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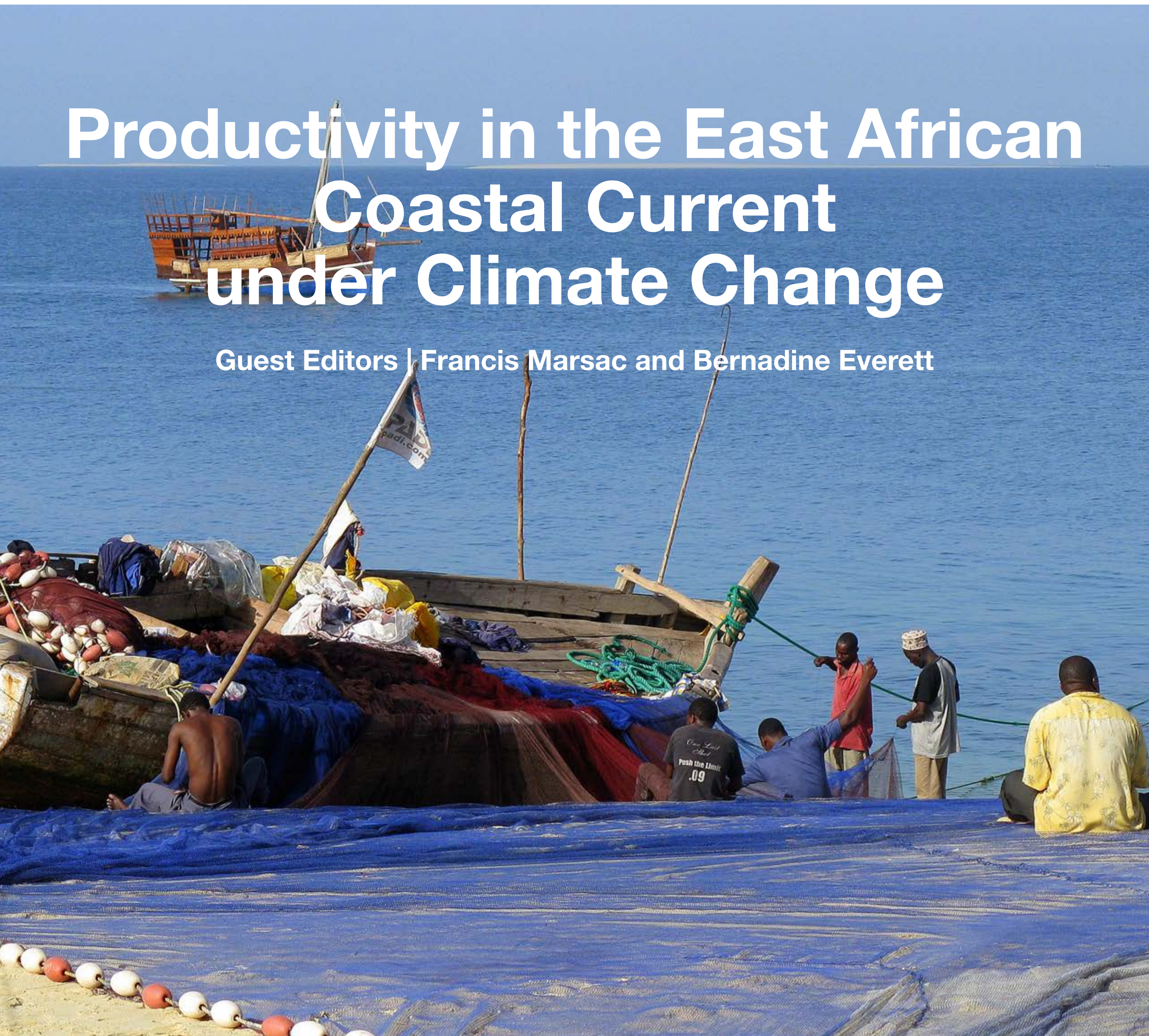

Productivity in the East African Coastal Current under Climate Change

Guest Editors | Francis Marsac and Bernadine Everett

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Age, growth and mortality of the anchovy *Stolephorus commersonnii* (Lacepède, 1803) (Clupeiformes) caught off the coast of Tanga, Tanzania

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Abstract
The population dynamics of *Stolephorus commersonnii* (Lacepède, 1803) from a ringnet fishery operating off the northern coast of Tanga Region were evaluated based on monthly length-frequency data collected from August 2016 to August 2017. The total length (TL) and total weight (TW) of 14,410 individuals ranged from 22 to 130 mm and from 0.39 to 14.64 g respectively. *S. commersonnii* exhibited a negative allometric growth pattern with the length-weight relationship model: $W = 0.00001 \times L^{2.886}$. The von Bertalanffy growth function was $L_t = 86.03 \times (1 - e^{-1.19(t - (-0.01))})$ using ELEFAN I from the FiSAT II software tool package. Growth performance index and longevity were estimated at (ϕ) = 3.9 and T_{max} = 2.5 yrs, respectively. The total (Z), fishing (F) and natural (M) mortalities were determined at 1.39, 0.53 and 0.86 yr^{-1}, respectively. The current exploitation rate (E_{cur}) was estimated at 0.38. *S. commersonnii* exhibited a year-round breeding pattern, with two recruitment peaks in March and June/July. Length-at-first-capture (L_{c50}) and length-at-first-sexual maturity (L_{m50}) were 40.51 and 57.35 mm TL, respectively, suggesting growth overfishing. The stock of anchovy indicates an overfishing scenario requiring management intervention such as reducing fishing effort levels, increasing mesh sizes and introducing seasonal closures during peak spawning periods.

