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Reproductive Potential of the Mackerel Scad, *Decapterus macarellus* (Cuvier, 1833) in the Coastal Waters of Tanzania

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Abstract

This study investigated the reproductive biology of *Decapterus macarellus* locally known as "Msumari", one of the most economically important scad fish along the coastline of Tanzania. Fish samples were collected from ring net artisanal fishers operating in Tanga and Bagamoyo coastal waters, monthly between April 2019 and September 2020. Findings indicated that *D. macarellus* spawns throughout the year with peaks in August at Tanga and September at Bagamoyo. Overall sex ratios (M: F) were 1:1.03 (Tanga) and 1:1.2 (Bagamoyo) in favour of females. The males and females of *D. macarellus* at Tanga attained the first maturity at 145.5 mm and 153.2 mm, respectively, whereas at Bagamoyo males attained first maturity at 149.9 mm and females at 156.9 mm. Batch fecundity was not statistically significant (U = 500.5; p = 0.73), with Tanga having mean values (± SE) of 46,105.9 ± 4243.4 ova and Bagamoyo 43,082 ± 2272.9 ova. Although this species appears to spawn all year round, management interventions such as seasonal closure and reduced fishing effort should be used during their spawning peaks to protect the spawners, recruits and ensure the species' long-term survival in the Tanzanian coastal waters.

Keywords: Scad; *Decapterus macarellus*; reproductive potential; ring net fishery; Tanzania.

Introduction

The Mackerel scad, *D. macarellus* (Cuvier, 1833), locally known as "Msumari" is among the most important small pelagic species caught together with other small schooling pelagic fishes along the coastline of Tanzania. Its importance emanates from its dominance in the small pelagic fish catches (van der Elst and Everett 2015). In addition, its smaller size compared to other scads (Bianchi 1985) makes it relatively cheaper, hence easily affordable to most local people along the coast. Like other small pelagics, scads including *D. macarellus* in Tanzania are mainly caught using ring nets operated by motorized dhows and large boats that involve light attraction during moonless nights (Muhando and Rumisha 2008). Fishing pressure on this group of fish has increased from 525 ring nets in 2018 (MALF 2018) to 666 ring nets in early 2020 as a result of rising demands both inside and outside the country (Sekadende et al. 2020).

A thorough understanding of reproductive biology is essential for assessing the effects of fishing pressure on fish populations and that could enable developing appropriate management strategies. Stock reproductive potential data are commonly used to determine harvesting limits and optimal harvesting strategies (Jakobsen et al. 2009). However, there is a paucity of biological information on scads, particularly *D. macarellus*, not only in Tanzania, but also throughout the Southwest Indian Ocean (SWIO) region. Currently, the knowledge on the biology of scads in the SWIO region is limited to two studies; one on the reproduction, age and growth of *D. macrosoma* from Mozambique (Sousa and Gjøsaeter 1987) and another on the feeding habits of *Selar clumenopthalmus* from Reunion (Roux and Conand 2000). Hence more studies are required to form a scientific basis for their conservation.

Studies and knowledge regarding age, growth and reproductive characteristics of fish are imperative inputs in the assessment and management of particular fish stocks. Such studies and knowledge are essential in the generation of valuable information about recruitment, longevity, mortality and stock structure, all of which can be used to ensure proper exploitation of a stock (Parmar and Bhatia 2014). Management measures such as minimum fish sizes to be landed, closed areas and season (Morgan 2008) are based on the reproductive characteristics of fish stocks. This study therefore, provides important information about spawning season, maturity status, size at first maturity, fecundity, and gonado-somatic index of *D. macarellus*, the knowledge that is essential in guiding proper management of such species in Tanzania, and the SWIO region.

Materials and Methods

Study areas

This study was conducted in Tanga and Bagamoyo coastal areas. Tanga is located in the northeastern part of Tanzania, while Bagamoyo is located in the Middle Eastern part. Each study area was represented by one study site with Kasera landing site located at S 05° 05′15.1" E, 039° 07′45.8" representing Tanga and Custom site located at S 06° 26′23.6" E, 038° 54′33.5" representing Bagamoyo (Figure 1). The sites were chosen based on the presence of a high number of ring net artisanal fishers as well as higher landings of small pelagic fishes (Muhando and Rumisha 2008), which guaranteed an adequate sample size. The locations of the two areas helped in the determination of whether the geographical position has any influence on the reproductive potential of this species.

