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Estimation of Growth and Mortality Parameters for Two Penaeid Species of Tanzanian Coastal Waters

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Abstract
Assessment of the growth and mortality parameters of Fenneropenaeus indicus and Metapenaeus monoceros was conducted. Samples for the study were collected during two ship surveys conducted in February and June 2011 and from land-based surveys on two sites at Bagamoyo and Nyamisati, which was conducted between February 2011 and December 2012. Length-based stock assessment FiSAT II software package was used for assessment. The growth parameters which were asymptotic size (L∞), growth coefficient (K), total (Z) and natural (M) mortality, exploitation rate (E) and recruitment pattern were estimated. The results of analysis indicate that asymptotic size (L∞) for F. indicus was 44.1 mm CL for zone 1, zone 2 and Bagamoyo while Nyamisati was 48.3 mm CL. The growth coefficient (K) was 0.42, 0.83, 0.3 and 0.65 per year for zone 1, zone 2, Bagamoyo and Nyamisati respectively. The natural mortality (M) value was low in Bagamoyo and high in zone 2 while exploitation rate (E) and was high at Nyamisati area and low at Bagamoyo site. The study observed high exploitation levels on the two land-based sites (Bagamoyo and Nyamisati) despite the existing moratorium on prawn commercial fishing activities since 2008 hence seasonal closure for artisanal fishers was recommended.

Introduction
The knowledge on growth and mortality of fish population is essential in understanding the dynamics of fish populations [1]. There are dynamic mathematical models such as Beverton and Holt, used in prediction of future yields and stock biomass at different levels of fishing strategies, which are important in defining management strategies [2,3]. Such models require knowledge of growth and mortality in order to derive them. Despite the difficulty in determining age of fish and prawns in tropical and subtropical waters the dynamic pool models have managed to do this. Following the development of the length-based stock assessment methodologies by Pauly, it is possible to investigate population dynamics of fish stocks in tropical waters [4].

The penaeid prawns have discontinuous growth pattern at individual levels [5]. The growth of prawns occurs by moulting process. The prawn undergoes relatively higher number of moults per year thus continuous growth models such as von Bertalanffy growth model are appropriate for their assessment [6]. This study used von Bertalanffy model to estimate growth parameters. The main input data was length frequency distribution data. The model usually estimates growth parameters by tagging or by modal progression analysis of length frequency data. The results of the latter method are fairly reliable if one or two main recruitments occur every year. In addition to von Bertalanffy model the development of length-based stock assessment models made possible investigations of dynamics of fish stock population to be done [4,7]. The objective of this study was to estimate the growth parameters of the two species using the length-based stock assessment models in order to define the levels of exploitation.

Sampling design and data collection
The study took place in three designated prawn fishing zones (zone 1, zone 2 and zone 3) within Tanzanian waters and two land-based sites at Nyamisati and Bagamoyo. The study on the three prawn fishing zones was conducted during the two shallow water prawn ship surveys TZA2011C202a (February 2011) and TZA2011C202b (June 2011) organized by South Western Indian Ocean Fisheries Project (SWIOFP), while the two land-based sites were visited and sampled on a monthly basis (April 2011 to December 2012). Sampling targeted two prawn species, namely, *Fenneropenaeus indicus and Metapenaeus monoceros*. In order to determine the population dynamics of the two species the length-based stock assessment model was used. The length frequency and length-weight relationship data obtained were used as input data to the von Bertalanffy growth function to determine the growth parameters [8]. The computer program FiSAT II (FAO-ICLARM Stock Assessment Tools) which resulted from merging LFSA (Length-based Fish Stock Assessment) developed at FAO with ELEFAN (Electronic Length Frequency Analysis) package developed at ICLARM was used [9,10]. The von Bertalanffy growth function is also incorporated in the program.