Keywords: Nitrate, Silicate, Productivity, Kenya, North Kenya Bank

Introduction
Anchovies belong to the order Clupeiformes within the suborder Clupeoidei comprising four families (Whitehead *et al.*, 1988). Two of these families, the anchovies (Engraulidae) and sardines or herrings (Clupeidae) form the bulk of small fish species in the pelagic ecosystem and fisheries of the world oceans (FAO, 2016; Checkley *et al.*, 2017). Anchovies have been reported to exhibit several biological characteristics 9such as short plankton-based food chains, fast growth, short-lived, relatively low fecundities and year-round spawning of some species) making them highly sensitive to environmental variability (Kawasaki, 1980; Checkley *et al.*, 2009). For example, clupeoid populations are noted for exhibiting large spatial and temporal fluctuations in abundance under the influence of environmental conditions (Cole and McGlade, 1998).

Several studies in the marine ecosystem have focused on areas subjected to upwelling events where anchovies and sardines cohabit (e.g. Benguela Current and Peru Current ecosystems) and fluctuations in abundance of the populations of both species have been reported (Lluch-Belda *et al.*, 1989; Barange *et al.*, 2009). Furthermore, Lluch-Belda *et al.* (1989) and Lindegren *et al.* (2013) found that the behavior of forming large aggregations subject clupeoid populations to high fishing

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pressure causing concern about the management of these unpredictable fisheries. However, these small pelagic fish species are reported to be resilient and can withstand high levels of predation and fishing pressure due to their high turnover rates (Mannini, 1992).

Ecologically, the anchovies play a paramount role in repackaging energy consumed by higher trophic levels (Checkley *et al*., 2017; Guénette *et al*., 2014). Arneril *et al*. (2011) observed that anchovies serve as zooplankton predators as well as prey for many other marine organisms including medium to large pelagic fishes and cetaceans. Economically, anchovies tend to be an easy target for both artisanal and commercial fishers due to their aggregative distribution patterns and formation of dense schools (Pitcher, 1995).

The pelagic fisheries resources off the coast of Tanzania are largely multispecies and multisector, with the small pelagic species, locally referred to as "*dagaa*", forming an important component of the sector (Bodiguel and Breuil, 2015). The official statistics of marine fish production in the Tanzania's territorial and internal waters is close to 70,000 tons per year with small pelagic fishes accounting for approximately one third of total catch (Bodiguel and Breuil, 2015). The anchovies are commercially important and form a significant component of the marine fisheries catch, serving as a fish protein source for most households in Tanga Region. The species are often harvested by small scale fishers who deploy small mesh-sized ringnets and purse seine nets using lights at night. Other gear for catching small pelagic fish species include small mesh-size gillnets and beach seines, which are considered illegal. The recently developed processing method for anchovies (salt-boiled and sun dried) was in response to the demands for fish products in the inland regions of Tanzania and the Democratic Republic of Congo (Fujimoto, 2018). Furthermore, Bodiguel and Breuil (2015) indicated that anchovies are marketed fresh in small quantities in the hinterland markets near the coast.

Despite the significant economic and ecological importance of *S. commersonnii* in the coastal waters of Tanga Region, there is a paucity of information on population parameters and stock status. Knowledge of population dynamics is essential for the development of fish stock assessment programmes with the aim of providing advice on the optimum exploitation level for sustainability of the species. In view of this limitation, the primary objective of this study was to establish the population dynamic parameters of Commerson's anchovy to evaluate its current exploitation rate within the northern coastal waters of Tanga Region.

Materials and Methods

Study area

The study focused on the northern coast of Tanga Region which comprises two coastal districts, namely Mkinga and Tanga City. Fish sampling was conducted at the two fish landing sites of Vyeru and Sahare corresponding to Mkinga and Tanga City respectively (Fig. 1). The criteria for the selection of study sites were based on geographical location, as well as the level and type of fishing activity (specifically using ringnets to target small pelagic fish species).

Fish sampling

S. commersonnii individuals were randomly sampled on a monthly basis for ten consecutive days from local fishers operating ringnets using motorized wooden boats between August 2016 and August 2017. The ringnets had a mesh size of 8 – 10 mm, were 80 m in length and had a depth of about 12 m. Total length (TL) was determined using a fish measuring board to the nearest mm and total weight (TW) to the nearest 0.01 g using an electronic scale. Samples were unsexed. Both researchers and local enumerators participated in fish sampling and measurements. The species was identified using the fish identification keys of Fischer and Bianchi (1984) and Smith and Heemsta (2003).

