Western Indian Ocean J. Mar. Sci. Vol. 13. No. 1, pp. 47 - 56, 2014

Reproductive Biology of the Common Octopus (*Octopus vulgaris* Cuvier, 1797) in South Kenya

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Keywords: *Octopus vulgaris*, reproduction, Shimoni, Vanga, Kenya

Abstract — Although common octopus catches are increasing globally, lack of information on the reproductive biology of the species has been a major concern in its management, particularly in Kenya. The present study aimed to investigate the reproductive biology of common octopus at Shimoni and Vanga on the Kenyan south coast. Sampling was undertaken monthly from November 2010 to November 2012 using a traditional fishing spear. The body weight (BW), total length (TL), dorsal mantle length (DML), ventral mantle length (VML) and gonad weight was recorded for each specimen. Maturity stages and gonadosomatic indices (GSI) were determined using standard methods. A total of 1 599 specimens (746 males and 853 females) were collected. The sex ratio was 1:1.1 (males: females) at both Shimoni and Vanga during the study period. Sexual staging of gonads indicated that the common octopus was breeding year round with a spawning peak from June to August. Fecundity estimates ranged from 5 200 to 389 000 oocytes (mean 154 057.6 ± 29 132). The lowest gonadosomatic index values were recorded during the month of September, indicating the end of the spawning period. The female length at first maturity ($DML_{50\%}$) was 10.8 cm, that for the male was 10.5 cm.

INTRODUCTION

The common octopus has been shown to spawn year-round with two main peaks in spring and autumn, although this varies depending on the study site (Hernández-García *et al.*, 2002; Silva *et al.*, 2002; Caverivière *et al.*, 2002; Oosthuizen & Smale, 2003). Zguidi (2002) reported that female common octopus normally attain sexual maturity at an average weight of 1 200-1 450 g in the Gulf of Gabès, Tunisia. He further found that females spawn from February to September with a peak between March and July. Mature males were recorded all year round. The breeding season was preceded by an inshore migration in autumn, with males migrating before the females (Zguidi, 2002). In early spring, a large number of adult females isolated themselves in shelters for spawning (Caverivière, 1990).

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Because of their solitary lifestyle, mating in common octopus does not involve long-term pairing, monogamy or intricate courtship (Hanlon & Messenger, 1996). Common octopuses are oviparous and have separate sexes with no sex reversal or hermaphroditism. After a successful mating and when conditions are right for fertilization, a female lays 100 000-500 000 eggs (Hanlon & Messenger, 1996). These are attached to the substratum inside the den, either individually or in a clump, and she protects and cares for them until they hatch. The hatchlings are then carried away by currents and they feed on plankton for 45-60 days. Only a few of the hatchlings survive to adulthood (Scheel, 2002). Sexual maturity drastically changes the female's life processes and activities. Her body stops growing and she remains in the den without food, discontinuing eating for the rest of her life. According to Anderson *et al.* (2003), female common octopus die soon after their eggs hatch as they are too weak to eat due to a massive decrease in their digestive gland weight. After mating, male octopuses are often seen engaged in undirected activities, even during the day, in the wild and in captivity. In captivity, this behaviour may continue for some time but, in the wild, it probably results in the octopus quickly becoming an easy prey. The entire life cycle of common octopus only lasts between twelve and fifteen months (Katsanevakis & Verriopoulos, 2005).

Gonzalez *et al.* (2011) found that the gonadosomatic index of female common octopus increased with sexual maturation in the Gulf of Alicante in the north western Mediterranean. Maximum values of the index occurred when reproductive activity was at its highest. In males, the testis and the Needham sac increase in weight before the beginning of the spawning season (Mangold, 1983)and males usually reach sexual maturity ahead of the females, but this does not prevent reproduction (Silva *et al.*, 2002). This is possible because females store sperm in their oviducal gland until they are sexually mature and the ova are ready for fertilisation (Hanlon & Messenger, 1996). The female can retain sperm inside their oviducal gland for up to two thirds of their life span. This also allows the females to collect sperm sacs from various partners before fertilisation of eggs.

