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Length Frequency Distribution, Mortality Rate and Reproductive Biology of Kawakawa (*Euthynnus affinis*-Cantor, 1849) in the Coastal Waters of Tanzania

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Abstract: This study explored important aspect of the basis for the highly complex population of kawakawa (*Euthynnus affinis*) within the coastal waters of Tanzania; by investigating length frequency distribution, mortality rate and reproductive characteristics. This information is essential for the sustainable management of the regionally-important recreational and economic *E. affinis* fishery. Fish were sampled on a monthly basis for two monsoon seasons using a ring net and artisanal fishermen boat. Maximum and minimum total length was 85 and 31 cm, respectively. Nonlinear least square fitting provided a complete set of von Bertalanffy growth estimates: L8 = 89.25 cm total length and K = 0.78. The estimated value of total mortality based on length converted catch curve using these growth parameters is Z = 1.78 $year^{-1}$. Natural mortality based on growth parameters and mean environmental temperature (T = 26.9°C) is M = 1.09 $year^{-1}$. The estimated annual instantaneous fishing mortality (F = 0.69 $year^{-1}$) was considerably grater than the target (F_{opt} = 0.43 $year^{-1}$) and limit (F_{limit} = 0.58 $year^{-1}$) biological reference point indicating that *E. affinis* is heavily overexploited. Reproductive aspects were assessed whereby female *E. affinis* was reported to reach maturity earlier than males which is an indication of phenotypic response toward a decline in population. Two peaks was revealed by the use of Gonad-Somatic Index (GSI), however an extended spawning period was noticed in a period between November to February following an increased water temperature. Although, these findings presents a snapshot concerning population structure and reproduction of *E. affinis*, further studies covering the entire coastal waters of Tanzania are recommended to aid the management and conservation strategies.

Key words: *Euthynnus affinis*, mortality, over-exploited, fishing mortality, Tanzania

INTRODUCTION

Kawakawa *Euthynnus affinis* (Cantor, 1849) is recognized as a keystone large pelagic fish for its role played in fisheries and marine ecosystem. Kawakawa is distributed throughout the Indo-West Pacific between latitudes 35°N and 25°S, longitudes 40°E and 137°W and water temperature ranging from 18-29°C (Froese and Pauly, 2007). The species makes up a substantial proportion of catch and consequently providing one of the most accessible sources of animal protein and income generation to the poor coastal communities in the Western Indian Ocean region. Its ecological and economic significance alone necessitate further research, however unsustainable resource utilization caused by the lack of sound policies on the other hand and an ever increasing human population along the coastline increased the urgency of the study. It is however important to understand some aspects of reproductive biology and population structure of kawakawa that could aid in the species management. This information are important because most policies developed to assist in the harvesting rates of fish are generally based on information on the species spawning period as well as size at sexual maturity (Wootton, 1999).

Information on the reproduction of fish species are important in understanding the life history of the species as well as being used in identifying species at high risk of overexploitation, e.g., species that form spawning aggregations that are predictable both in time and space (Domeier and Colin, 1997; Rhodes and Sadovy, 2002). Furthermore, reproductive aspects such as maturation of fish are important as they express the relationship between environmental drivers and genetic setting. This information provide evidence of geographical and reproductive isolation of fish populations (Begg, 2005). In

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addition, fishing mortality has been reported as one of the selective pressures leading to a rapid evolution of maturation patterns in heavily exploited fish stocks (Barota *et al*., 2005; Silva *et al*., 2006). Unfortunately robust information on the population structure such as length frequency distribution and reproductive biology of kawakawa are still lacking in the Western Indian Ocean region, making it difficult to develop management models for this species. However, demand for fish food is increasing both at national and global level consequently necessitating the need to understand reproductive and population structure aspects to aid in the management planning of this species. The objective of this study was to investigate the size structure, growth parameters, mortality and reproductive aspects such as sex ratios, length at first maturity and spawning patterns of kawakawa.

