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Size-distribution and length-weight relationship of a deep-water population of *Holothuria scabra* (Jaeger, 1833) in Zanzibar, Tanzania

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Abstract
A study was carried out on the size distribution, length-weight relationship and condition factor of a deep-water population of the commercially important tropical sea cucumber *Holothuria scabra* in Zanzibar, Tanzania. Samples were collected from fishers and supplementary information gathered. The deep water (15-20 m) population of *H. scabra* is dominated by large sized individuals that have already attained maturity. There was no significant difference in size between male and female individuals (p>0.05). The sex ratio in this population significantly differed from 1:1 in favour of male individuals (p=0.01). The results showed significant correlation between length and weight for male, female, indeterminate individuals, and pooled data, with r values of 0.681, 0.794, 0.821 and 0.680, respectively. Moreover, the b-value for male, female, indeterminate individuals and pooled data was 1.288, 1.439, 1.686 and 1.407 respectively, which revealed that individuals of deep-water *H. scabra* exhibit negative allometric growth. The mean condition factor (K) value when all data were pooled together was 4.213±0.106 indicating that individuals were in good condition and came from a healthy environment. This study fills a key information gap that is relevant to the management of the *H. scabra* fishery in the country.

Keywords: *Holothuria scabra*, Size distribution, Length-weight relationship, Condition factor, Allometric growth, Zanzibar

Introduction
Sea cucumbers constitute an important part of marine fisheries in Tanzania (Semese *et al.*, 1998) and have provided a source of income to individual collectors as well as revenue at a national level through export (Eriksson *et al.*, 2010). However, as in other producing countries across the region, the resource has already dwindled in Tanzania as evidenced by catch reduction, dominance of small size individuals (Jiddawi, 1997; Mgaya and Mmbaga, 2007; Mmbaga, 2013) and a decrease in the number of exporters (Marshall *et al.*, 2001).

Despite the crucial role played by sea cucumbers both economically and ecologically, the status of wild stocks of commercially important species is unknown and has not yet been quantified in Tanzania (Mmbaga and Mgaya, 2004), even though the resource could be at high risk. Unlike in mainland Tanzania where a total moratorium on sea cucumber fishing has been implemented for more than a decade (Eriksson *et al.*, 2010) (though its enforcement is still questionable), the situation is much worse in Zanzibar, where the fishery is still operating despite a directive aimed at prohibiting it.

As shallow water (near shore) sea cucumbers have already been depleted in Zanzibar, sea cucumber collectors are now moving further off-shore (Eriksson *et al.*, 2010); a common practice along the whole west coast of Unguja Island. This represents a significant threat to the sea cucumber population, ecosystem (Uthicke, 1999) as well as the safety of fishers (Eriksson *et al.*, 2010).

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Holothuria scabra, commonly known as sandfish, is one of the more commercially important tropical species and contributes a significant portion of the total sea cucumber catch in Tanzania (Mmbaga and Mgaya, 2004). It is a deposit-feeding species found in low-energy environments behind fringing reefs up to 20 metres deep or within protected bays and shores of the tropics (Hamel et al., 2001). The deep-water populations (>10 m depth) (Ram et al., 2016) are the last potential group of breeders that the ecosystem relies on to repopulate the dwindling shallow water population of H. scabra. However, they are at high risk of being overfished due to the existing fishing pressure which is influenced by high prices obtained for the species by collectors. With existing fishing pressure on the deep-water H. scabra population, it is most likely the species will disappear in the near future, unless appropriate and effective management measures are taken.

Knowledge on the size composition of harvested individuals and their length-weight relationships is crucial in fisheries management (King, 2007; Ahmed et al., 2018) as they provide information about the impact of harvesting on the population and distribution of different-sized individuals both temporally and spatially (Montgomery, 1995; Natan et al., 2015). The length-weight relationship is the standard method used in fisheries biology to estimate average weight of an animal at a given length group or class (Froese, 2006; Gerritsen and McGrath, 2007). Moreover, this can also be used to determine condition factor which in turn determines the well-being

Figure 1. The study site (Fuji-Kama fishing ground) in Unguja Island, Zanzibar, Tanzania.
or relative fatness of an organism and the health of its environment (Natan et al., 2015; Aydin, 2016; Ram et al., 2016). However, this information is missing for the *H. scabra* population in Zanzibar and Tanzania as a whole, especially for those found in deeper waters, which presents a key information gap that is relevant to their management. The present study aimed to determine the size distribution, length-weight relationship and condition factor (K) of deeper water *H. scabra* along the coast of Zanzibar, Tanzania.