Information on the common octopus reproductive biology is important as it provides an insight to the fishery needed for its management. For example, while fecundity studies provide an understanding of the reproductive potential of the species, information on the spawning season, mode of reproduction and spawning migrations yield information on the recruitment potential of the stock. The small-scale fishery on the common octopus is of great soci0-economic importance on the Kenyan coast and it is an valuable resource, yielding almost 394 metric tonnes a year (McClanahan & Mangi, 2001). Nevertheless, no reproductive biology studies have been undertaken on the species in Kenyan coastal waters (State Department of Fisheries, unpubl. data). This study on the reproductive biology of the species is intended to inform policy in the management of the fishery in Kenya.

METHODS

Sampling for common octopus was carried out at Shimoni and Vanga along the Kenyan South coast between November 2010 and November 2012 (Fig. 1). The two study sites are among the main fishery landing sites on the Kenyan coast. Shimoni is at 4°38' S; 39°23' E, lying some 70 km south of the main octopus markets in Mombasa. Vanga is at: 4°39' S; 39°14' E and it is the southernmost fishing village on the Kenyan border with Tanzania.

Common octopuses were collected on a monthly basis at both Shimoni and Vanga, predominantly during low spring tides, using a traditional spear. The following was recorded for each individual: sex, total body wet weight (BW), total length (TL) - measured from the end of the longest arm to the posterior end of the mantle, total gonad wet weight, dorsal mantle length (DML) - measured from the midpoint between the eyes to the posterior tip of the body, and the ventral mantle length (VML) - measured from the anterior border of the mantle ventral midline to the apex of the mantle.