MATERIALS AND METHODS

Study site and sampling protocol: This study was conducted in the coastal waters of Dar Es Salaam, Tanzania (Fig. 1) for two monsoon seasons starting from April-September 2008 (southeast monsoon) and from November 2008-February 2009 (northeast monsoon). Fish were sampled monthly between April-September 2008 and November 2008-February 2009 from the artisanal fishermen ring net fleets. Specimen were kept chilled in an ice chest and transported to the laboratory at the University of Dar es Salaam where Total Length (TL) in nearest centimeter (TL±0.1) and weight to the nearest gram (W±0.1) was recorded. Gonads of both sexes were removed and weighed to the nearest gram and preserved in 10% formalin.

Length-frequency distribution: Length frequency data such as mean, minimum and maximum TL was determined on seasonal basis. Parameters of the length-weight relationship were obtained by fitting the power function $W = aTL^b$ to length and weight data where: W is the total wet weight, a is a constant determined empirically, TL is the total length in cm and b is close to 3 for species with isometric growth. Length-weight relationships of kawakawa were assessed on sex and seasonal basis. Length group at which fishing mortality (F $year^{-1}$) is high was determined using length-structured Virtual Population Analysis (VPA) model. Length measurements were pooled into groups of 5 cm length intervals and monthly data were then analyzed using FISAT II software (Version 1.2.2). Prediction of the maximum length from extreme values was obtained by fitting a graph of extreme length against cumulative probability.

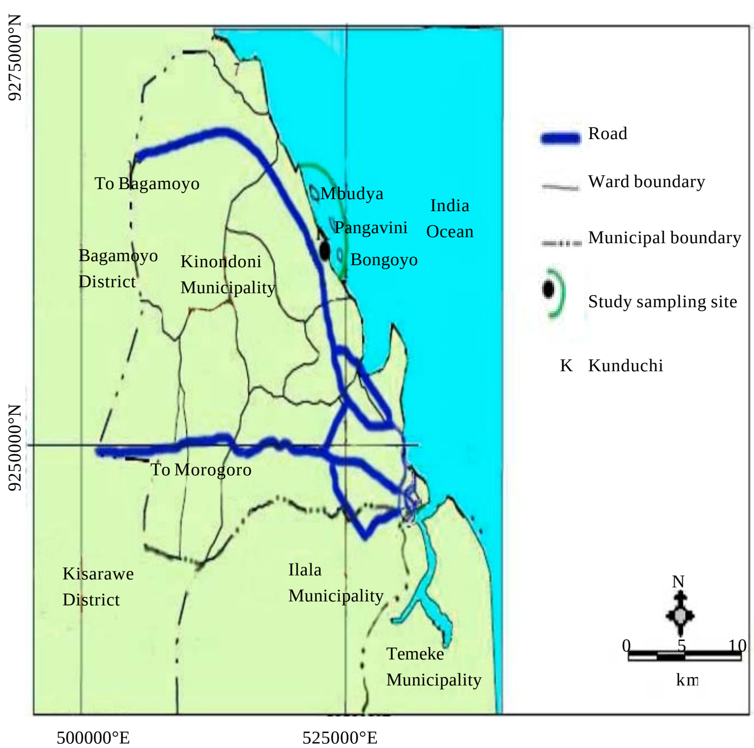

Fig. 1: Location of Dar es Salaam where kawakawa were sampled

Growth and mortality: The growth parameters K and L_∞ of the von Bertalanffy growth function were estimated by ELEFAN 1 as defined by Sparre and Venema (1998). Instantaneous total mortality (Z) was estimated from a length-converted catch curve which makes use of growth parameters and length frequency data. Natural mortality (M) will be calculated from Pauly's M equation which makes use of environmental temperature (i.e., annual mean habitat temperature for the study area was 26.9°C) and the VBGF growth parameters K and L_∞. The instantaneous fishing mortality (F) was taken as the difference between total and natural mortality: F = Z-M. The level of exploitation ratio (E)-fraction of death caused by fishing which maximizes yield recruit^{-1} was estimated using the relative yield recruit^{-1} (Y/R) and biomass recruit^{-1} model of Beverton (1966). The Beverton and Holt (1996) yield recruit^{-1} model modified by Pauly and Soriano (1986) was used to determine the size at which yield recruit^{-1} would be maximized (Lmax). Resource status was evaluated by comparing estimates of the fishing mortality rate with target (F_{opt}) and limit (F_{limit}) biological reference points (BRP's) which were defined as; Fopt = 0.5 M and F_{limit} = 2/3 M, following Patterson (1992).