Monthly length frequency data were pooled and grouped into classes. The smallest mid-length and class interval were defined and used to calculate subsequent classes. The resulting data were then entered into FiSAT II program then the assess menu routines in the program was used to estimate parameters such as L (the length attained by the fish if it has to grow infinitely), K (the rate per year at which the asymptotic length is approached), M (natural mortality), Z (total mortality which is a sum of natural mortality and fishing mortality).

Data analysis

Estimation of growth parameters

From the length-frequency data of each prawn species caught, the growth parameter estimation was done using means of direct fit of length-frequency data of which the $L\infty$ values were estimated using ELEFAN I. Then non-parametric scoring of von Bertalanffy Growth Function (VBGF) fit using ELEFAN I was done to obtain K scan values.

The growth of the prawns was assumed to follow the von Bertalanffy growth function:

$L_t = L\infty (1 - \exp - K(t - t_o))$ (1)

Where Lt = Length at time t

$L\infty$ = Asymptotic length of the fish i.e. the length of an "infinitely old fish"

K= "Curvature parameter" which determines how fast fish approach $L\infty$

t_o= Theoretical time when a fish has zero length

t = Time

The values obtained were used in fitting the VBGF plot as input parameters in the mortality estimation.

Estimation of mortality parameters

The total instantaneous mortality (Z) was estimated from steady-state sample whereby the length converted catch curves method was used while the natural mortality (M) was estimated using Pauly's M equation [11,12]:

$$\ln M = -0.0152 - 0.279 \ln L\infty + 0.6543 \ln K + 0.463 \ln T \qquad (2)$$

Where

T= The average annual surface water temperature off the coast of Tanzania which was 28° C.

M= Natural mortality

$L\infty$ = Asymptotic length of the fish i.e. the length of an "infinitely old fish"

K="Curvature parameter" which determines how fast fish approach $L\infty$

Fishing mortality (F) was derived from the difference between total mortality (Z) and natural mortality (M). Following the estimations of Z, M and F, the routine was also used to obtain the exploitation rate (E).

Projection of the recruitment patterns

The output from the estimation of growth parameters was used to project recruitment pattern in FiSAT II. This routine reconstructs the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse. The input parameters used were L and K and output was a graph showing seasonal pattern of recruitment of the species.

Results

Estimation of growth and mortality parameters

The growth and mortality parameters for the two species under study are indicated in Table 1. The outcome interfaces of K-scan, von Bertalanffy Growth Function (VBGF) plots and Length-Converted Catch Curve plots are presented in Figure 1 to 4. The values for all parameters observed were different for species and sites. The results indicated that the species *F. indicus* had larger L∞ value at Nyamisati site and the same value in other areas of the study. The species *M. monoceros* was observed to have low value of L∞ at Nyamisati site and highest value within zone 1.

Table 1: Growth and mortality parameters of F. indicus and M. monoceros from two land-based study sites (Bagamoyo and Nyamisati) and two ship survey fishing grounds (zone 1 and 2)

Site/ Locality	Species	L∞ (mm)	K /year)	M	Z	F	E=F/Z
Nyamisati	F. indicus	48.3	0.65	1.18	2.38	1.2	0.50
Nyamisati	M. monoceros	29.4	0.59	1.27	2.67	1.4	0.52
Bagamoyo	F. indicus	44.1	0.30	0.73	1.05	0.32	0.30
Bagamoyo	M. monoceros	44.1	0.82	1.41	2.91	1.5	0.52
Zone 1	F. indicus	44.1	0.42	0.91	1.08	0.17	0.16
Zone 1	M. monoceros	52.5	0.84	1.36	2.5	1.14	0.46
Zone 2	F. indicus	44.1	0.83	1.42	2.02	0.6	0.30
Zone 2	M. monoceros	46.2	0.65	1.19	2.23	1.04	0.47