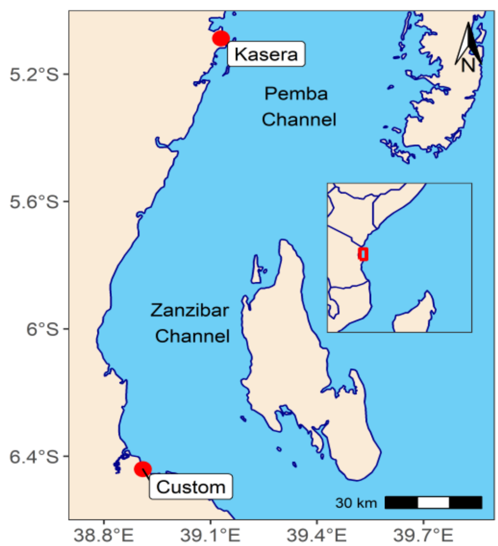

Figure 1: Location of sampling sites along the coasts of Tanga and Bagamoyo.

Samples and data collection

Sample collection

Fish samples were collected monthly from April 2019 to September 2020. At each site, fish samples representing a particular month were collected for four consecutive days. Fish samples comprising of all landed small pelagics were purchased from pre-identified ring net artisanal fishers who operated during moonless nights. In each sample, individuals of *D. macarellus* were sorted out after being identified using a fish taxonomic key by Smith (2003) and Bianchi (1985). The samples were kept chilled in boxes to slow down the bacterial digestion process before further analysis.

Data collection

The total length (TL) of each specimen was measured to the nearest millimetre (0.1 mm) using a measuring board, while the total body weight (TW) and gonad weight (GW) was measured to the nearest gram (0.01 g) using a digital sensitive balance. The sex of each individual fish was determined through macroscopic examination of the gonads after dissection, whereby the shape, the colour of testis and ovaries were used to assign sex and the gonadal maturity stages of the fish. The gonadal maturity stages were assigned based on five stages (I = immature, II= maturing virgin and recovering spent (still immature), III = Developed (mature), IV = Spawning/Ripe and V = spent) as per Holden and Raitt (1974). Sex ratios were expressed as the proportions of males to females.

Timing of spawning activities was established using (i) Maturity stages and (ii) Gonadosomatic index (GSI) of the fish. The gonadosomatic index was determined as

$$\mathrm{GSI} = \frac{\text{Paired gonadal weight}}{\text{Eviscerated weight of fish}} \times 100$$

The spawning period was therefore deduced from the seasonal fall in the values of GSI in relation to the proportions of maturity stages.

The size at which 50% of the fishes were mature was regarded as the size the species attained maturity for the first time. Only mature individuals in stage III and above were considered for determination of size at 50%. The total length at first maturity (TL_{50}) was calculated using a Bayesian estimation for the logistic regression model by involving openBUGS computer software (CMFRI 2017). The total numbers of both mature and immature individuals were counted for both sexes for each length class of 1 mm interval, and then the proportion of mature individuals [$P_{(x)}$] was calculated. The Logistic regression model to fit sigmoid curves to the proportion of mature individuals by length was defined as;

$$P(\chi) = \frac{e^{b}0 + e^{b_1}\chi}{1 + e^{b_0} + b_{1_\chi}}$$

Where, $P_{(\chi)}$ is the probability that a fish is mature in a given length. The parameters in the model b_0 and b_1 determine the shape and location of the sigmoid curve.

From this formula, the logistic regression model for estimating size at first maturity was given as;

$$x = \frac{\ln\left(\frac{P}{1-P}\right) - b_0}{b_1}$$

Where b_0 and b_1 are the estimates of the parameters in the logistic regression model, and p is the proportion of mature fish having length x in the observed data. The Markov Chain Monte Carlo (MCMC) simulation technique was used to find the posterior distribution that fits a model and draw samples from the joint posterior distribution of the model parameters (Ojo et al. 2017).