Reproductive characteristics: To determine the periodicity of spawning goads were classified according to the scale of maturity developed by West (1990). Mean monthly Gonado-Somatic Indices (GSI) were calculated for each sex by expressing:

$$\frac{W_g}{W_t\text{-}W_g}\times 100$$

where, W_g is gonad weight and W_t is total fish weight. The spawning period were established by plotting monthly GSI indices against the sample period. Length-at-maturity that length when 50% of the sampled fish in a size class are sexually mature, was calculated by fitting a logistic ogive to the proportion of reproductively active fish during the spawning season in centimeter size classes. Thus the frequency of mature stage 3-5 and 5 was used as a response variable and the total length as the explanatory variable. The two-parameter ogive is described by the equation:

$$PL = (1+\exp(L\text{-}L50))^{-1}$$

where, PL is the percentage of mature fish at length L, L50 the length-at-maturity.

Statistical analysis: Independent sample t-test was performed to investigate the difference between the mean length of both male and female kawakawa on seasonal basis. The degree of association (R^2) between total length and weight was determined using Person correlation. Gonad-somatic index was tested for normality and independent sample t-test was used to assess seasonal variations. All these analysis above was performed in a computer software programme known as GraphPad Instat whereby the $p<0.05$ were used a significance level. In addition, estimation of growth parameters (K and L_∞), prediction of the maximum length from extreme values, mortality, length-structured VPA model, fishing mortality, yield recruit^{-1} and biological reference points such as Fopt and F_{limit} were computed using a computer software programme known as FISAT II (Version 1.2.2).

RESULTS

Length-frequency distribution: The mean length for both sex during southeast and northeast monsoon seasons was 52.25±0.32 and 46.23±0.52 cm, respectively ($p<0.05$). During southeast and northeast monsoon the mean length for male kawakawa was 51.33±0.51 and 45±0.01 cm, respectively ($p<0.05$). The minimum and maximum length for male was 30 and 70 cm during northeast monsoon while a length of 37 and 85 cm was measured during southeast monsoon season. Mean length of female kawakawa was 47.23±0.44 during southeast monsoon and 44.8±0.07 cm in northeast monsoon while minimum and maximum length was 39, 82, 34 and 75 cm in the respective season. During southeast monsoon male were on average 4.10 cm longer than females which indicates that the difference between means for male and female was statistically significant ($p<0.05$). Contrary, the mean length for male was 0.2 cm longer than female which indicates that the difference between means was not statistically significant ($p>0.05$). Length frequency distribution data is given in Table 1. Length frequency distribution of kawakawa fitted in VBGF curve is given in Fig. 2. Maximum length estimation was performed whereas the observed and predicted extreme length of 85.00 and 94.08 cm was recorded, respectively. Length-structured virtual population analysis showed that fishing mortality was highest (F = 4.36 year^{-1}) and lowest (0.38 year^{-1}) at mid length of 50 and 30 cm TL, respectively (Fig. 3).

The length weight relationship of both male and female was analyzed whereby the exponential form of equation $W = 0.002\times TL^{3.31}$ indicates positive allometric growth (Fig. 4). The value of coefficient of correlation (R^2) estimated for the species was 0.94 ($p<0.05$) which showing that the relationship between length and weight of the fish was highly significant. The effect of sex and seasons on exponent b for fish caught during southeast

Table 1: Length frequency data for kawakawa collected monthly from November 2008 to September 2009

	Months									
	2008			2009						
Class interval	Nov.	Dec.	Jan.	Feb.	Mar.	April	June	July	Aug.	Sep.
31-35	9	6	21	18	3	2			5	
36-40	34	28	1	46	12					18
41-45	61	85	167	62	66	80	44	38	20	134
46-50	77	240	225	152	53	138	69	58	176	146
51-55	198	16	90	134		19	10	8	19	5
56-60	1		10			1			5	6
61-65	14		1	2		1	2			
66-70			12	1	2			3	2	6
71-75		8				5			5	1
76-80			1	8			8	10	4	12
81-85					1		3	1	1	4
	394	383	528	423	137	246	136	118	232	337

