0.7666	0.5876	0.001*
	Female	45.66	1.9218	0.7636	0.5831	0.001*
Uroa	All	50.87	1.8036	0.8040	0.6464	0.001*
	Male	60.35	1.7175	0.7732	0.5978	0.001*
	Female	48.21	1.8174	0.8037	0.6459	0.001*

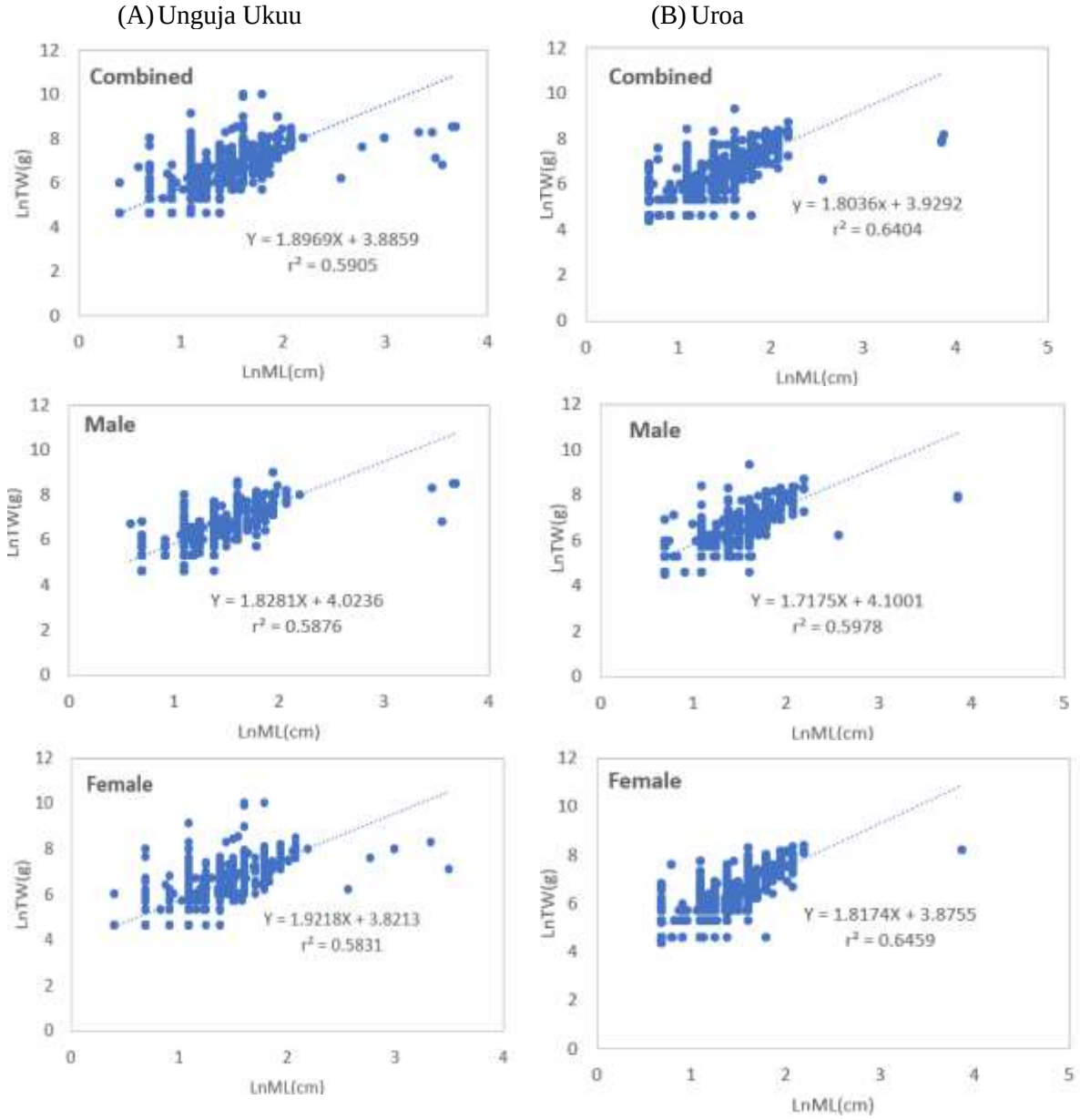

Figure 5. *Length-weight relationship of Octopus cyanea species within sites, (A) Unguja Ukuu and (B) Uroa for between species and overall, for each site.*