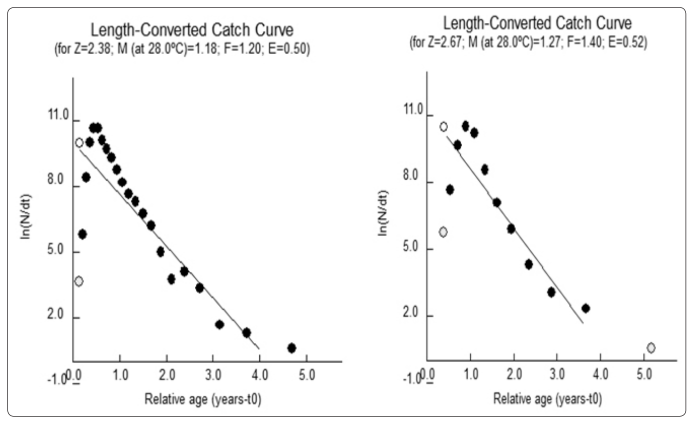

Figure 1: Length-converted catch curves for F. indicus (left) and M. monoceros (right) at Nyamisati site based on the estimated growth parameters in ELEFAN I

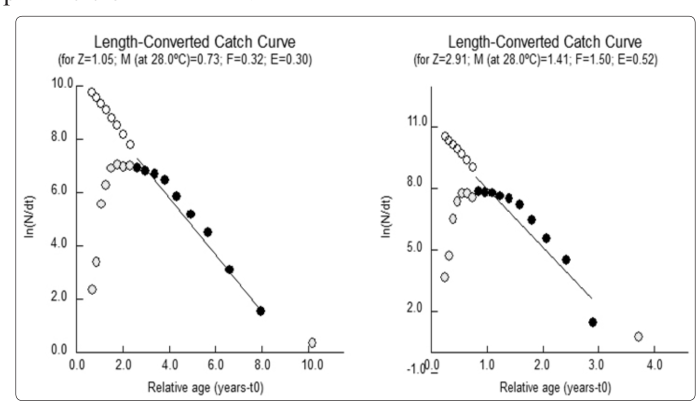

Figure 2: Length-converted catch curves for (a) F. indicus and (b) M. monoceros at Bagamoyo site based on the estimated growth parameters in ELEFAN I

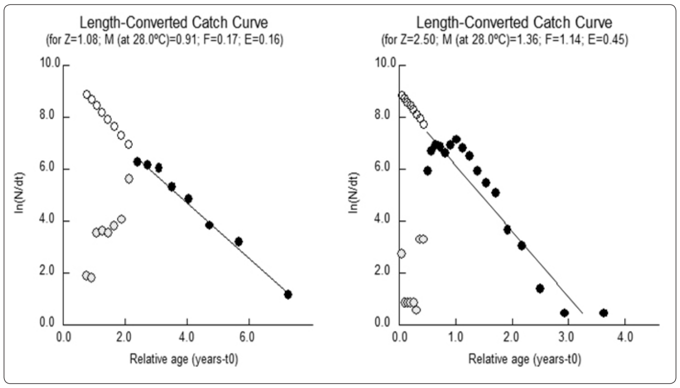

Figure 3: Length-converted catch curves for F. indicus (left) and M. monoceros (right) in zone 1 based on the estimated growth parameters in ELEFAN I

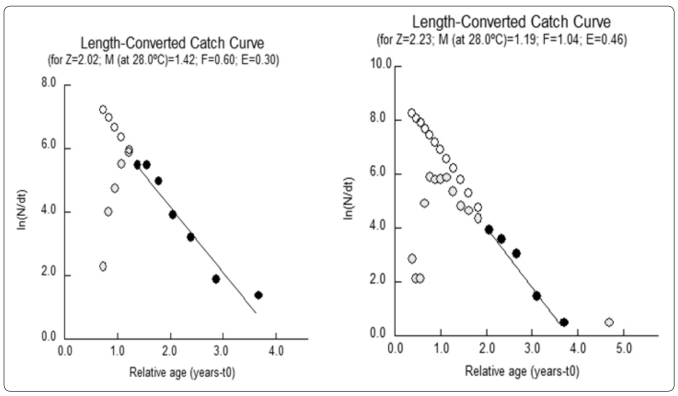

Figure 4: Length-converted catch curves for F. indicus (left) and M. monoceros (right) in zone 2 based on the estimated growth parameters in ELEFAN I