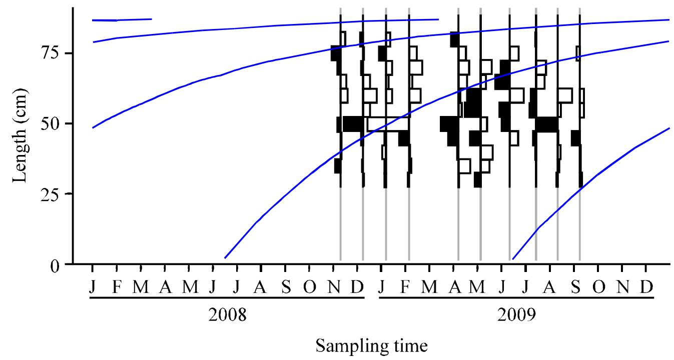

Fig. 2: Length-frequency distribution of kawakawa with the growth curve estimated by ELEFAN 1

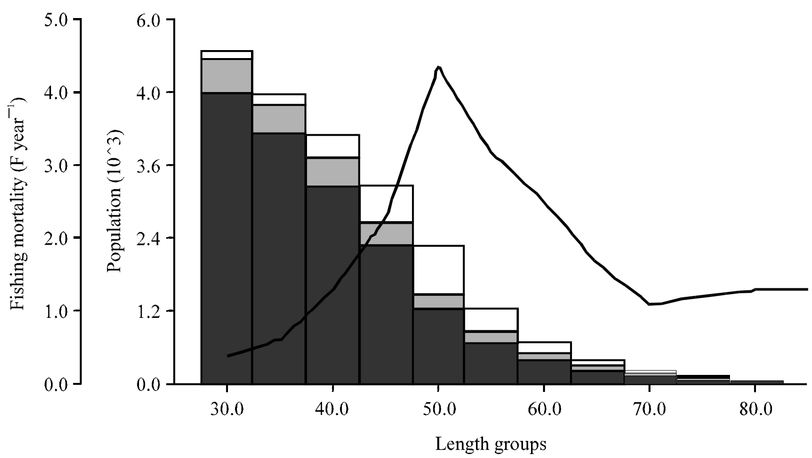

Fig. 3: Length-structured virtual population analysis of kawakawa

monsoon gave values of exponential equation in the form of $W = 0.003\times TL^{2.91}$ for male and $W = 0.01\times TL^{3.2}$ for female indicating negative and positive allometric growth, respectively. The value of coefficient of correlation (R^2) estimated for kawakawa was 0.94 and 0.89 for male and female, respectively which is an indication that the relationship between length and weight of this species was highly significant ($p<0.05$). Likewise, the exponent b for male ($W = 0.008\times TL^{2.9}$, $R^2 = 0.99$) and female ($W = 0.0004\times TL^{3.3}$, $R^2 = 0.98$) collected during northeast monsoon indicated negative and positive allometric growth, respectively. Correlation coefficient R^2 showed that the relationship between length and weight for this fish species was highly significant