4. Discussion

The length-weight relationship is a fundamental metric in fisheries biology, providing crucial insights into the condition and health of marine species such as the Octopus. This relationship is indicative of various factors, including the maturity and fecundity of the population, and serves as a reliable predictor of biomass and yield (Froese, 2006). In the context of Zanzibar, where marine resources form a vital part of the local economy, understanding the length-weight dynamics of Octopus can significantly aid in the sustainable management of this species. Studies conducted in similar ecosystems have shown that environmental variables such as water temperature, salinity, and available food sources can influence these relationships (dos Santos & Haomovici, 2002). By examining the length-weight and length-length relationships of the Octopus in Zanzibar, this research aims to provide information that can inform effective conservation strategies and ensure the long-term viability of octopus fisheries in the region. This approach helps assess the health of the octopus population and implement regulations that could mitigate the impacts of overfishing and environmental change (Lefkaditou & Kaspiris, 1998).

In assessing the growth patterns of octopuses in Zanzibar, the length-weight relationship (LWR) is a crucial indicator of their physiological condition and environmental adequacy. The LWR parameter 'b' plays a pivotal role in determining the type of growth an organism exhibits. Isometric growth, where $b = 3$, suggests a stable and proportionate increase in size without changes to body shape, indicating a balanced environment. Conversely, negative allometric growth, characterised by $b < 3$, signifies that octopuses are becoming slenderer as they lengthen (Arreguín-Sánchez, 2000; Granados *et al.*, 2000), which may be a response to suboptimal environmental conditions such as inadequate food supplies or lack of optimum temperature (Hamdi *et al.*, 2012). Positive allometric growth, where $b > 3$, is observed when octopuses appear fatter with length increase, suggesting favourable conditions, including abundant food, suitable water temperature, and oxygen levels (Pauly, 1993).

Our study evaluated the length-weight relationship of octopus species in Zanzibar for males, females and overall, for the samples collected in 2000 and indicated that the Octopus of Zanzibar undergoes negative allometric growth ($b < 3$), indicative that octopuses from this species in this region tend to grow more in length relative to total weight. The growth patterns of cephalopods are significantly influenced by environmental conditions such as food availability, dissolved oxygen levels and temperature (Rivas *et al.*, 2019; Zhao & Shen, 2024).), which can affect their growth rates, body shape, and reproductive behaviours (Liang *et al.*, 2025). Cephalopods show high adaptability to environmental changes, optimising energy accumulation and metabolic distribution during growth and reproductive phases (Boyle & Rodhouse, 2005). Dissolved oxygen, for example, is crucial for their survival and growth, with specific concentration ranges being optimal depending on the species and life stage (Yang *et al.*, 2025). Temperature also plays a critical role in their life cycles, influencing key stages like egg laying, hatching, and overall population dynamics (Xiang *et al.*, 2024). Seasonal temperature changes can drive the migration patterns of cephalopods, further indicating the profound impact of environmental factors on their biological processes (Xu *et al.*, 2024). The exponent 'b' values, which ranged from 1.7175 to 1.9218 between sexes and 1.8036 to 1.8969 across sites, indicated a predominantly negative allometric growth. This suggests that the increase in weight is not proportionate to the increase in length, which could be influenced by factors such as food availability and optimal temperature conditions. This differential growth pattern across sites and between sexes could reflect adaptive responses to local environmental pressures or resource availability, aligning with the variations observed in similar species across different habitats. Similar growth trends have been documented in cephalopod studies from regions like Guard and Mgaya (2003) in Tanga, Mtwara and Mafia in Tanzania, Maulita *et al.*, 2017 in Indonesia and Mexico by Granados-Alcantar *et al.*, 2020