Recruitment patterns

The reconstruction routine of the time series length frequency data of the two land-based sites and data for two zones collected from the ship surveys was performed and the result obtained for the relative time corresponded to the sampling month. The general result indicates that recruitment is occurring throughout the year with some months having high recruitment pulses (Table 2). The recruitment pattern for *F. indicus* indicated two peaks (April and September) at Nyamisati site and one peak (July) for Bagamoyo, zone 1 and zone 2. For *M. monoceros* recruitment peaks were observed in the month of June in Bagamoyo site, July at Nyamisati, May and November in zone 1 and October in zone 2 (Figures 5 and 6).

Table 2: Recruitment pattern indicating the relative strength in percentage of each pulse within a year at different sites. (F.i = Fenneropenaeus indicus and M.m = Metapenaeus monoceros)

	% Recruitment							
Site	**Nyamisati**		**Bagamoyo**		**Zone 1**		**Zone 2**	
Relative time / species	F. i	M. m	F. i	M. m	F. i	M. m	F. i	M. m
Month 1 (Feb)	2.61	0.59			4.52	0.79	1.74	0
Month 2 (Mar)	7.7.8	3.22	3.76	5.16	2.99	3.2	4.54	1.01
Month 3 (Apr)	**10.21**	5.08	6.68	11.53	**9.11**	11.45	5.78	1.72
Month 4 (May)	5.71	4.9	4.91	17.31	3.03	**14.51**	8.82	6.4
Month 5 (June)	6.87	9.07	12.58	**19.28**	13.29	7.49	13.92	8.1
Month 6 (July)	12.44	**17.31**	**20.05**	15.87	**16.87**	2.29	**23.18**	12.01
Month 7 (Aug)	12.93	12.27	13.02	7.29	13.8	7.27	13.97	15.07
Month 8 (Sept)	**14.64**	13.12	11.91	4.36	7.99	3.24	13.5	18.02
Month 9 (Oct)	10.56	12.72	10.41	6.23	8.6	11.25	9.12	**26.23**
Month 10 (Nov)	11.66	10.78	7.08	**6.67**	8.94	**21.02**	4.98	9.88
Month 11 (Dec)	4.56	10.94	6.27	4.89	**10.81**	16.92	0.45	1.24
Month 12 (Jan)	0	0	3.33	1.41	0	0	0	0.25

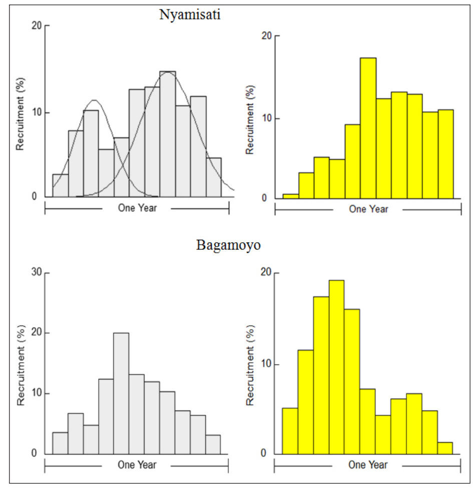

Figure 5: Recruitment pattern plot for F. indicus (left) and M. monoceros (right) at Nyamisati (top) and Bagamoyo (bottom) sites showing the estimates of the recruitment pulses for one year in different months (y-axis are in different scales)