**Methodology**

**Study site and sample collection**

This study was conducted at the Fuji-Kama fishing ground located on the west coast of Unguja Island, Zanzibar between 6°2'30"S to 6°7'30"E, 4 km off the coastline (Fig. 1). The water depth of the fishing ground is between 15-20 m and the sea floor is characterized by muddy-sandy sediment with no seagrasses. The sea cucumber population in the fishing ground is dominated by *H. scabra*. Sea cucumber samples were collected directly from the fisherman who fish within the studied fishing ground. Prior to the study, the fishermen were requested to collect all *H. scabra* encountered, regardless of size.

**Measurements**

Upon the arrival of fishers at the landing site, sea cucumbers were transferred from drums to trays filled with sea water to allow them to relax for five minutes. When they were fully relaxed, total length was measured from the mouth to the anus using a ruler to the nearest 0.5 cm. The total body weight of each individual was measured, followed by dissection and removal of all internal organs (guts, respiratory trees and reproductive system), after which the body wall weight was measured to the nearest 0.1 g. Gonad samples were taken from each individual and stored in a plastic container for microscopic examination and determination of their sex (presence of eggs or sperm). Unsexed individuals which had no sperm and eggs in their gonad were recorded as indeterminate.

**Length-weight relationship**

Length-weight relationship was estimated using the power function (Pauly, 1984)

\[ W = a L^b \]

Where \( W \) = Weight in g, \( L \) = Length in cm, \( a \) = Intercept, \( b \) = Slope

The value of \( b \) from the power function equation was tested and used to determine growth patterns of the sea cucumber (i.e. isometric growth (\( b=3 \)) or allometric growth (\( b \neq 3 \))) by using the Students t-test (after Pauly, 1984). The coefficient of determination (\( R^2 \)), that is, the degree of relation between the length and weight, was computed by linear regression analysis.

**Condition factor (K)**

Fulton’s condition factor (K) was analysed according to Pauly (1984)

\[ K = \frac{100W}{L^3} \]

Where \( K \) = Condition factor, \( W \) = weight in g, \( L \) = Length in cm

**Statistical analysis**

All data were tested for normality and homogeneity of variances using Shapiro-Wilk and Levene’s test, respectively. Chi-square was used to test whether the sex ratio significantly deviated from 1:1. The mean differences in body weight, total length and condition factor (K) between male, female and indeterminate *H. scabra* were tested using a one-way ANOVA.

**Results and discussion**

**Sex ratio**

A total of 179 individuals of *H. scabra* were collected between August and September, 2019. The number of samples collected per sampling day is presented in Table 1. There were significantly more male than female *H. scabra* in this population during the study period, with 104 (58.1%) males, 70 (39.1%) females and 5 (2.8%) sexually undifferentiated (indeterminate) individuals. The chi-square test results show that the sex ratio significantly deviated from 1:1 (\( x^2 = 6.644, df=1, p=0.01 \)).

A male-biased sex ratio for *H. scabra* has been also reported by Conand (1993), Mercier et al. (2000), Al-Rashdi et al. (2007) and Muthiga et al. (2009) from New Caledonia, Solomon Islands, Sultanate of Oman, and Kenya, respectively. However, their sex ratio values were not significantly different from 1:1. Muthiga et al. (2009), from data collected in three different years, reported a shift in sex ratio from precisely 1:1 in the first year towards significantly more males than females in the last year of their study. The same result was also reported by Natan et al. (2015) from Indonesia which is comparable to the findings of the present study.
Hasan (2005) has pointed out that a population with more male than female individuals may be an indication of increase in fishing pressure, which is also possible in the current study. As shallow water sea cucumber populations are already depleted locally, fishermen are now shifting their efforts toward deep-water populations. Other authors have interpreted this phenomenon in different ways, for example: this might be due to high mortality of larvae, juveniles and adults of female individuals (Hoareau and Conand, 2001); or limited dispersal ability of female larvae as reported for other holothurians species (Uthicke and Benzie, 1999).