The positive correlation between length and weight in Octopus, as indicated by the Coefficient of correlation (r) values exceeding 0.5 for combined sexes, males and females, underscores a significant and consistent growth pattern across different demographic segments. This trend is further corroborated by the findings from both sites, where the Coefficient of determination (r^2) and correlation coefficient (r) range from 0.5831 to 0.8037, demonstrating a robust length-weight relationship. Such a strong correlation supports good data fit and suggests a reliable predictive model for octopus growth under varying environmental conditions. The positive correlation between length and weight in octopuses highlights significant insights into their biology and environmental adaptability (Anderson and Roadhouse (2001). The consistent and strong correlation across sexes and sites points to stable and healthy octopus populations capable of sustaining growth under various environmental conditions, indicating their resilience to ecosystem changes. These findings highlight that biological facts are crucial for predicting how octopus populations might respond to environmental changes or fishing pressures, thereby aiding in developing responsive and sustainable fisheries management policies.

This study revealed distinct weight distribution and seasonal growth patterns in octopus populations across two different sites, Unguja Ukuu and Uroa. In Unguja Ukuu, the weight classes predominantly ranged from 300g to 450g, with peaks during August and secondarily from 600g to 750g. These weight classes reflect significant biological growth periods, with males showing a broader weight distribution over the months, particularly in April and February, while females were most notable in March and April. Such differences likely indicated sex-specific growth strategies or differential resource utilisation between males and females, which could be influenced by reproductive cycles or environmental resource availability (Doubleday *et al.*, 2016). In Uroa, the weight range was generally lower, with the most common weights between 200g to 400g. This site peaked at a lighter weight class than Unguja Ukuu,

suggesting possible site-specific environmental factors influencing growth, such as food availability or habitat conditions (Anderson and Roadhouse, 2001).

The seasonal weight fluctuations, with peaks in June and October across both sites, highlight potential optimal growth conditions linked to environmental factors or prey availability (Boyle and Rodhouse, 2005). Similar patterns of findings have been reported by Hamad and Muhando, 2023 and Guard and Mgaya 2003 in Tanzania. However, the pattern has differed in places such as Madagascar, where the weight seasonal fluctuations were documented in April–June (Raberinary and Benbow, 2012). Males consistently showed higher mean weights than females, suggesting sex-specific growth strategies potentially influenced by reproductive or metabolic differences (Marian, 2015). Significantly, males demonstrated higher mean weights than females in both locations across most of the year. This consistent pattern of sexual dimorphism in weight could indicate different life history strategies where males might grow larger to enhance competitive success for mating opportunities or have longer growth periods before maturity (O'Brien *et al.*, 2016). These findings suggest that management strategies must consider these varied growth patterns and sex-specific dynamics to manage and conserve octopus populations in these regions effectively. Such strategies could include setting different size limits for capturing or protecting specific habitats during crucial growth or breeding periods to sustain healthy populations.

5. Conclusion

This study on octopus populations in Unguja Ukuu and Uroa reveals significant insights into their growth patterns and environmental responses, demonstrating a consistent positive correlation between length and weight, indicative of stable and healthy populations. Seasonal weight fluctuations suggest optimal growth periods potentially linked to environmental factors like food availability and temperature. Males consistently exhibited higher weights than females, pointing to sex-specific growth strategies and possibly different reproductive or metabolic needs. The observed negative allometric growth suggests that octopuses may adapt to suboptimal environmental conditions by growing in length more than weight. These findings are crucial for formulating effective management and conservation strategies, such as size-specific harvesting regulations and seasonal habitat protections, to ensure the sustainability of octopus populations in Zanzibar, ultimately contributing to preserving marine biodiversity and supporting local fisheries' long-term viability.

Authorship contribution statement

Ali M. Ussi: Conceptualization, Methodology, Investigation, Formal Analysis and Writing – original and final drafts. **Narriman S. Jiddawi:** Conceptualization, Methodology, Investigation, Reviewing. **Salum S. Hamed**: Methodology, Investigation and writing.

Animal ethics

Research permission was obtained from the office of the Second Vice-President office of the revolutionary government of Zanzibar. The Department of Fisheries was aware of the collection of fisheries data.

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Declaration of Interest

Authors declare that they have no conflict of interest regarding this manuscript or any part.

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