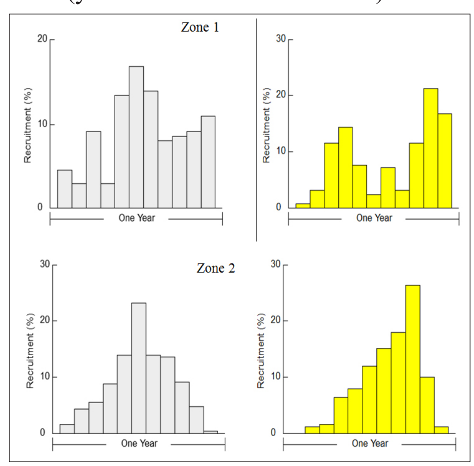

Figure 6: Recruitment pattern plot for F. indicus (left) and M. monoceros (right) at zone 1 (top) and zone 2 (bottom) showing the estimates of the recruitment pulses for one year in different months (y-axis are in different scales)

Discussion

Growth and mortality

This study established that F. indicus have asymptotic length (L∞) ranging from 44.1 mm to 48.3 mm CL and K 0.3 to 0.83 y-1. For *M. monoceros* L∞ ranged from 29.4 mm to 52 mm CL and K 0.59 to 0.84 y^{-1}. Penaeid prawns are characterized by a short life span in the order of two years [13]. Such short-lived animals like prawns have rapid growth and reach their asymptotic length in a year or two and are characterized by a high K-value [2,13]. There are various assessments conducted for the same two species in Tanzanian waters.

Wakwabi ade the assessment based on data from TAFICO vessels [14]. TAFIRI made assessment based on surveys data in 2001 and 2009 and additional data were collected in 2011 (Table 3) [15,16]. Reviewing the trend on the growth parameter observed indicated the high value in 1990's and then a decrease in the values in 2000's then an increase in 2011. On the mortality parameters the 2009 survey estimated high values for both natural mortality (M) and fishing mortality (F). The higher exploitation rate (E) and fishing mortality (F) were also estimated during the 2009 survey. This observation justifies the earlier claim that the fishery was under high levels of exploitation when considering F and E values before this study.

Table 3: Growth and mortality parameters of F. indicus and M. monoceros for two fishing grounds (zones 1and 2) observed in different studies conducted in Tanzanian waters

Species	Fishing zone	Year	L∞	K	M	Z	F	E= F/Z	Source
F. indicus	Zone I	1990*	50	2	2	5.6	3.6	0.64	Wakwabi, 1990
		2001	19.5	0.6	1.4	2.23	0.86	0.39	Bwathondi et al., 2002
		2009	24.6	1.3	2.1	13.2	11.1	0.84	Mwakosya et al., 2010
		2011	44.1	0.4	0.9	1.08	0.17	0.16	Current study
M. monoceros	Zone I	1990*	40	2	2	7.4	5.4	0.73	Wakwabi, 1990
		2001	15.5	0.5	1.3	1.38	0.09	0.07	Bwathondi et al., 2002
		2009	21.4	1.9	2.9	16.6	13.8	0.83	Mwakosya et al., 2010
		2011	52.5	0.8	1.4	2.5	1.14	0.46	Current study
F. indicus	Zone II	2001	16.9	0.5	1.3	1.53	0.27	0.18	Bwathondi et al., 2002
		2009	22.5	1.7	2.6	8.8	6.16	0.7	Mwakosya et al., 2010
		2011	44.1	0.8	1.4	2.02	0.6	0.3	Current study
M. monoceros	Zone II	2001	15	0.4	1.2	1.5	0.17	0.11	Bwathondi et al., 2002
		2009	17.8	1.8	2.9	7.94	5.08	0.64	Mwakosya et al., 2010
		2011	46.2	0.7	1.2	2.23	1.04	0.47	Current study

*The parameters for that year are for females only and combine data from two zones