The batch fecundity of each female was determined by counting the hydrated eggs from mature gonads in stages III and IV using a volumetric method. Ovaries were preserved in bottles containing Gilson's fluid to facilitate the release of eggs from the ovarian tissues. Then samples of ovaries in bottles were kept at room temperature for three months, but frequently agitated to facilitate the release of the eggs/ovaries from the ovarian tissues. Thereafter, the eggs were cleaned with tap water then diluted with water at a volume ranging from 200 ml and 3000 ml. The mixture of eggs and tap water was transferred into plastic jars of 200 mm diameter and 175 mm height. The mixture was stirred using a plastic ruler until evenly distributed before a 1 ml sub-sample was taken using a 1 ml scoop. The eggs were then counted under a compound Zeiss microscope at X 2.25 magnification. The average of three sub-samples was used in the analysis and was considered as the number of ova in a mixture of specified volumes (Murua et al. 2003). The batch fecundity was estimated as per Holden and Raitt (1974) as follows;

$$F = \frac{n \times V}{v}$$

Where n = number of eggs in the subsample, V = volume to which the total number of eggs is made up and v = volume of the subsample. The relationships between batch fecundity (BF) and size (total length (TL), and body weight (BW)) and ovary weight (OW) were established using linear regression analysis. For egg diameter measurements, the same procedures of preserving the gonads in Gilson's fluid as in fecundity analysis were followed, except that for this measurement, ovaries from stages I to IV were all included in the analysis. Five ovaries for each stage from both sites were analysed. One-millilitre subsample of the mixture was drawn and then placed on a microscope for measurements. Diameter of 100 ova was randomly measured per ovary and the measurements for all five ovaries in each maturity stage were used to establish ova diameter frequency polygons. The egg diameter (in µm) was measured at a X 4 magnification using a compound microscope CAM equipped with a Top view 3.7 software mounted to the computer and recorded.

Data analyses

The normality of the data was checked with Shapiro-Wilk test and homogeneity of variances was tested by Levene's test. All data that did not show normal distribution were log (x + 1) transformed before further analysis. The difference in mean GSI values among months were tested using Kruskall-Wallis test, which was followed by Dunn-Bonferroni–a *post hoc* multiple test. The geographical variation effect in mean GSI values of the two sexes was tested using two-sample *t*-test. Chi-square test was used to test the variation in the sex ratio and differences in size at first maturity. The difference in batch fecundity estimates between study areas was tested using the Mann- Whitney U test. Linear regression was applied to determine the relationship between batch fecundity and body sizes (total length and weight of the fish) and ovary weight. Statistical data analyses were performed using Minitab 17.0, SPSS 20, Origin 8.5 analytical software and R version 4.0 program. A 0.05 significance level was used for all the tests.

Results

Gonadosomatic index

The monthly average gonadosomatic index (GSI) for *D. macarellus* ranged from 0.17% to 2.30% for males and 0.34% to 4.30% for females at Kasera (Tanga), whereas at Customs (Bagamoyo), the values ranged from 0.20% to 3.62% for males and 0.26% to 3.77% for females. The mean GSI of both sexes at the two study areas were consistently higher during the southeast monsoon (June to September) coinciding with the presence of a high proportion of ripe gonads (stage IV). Other small peaks were observed in February and January in Tanga and Bagamoyo, respectively. Moreover, the highest GSI values of both sexes of *D. macarellus* from Tanga and Bagamoyo occurred in August and September, respectively (Figures 2a & 2b). On the other hand, higher proportions of juveniles (individuals in stages I and II) were observed from November to December and October to December in Tanga and Bagamoyo, respectively. An additional high proportion of juveniles was noted from March to May in Tanga.