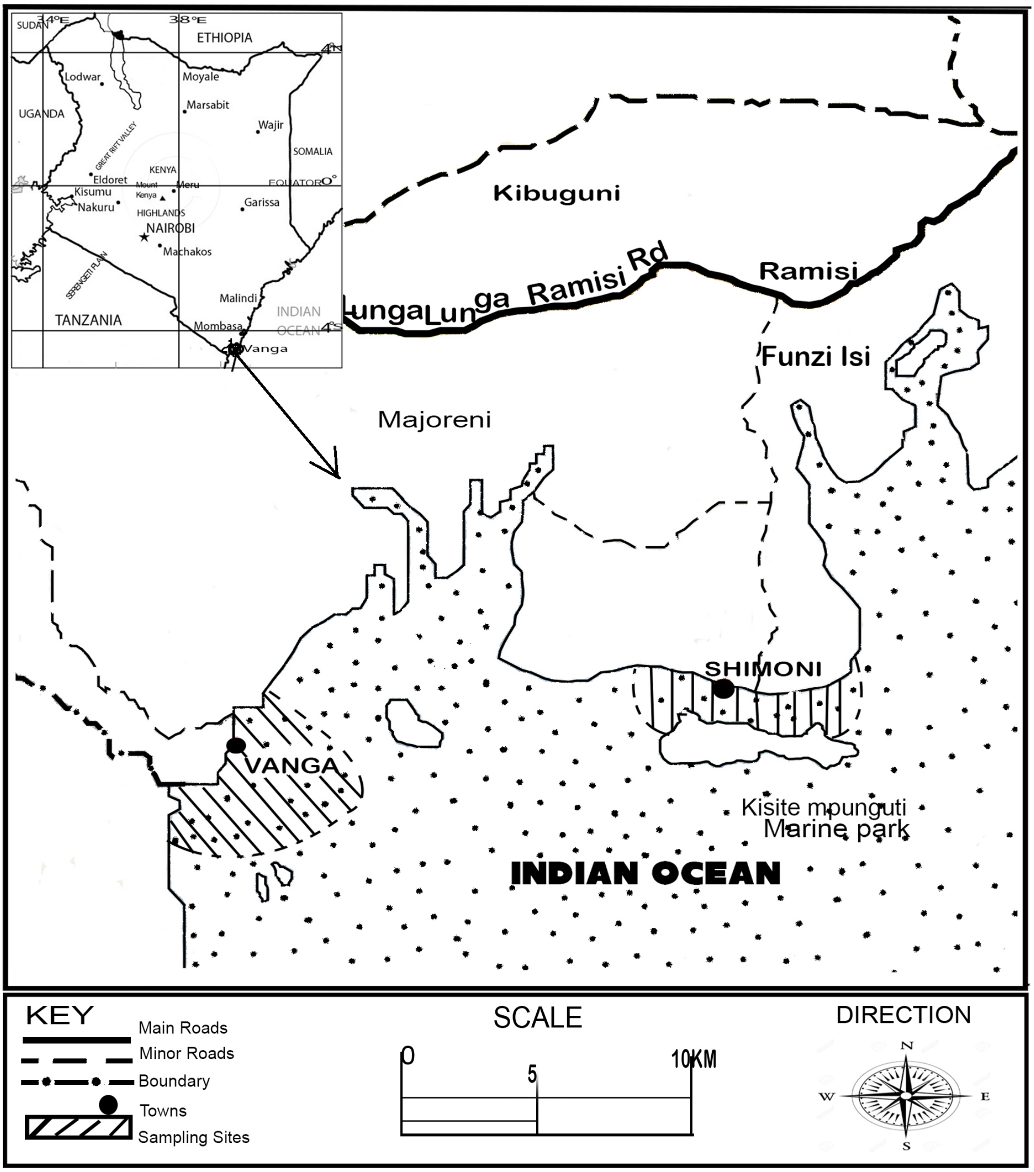

Figure 1. The location of the study areas, Shimoni and Vanga, on the south coast of Kenya.

Assessment of the sex ratio

Sex was determined by the presence of a spermatophoric groove and hectocotylus on the third right arm of males and the absence of these features in females. Only common octopus whose sexes could successfully be determined were used to calculate sex ratios and these were analysed on a monthly, seasonal and annual basis.

Significant deviations in the ratios from 1:1 were tested using the chi-squared (χ^2) test.

$$\chi^2 = \sum (f-F)^2/F$$

Where;

f = observed number of individuals of each sex.

F = expected number of individuals of each sex.

Assessment of the size at first maturity

Maturation and reproduction were assessed using a four point maturity scale (Inejih, 2000) for males (Table 1) and five point maturity scale for females (Table 2).

Common octopus belonging to maturity stage II onwards were considered mature and were used in the size at first maturity calculations; all the sampling data were pooled for this. The DML at which 50% of common octopuses were mature was considered the length at first maturity.

The size at first maturity ($DML_{50\%}$) was estimated by fitting the length-frequency distribution of the proportion (P_i) of mature females to a logistic model, $P_i = 1/(1+\exp[-a + bDML_i])$, where $DML_{50\%} = -a/b$, using nonlinear methods, and deriving the regression line by the least squares method using the Gauss-Newton algorithm (Quinn & Keough, 2002).

Here:

P_i = represents the relative frequencies of fully mature individuals in length class DML_i

'a' and 'b' = are the regression constants, and

$DML_{50\%}$ = is the dorsal mantle length at 50 % sexual maturity.

The body weight (BW) at first maturity was estimated following the same procedure.

Table 1. The four reproductive stages of male common octopus.

Stage	Description
Stage I: Immature	Indistinct accessory gland systems and testis.
Stage II: Maturing	Testis was larger than the accessory gland and visible through the wall of the genital bag.
Stage III: Mature	Testis and accessory gland of similar size and spermatophores present in the Needham's sac and/or penis.
Stage IV:Post-spawning	Testis small and striated and spermatophores present in the penis and/or Needham's sac.