The growth parameters observed in this study for *F. indicus* revealed a closer trend of L∞ and lower K values when compared to the values obtained from other areas. Villarta reported growth parameter values for *F. indicus* in Manila Bay (L∞ 40.5 to 41.5 mm and K 1 to 1.2 y^{-1}), Punnaikkayal, India (L∞ 43.4 to 44.7 mm and K 1 to1.2 y^{-1}) and Manappad, India (L∞ 40.7 to 42.34 mm and K 1.1 y^{-1}) [17]. Those values have closer trends to the values observed under this study. Fishing mortality has been suggested to be seasonal and increasing with increased fishing effort and not constant with age [18]. The fishing mortality estimated under the present study ranged from 0.17 y^{-1} to 0.6 y^{-1} for *F. indicus* while *M. monoceros* fishing mortality rate ranged from 1.04 y^{-1} to 1.14 y^{-1}. The higher mortality rate was observed in zone 1 for the two species during ship surveys. During the land-based surveys higher mortality rate for the species *M. monoceros* was observed in Bagamoyo while Nyamisati recorded higher mortality rate for *F. indicus*. Garcia estimated fishing mortality for penaeid species to be around 1.6±0.3 y^{-1}, a case which can occur within a fairly developed fishery and in another case the fishing mortality was estimated to be around 0.9 to 1.4 per month, which is equivalent to 10.8 -16.8 y^{-1} [18]. The latter case is possible for a fishery, which is concentrated in a short period of time (such as weeks) and targets recruitments of early biological stages [18].

Recruitment pattern

Recruitment pattern

The derived recruitment pattern for the two species indicated the occurrence of recruitment process throughout the year with unequal strength. Major recruitment peaks (i.e. % recruitment > 10%) for *F. indicus* accounted for 54.7% to 72.4% and the remaining 27.6% to 45.3% for the minor peak. On the other hand, the major recruitment peaks for *M. monoceros* accounted for 63.9% to 77.1% and 22.9% to 36.1% for the minor peak. Based on the observed recruitment pulses the spawning activity peaks for both *F. indicus* and *M. monoceros* is concentrated during the southeast monsoon (April to September) but there is a minor recruitment pulse occurring during northeast monsoon period. Teikwa in Bagamoyo area observed high recruitment peaks during February-June while lowest abundances were observed from July to December [19]. It has been reported that a double peak pattern of reproduction appears to be typical for penaeid prawns with seasonal variability in spawning patterns as it was observed in the present study [17,20,21]. However, despite observing double recruitment peaks mature females were present throughout the study period, which suggested that recruitment is occurring throughout the year.

Conclusion

This study indicated that *M. monoceros* is having higher exploitation level (E= 0.46 – 0.52) compared to *F. indicus*. It is suggested that if natural mortality is less than or equal to fishing mortality (i.e., if E > 0.5) then the stock is said to be overexploited [17,22]. Based on that suggestion *M. monoceros* can be considered to be over exploited while *F. indicus* to be on the underexploited. Despite the closure of commercial prawn fishing activities in 2008 the study observed high exploitation levels at the two land-based sites (Bagamoyo and Nyamisati) and for *M. monoceros* for the two ship surveyed zones. This situation is attributed to the continued fishing activities by artisanal fisherfolk during the closed season and fishing in the nursery areas. The fishers utilize small beach seines or gill nets of mesh sizes ranging from 1.5 to 2.5 inches (personal observation in the field), thus essentially exploiting under sized prawns in varying proportions. The current measures of closed season for six months each year and imposed moratorium of trawls has been insufficient to conserve the prawn fishery in Tanzania. Therefore, initiatives are required to reduce the fishing effort by application of seasonal closure for artisanal fishers. Spawning and nursery grounds should be protected through involvement of fishers' communities in beach management units (BMU) or fishers association groups. Other initiatives could be through imposition of ecosystem based fisheries management (EFM), which will target prevention of ecosystem overfishing by reducing fishing and natural mortality rates. Also by improving the national statistics on catch and fishing effort and increasing the scientific efforts to make year-to-year analysis to adjust computations of fishing mortality and age at first capture based on the gradual decreasing scenario of fishing effort.

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