The mean female GSI varied significantly among months (Kruskall-Wallis test, $H_{(8)}$ = 547.13, p = 0.000 and $H_{(8)}$ = 588.7, p = 0.000 in 2019 and 2020, respectively, at Tanga; $H_{(8)}$ = 665.91, p = 0.001 and $H_{(8)}$ = 1,249. 86, p = 0.000 in 2019 and 2020, respectively, at Bagamoyo). The mean male GSI followed a similar pattern across the months (Kruskall-Wallis test, $H_{(8)}$ = 427.50, p = 0.000 and $H_{(8)}$ = 617.28, p = 0.000 in 2019 and 2020, respectively, at Tanga; and $H_{(8)}$ = 508.87, p = 0.000 and $H_{(8)}$ = 1018.02, p = 0.00 in 2019 and 2020, respectively, at Bagamoyo). The Dunn-Bonferroni *post hoc* test revealed peak spawning in the months of August for Tanga and September for Bagamoyo for the two sexes and had higher significant different values compared to almost all other months ($p = 0.000$) at both sites with exception of July and September in Tanga and in July and August in Bagamoyo ($p > 0.05$). Moreover, the gonado-somatic index (GSI) values differed significantly between sexes, with females possessing higher values than males ($t_{(3463)} = -13.81$; $p = 0.000$ and $t_{(4795)} = -2.507$; $p = 0.012$ at Tanga and Bagamoyo, respectively). Furthermore, the mean GSI for the two sexes was significantly higher in Bagamoyo than in Tanga ($t_{(3234)} = -17.09$; $p = 0.000$ and $t_{(4774)} = -6.58$; $p = 0.000$, for males and females, respectively).

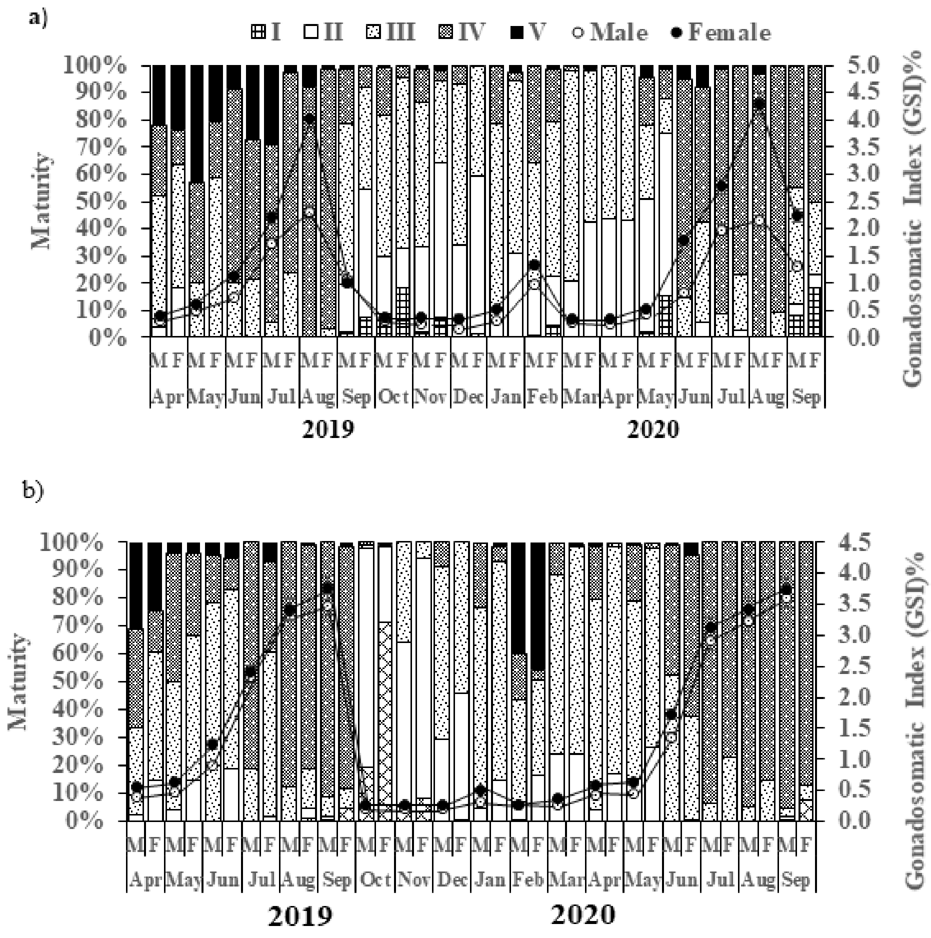

Figure 2: Monthly variation in mean gonadosomatic index (GSI) and maturity stages of *D. macarellus* from (a) Kasera (Tanga) and (b) Customs (Bagamoyo). Maturity Stages: I = immature, II = maturing virgin and recovering spent, III = Developed (mature), IV = Ripe and V = spent).

