SUMAIT University Journal (SUJ)
eissn (2953-2698)
Issue No.16 December 2024

Assessment of Day Octopus (*Octopus cyanea*, Gray 1849) Fisheries Characteristics in Zanzibar

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Received: October 2024, Accepted: December20224 pulpited December20224

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Abstract:
The day octopus (Octopus cyanea, Gray 1849), a major commercially exploited reef species in Zanzibar, has recently been characterized by limited information on stock status, ideal to inform effective management policies. This study examined the O. cyanea growth, mortality rates, and recruitment patterns in Matemwe and Michamvi, Zanzibar, using Dorsal Mantle Length (DML) frequency data from catch landings between October 2020 and September 2021. Octopus sizes ranged from 2 to 10.5 cm DML with an average body weight of 2.2 kg ± 0.02 kg in Matemwe and 2.1 kg ± 0.01 kg in Michamvi. The Growth Coefficients (K) were 1.8 year^{-1} and 2.3 year^{-1}, with Asymptotic Lengths ($L\infty$) of 10.5 cm and 9.5 cm, and Growth Performance Indices (Φ') of 2.33 and 2.4 for Matemwe and Michamvi, respectively, typically reflecting fast growth rates. In Matemwe, total mortality (Z) was 6.96 year$^{\sim 1}$, with natural mortality (M) of 4.20 year$^{\sim 1}$, fishing mortality (F) of 2.76 year$^{\sim 1}$, and exploitation rate (E) of 0.40 year$^{\sim 1}$. In contrast, at Michamvi, Z was 5.75 year$^{\sim 1}$, M was 3.48 year$^{\sim 1}$, and F was 2.27 year$^{\sim 1}$, E was 0.39 year$^{\sim 1}$ all of which suggest a sustainable harvesting rate in line with current management practices. Recruitment occurred year-round, with notable peaks in April at Matemwe and February at Michamvi, reflecting the influence of geographical and human-related factors on recruitment. This study emphasizes the need for improved management policies to mitigate the effects of intense fishing pressure on O. cyanea in Zanzibar. Management options such as size restrictions, and fishery closures should be enhanced to balance exploitation with regenerating capacity, ensuring the sustainability of the fishery.

Keywords: *Octopus cyanea*, growth, mortality, recruitment, Zanzibar

1. INTRODUCTION

The day octopus (*Octopus cyanea* Gray, 1849) is a reef-associated species that has been harvested for decades in intertidal areas of Zanzibar and across most regions of the Western Indian Ocean (WIO), using local fishing gear such as sticks and hooks [1]. Skin-diving also captures this species in subtidal waters, using spears and harpoons [2].

Historically, octopus fishing in Zanzibar was primarily a gleaning activity carried out by women and children. However, men now dominate the fishery, leading to increased hunting pressure [3]. This sector has intensified due to rising demand for octopus to support tourism, higher prices, and growing coastal populations, all contributing to declining catches [5,6]. Consequently, fishing efforts have increased, with longer distances, extended fishing times, smaller catch sizes, and reduced overall yields [4]. These factors threaten the reproductive potential and long-term sustainability of *O. cyanea* populations, posing risks to Zanzibar's blue economy, particularly within the fisheries and tourism sectors [5]. Climate change, non-compliance with fishing regulations, inadequate data integration, and poor management practices also exacerbate these issues [6].

Assessing *O. cyanea* population in Zanzibar is urgent to understand the status of the stock which is essential for effective management [7]. Key parameters for this assessment include growth, mortality rates, and recruitment patterns. Population growth, defined as the gradual rise in the biomass of a stock, has significant management implications in fisheries science [8]. For example, rapid population increase may indicate a healthy stock, but can also point out underlying ecological changes [9]. As a result, constant monitoring is necessary to confirm whether the reported growth is not merely a short-term fluctuation or a response to environmental changes [10].

Fishing mortality is crucial for stock assessment, as it affects fish population health and their ability to endure fishing pressure [11]. Mortality and exploitation rates can best inform the harvesting intensity to guide the formulation of appropriate fishing rules [12]. Recruitment refers to the addition of new individuals to the stock through reproduction and juvenile survival, and understanding recruitment patterns helps in creating effective regulatory measures like fishing closures [13]. The exploitation of *O. cyanea* is influenced by climatic and human pressures, which impact ecosystem health and fish stocks[14]. Thus, detailed data on growth rates, mortality, and recruitment are essential for understanding *O. cyanea* dynamics in Zanzibar [2].