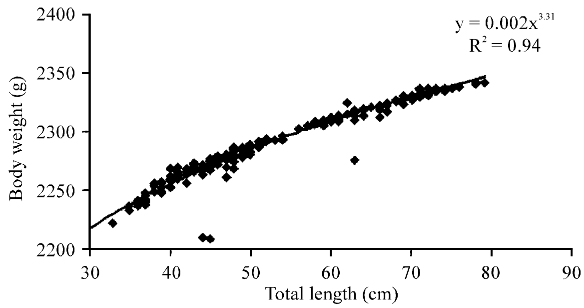

Fig. 4: Length-weight relationship of kawakawa

Fig. 5: Length-converted catch curve of kawakawa

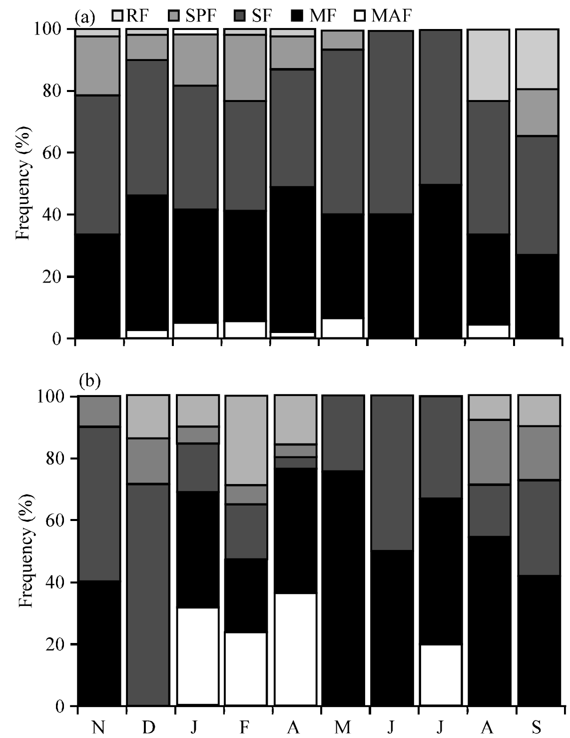

Fig. 6(a-b): Monthly maturity stages of (a) Female and (b) Male kawakawa

($p<0.05$). Analysis showed estimated exponent 'b' was close to 3 which indicated the growth was more or less isometric.

Growth and mortality: The growth parameters; L8 = 89.25 cm and K = 0.78 was estimated from the best fit given by VBGF growth function. The total mortality (Z) derived from length-converted catch curve was 1.78 year^{-1} (Fig. 5). The annual instantaneous rate of natural Mortality (M) derived from the Pauly (1980) equation (1983) was estimated as 1.09. Annual instantaneous rate of fishing mortality was 0.69 year^{-1} while exploitation ratio (E)-fraction of death caused by fishing was E-50 = 0.28 and E-max = 0.42. Therefore, maximum yield per recruit could be obtained at an exploitation rate of 0.42 and at mid class of 50 cm total length. Resource status was assessed whereas the annual instantaneous fishing mortality (F = 0.69 year^{-1}) was considerably grater than the target (F_{opt} = 0.43 year^{-1}) and limit (F_{limit} = 0.58 year^{-1}) biological reference point.

Reproduction

Gonad development and size at maturity: There was no immature kawakawa caught during the study period while few 'maturing' female (MAF) were observed in February and January (Fig. 6). However, few 'maturing' male (MAM) was observed in January, February, April and July (Fig. 6). Female and male at 'mature' (MAF) and 'spawning' stage (SF) were observed throughout the study; however the largest proportion was registered in November, December, January, February and September (Fig. 6). It was observed that fish at 'mature' and 'spawning' stages were the most prevalent in both sexes for the study period. Few individuals at 'spent' and 'resting' stage were reported in this study. Length at maturity was estimated from the graph of the proportion of mature fish against the total length where as female attained maturity earlier (L_{50} = 47 cm TL) than males (L_{50} = 52 cm TL) (Fig. 7).

Spawning season: The gonad-somatic index for female and male ranged from 1.5-4.3 and 1.4-2.2, respectively. The GSI for female (t = 9.56, p = 0.001) and male (t = 6.44, p = 0.001) was found to be significantly higher during northeast monsoon than in southeast monsoon season. Monthly variations in GSI of female and male kawakawa are shown in Fig. 8. The maximum GSI for males was 2.2±0.21 and 2.1±0.06, respectively. Smallest value of GSI for males was reached in April (1.2±0.26). Spawning for female peaked in January (3.9±0.76) and June (4.3±1.70). Spawning activity was observed all year round; however a bimodal pattern with extended spawning season from

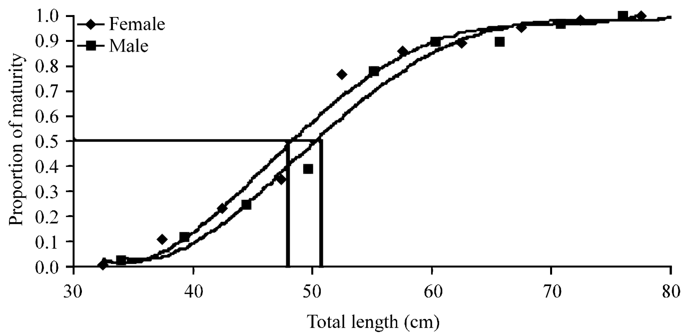

Fig. 7: Length at first maturity (L_{50}) for male and female kawakawa

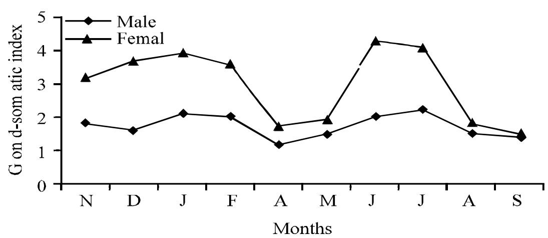

Fig. 8: Monthly mean GSI (mean±SE) of (a) Male and (b) Female kawakawa

November to February and short spawning period from June-July was noticed. An extended spawning season was noticed during northeast monsoon following increased water temperature.