Size at first maturity

The total fish length at first maturity indicates that males attained the first maturity at smaller sizes than females in both areas. The TL at 50% of males and females in Tanga was estimated at 145.5 mm and 153.2 mm, whereas in Bagamoyo the size was 149.9 mm for males and 156.9 mm for females (Figure 3a & b). The difference in size at first maturity between males from Tanga and Bagamoyo were not significant (Chi-square test, $\chi^2_{(1)} = 0.054$, $p = 0.816$). Similarly, the differences in size at first maturity between females from Tanga and Bagamoyo were not significant ($\chi^2_{(1)} = 0.052$, $p = 0.820$).

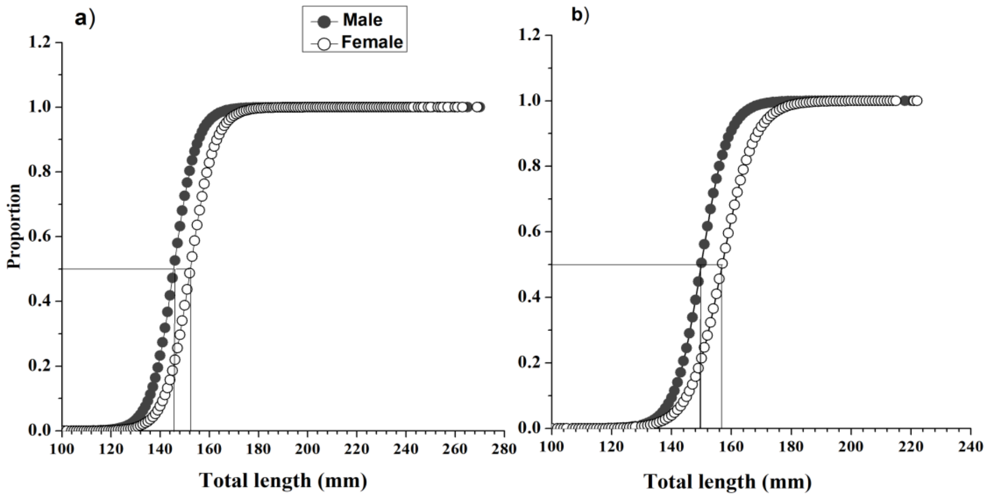

Figure 3: Sizes at-first sexual maturity of male and female *D. macarellus* from (a) Tanga and (b) Bagamoyo.

Sex ratio

A total of 4,267 and 4,809 specimens of *D. macarellus* were sexed at Tanga and Bagamoyo, respectively. The overall sex ratio of *D. macarellus* in Tanga was 1:1.03 (M: F) which was not significantly different from a normal ratio of 1:1 ($\chi^2 = 1.3$; $df = 1$; $p = 0.25$). For Bagamoyo, the overall sex ratio was 1:1.2, being significantly higher in favour of males ($\chi^2 = 56.88$; $df = 1$; $p = 0.001$).