Table 2. The five reproductive stages of female common octopus.

Stage	Description
Stage I: Immature	Ovary small, generally weighing <3 g with no follicles and a thick outer wall; small white oviducal glands located mid-way down very narrow proximal and distal oviducts.
Stage II: Maturing	Ovary slightly larger with a thinner wall than stage I and follicles and/or very small eggs; oviducts longer and white oviducal glands larger and positioned further up the proximal oviduct.
Stage III: Mature	Ovary very large (>20 g), packed tightly with elongated, striated but unstalked eggs; oviducal glands large and dark in colour and positioned high up the proximal oviduct.
Stage IV:Pre-spawning	Majority of remaining eggs stalked, fully formed and less compressed than in stage III; eggs present in the oviducts and dark oviducal glands, located further down the proximal oviduct.
Stage V: Post-spawning	Ovary shrunken with only follicles and a few fully-formed eggs; oviducts slightly reduced in size unless containing eggs; oviducal glands smaller but still dark in colour.

Assessment of gonad maturity

In the laboratory, portions of the middle region of the ovary were cut and preserved in Bouin's solution for histological study. These were dehydrated in an alcohol gradient (30%, 50%, 70%, 80%, 90%, 95%, 100%), cleared in xylene, embedded in paraplast wax, sectioned in 5 µm slices and stained in iron haemotoxylin and eosin (Carson, 1992). The final preparations were examined under a dissecting microscope (40× magnification) for identification of the maturity stages.

Assessment of Gonadosomatic Index

The gonadosomatic indices (GSI) were calculated by comparing the monthly frequency of males and females in each maturity stage with their monthly average body mass (Kume & Joseph, 1969).

$$GSI_m = (\text{Testis weight/ Total Tissue Weight}) \times 100$$

$$GSI_f = (\text{Ovary weight/ Total Tissue Weight}) \times 100$$

Where:
m = males
f = females

Assessment of relative fecundity

The fecundity of approximately ten female octopus with mature ovaries was analysed each month. Gonad sections from these specimens were stored in Gilson's fluid for three months in plastic bottles, vigorously shaken from time to time to aid in the release of oocytes from the ovarian walls. Before counting the eggs, the contents of each bottle were poured into a petri dish and oocytes not liberated from the ovarian tissue were removed by teasing. The oocytes were repeatedly washed in tap water and transferred to a one litre beaker containing tap water. A plastic ruler was used to stir the egg suspension vigorously to ensure an even distribution of the oocytes and, after ten strokes of the ruler, a subsample was removed using a Labsystem pipette. One aliquot usually yielded sufficient numbers of large and small oocytes to counts and measure. The oocytes were pipetted into a zooplankton chamber, and their diameter was measured using a calibrated eye-piece graticule under a dissecting microscope at 40× magnification.

The fecundity (F) of each octopus was calculated following the formula published by Simpson (1951):

$$F = (V/V_i)\, n \times (W/W_i)$$

Where:
n = number of oocytes in the subsample;
V = volume of the egg suspension;
V_i = volume of subsample;
W = weight of the ovary;
W_i = weight of fixed portion of the ovary.

RESULTS

Sex ratios

While the sex ratio (M:F) of common octopus at Shimoni was 1:1.2, at Vanga it was 1:1. The monthly ratios were variable (Figure 2) but a chi-squared test (Shimoni: $\chi^2 = 6.2$, df = 1, $p > 0.75$; Vanga: $\chi^2 = 1.7$, df = 1, $p > 0.05$) revealed no significant differences in the monthly or annual sex ratios. Seasonally, a significant difference emerged in the sex ratios ($p < 0.05$) in favour of females during the northeast monsoon (NEM) months of February-September. No significant difference was detectable during the southeast monsoon (SEM) months of May-August.