Although similar population studies have been conducted in various regions, including Hawaii [15], Tanga and Mtwara [16], Mafia Island [17], and Mauritania [18], as well as experimental diet studies in Zanzibar [19], significant knowledge gaps remain regarding key parameters in Zanzibar's *O. cyanea* fisheries. To address these gaps, this study focused on assessing critical fisheries characteristics of *O. cyanea*, with particular attention to growth, mortality, and recruitment patterns. The aim is to provide comprehensive insights that will guide sustainable management practices in the octopus fishery, ultimately contributing to the prosperity of local communities and the broader national economy in Zanzibar.

MATERIALS AND METHODS

2.1 The study area

The study was conducted at Matemwe 5◦ 53′ S, 39◦ 20' E and Michamvi 6◦ 09'S, 39◦ 29′ E in Unguja Island, Zanzibar (Fig.1). Unguja is the largest island in the Zanzibar archipelago, situated 40 kilometers from Mainland Tanzania, and it comprises approximately 1,150,935 inhabitants [20]. The interchanging Northeast and Southeast monsoon winds are responsible for the island's warm and humid climate [21].

Geomorphologically, Matemwe and Michamvi are bounded by fringing reefs located a few meters below the shoreline, which provide suitable habitats for octopuses. The seascape and biotope characteristics of the Chwaka creeks, which are close to the Michamvi site and further north to the Matemwe site, play a significant role in the nutrient supply to the open ocean. This nutrient flow indirectly supports the biodiversity in the peripheral areas of the creek, including octopuses.

Primarily, the selection of study sites was based on the extent to which the local societies rely on octopus fishing as their main livelihood. This necessitates the assessment of the status of octopus stock to guarantee the sustainability of their benefits.