Size distribution
The overall size of all collected individuals expressed as body weight (BW), body wall weight (BWW) and total length (TL) ranged from 410 to 1957.8 g (1077.63±20.75 g (SE)), 220 to 960.6 g (579.42±9.44 g (SE)), and 20 to 42 cm (29.83±0.29 cm (SE)), respectively. There was no significant difference in average size between male and female individuals (Table 2). However, female individuals were slightly longer and heavier than males. Indeterminate individuals had significantly lower body weight, body wall weight and total length (p<0.05) compared to sexed individuals (Table 2). The size distributions (total length, body weight and body wall weight) of collected individuals are shown in Fig. 2A, 2B and 2C respectively. More than 85% (153) of all collected individuals from this population had a length between 25 and 35 cm, 9.5% (17) were below 25 cm, 5% were above 35 cm, with no individuals smaller than 20 cm (Fig. 2).

Size at first sexual maturity for *H. scabra* in Tanzania has been found to be 16.8 cm (Kithakeni and Ndaro, 2004) from samples collected in Dar es Salaam, mainland Tanzania. Therefore, it can be concluded that all individuals collected in the present study had already reached maturity as they were all greater than 20 cm. Even if it is assumed that the size at first maturity is 25 cm, which is the highest ever recorded for *H. scabra* (India and Northern Australia) (Lee *et al.*., 2018), the majority (>90%) of all individuals collected in the present study would have already attained maturity. The presence of indeterminate individuals in this population does not signify that these individuals had not reached maturity, but rather that their gonads were in a resting stage during their collection. Individuals

| Date       | Number of Sample | Male | Female | Indeterminate |
|------------|------------------|------|--------|---------------|
| 24/08/2019 | 23               | 13   | 10     | -             |
| 27/08/2019 | 10               | 4    | 6      | -             |
| 29/08/2019 | 29               | 13   | 16     | -             |
| 01/09/2019 | 17               | 9    | 8      | -             |
| 05/09/2019 | 40               | 30   | 9      | 1             |
| 09/09/2019 | 34               | 18   | 12     | 4             |
| 15/09/2019 | 26               | 17   | 9      | -             |
| Total      | 179              | 104  | 70     | 5             |

Table 2. Mean size comparison between male, female and indeterminate individuals. Values on the same row with different superscripts indicate significant differences.
with gonads at different maturation stages have been reported to occur throughout the year in Tanzania (Kithakeni and Ndaro, 2002).

The present findings add to the number of studies that support the fact that large sized individuals are found in deeper waters, probably migrating from the intertidal zone as they grow bigger (Mercier et al., 2000). For instance, in the Solomon Islands, individuals >25 cm were mainly located in the deep water zone and small size individuals (4-15 cm) were found in shallow (intertidal) waters (Mercier et al., 2000). However, James (1994) reported individuals of 30-35 cm in 5-10 m depth in India which is contrary to other studies. Murphy et al. (2011) suggests that it may be difficult to find small size sea cucumbers as they burrow during the day and become active at night.

The size frequency distribution of sea cucumber populations can either be unimodal, bimodal or plurimodal (Hamel et al., 2001) depending on the population. In this study, the size (length) frequency

Figure 2. Size distribution of collected Holothuria scabra from the deep-water population. (A): Length, (B): Body weight and (C): Body wall weight.
distribution was unimodal with 12.3% of all individuals having a length of 32 cm (Fig. 2A). Conand (1994) and Natan et al. (2015) reported a plurimodal length frequency distribution with poorly defined modes in New Caledonia and Indonesia respectively. However, Basker (1994), Uthicke and Benzie (1999), and Al-Rashdi et al. (2007) recorded a unimodal length frequency distribution from India, Australia and the Sultanate of Oman, which is comparable to the present study. However, their modal value was smaller (23 and 26.9 cm) than the value recorded in the present study.

Based on published records, the maximum length and body weight of *H. scabra* ever recorded was 70 cm in China and 2 kg in India, respectively (Hamel et al., 2001). The maximum length and body weight recorded in the present study is smaller than this, but average body weight was higher than other reported values, for example: 300 g (Papua New Guinea, Sultanate of Oman, India), 335 g (Australia), 500 g (Egypt) and 580 g (New Caledonia) (Purcell et al., 2012).