DISCUSSION

Length-frequency distribution: Population structure of fish depicted in length frequency distribution provides useful information that can aid in fisheries management. According to Langlois *et al*. (2011) understanding the size structure of fish populations is fundamental to understanding growth, reproduction and recruitment with changes in size as an early indicator of disturbance. Length-frequency distributions observed in this study provides snapshots of the size structure of the species present in Tanzania coastal waters. Large number of catch ranged at a mid length of 50 cm total length which was also a size constituted majority of kawakawa at mature and spawning stage. Sex and season was observed to have the effects on the length weight relationship of kawakawa. In this study male and female samples showed deviations from the hypothetical value of three. Males showed negative allometric growth, i.e., they allocated more energy to axial growth rather than to biomass. Female revealed positive allometric growth that is, they grew more in weight than in length. Froese (2006) stated that specimens with increases in height or width more than in length should be a result of notable ontogenetic change in body shape size which is rare, or because large specimens were thicker than small specimens. This species did not present an isometric growth showing that length and biomass of kawakawa does not grow equally. Nevertheless, these values estimated for b were very close to three and within range 2.5-3.5 as defined by Carlander (1977). Beverton (1966) reported that changes of exponent b values depends primarily on the shape and fatness of the species, however various factors such as seasons, sampling time and sex are responsible for the differences in the length-weight relationships of fishes. Also factors like water temperature, salinity, food (quantity, quality and size) and time of year, sex, gonad maturity, stomach fullness, health and habitat, stage of maturity and length ranges of the specimen caught are responsible for variations in the length weight relationship (Froese, 2006).

Growth and mortality: The total mortality rate ($Z = 1.78$ year^{-1}) derived from the length converted catch curve is considerably slightly smaller than previous estimates for this species. Pauline and Janaka (1991) obtained the total mortality of 1.89 year^{-1} on the west coast of Sri Lanka. However, variations in the total mortality and consequently fishing mortality rates might have been caused by differential targeting of younger schooling fish. It could also be caused by ontogenetic and/or seasonal migrations of this species. A study by McPheron and Williams (2002) showed that most fishing gears have a tendency of catching larger numbers of older fish than their actual representation in catches would suggest. Thus size specific selectivity by fishing gears would explain the small proportion of larger and older fish in the length frequency distributions. However, the impact of fishing cannot be underestimated given the limited regulation and intensity of fisheries targeting kawakawa in the western Indian Ocean region.

The instantaneous natural mortality rate ($M = 1.09$ year^{-1}) was considerably higher than the estimated value of 0.9 year^{-1} by Pauline and Janaka (1991) in the coastal waters of Sri Lanka. Since these values were estimated from the empirical equation of Pauly (1980) which is known to overestimate M (Newman *et al*., 2000), there is a probability of actual fishing mortality to be lower than the one estimated in this study. The fishing mortality rate of 0.69 year^{-1} was considerably grater than the target ($F_{opt} = 0.43$) and limit ($F_{limit} = 0.58$) biological reference point, suggesting that the stock was heavily overexploited in the current fishing grounds. Since the present results suggest that the resource is heavily over-exploited there is a need to make review on the suitability of using ring net to catch kawakawa, reconsideration of mesh size regulations and a substantial reduction in fishing effort would required if management objectives are to be achieved. Also these results shows that kawakawa in this region is threatened by recruitment over-fishing associated with the intensive harvest of mature fish. However, results on the yield recruit^{-1} showed that the stock of kawakawa can be maximized at an exploitation rate of 0.42 year^{-1} (mid class 50 cm total length). According to Gulland (1970), it was reported that in an optimally exploited stock, fishing mortality should be about equal to natural mortality, resulting in an exploitation rate of 0.5 year^{-1}. Since our estimate of exploitation rate is 0.42 year^{-1}, it can be said that, the stock of kawakawa in the coastal waters of Tanzania is slightly exploited. Therefore, there is obtainable potential for the development of this fishery.