Data analysis

The relationship between body length (L) and weight (W) was determined using the length-weight relationship (LWR) model: $W = aL^b$ where 'a' and 'b' are constants for the model (Le Cren, 1951). The Student's t-test was used to test for significant differences of regression coefficients between the calculated 'b' and cube law of the LWR model. The relative condition factor (K_n) was calculated according to Le Cren (1951): $Kn = \frac{W}{aL^b}$.

The monthly length frequency data were grouped into 5 mm size class intervals for the estimation of growth parameters. The asymptotic length (L_∞) and instantaneous growth rate (K) were determined using the ELEFAN I from the FiSAT II software tool package (FAO-ICLARM Stock Assessment Tools, Ver 1.2.2, 2005) to generate the von Bertalanffy growth function (VBGF): $L_t = L_\infty \times (1 - e^{-K(t - (-t0))})$. The theoretical age at birth (t_0) was calculated independently, using the empirical formula by Pauly (1979): $Log_{10}(-t_0) = -0.3922 - 0.275 x Log_{10}(L_\infty) - 1.038 x Log_{10}(K)$. The growth performance index (ϕ) was determined following an expression by Munro and Pauly (1983): $2 \times Log_{10}(L_\infty) + Log_{10}(K)$. Longevity ($T_{max}$) was estimated according to Pauly (1983): $T_{max} = \frac{3}{K} + t_0$.

The total mortality (Z) was estimated using the FiSAT II software tool package from the length-converted catch curve of size classes descending towards the right arm. Natural mortality (M) was calculated using an empirical formula assuming the mean habitat temperature (T) to be 27° C (Pauly, 1980): $Log_e(M) = -0.0152 - 0.279 \times Log_e(L_\infty) + 0.654 \times Log_e(K) + 0.4634 \times Log_e(T)$. Fishing mortality (F) was obtained by substitution in the equation according to Gulland (1983): $F = Z - M$. The optimum fishing mortality (F_{opt}) was estimated using the equation by Pauly (1984): $F_{opt} = 0.4 \times M$.

The current exploitation rate (E_{cur}) was estimated using the expression by Gulland (1983): $E = \frac{F}{Z}$. The ascending left arm of the length-converted catch curve was used to analyze the probability of capture of each length class fitted in the FiSAT II software tool package to obtain length-at-first capture (L_{c50}). Additionally, the cumulative probability of capture was assessed at (L_{c25}) and (L_{c75}) corresponding to 25% and 75% respectively for the fish retained by the gear. The one-year recruitment pattern was determined using the FiSAT II software package by backward projection of the set of length–frequency data with inputs of L_∞ and K. The length-at-first sexual maturity (L_{m50}) was estimated using the expression by Hoggarth *et al.* (2006): $L_{m50} = \frac{2 \times L_\infty}{3}$. Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) were predicted based on the Beverton and Holt yield per recruit analysis assuming a knife-edge selection model incorporated into the FiSAT II

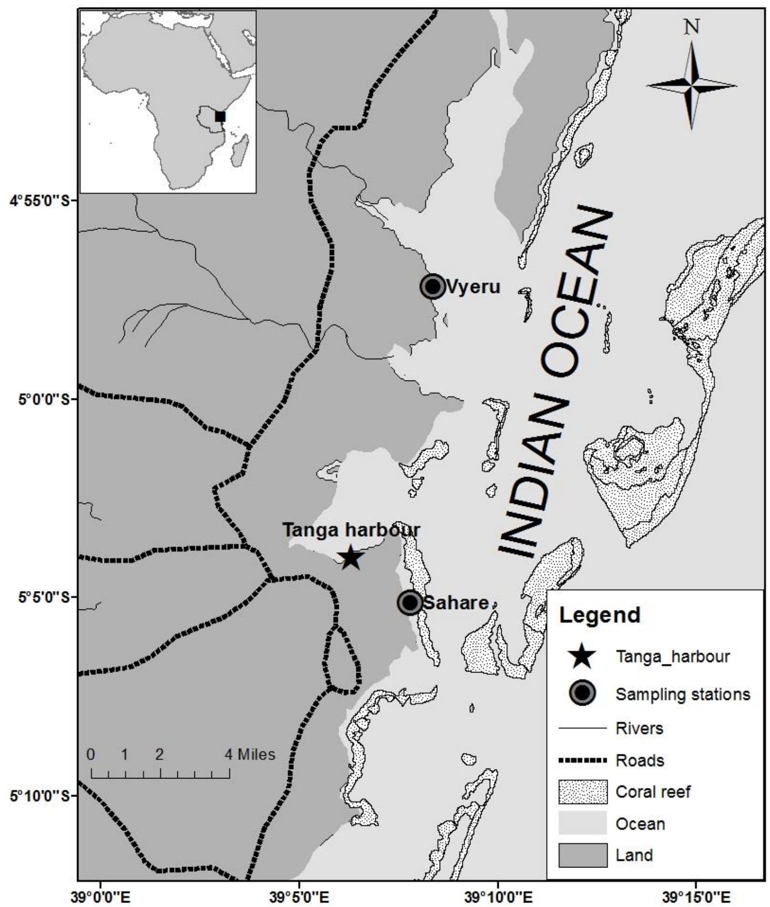

Figure 1. Map of the northern coast of Tanga Region showing the fish landing sites of Vyeru and Sahare.