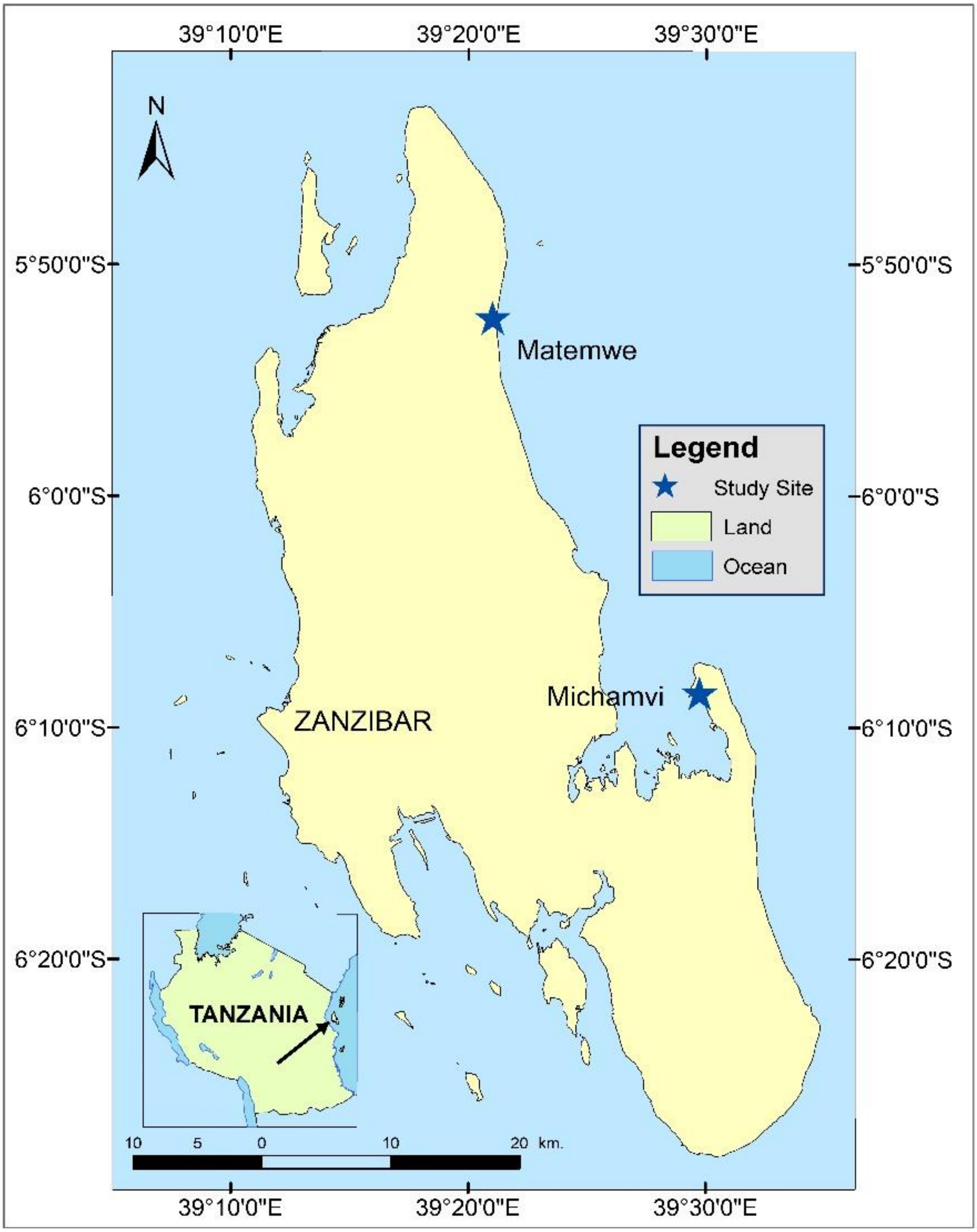

Fig. 1: A Map of Unguja Island showing the location of study areas.

2.2 Biological sampling

Monthly fieldwork activities were carried out for a period of twelve (12) months, from October 2020 to September 2021, to collect catch-landing data for *O. cyanea*. Sampling was conducted during spring tides, specifically on the 13^{th} to 17^{th} days and the 25^{th} to 29^{th} days of the lunar cycle for the full-moon and half-moon phases, respectively. These days considered appropriate for abundant octopus catch landings in Zanzibar. At each study site, sampling was conducted for two days per tide.

On each sampling day, octopus samples were randomly selected from fishermen and local buyers who purchased octopuses from artisanal fishers. Once sampled, the individual octopus was morphometrically measured. The measurements recorded were dorsal mantle length (DML) in centimeters and body wet weights (W) in kilograms. The DML was measured from the starting of the mantle via the posterior end of the mantle using a measuring board with an accuracy of 0.1 cm. However, the body wet weight was measured using a digital weight scale with an accuracy of 0.1 kg.

2.3. Data analysis

To determine the size of individual *O. cyanea* catches across months, the Shapiro test was used to check the normality of the data, while the homogeneity was tested using Levene's test. Since the data did not comply with parametric assumptions, a Kruskall Wallis test was conducted, followed by a post-hoc pairwise Wilcoxon test to pinpoint where the significant difference in individual size lies across months.

2.4 Determination of growth rate (Growth coefficient (K) Asymptotic length ($L\infty$*), and Growth performance index (*ϕ'*)*

The analysis of growth rate followed the Von Bertalanffy Growth Function (VBGF); $Lt = L\infty\,[1-e^{-K\,(t-t0)}]$ [22]. Where the Electronic Length Frequency Analysis **(ELEFAN)** technique from the FISAT II software was used to determine the best estimates of the von Bertalanffy growth coefficient (K) and an average length of octopus growth at favorable growth conditions ($L\infty$) using the monthly length frequency data. Afterward, the growth performance index (ϕ') was calculated using the formula $\text{Log } K + 2 \text{ Log } (L\infty)$, concerning the population parameters derived from the VBGF as outlined by [23].

2.5 Determination of total mortality (Z)

The monthly length frequency catch data was used to estimate the total mortality coefficient using a linearized catch [24]. This method assumes that the total mortality rate is constant across age classes and that recruitment is stable over the period assessed. The mathematical formula used was $\ln(Nt) = \ln(N0) - Z.t$, Where *Nt* represents the number of octopuses at a time, *N0* denotes the initial number of octopuses at a time, *Z* signifies the total mortality coefficient, *t* denotes the time.

2.6 Determination of natural mortality (M)

Natural mortality was calculated after Pauly's equation [25]. $\ln(M) = -0.0152 - 0.279\ln(L\infty) + 0.6543\ln(K) + 0.463\ln(T)$. M is natural mortality, $L\infty$ is asymptotic length, K is VBGF growth constant, and T is the Sea surface temperature (°C). Fishing mortality (F) was determined using the formula $F = Z - M$ [26].