Fecundity

The number of hydrated eggs per female *D. macarellus* ranged from 11,733 to 90, 667 with a mean count (± SE) was 46,105.9 ± 4243.4 eggs for fish of 155 and 250 mm, respectively, in Tanga, and from 23,167 to 80,333 with a mean of 43,082.8 ± 2272.9 eggs for fish of 174 mm and 222 mm, respectively, in Bagamoyo. The relative fecundity ranged from 259.7 to 653.8 eggs per g of fish with a mean (± SE) of 547.2 ± 21.3 eggs per fish gram in Tanga, whereas at Bagamoyo, it ranged from 531.1 to 807.7 eggs per g of fish with an average (± SE) of 661. 9 ± 19.9 eggs per fish gram. The linear regression analysis indicated an increase in batch fecundity (BF) with total length (TL), weight (W) and ovary weight (OW) (Figures 4 & 5). The relationships between batch fecundity and total length was significant ($F_{(1, 32)} = 166.0$; $p = 0.000$, $r^2 = 0.84$ and $F_{(1, 29)} = 118.0$; $p = 0.000$, $r^2 = 0.80$) for Tanga and Bagamoyo, respectively (Figure 4a and 5a). The relationship between batch fecundity and body weight was also significant ($F_{(1, 32)} = 188.2$; $p = 0.000$, $r^2 = 0.85$ and $F_{(1, 29)} = 132.9$; $p = 0.000$, $r^2 = 0.82$) for Tanga and Bagamoyo, respectively (Figure 4b and 5b). The relationship between batch fecundity and ovary weight was less strong as compared with total length and weight, $F_{(1, 32)} = 61.42$; $p = 0.000$, $r^2 = 0.66$ and $F_{(1, 29)} = 9.44$; $p = 0.005$, $r^2 = 0.25$) at Tanga and Bagamoyo, respectively (Figure 4c and 5c).

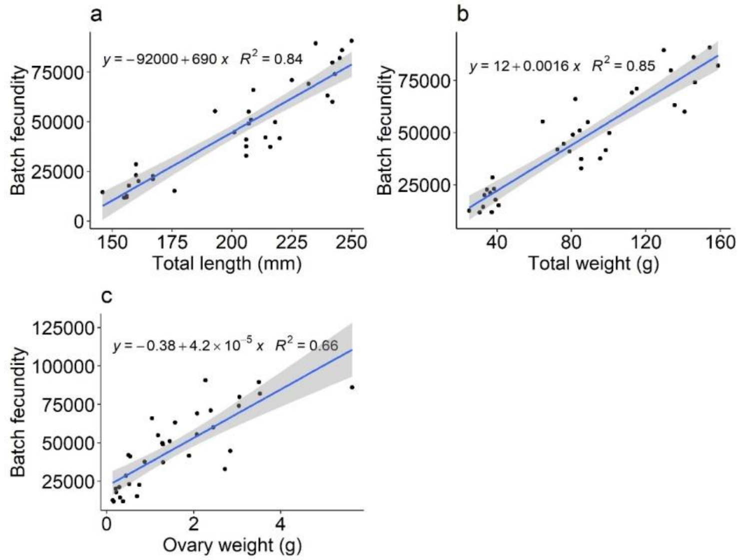

Figure 4: Relationship between batch fecundity and total length (a), total weight (b) and ovary weight (c) of *D. macarellus* at Tanga. Lines represent the linear regression.

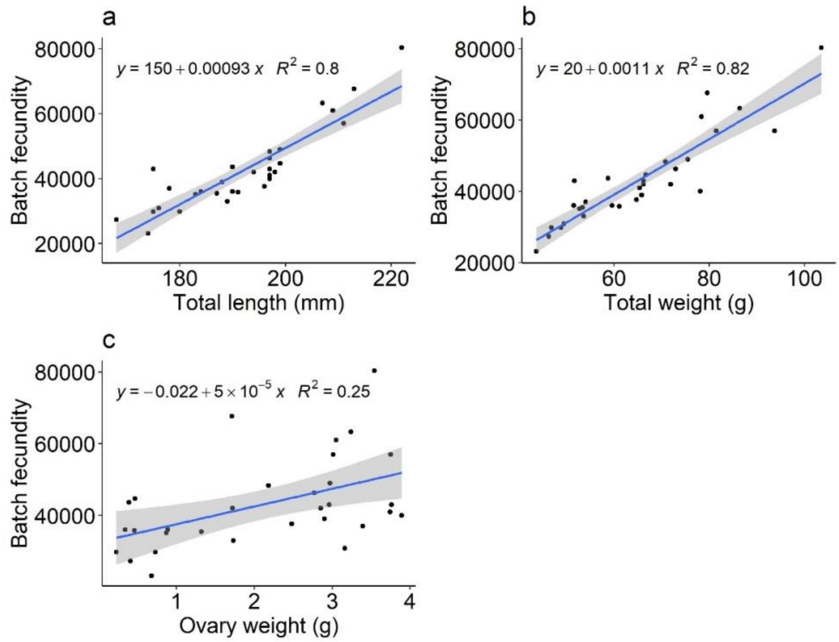

Figure 5: Relationship between batch fecundity and total length (a), total weight (b) and ovary weight (c) of *D. macarellus* at Bagamoyo. Lines represent the linear regression.