software tool package. The outputs generated include optimum exploitation rate (E_{max}) to produce maximum yield per recruit, exploitation rate ($E_{0.1}$) at which the marginal increase of Y'/R is 10% of the virgin stock, and exploitation rate ($E_{0.5}$) under which the stock is reduced to half its virgin biomass per recruit. Furthermore, the yield isopleths to produce yield contours were plotted to identify the impact on yield, based on the critical values of L_{c50}/L_{∞}, E_{max} and M/K to help position the stock of Commerson's anchovy according to the Pauly and Soriano (1986) quadrant rule.

Results

A total number of 14,410 individuals were measured to study the population dynamics of *S. commersonnii*. The size frequency distribution ranged from 22 to 130 mm TL weighing between 0.39 and 14.69 g TW. The mean (± s.e.) size of the exploited individuals was 77.8 ± 0. 07 mm TL with the bulk (75%) of fish occurring between 73 and 88 mm TL (Fig. 2a). The length–weight relationship parameters essential for predicting growth patterns and well-being of individuals in a population are presented in (Fig. 2b). Commerson's anchovy exhibited a negative allometric growth pattern with a mean (± s.e.) growth coefficient of b = 2.89 ± 0. 01, differing significantly from the cube law of LWR (df = 14308; t = -16.07; p< 0.001). Monthly variations of growth coefficients 'b' are shown in Table 1 indicating that both positive and negative allometric growth patterns occurred in *S. commersonnii* throughout the study period, except in December that showed an isometric growth pattern. *S. commersonnii* had a mean (± s.d.) relative condition factor of K_n = 1.17 ± 0. 09, with the lowest (K_n = 1.12 ± 0. 09) and highest (K_n = 1.26 ± 0. 21) occurring in April/May and September respectively.

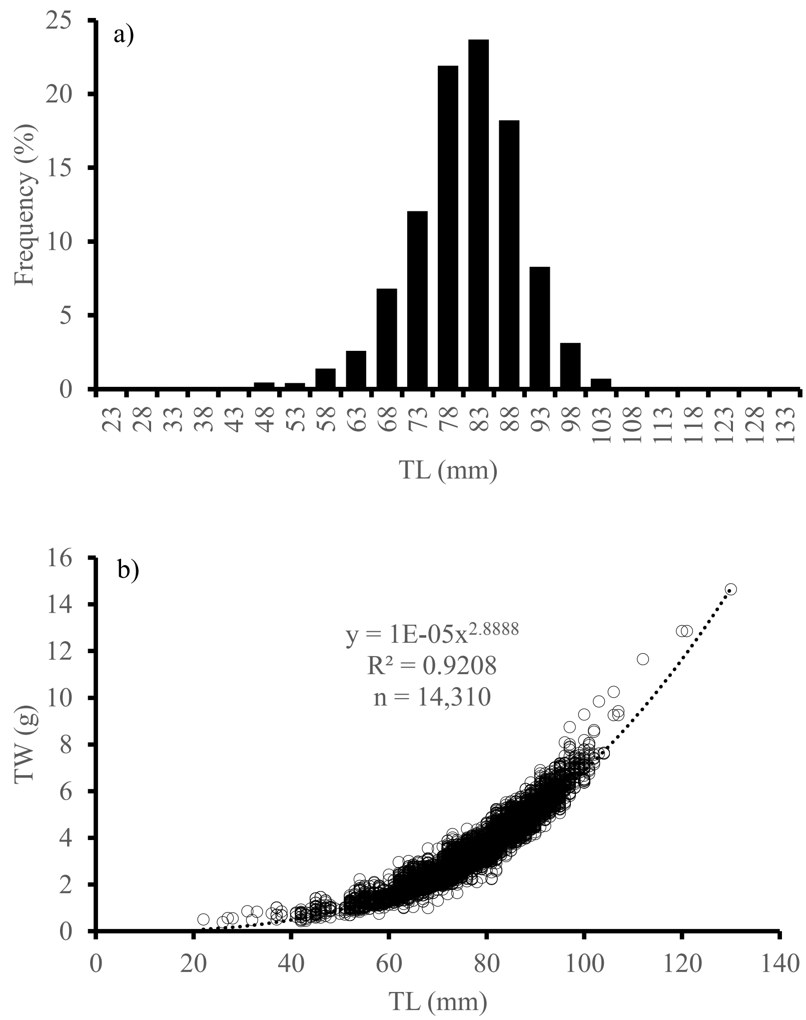

Figure 2. a) Population size structure and b) length-weight relationship of *Stolephorus commersonnii* from the ringnet fishery off the coast of Tanga during the 2016/2017 sampling season.