Sex ratio at different sizes

There were no significant differences (p >0.05) in the sex ratio (M:F) in most size classes at either Shimoni or Vanga up to 18 cm (Shimoni) or 19 cm (Vanga) DML, at which size only females were found (Figure 3); females clearly grew larger than males. At Vanga, only females were found in the length class of 5 cm; this was probably a sampling artefact.

Size at sexual maturity

Analysis of the length at first maturity revealed that the female size at first maturity ($DML_{50\%}$) was 10.8 cm and that of males was 10.5 cm (Fig. 4).

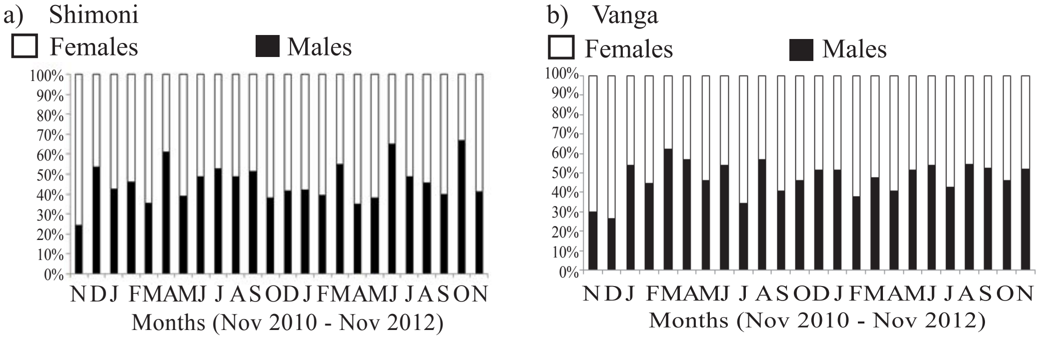

Figure 2. Variation in monthly sex ratios of common octopus at a) Shimoni and b) Vanga.

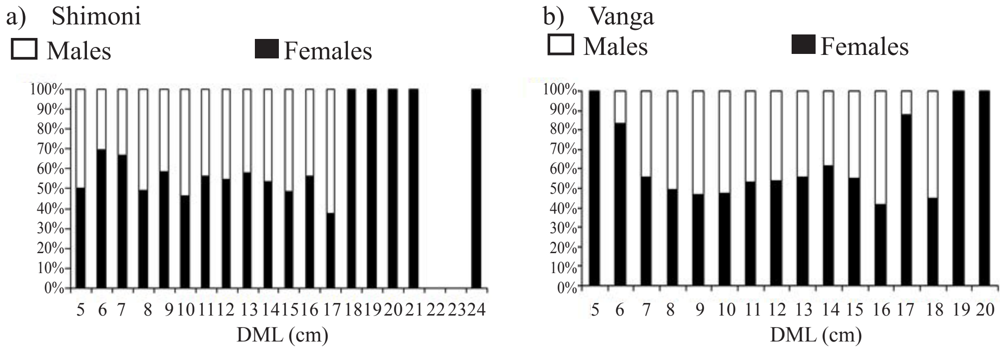

Figure 3. Sex ratios in the different size classes of common octopus at a) Shimoni and b) Vanga.