Ova diameter

The size of eggs of *D. macarellus* from Tanga indicated an increasing trend from 26. 37 ± 0.96 µm to 424 .09 ± 6.05 µm for a female of stages I to IV (Figure 6). A similar trend was observed for eggs from Bagamoyo with an increase in size from 19.44 ± 1.27 µm to 513.32 ± 4.83 µm (Figure 6). The egg sizes of full mature females (stage IV) were significantly larger than those of maturity stage III, ($t_{(727)}$ = -22.94; p = 0.000 and $t_{(637)}$ = -29.77; p = 0.000 in Tanga and Bagamoyo, respectively). The findings further showed that the immature (stages I and II) as well as mature and ripe (stages III and IV) ovaries in both areas depict unimodal frequency distribution (Figure 6a and b).

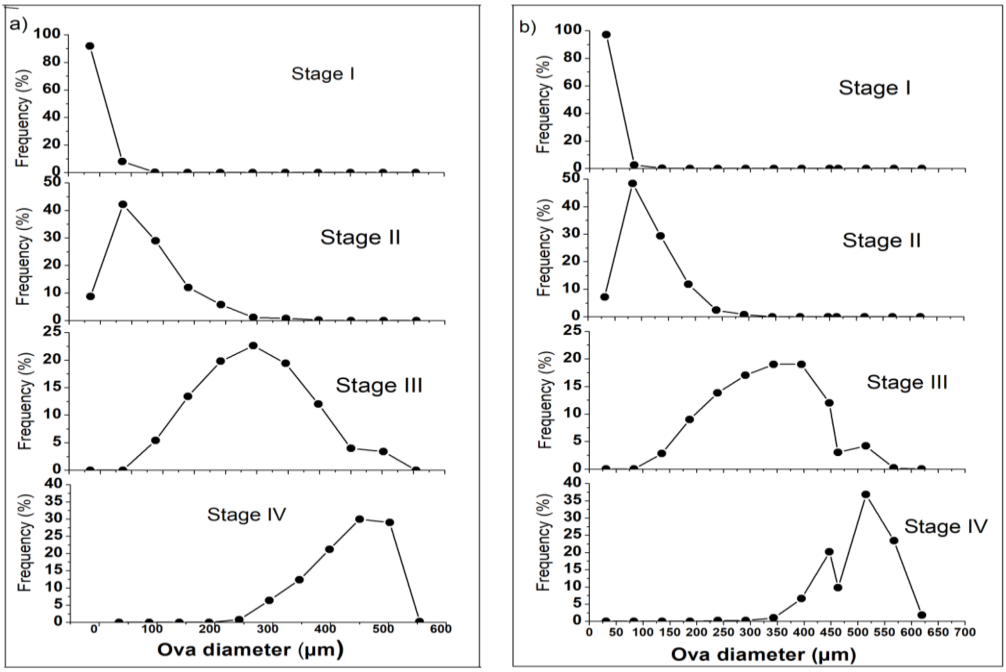

Figure 6: Ova diameter frequency distribution of *D. macarellus* from a) Tanga and b) Bagamoyo.

Discussion

The occurrence of higher values of GSI which corresponded with a high proportion of ripening and full ripe eggs (stages III and IV individuals) over several months during this study suggests a unimodal with protracted spawning pattern for *D. macarellus*. Similar observations were made in Cabo Verde where the spawning of *D. macarellus* occurred between March-April and July-October (Costa et al. 2020), and in Japan where the spawning of *D. macarellus* occurred between April to July (Shiraishi et al. 2010). Protracted spawning behaviour has also been reported in other species of the same family, including *D. russeli* in India (Poojary et al. 2015) and *D. macrosoma* from the coastal waters of San Fernando, Indonesia (Rada et al. 2019).