Table 1. Monthly variations in mean relative condition factors (K_n ± s.d.) and mean growth coefficients (b ± s.e.) with corresponding Student's t-tests for the cube law of *Stolephorus commersonnii* caught in ringnets off the coast of Tanga from August 2016 to August 2017 (*** = $p< 0.001$, ** = $p< 0.01$, * = $p< 0.05$ and NS = $p> 0.05$).

Month	K_n ± s.d.	b ± s.e.	*df*	*t*	*p*	Remarks
Aug-16	1.21 ± 0.18	2.74 ± 0.03	1200	-10.35	***	Allometric (-)
Sep-16	1.26 ± 0.21	2.53 ± 0.03	663	-17.94	***	Allometric (-)
Oct-16	1.22 ± 0.13	2.93 ± 0.02	1053	-2.85	**	Allometric (-)
Nov-16	1.18 ± 0.11	2.88 ± 0.02	1459	-5.98	***	Allometric (-)
Dec-16	1.13 ± 0.09	3.03 ± 0.02	1143	1.67	NS	Isometric
Jan-17	1.14 ± 0.15	2.88 ± 0.03	1151	-4.39	***	Allometric (-)
Feb-17	1.16 ± 0.16	2.54 ± 0.03	984	-13.83	***	Allometric (-)
Mar-17	1.15 ± 0.10	2.86 ± 0.02	1244	-6.01	***	Allometric (-)
Apr-17	1.12 ± 0.10	3.11 ± 0.03	1125	3.93	***	Allometric (+)
May-17	1.12 ± 0.10	3.15 ± 0.03	1197	5.26	***	Allometric (+)
Jun-17	1.20 ± 0.22	2.92 ± 0.03	898	-2.58	*	Allometric (-)
Jul-17	1.20 ± 0.10	3.06 ± 0.02	1301	2.31	*	Allometric (+)
Aug-17	1.18 ± 0.12	3.23 ± 0.03	866	7.49	***	Allometric (+)
Overall	1.17 ± 0.01	2.89 ± 0.01	14308	-16.07	***	Allometric (-)

The growth parameters obtained for *S. commersonnii* were: asymptotic length (L_∞) = 86.03 mm TL, instantaneous growth rate (K) = 1.19 per year, theoretical age at birth (t_0) = −0.01 years, and growth performance index (ϕ) = 3.9 (Fig. 3a). The longevity (T_{max}) of *S. commersonnii* was calculated at 2.5 years. The restructured length-frequency data superimposed with the estimated VBGF curves revealed that approximately three cohorts were sampled during the study period (Fig. 3b).

Total mortality (Z) was estimated at 1.39 yr^{-1}, natural mortality (M) at 0.86 yr^{-1}, and fishing mortality (F) at 0.53 yr^{-1}, being higher than optimum fishing mortality (F_{opt} = 0.34 yr^{-1}). The current exploitation rate (E_{cur}) was estimated at 0.38 (Fig. 4a). The length-at-first capture (L_{c50}) of *S. commersonnii* was 40.51 mm TL with the corresponding capture at L_{c25} and L_{c75} 37.94 and 43.08 mm TL respectively (Fig. 4b). The length-at-first sexual maturity (L_{m50}) was 57.35 mm TL being higher than L_{c50}. Recruitment of *S. commersonnii* was noted to be year-round and bimodal, peaking in March and June/ July (Fig. 5). Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) are illustrated in Fig. 6a. The maximum relative yield-per recruit of *S. commersonnii* was achieved at the optimum exploitation rate of E_{max} = 0.63. The exploitation rate at which the marginal increase of Y'/R is 10% of the virgin stock was $E_{0.1}$ = 0.56 and the exploitation rate where the stock is reduced by half of its virgin biomass was $E_{0.5}$ = 0.37. The yield isopleths from which the yield contours predicted the response of relative yield-per-recruit of the Commerson's anchovy to changes in E_{max}, L_c/L_∞ and M/K are shown in Fig. 6b. Stock position of *S. commersonnii* within the investigated area fell at the edge in quadrant D of an overfished fishery with Y'/R corresponding to the 0.101 contour. The lowest Y'/R (x = 0.017) could be obtained in quadrant A of an undeveloped fishery with values of L_c/L_∞ = 1 and E = 0.1, whilst the highest Y'/R (y = 0.161) was located in Quadrant C of a fully developed fishery with values of L_c/L_∞ = 0.9 and E = 1.