2.7 Determination of the exploitation rate (E)

The rate of exploitation (E) was calculated as, $E = F/Z$ which is the ratio of fishing mortality (F) to total mortality (Z) [27].

2.8 Determination of recruitment patterns

The recruitment patterns were analyzed in FiSAT II software using the Normal Separation Method for Separation of Normally Distributed Components in Length-Frequency Data (NORSMSEP). The technique involved splitting the data into distinct normally distributed components, which represent different cohorts within a population over time [28].

2. RESULTS

3.1 Monthly average size of individual octopus

A total of 3,276 *O. cyanea* catches were analyzed, with 1,666 (51%) from Matemwe and 1,610 (49%) from Michamvi. The dorsal mantle length (DML) of octopuses in both locations ranged from 2 cm to 10 cm, with an average body weight of 0.91 kg±0.52 kg in Matemwe and 1.3 kg± 0.48 kg in Michamvi (Fig. 2). Generally, there was no statistically significant variation in octopus sizes between months at Matemwe (H = 7.371, p = 0.052, DF=11). In contrast, in Matemwe, a statistically considerable size variation was found between months at Michamvi (H = 13.717, p = 0.003, DF=11).

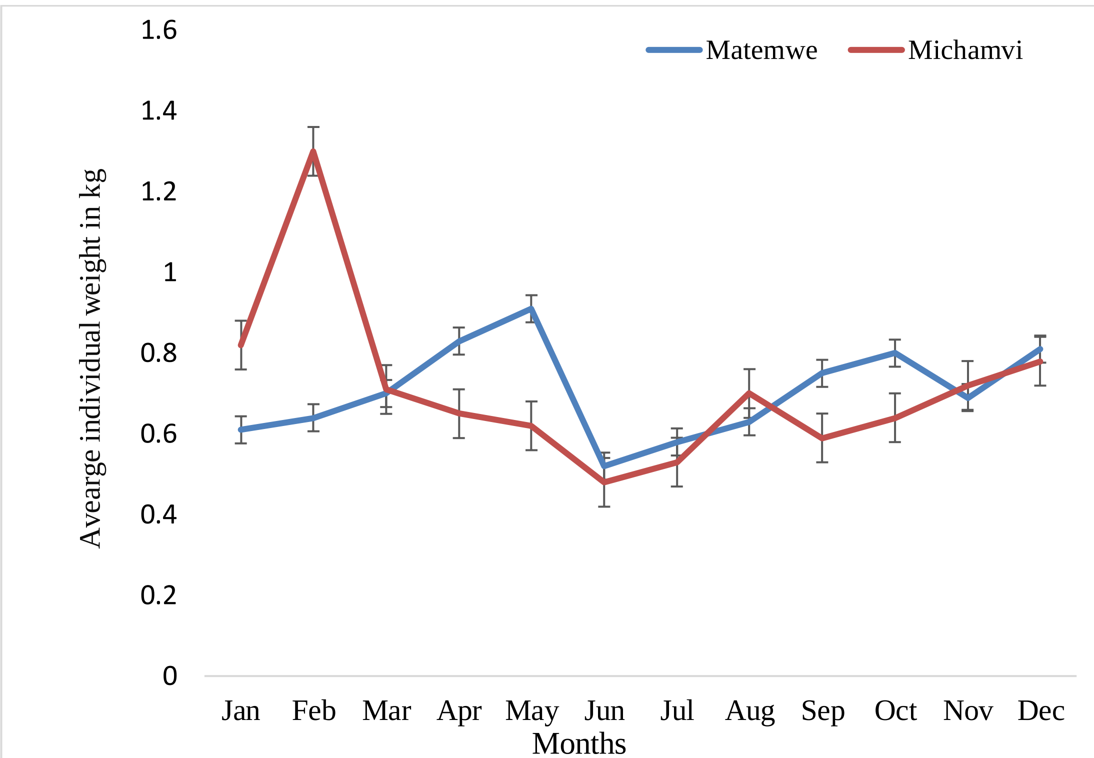

Fig. 2: Monthly individual catch size of *O. cyanea* in Zanzibar.

3.2 Growth rate

The growth rate of *O. cyanea* in two study sites indicated insignificant differences in habitat quality (Tab.1). Generally, the estimate of growth parameters represents the suitable growth rate of typically tropical species. The asymptotic length ($L\infty$) showed a relatively similar maximum growth size, whereas the growth performance index **(Φ′)** suggested analogous growth efficiencies across the two study sites.