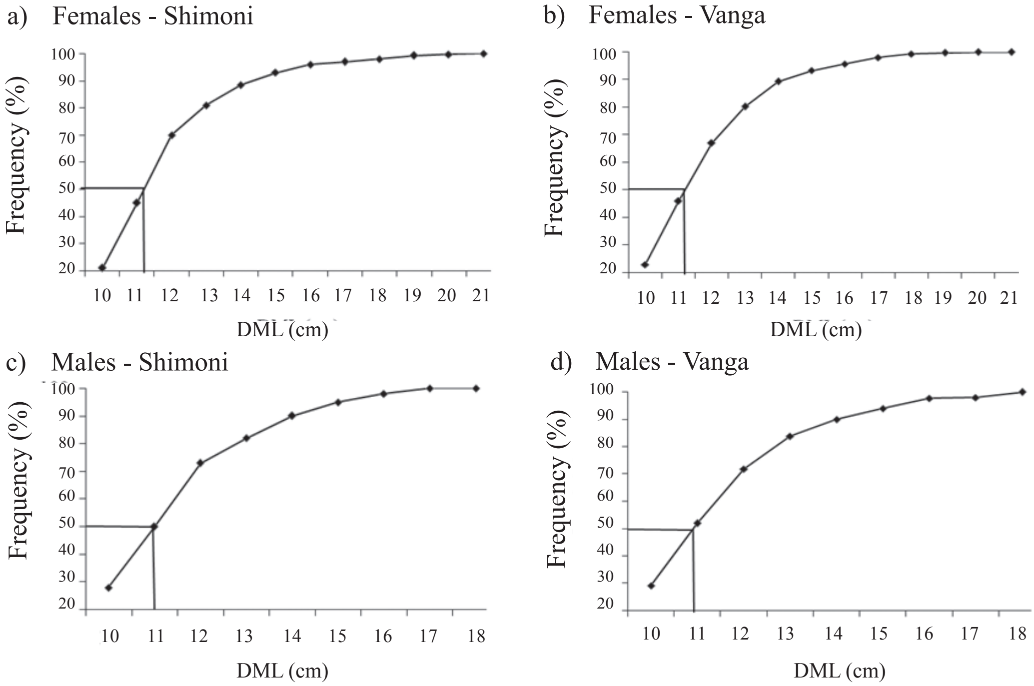

Figure 4. Cumulative frequency curves of length of maturity stages II, III and IV in common octopus in southern Kenya: a) females at Shimoni, b) females at Vanga, c) males at Shimoni and d) males at Vanga.