Discussion

The estimated monthly values of growth coefficients ('b') from the LWR model indicated that *S. commersonnii* exhibits an allometric growth pattern as observed for most anchovy species (Aripin and Showers, 2000; Abdurahiman *et al.*, 2004; Sag'lam and Sag'lam, 2013). These values were within the acceptable and expected range of between 2.5 and 3.5 which is typical for most tropical fish species (Froese, 2006). This notion is supported by the statement that an ideal fish with a 'b' value of 3 is rarely observed in the natural environment (Allen, 1938). The Commerson's anchovy maintained a relative condition factor greater than a unit; an indication of individuals in

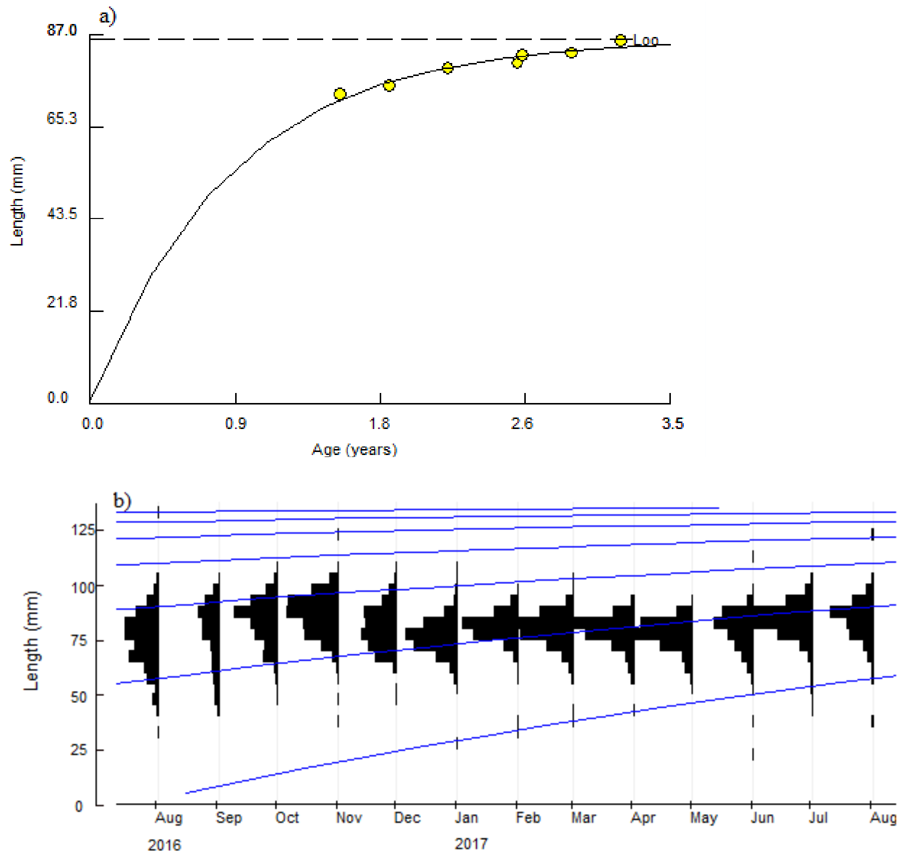

Figure 3. a) Length-at-age and b) von Bertalanffy growth function curves superimposed on restructured monthly length-frequency distributions of *Stolephorus commersonnii*.

good growth condition throughout the study period. The observed seasonal variation in relative condition factor was in agreement with other anchovies in the Black Sea (Sag'lam and Sag'lam, 2013). Preetha *et al.* (2015) suggested that variations in relative condition factor of the Commerson's anchovy in India might indicate the reactions of the fish populations to environmental changes, food abundance and spawning conditions affecting fish growth within the habitat. Higher K_n values occurred during the northeast (NE) and southeast (SE) monsoons; an indication that both seasons support abundant food and possibly favouring a protracted spawning season for most of the anchovies by providing sufficient forage to sustain the energetic costs of repeated gonad maturation (Milton *et al.*, 1990). The lowest K_n value in April/May might indicate a period of low reproductive activity or changes of environmental parameters associated with a high influx of freshwater and associated sediment load in the inshore water as a result of heavy rain (pers. obs.). The Commerson's anchovy is reported to be a coastal pelagic species that sometimes inhabits bays and estuarine habitats in Tanzania (Bianchi, 1985).

The present study is the first investigation on the population parameters of *S. commersonnii* off the coast of Tanzania. The Commerson's anchovy is a small pelagic fish (asymptotic length of 86 mm TL), with fast growing (instantaneous growth rate of 1.19 yr^{-1} and growth performance index of 3.9). The species was also found to be short-lived, having a life expectancy of 2.5 years. These growth parameters are in agreement with published information for most of the anchovies studied in the Philippines (Ingles and Pauly, 1984). Worldwide studies on the population parameters of engraulids indicated that they are fast growing, short lived and have relatively high rates of natural mortality (Newberger and Houde, 1995). This is further supported by Arneril *et al.* (2011) who found that, particularly small pelagic fishes, have natural mortality rates which are often higher than fishing mortality rates. The results of the present study clearly reflect that *S. commersonnii* exhibited these characteristics.