3.1 Mortality coefficients (Z, M, and F) and exploitation rate (E)

The estimated parameters of mortality for *O. cyanea* showed that total mortality (Z), Natural mortality (M), fishing mortality (F), and exploitation rates (E) were all higher in Matemwe compared to Michamvi (Fig. 3).

Table 1: Estimated growth parameters for *O. cyanea* in Zanzibar.

Site	**Growth Coefficient (K) (year^{-1})**	**Asymptotic Length (L∞) (cm DML)**	**Growth Performance Index (Φ′)**
Matemwe	1.8	10.5	2.33
Michamvi	2.3	9.5	2.4

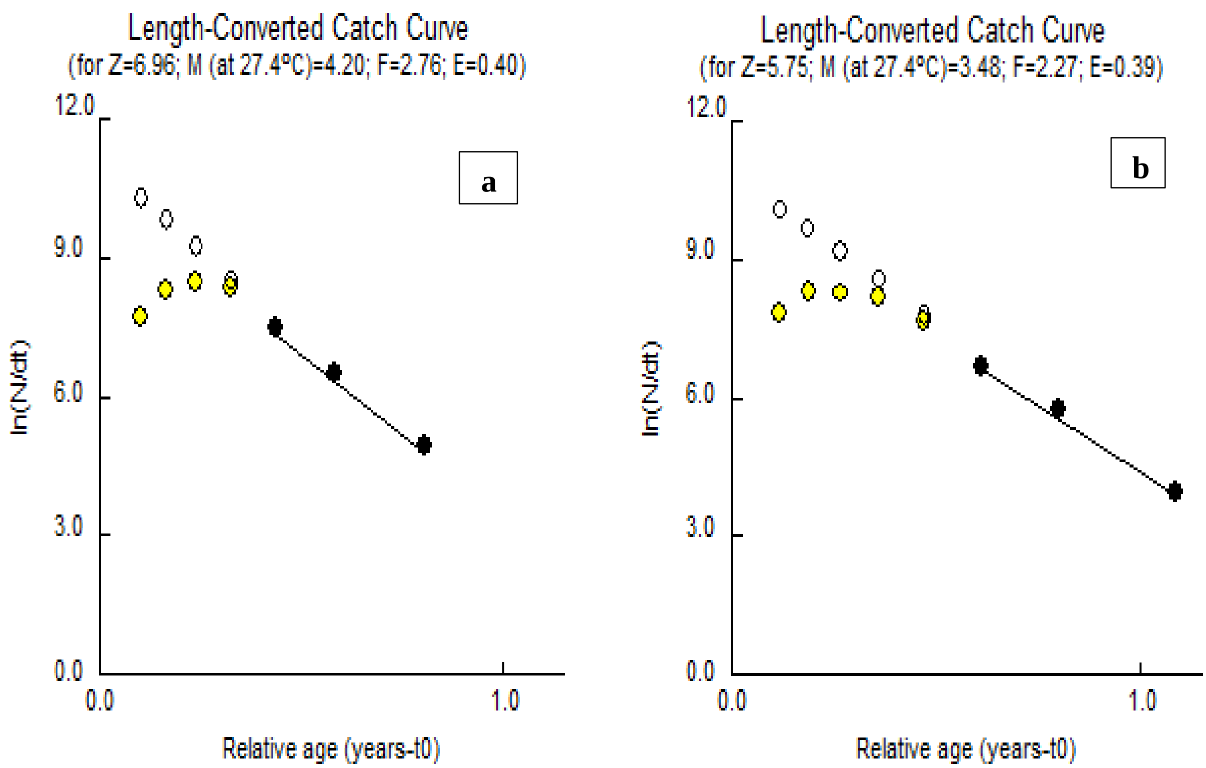

Fig. 3: Mortality coefficients of *O. cyanea* in (a) Matemwe and (b) Michamvi, Zanzibar