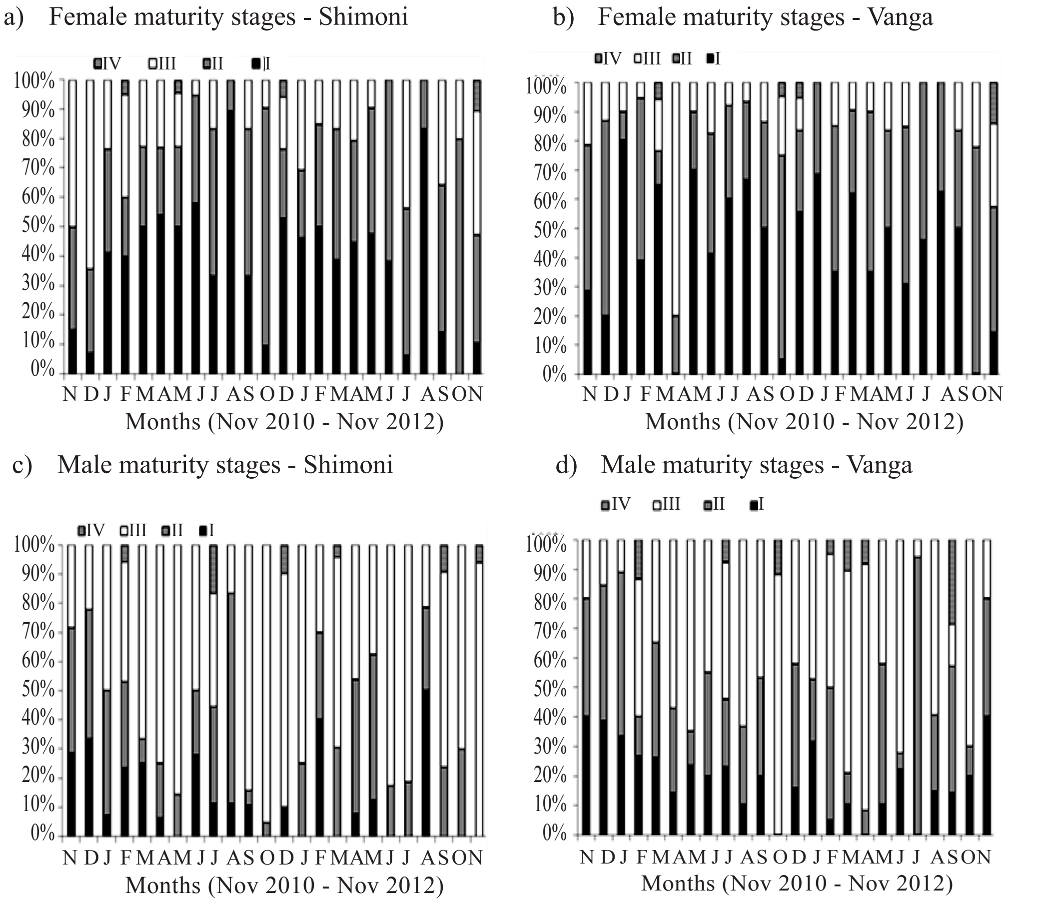

Figure 5. Monthly percentages of common octopus at different stages of maturity in southern Kenya: a) females at Shimoni, b) females at Vanga, c) males at Shimoni and d) males at Vanga.

Gonad maturity

The monthly gonad development of common octopus at Shimoni and Vanga is shown for the entire sampling period in Figure 5.

Gonadosomatic Index (GSI)

Gonadosomatic indices of male and female common octopus at Shimoni revealed that low GSI values occur during the months of August and September. High GSI values were recorded during the months of April, May, November, and December. Both sexes yielded high GSI values during the northeast monsoon, compared to the southeast monsoon. The monthly GSI values for females and males at Vanga were low during the months of August and September. High GSI values were recorded during the months of April, October, and November.

Fecundity

The lowest number of oocytes counted in a single female octopus was 5 200 while the highest was 389 000. The mean fecundity was 154 057.61 ± 29 131.97 (SD). Fecundity was highest in the months of January, September and April and lowest in the months of March, August and, particularly, May. No significant difference in annual fecundity was noted ($p>0.05$, $t = -0.7279$, $d = 22$ and $p = -0.474$). Variations in the seasonal (NEM and SEM) mean fecundity were significantly different ($p<0.05$, $t = 0.5185$, $df = 22$ and $p = 0.031$). The mean diameter of the long axis of eggs in common octopus was 0.14 ± 0.02 cm.

DISCUSSION

The sex ratio recorded in the current investigation concurs with studies by Otero *et al.*, (2007), who reported a sex ratio of 1:1 for common octopus in the Balearic Islands and along the Galician coastline in the north-western Mediterranean. The dominance of females in the larger class sizes in this study (Fig. 3) was also evident in several parts of the Atlantic Ocean (Silva *et al.*, 2002). This was attributed to a number of factors, among them differences in growth rates of the two sexes (Silva *et al.*, 2002; Mangold, 1983). A slightly greater prevalence of males detectable in some months in the current study (Fig. 2) may be an indication that females were moving from fishing grounds for breeding purposes; similar shifts in the sex ratio have been found in the Mediterranean Sea (Mangold-Wirz, 1963) and Morocco-Mauritania (Hatanaka, 1979; Dia, 1988). It has been stated that such variations in the sex ratio are difficult to explain but some authors attribute it to a combination of factors such as migration associated with sexual maturation and spawning processes (Mangold-Wirz, 1963); feeding behaviour related to reproduction; post-spawning mortality; and differences in the growth rates of the sexes (Mangold, 1983). Differences in the sex ratios found in other areas could be attributed to the sampling strategy (Caverivière *et al.*, 2002). In South Africa, Oosthuizen (2003) established that females were dominant in intertidal areas but no differences were found sub-tidally. Most females found in the sub-tidal zone, where they gather for mating, were mature (Mangold, 1983).