The peak reproductive period of this species in the present study (August for Tanga and September for Bagamoyo) is contrary to that observed in Cape Verde (March and July) (Costa et al. 2020). The observed disparities could be due to differences in the onset of the favourable conditions that are often synchronized with the spawning activities including food availability, weather and hydrographical conditions that vary from place to place (Poojary et al. 2015). Cape Verde is at about 15°N, 23°W experiencing a warm Gulf stream, whereas the study areas are located at 5°S, 38°E and 6°S, 38°E. The present study revealed that spawning occurred from May at both sites, coinciding with the usual long rainy season along the Tanzanian coast which starts in March to May ensuring plenty of food for enhanced development of the gonads and spawning thereafter. The other small spawning peaks also coincide with the short rains period that prevails in September and October.

The significantly higher GSI values observed for females as compared to males in both areas is influenced by the gonadal weight especially when they ripen. The female reproductive cells (eggs) are usually bigger compared to the sperms because much more energy is invested in their production for the nourishment of the fry.

The attainment of sexual maturity by males of *D. macarellus* at a smaller size than females as observed in the present study is a characteristic of most fish species inhabiting tropical waters. This could be attributed to the amount of energy directed towards gonad development between the two sexes (Morgan 2004). Males require less energy for gonad development and maturation, and therefore take a shorter time compared to females that need a large amount of energy for the development of the eggs which are many times bigger compared to male reproductive cells, and therefore require longer time which is translated to an increase in the body sizes. The sizes at first maturity for both sexes of *D. macarellus* observed in the present study were relatively smaller compared to those reported in Prigi waters, Indonesia where size at first maturity was at TL of 240.3 mm and 239.3 mm for males and females, respectively (Bintoro et al. 2020), and 177 mm TL in North Sulawesi, Indonesia, for both sexes (Pratasik et al. 2020). The observed differences in sizes at first maturity in the same species inhabiting different places can be attributed to high fishing mortality which is known to induce early maturation to enable the fish to compensate for the losses due to fishing (Lappalainen et al. 2016).

The overall sex ratio of 1:1 (M: F) that was observed in Tanga could be contributed by the major type of fishing gears used to catch the small pelagic fish species, i.e. the ring net which is unselective, and therefore the likelihood of having a sex ratio of almost 1: 1 being greater. This state also suggested a stable state or equilibrium in population as has also been observed in Prigi waters, Indonesia (Bintoro et al. 2020). On the other hand, the slight dominance of females observed in Bagamoyo translates to a healthy reproductive potential of a fish population which is determined by the number of females available for egg production. A male-dominated sex ratio may affect the population and viability of sensitive stocks (Ospina-Alvarez and Piferrer 2008). The dominance of males in the overall sex ratio of genus *Decapterus* is not uncommon, as it has also been observed in other places including for *D. macarellus* in Samudera, Indonesia (Widiyastuti et al. 2020), and for *D. russelli* in Maharashtra, India (Poojary et al. 2015).

The present study revealed a direct correlation between batch fecundity with size (total length, total weight) and ovary weight in both study areas. Similar observations were made for species within the same genus, i.e. *D. russelli* from Maharashtra waters, India (Poojary et al. 2015) and *D. punctatus* from Florida waters in the USA (McBride et al. 2002). Such correlation indicates an isometric type of growth, meaning that an increase in length is accompanied by an increase in weight thereby creating more space for accommodating more eggs (Jonsson and Jonsson 1997, Da Silva et al. 2019).

Conclusion

This study revealed that *D. Macarellus* exhibited protracted spawning which occurs between June and September for both Tanga and Bagamoyo, with peaks in August and September, respectively. This kind of reproduction is a strategy of the species to ensure its continued survival in the environment. On the other hand, the findings showed that 1:1 (M: F) sex ratio of this species was influenced mainly by the type of fishing gear used to catch the fish from which the samples were taken. Such a ratio is not healthy in terms of reproduction potential which in most fish species is determined by the large number of females that are responsible for egg production. Therefore, the management of this species should be directed at minimizing the fishing pressure on small pelagics by introducing seasonal closures especially during peak spawning season and the next two months to protect the immature fish and by controlling the mesh size of the ring nets used to enable immature fish to escape to minimize recruitment and growth overfishing, respectively.

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