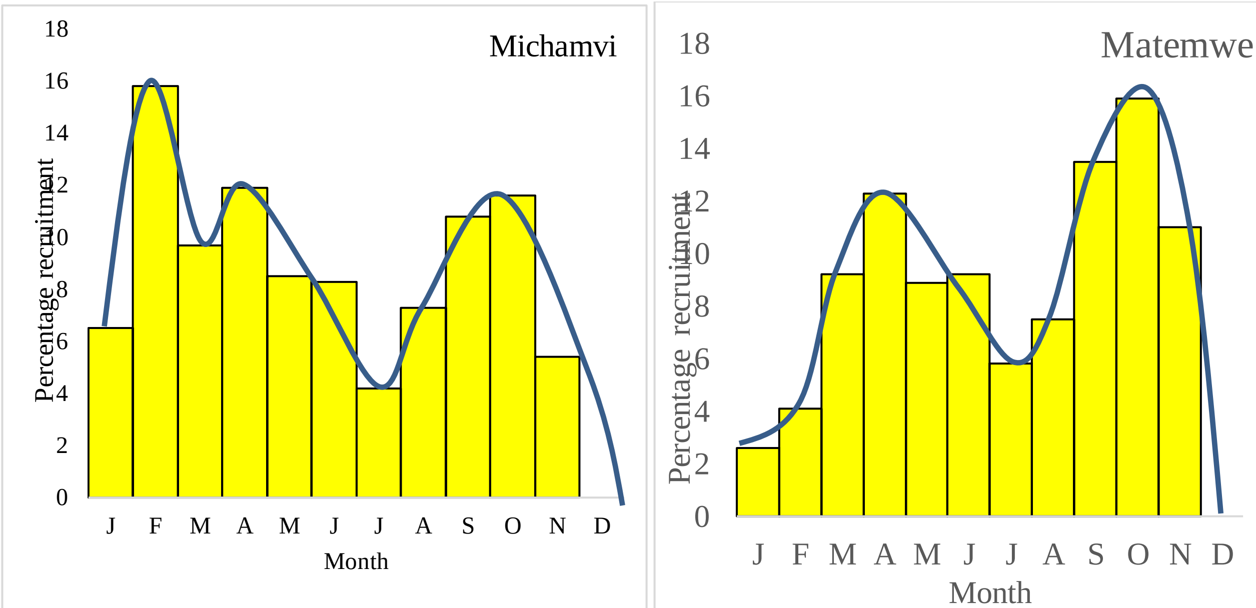

Fig. 4: Recruitment patterns of *O. cyanea in Zanzibar using the NOMSEP recruitment model*

3.1 Recruitment pattern

The recruitment analysis reveals seasonal patterns of recruitment for *O. cyanea* in Zanzibar, showing distinct monthly fluctuations in recruitment at two study sites, with several minor cohorts and two major pulses in Matemwe, in contrast to three consistent peaks in Michamvi (Fig. 4). For Matemwe, recruitment shows a significant peak in October (15.9%) and smaller peaks in September (13.5%) and April (12.3%). Conversely, Michamvi has its highest recruitment in February (15.8%) and also shows peaks in March (11.9%) and October (11.6%). Both sites show no recruitment in December, highlighting a clear seasonal trend in fish recruitment.

3. Discussion

Generally, this study assessed the stock status of *O. cyanea* in Zanzibar from 3,276 individuals sampled in Matemwe and Michamvi villages of Unguja Island, Zanzibar. The analysis involved the key population parameters such as growth, mortality, and recruitment patterns using the von Bertalanffy Growth Function, Length-Converted Catch Curve by Beverton and Holts, and the NOMSEP recruitment model, respectively. The statistically significant monthly variation in octopus sizes at Matemwe, suggests that size distribution fluctuates due to environmental changes, seasonal breeding, and fishing pressure. This variability could reflect differences in recruitment and growth rates that respond to optimal growth conditions like food availability and dissolved oxygen [29].

The growth rates of *Octopus cyanea* at Matemwe and Michamvi showed slight habitat differences, with growth coefficients (K) of 1.8 and 2.3 year^{-1} and asymptotic lengths ($L\infty$) of 10.5 cm and 9.5 cm DML, respectively. The K at both sites are consistent with tropical species, typically with fast growth rates and reaching asymptotic sizes within a reasonable time frame, indicating that both habitats were largely conducive to their growth and survival. These parameters are important for understanding how the species may respond to fishing pressures, as higher growth rates can help sustain populations under moderate exploitation levels. The similar growth performance indices (Φ') across both sites notably suggest growth considerable overall growth performance [19]. A recent study on octopus fisheries in Zanzibar, such as that of [30], has highlighted the importance of habitat quality in determining proper octopus growth. However, a slight difference noted between the sites likely reflects local variations in environmental factors, such as habitat structure and food availability, which can influence growth rates.