The ratio of Z/K quantifies the relationship between growth and mortality. Etim *et al.* (1998) indicated that in populations where Z/K = 1, the mortality balances growth, Z/K< = 1 is growth-dominated, and Z/K = >1 is

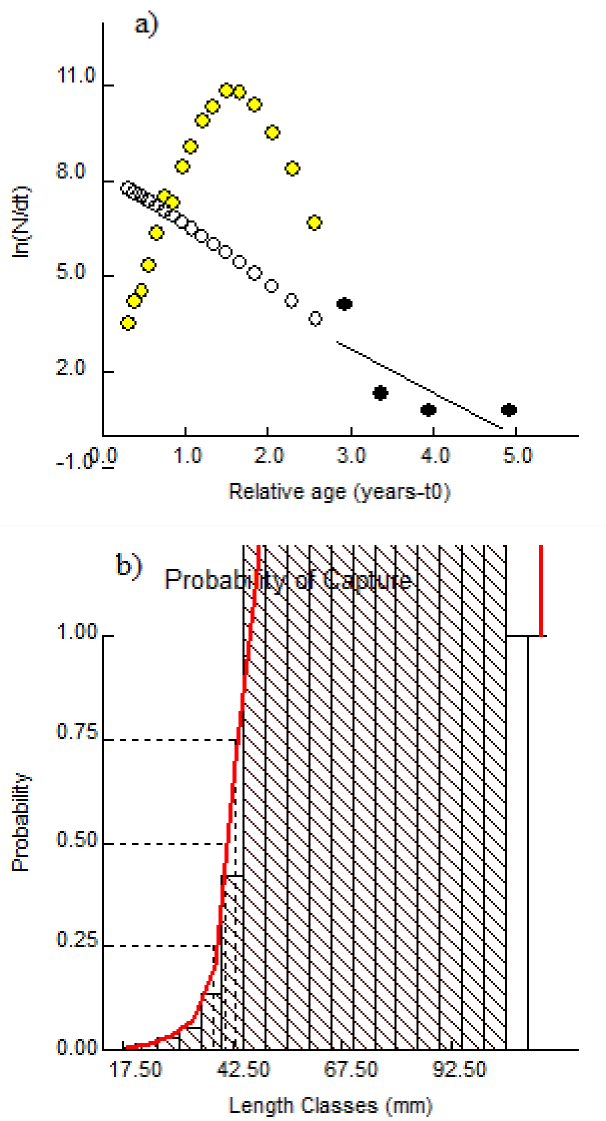

Figure 4. a) Length converted catch curve (solid dots = points used in calculating total mortality (Z) through least square linear regression analysis) and b) probability of capture of *Stolephorus commersonnii* at 0.25, 0.5 and 0.75 to estimate size-at-first capture.

mortality dominated. In this study, *S. commersonnii* exhibited Z/K = 1.15, an indication that the population is mortality dominated. This observation could be dependent on the density of predators with the species forming a major source of food for both pelagic and demersal fishes, marine mammals and seabirds (Bozzano *et al.*, 1997; Blanco *et al.*, 2001; Stergiou and Karpouzi, 2002) contributing to high natural mortality (M = 0.86 yr^{-1}). High fishing mortality (F) could be the result of intensive fishing pressure caused by small-mesh sized ringnets (8 – 10 mm) and about 1,126 and 1,184 fishers targeting small pelagics in Mkinga District and Tanga City respectively (MLF, 2016). Furthermore, the observed fishing mortality (F = 0.53 yr^{-1}) was higher than optimal fishing mortality (F_{opt} = 0.34 yr^{-1}); an indication of a heavily exploited Commerson's anchovy population.

This contention is further supported by the fact that the length-at-first capture (L_{c50} = 40.51 mm TL) was relatively lower than the length-at-first sexual maturity (L_{m50} = 57.35 mm TL). The *S. commersonnii* fishery is therefore under the regime of catching smaller fishes at higher fishing effort; a condition termed growth overfishing. Moreover, the ratio of the length-at-first capture to the asymptotic length L_{c50}/L_{∞} = 0.47) suggests that younger fish constituted the catch of ringnets. The yield isopleths diagramme in this study placed the Commerson's anchovy stock at the edge of quadrant D, corresponding to the region of overfishing. Quadrant D has been referred to as a fishing regime where small fish are caught at high effort levels (Pauly and Soriano, 1986). Possible management interventions could include the introduction of harvest control rules such as an increase of mesh size of ringnets, restricting fishing during daytime and the spawning season, and limiting the number of fishers through fishing licenses. However, the suggested interventions require scientific data supported by a detailed stock assessment study.