Moreover, the average length recorded in the present study is quite high, exceeded only by 37 cm mean length in Egypt (Purcell et al., 2012). The values from other countries such as Australia, New Caledonia, Papua New Guinea and India ranged from 19 to 25 cm (Purcell et al., 2012). The difference in size of *H. scabra* from different populations or countries could be attributed to differences in environmental factors (Uthicke and Benzie, 1999) such as food availability (Morgan, 2001; Pitt, 2001), fishing pressure (Uthicke and Benzie, 1999; Hasan, 2005) and the depth where the samples were collected (Kithakeni and Ndaro, 2002) in addition to the actual biological differences of individuals between populations. Furthermore, it could be due to inconsistency of measurement methods between studies since body length and weight of sea cucumber are highly variable (Hamel et al., 2001).

**Length-weight relationship**

The calculated correlation coefficient (r) values for male, female, indeterminate and pooled data ranged from 0.680 to 0.821 while the respective tabulated
r values ranged from 0.114 to 0.805 (Table 3). The calculated r was found to be larger than critical r which indicates highly significant correlation between length and weight for male, female, indeterminate and pooled data. Moreover, the coefficient of determination ($R^2$) value which shows the percentage contribution of the independent variable to the dependent variable ranged from 0.411 to 0.613 (Fig. 3). The $R^2$ value in this study is smaller than that reported by Lee et al., (2018) ($R^2=0.90$), Al-Rashdi et al. (2007) ($R^2=0.80$) and Natan et al. (2015) ($R^2=0.43-0.68$) from Fiji, Sultanate of Oman and Indonesia, respectively.

The length-weight relationship results (Table 3 and Fig. 3) also show that the b values for male, female, indeterminate and pooled data ranged from 1.288 to 1.686. The b value was significantly less than 3, so it can be concluded that the growth pattern of deep-water *H. scabra* is negatively allometric. Such growth patterns have also been reported elsewhere, for example in Indonesia (b=1.264 to 2.127; Natan et al., 2013), Sultanate of Oman (b=2.18; Al-Rashdi et al., 2007), Vietnam (b=2.84; Pitt and Duy, 2004), and New Caledonia (b=2.28; Conand, 1990; b=1.26; Purcell et al., 2009). This indicates that at a given length, the individuals collected from deep water in Zanzibar are leaner than in these other locations, except for those collected in the Purcell et al. (2009) study. The value of b in length-weight relationships is always changing depending on the animal’s habitat, physiological condition, maturity stage and food availability (Froese, 1998; Natan et al., 2015). Moreover, the differences could be attributed to the actual differences existing between individuals in relation to the environmental conditions around them, or the inconsistency in procedures used to estimate length and weight between studies (Al-Rashdi et al., 2007).

**Condition factor (K)***

The mean K value for *H. scabra* from this population was 4.213±0.106 when all data were pooled together. One-way ANOVA results show no significant differences in K values between male, female and indeterminate individuals ($F=0.607$, df=177, p=0.799). However, male individuals have a slightly higher mean K value than female individuals. The overall mean K value reported in this study is high which indicates that *H. scabra* from this population are in good physical condition and come from a healthy environment (Pauly, 1984).

**Conclusions**

It can be concluded that the deep-water population of *H. scabra* on the west coast of Unguja Island, Zanzibar mainly consists of large sized mature individuals. The sex ratio in this population is significantly different from 1:1 in favour of males, indicating high fishing pressure. Like other sea cucumber species, *H. scabra* from this study shows negative allometric growth, i.e. length increment is faster than weight increment. The condition factor (K) recorded reveals that the individuals were in good condition and come from a healthy environment. This study provides baseline information on the overall condition of the deep-water population of *H. scabra* in the coastal waters of Zanzibar, hence contributing towards better management of the species. Since this group of individuals consist mainly of potential breeders which are expected to repopulate dwindling shallow water populations, management measures such as temporal (seasonal) closure or total prohibition should be enforced to minimize fishing pressure on deep water populations. However, more studies are needed on the reproductive biology, spawning pattern and stock status of the species across the Zanzibar Islands and Tanzania as a whole.

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