The estimate of mortality parameters of *O. cyanea* fisheries in Zanzibar was slightly higher in Matemwe compared to Michamvi, suggesting increased overall mortality factors, potentially from a combination of higher fishing pressure and ecological stresses [31]. The exploitation rates are almost similar between the sites, signifying that the proportion of the population removed by fishing is almost identical. However, the rates for both sites are within the range of acceptable critical value of 0.5 year^{-1}, indicating the impact of management on the resilient O. cyanea population to sustain fishing pressure without significant long-term effects [32]. The Mnemba atoll is an important snorkeling site and marine sanctuary in Matemwe that contributes to the recovery and sustainability of *O. cyanea*. Such protected areas can lead to spill-over effects, where young and adult octopuses migrate frequently from the sanctuary to adjacent fishing grounds, enhancing local fishery productivity and supporting long-term fisheries [33]. On the other hand, the implementation of temporal octopus closure at the Michamvi site offers robust recovery for the *O. cyanea* population to withstand the harvesting pressure. Closure assists mitigate the impact of overfishing by providing a refuge for breeding individuals, which is critical for maintaining healthy stock levels. This underlines the need for adaptive management strategies to ensure that exploitation does not exceed sustainable limits, as emphasized by [22] in their review of fisheries management. These findings align with those found by [34] who noted that proper management of the octopus population can adversely affect octopus population sustainability. These highlight the positive consequences the management initiatives could have in strengthening ecosystems healthy. Thus, Management strategies should focus on reducing fishing mortality and promoting sustainable fishing practices to ensure the long-term sustainability of Zanzibar's octopus populations [35].

Seasonal recruitment patterns observed at both sites suggest specific times of the year when environmental conditions are suitable for successful recruitment. Generally, biannual recruitment cohorts were determined, in both sites, with a third projecting peak in February at the Michamvi site. The two peaks could ideal coinciding with southeast monsoon wind (SEM) and northeast monsoon (NEM). The SEM typically occurs from May to September and is characterized by heavy rainfall and strong winds from the southeast [36]. This seasonal change in wind patterns affects ocean currents, leading to nutrient upwelling on the East African coast [37]. The cooler and nutrient-rich waters trigger suitable conditions for plankton blooms, which serve as food for juveniles, enhancing an initial recruitment pulse of juveniles [38]. In contrast, the NEM from November to March brings warmer and less turbulent waters, which are ideal for the maturation and reproductive success of the juveniles, creating a secondary recruitment pulse [17]. This cyclical monsoon impact on sea temperature and nutrients aligns with similar recruitment patterns observed in tropical marine ecosystems across various geographical regions, emphasizing the monsoon's important role in octopus population dynamics [18]. The third peak noticed during February in the Michamvi site could be linked to voluntary octopus closure, reflecting how localized management strategies may affect population dynamics. Contrarily, less recruitment events witnessed during stressful environmental conditions like in December were found in both sites [36]. The fact that recruitment drops to zero in December suggests that this month is unfavorable for reproduction or larval settlement, potentially due to changes in water temperature and higher predation [39]. These differences between the two sites suggest spatial heterogeneity in the conditions that influence fish recruitment on Zanzibar's reefs.

4. CONCLUSION AND RECOMMENDATIONS

This study provides comprehensive analysis of key population parameters; growth, mortality, and recruitment of *O. cyanea* in Zanzibar, offering insights into the current dynamics of this valuable fishery. The findings highlight rapid growth rates of *O. cyanea*, suggesting that the species has the potential to recover quickly if appropriate management measures are implemented. Likewise, mortality and exploitation rates were nearly optimal which could be linked with the influence of management practices on fishery’s sustainability. Recruitment was consistent throughout the year, with peaks corresponding to the SEM, NEM, and temporal octopus closures. Despite the fast growth rate, optimal exploitation, and year-round recruitment, there should be enhancement of existing regulations, including size restrictions, and seasonal closures particularly during the peak breeding seasons, ultimately to balance the exploitation with regenerating capacity, ensuring the sustainability of the fishery.

ACKNOWLEDGMENT

We are thankful to the South West Indian Ocean Fisheries Governance and Shared Growth Program (SWIOfish) project, Zanzibar, for financial support. Our sincere gratitude also goes to the administration of the Department of Natural Sciences of the State University of Zanzibar for the administrative and academic support provided in various aspects of this study.

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