The recruitment pattern observed in this study was year-round, though bimodal, conforming to the assertion by Pauly (1982) where two peaks of recruitment per year is a general feature of most tropical fish species. The current year-round recruitment pattern may be

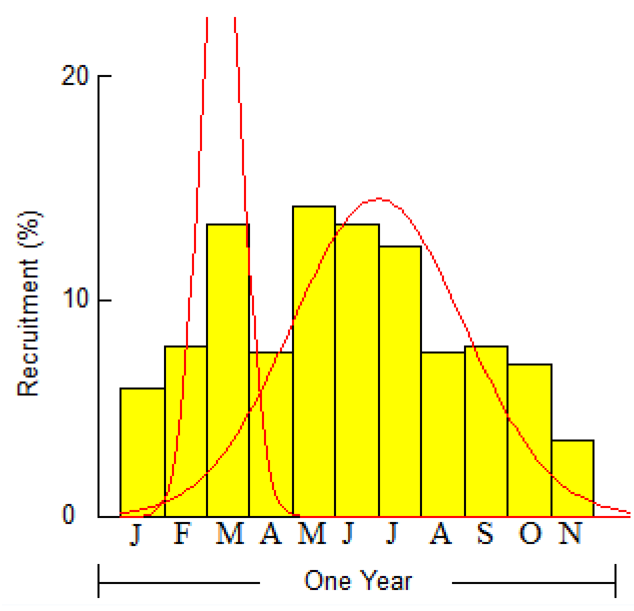

Figure 5. One-year recruitment pattern of *Stolephorus commersonnii* into the ringnet fishery off the northern coast of Tanga Region, Tanzania.

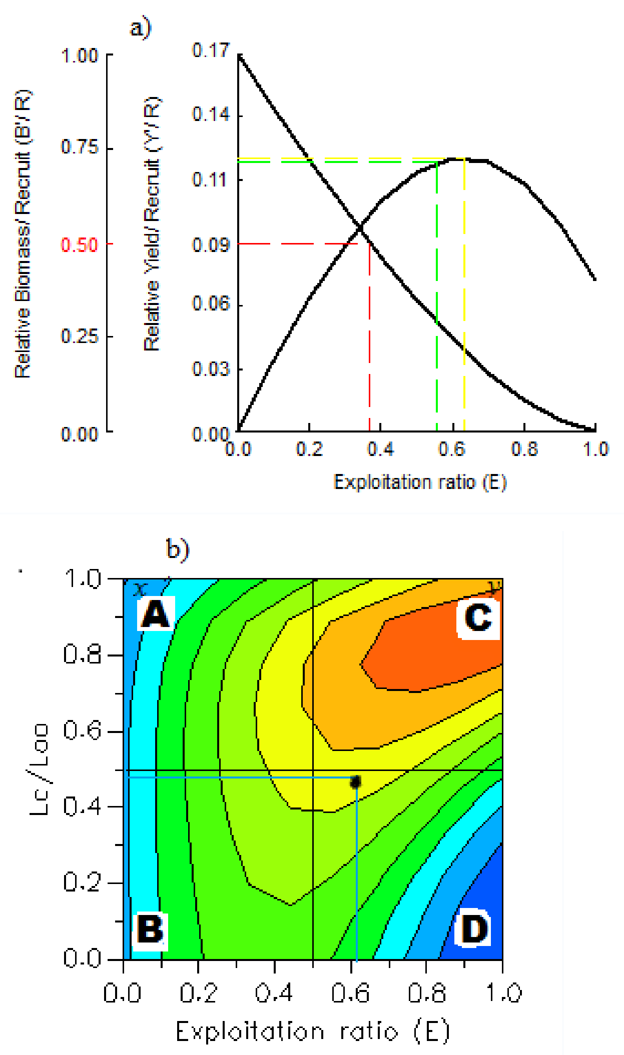

Figure 6. a) Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R) and b) yield isopleths diagram showing stock position of *Stolephorus commersonnii* placed at the edge of quadrant D fishing regime (A = under-fishing, B = developing fishery, C = fully developed fishery and D = over-fishing according to Pauly and Soriano (1986)).

an indication that the *S. commersonnii* fishery in Tanga Region is not suffering from recruitment failure, possibly offsetting the effects of overfishing reflected by its dominance in catches throughout the year (MLF, 2016). *S. commersonnii* conformed to the general observation that small pelagic fish species have a high turnover rate and are capable of withstanding high total mortality (Z) caused by fishing pressure (F) and natural mortality (M) due to predation pressure (Mannini, 1992).

The general productivity of a fish stock is determined by its life history pattern and its absolute abundance. This study has established that the Commerson's anchovy is a small, short-lived, pelagic, schooling fish often occurring in inshore waters, and most likely occupies a low trophic level. Furthermore, the year-round recruitment and fast growth to reach size-at-first sexual maturity is likely to attribute to the high turnover rate exhibited by *S. commersonnii*.

Based on this data-limited study, it is concluded that *S. commersonnii* off the northern coast of Tanga Region has a mortality dominated population under the regime of an overexploited fishery. For sustainability of the species management interventions are proposed leading to harvest control rules such as reducing fishing effort through licensing, increasing the mesh size of ringnets, restricting fishing during daytime, and introducing closed fishing seasons during peak spawning periods. It is further recommended that a stock assessment study is carried out that synthesizes information on life-history, and includes fishery monitoring and resource surveys for estimating stock size and harvest rate relative to sustainable reference points. The proposed stock assessment study should be aimed at providing advice on the optimum fishing effort that will produce the maximum sustainable yield in weight from the fish population, to ensure the well-being of Tanga coastal communities in the long term.

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