Reproductive characteristics: The presence of both sexes in the study area throughout the study period was of interest. Likewise, kawakawa is known to be seasonal migrant; therefore capturing mature gonads throughout the study may possibly indicate the likelihood of the presence of both resident and migratory stock. Therefore the theory of homogenous stock of kawakawa in the western Indian Ocean is questionable. Furthermore, kawakawa at mature stage were captured throughout the study indicating presence of local breeding ground in the coastal waters of Dar es Salaam. Gonads examination has shown few individuals at maturing stage 2, spent and resting-maturing stage while the catch was dominated individuals at matured stage 3 and spawning stage 4. This is an indication that few individuals of the population are allowed to spawn twice before entering into fisheries leading to recruitment over fishing. These are the stages with mature gonads which may increase their girth and hence more vulnerable to the fishing gears. Temporal trends in fish maturation have often been interpreted as compensatory density-dependent effects that regulate population growth (Rose *et al*., 2001). Density-dependent changes in maturation arise from food limitation attributable to increased intraspecific competition. Also length of maturation may be directly affected through changes in the quantity of energy reserves available for gonad development as observed in other fishes by Morgan (2004), or indirectly via changes in growth which in turn influence the triggering of maturation.

Temporal trends in maturation and length is an important trait of life history necessary for the success of fishery management, thus fundamental to establishment of the means that avoid exploitation of young specimens and the consequential reduction of spawning stock. In this study female were observed to attain maturity earlier than male ($L_{50} = 52$ cm TL). These results are deviates slightly from that of Ommaney (1953) and William (1963) in Seychelles and East African coastal waters whereas sexual maturity measured 50-65 cm TL and 55-60 cm total length, respectively. Differences in the fishing grounds, fishing pressure, sampling time and season could be the reasons for the differences in the size at maturity. Early maturity for females reflects a phenotypic compensatory response to a significant decline in population size of kawakawa as reported to other fish species by Trippel (1995) in the Eastern Gulf.

This study indicates two spawning peaks for kawakawa in the coastal waters of Tanzania; one of it being in northeast monsoon and the second one in southeast monsoon season. Although, monthly variation in the gonad-somatic index offer not only additional proof for the spawning season but also pin pointing the major phases of the reproductive cycles of this species. Fish were caught early during the breeding season (November to February and June to July) having mature eggs and high gonad somatic index. For specimen caught in April, May, August and September despite of having mature eggs but lower gonad-somatic index suggests that, the ova in one ovary mature and are released at different times during the spawning season. These observations suggest the occurrences of repeated spawning habits which may arise in response to the risk associated with spawning at a particular time. This study observed increased spawning activity during northeast monsoon when water temperature is at optimal. An extended or longer spawning duration from November to February indicates an even greater degree of environmental variability compared to the short spawning period from June-July in southeast monsoon. Therefore water temperature is likely to be the principal environmental factor that trigger for kawakawa gonad development and subsequent spawning activity.

Robertson (1991) reported that timing of spawning is determined by optimal environmental conditions allowing the greatest survival and fitness for larvae, juveniles and/or adults.

CONCLUSION AND RECOMMENDATIONS

Mean total length for both sexes was significantly higher during southeast monsoon than in northeast monsoon season. Fishing mortality was highest at mid length of 50 cm total length. The value of b coefficient estimated for the species was close to 3 showing that growth is near isometric. Annual instantaneous fishing mortality was considerably grater than the target F_{opt} and limit F_{limit} biological reference point indicating that kawakawa is heavily overexploited. Kawakawa has two spawning peak; the extended one during northeast monsoon when water temperature is optimal. Short spawning period was noticed from June to July during southeast monsoon. The results of this study have raised several questions that need to be answered before the implementation of a successful management strategy. More research is required so as answer the following fundamental questions: (1) Where is the spawning habitat of kawakawa? (2) Where do kawakawa migrate during its life cycle? (3) What is the stock structure of kawakawa? and (4) Does their appearance correspond to spawning migration?

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