The size at first maturity recorded in the present study of 10.8 cm DML for females and 10.5 cm DML for males was lower than that reported by Mangold (1983). Sánchez and Obarti (1993) recorded a size at first maturity of 11-13 cm DML for both males and females in Spanish Mediterranean waters. Similar studies by Guerra (1975) in the Mediterranean revealed that males reached sexual maturity much earlier than females. Dia (1988) found that males in the Gabes Gulf were smaller than females at sexual maturity. Other studies have also indicated that males reach sexual maturity earlier than females (Gonçalves, 1993; Silva *et al.*, 2002; Oosthuizen & Smale, 2003; Mangold-Wirz, 1963; Dia, 1988) but the size at which this occurs varies.

Mature females and males were collected throughout the sampling period which may indicate that common octopus spawn throughout the year on the Kenyan south coast. This concurs with the findings of Silva *et al.* (2002) and Oosthuizen and Smale (2003) in the Gulf of Cádiz and South Africa. In a similar study conducted in the Mediterranean, the reproductive period of common octopus seemed to extend almost throughout the year from January to October, but with one or more spawning peaks (Mangold-Wirz, 1963). In the present study, mature females at stage III were recorded in all months except June - August which may indicate that the majority of mature females were in their nests spawning. A high number of spent females were recorded in the months of November and December, providing evidence of a post-spawning season.

The low GSI values we encountered during the months of August and September may be an indication of reduced spawning during that period. Guerra (1975) reported that, in female common octopus, the GSI increases with sexual maturation and maximum values are attained when reproductive activity is at its highest. In males, the testis and the Needham sac (which acts as a reservoir for spermatophores before mating) increase in weight before spawning commences in females.

The range in fecundity of 5 200 and 389 000 eggs we measured in gravid females fell within the range recorded by Oosthuizen and Smale (2003) in South Africa and Silva *et al.* (2002) in the Gulf of Cádiz; their estimates fell between 12 000 and 500 000 eggs per female. The high fecundity we recorded in the month of April may be indicative of a pre-spawning peak in their development, and the drop in fecundity which commenced in June may be an indication that this was the start of spawning. The spawning season of common octopus in the Kenyan South coast may thus occur during the months of June, July and August. The mean egg diameter of 0.14 ± 0.02 cm recorded in the present study was lower than that measured by Isshiki *et al.* (2012) in Tokyo Bay, Japan, wher the mean diameter of the long axis of common octopus eggs was 0.23 ± 0.03 cm. Other similar studies by Hatanaka (1979) estimated a mean length of oocytes at 0.32 ± 0.08 cm, ranging from 0.17 to 0.49 cm. The smaller mean egg size we recorded may be attributable to the smaller mean body sizes of octopus in our study.

The northeast and southeast monsoon seasons seemed to have no influence on the spawning patterns of common octopus on the Kenyan south coast. This is in contrast with results from the Gulf of Cádiz (SW Spain) and the north western coast of Africa which revealed that a number of factors such as climatic conditions affected the spawning pattern of common octopus (Hatanaka, 1979; Hernández-García *et al.*, 2002; Silva *et al.*, 2002). In Spain, spawning peaked during spring and extended up to the onset of winter Silva *et al.* (2002).

Based on the results of this study which have revealed that female common octopus attain maturity at 10.8 cm DML and males at 10.5 cm DML on the Kenyan coast, it is recommended that a minimum size limit of 10.8 cm DML be imposed as a precautionary measure for their harvest to ensure maturation of both males and females before they enter the fishery.

Acknowledgements – GMK is extremely grateful to the Ministry of Education, Science and Technology, Kenya, for financial support which enabled him to undertake this study. Our sincere thanks also go to the artisanal fishermen, the staff of the State Department of Fisheries, Kenya Marine and Fisheries Research Institute, the University of Nairobi and all those who helped us in one way or another in this study.

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