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Short Communication

Using otolith weight to estimate total mortality of blackspot snapper, *Lutjanus fulviflamma* (Lutjanidae) at Mafia Island, Tanzania

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Abstract—The relationships between fish age and the length, height and weight of their otoliths are unknown for many marine fish species in East Africa. In this study, results indicate a significant positive linear relationship between age of *Lutjanus fulviflamma* (Forsskål, 1775) and otolith weight and an exponential function with otolith length and height. No statistical difference in instantaneous total annual mortality (Z) of blackspot snapper was found between that estimated from true age determined from annuli reading in sectioned otoliths and predicted age from otolith weight. Therefore, it is suggested that otolith weight could present an easy, quick and reliable technique to estimate Z and population age structure of blackspot snapper — both important for fisheries management purposes. For the method to provide an accurate measure of age, counting of annuli in otoliths of a sub-sample of the population is needed for calibration.

INTRODUCTION

Population age structure and life history parameters such as growth, mortality and age at maturity and recruitment are essential for management of commercially exploited fish stocks. However, the routine technique to determine age of an individual fish through counting of annuli formed in otoliths has some disadvantages. Firstly, the method is expensive and time consuming due to increased complexity in otolith preparation making it economically impractical when a large number of individuals have to be aged (see Bedford, 1983). Secondly, the method requires two or more highly experienced age-readers to verify age assigned to individual fish (Kimura & Lyons, 1991).

Total annual mortality (Z) represents one of the basic parameters in population dynamics that are essential for fish stock assessment for conservation and management purposes, yet few studies have made attempts to estimate Z for coral reef fishes. Instantaneous total annual mortality of fish has been estimated using a linearized catch curve based on age composition data, where the natural logarithm of the number of fish in each age class is plotted against the corresponding fish age and Z is estimated from the descending slope (Sparre & Venema, 1992). There are few studies devoted to age with subsequent determination of Z being one of the fundamental criteria necessary for the management of tropical reef fishes under threat. Factors such as extended reproductive cycles, unclear seasonality of growth and almost uniform water temperatures are attributable to weakly annuli formation on otoliths used to age tropical reef-fishes (Brothers, 1982).

Previous studies have shown that there is a positive linear relationship between fish age and

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otolith weight (e.g. Fletcher, 1991, 1995; Fletcher & Blight, 1996), but not with fish length, otolith length or otolith height (Radtke *et al.*, 1985; Fowler & Doherty, 1992; Newman *et al.*, 1996). Fletcher & Blight (1996) recommended the use of otolith weight to age individuals of pilchards (*Sardinops neopilchardus*) because otolith weight increased throughout the entire lifespan of an individual fish. Cardinale & Arrhenius (2004) suggested the otolith weight technique be used to age haddock (*Melanogrammus aeglefinus*) since it is objective, fast, totally replicable and has the same level of accuracy as that of annuli counting in otoliths.

Blackspot snapper (*Lutjanus fulviflamma*) is one of the most important reef fish species for small-scale artisanal fisheries in Mafia Island (Kamukuru, 2003). Despite widespread occurrence of *L. fulviflamma* in the western Indian Ocean region (Richmond, 2002) and use of its otoliths to age fish (Kamukuru *et al.*, 2005), understanding of the relationship between fish age and otolith length, height and weight has remained obscure. This paper aims to develop a simple and cost-effective technique for estimation of instantaneous total annual mortality of blackspot snapper using otolith weight.

MATERIALS AND METHODS

Blackspot snapper were collected using seine nets (19 - 64 mm stretched mesh size) to include as wide a size range as possible from shallow waters (< 10 m deep) at Mafia Island centred at 07°53′ S; 39°45′ E between May 1999 and April 2001. For all 12,564 specimens, total fish length (TL) was recorded to the nearest mm using a measuring board. Left and right sagittae (hereinafter referred to as "otoliths"), were removed from a sample of 2,492 specimens and stored to dry at room temperature in cross-referenced envelops for two months prior to measuring length (OTL) and height (OTH) in anterior-posterior and dorsal-ventral orientations, respectively, using a dial calliper to the nearest 0.1 mm. Otoliths weight (OTW) was determined to the nearest 0.1 mg on a Mettler AE 100 balance. The techniques for preparing, embedding, sectioning, mounting and reading of annuli in otoliths to estimate fish age (hereinafter referred to as "true age") in years is described in Kamukuru *et al.* (2005). Symmetry of left and right otoliths for OTL, OTH and OTW was determined by the paired t-test (Zar, 1999). Relationship between fish age and OTL and OTH was determined using the exponential function. A least-squares linear regression analysis was used to determine the relationship between fish age and OTW. Instantaneous total annual mortality (Z) was estimated from descending slopes of linearized catch curves based on true age and predicted age from otolith weight (Sparre & Venema, 1992). Student's t-test was used for comparing two slopes used to estimate Z. Significance level was set at $\propto = 0.05$ for all statistical tests used (Zar, 1999).

RESULTS

Otolith analysis was performed in 2,492 individual fish from which only 2,320 specimens were successfully aged. The collected blackspot snapper had size range between 88 and 297 mm total fish length and a range in age from 0 to 18 years. There were no statistical differences in otolith length, height and weight between left and right otoliths (OTL: t-Stat = -1.323; d.f. = 2489; p = 0.225, OTH: t-Stat = -1.604; d.f. = 2489; p = 0.058 and OTW: t-Stat = -0.807; d.f. = 2491; p = 0.521). Therefore, otolith length, height and weight used in subsequent analyses refer to the average measurements of the left and right sagittae for the individual fish. Table 1 shows otolith length, height and weight for each age group with a considerable variation in otolith weight within each age-class. Consequently, the range of otolith weights overlapped adjacent age-classes. Otolith length and height reached their upper limit at about 12 years of age while otolith weight increased linearly with fish age (Fig. 1 a,b,c).

Age structure was estimated for 12,564 individual blackspot snapper using true age and predicted age (Fig. 2). The slopes of the least-squares linear regression analysis, used to estimate instantaneous total annual mortality (Z) of blackspot snapper using true age (determined from annuli in sectioned otoliths) and predicted age (estimated from otolith weight) did not deviate significantly from linearity (ANOVA; r = 0.98 and 0.99; d.f. = 12 and 13; F = 288.5 and 494.6 respectively; p = < 0.001). Fig. 3 shows that Z (±

Table 1. Age, sample size (n), mean (±S.D.), coefficient of variation (CV) and range of otolith length, height and weight of *Lutjanus fulviflamma*

Age (yr)	n	Length (mm)		Height (mm)		Weight (mg)		
		Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Range
0	20	4.5 ± 0.5	11.1	2.5 ± 0.3	12.0	10.8 ± 3.0	27.8	6.9 - 15.2
1	87	5.4 ± 0.4	7.4	3.1 ± 0.2	6.5	18.5 ± 3.7	20.0	10.8 - 28.8
2	156	6.0 ± 0.4	6.7	3.4 ± 0.2	5.9	24.5 ± 4.0	16.3	16.3 - 38.7
3	291	6.7 ± 0.5	7.5	3.8 ± 0.3	7.9	32.6 ± 5.9	18.1	20.9 - 50.1
4	413	7.5 ± 0.4	5.3	4.2 ± 0.2	4.8	43.5 ± 6.6	15.2	29.3 - 62.5
5	300	8.0 ± 0.4	5.0	4.5 ± 0.2	4.4	52.2 ± 5.8	11.1	37.0 - 79.4
6	200	8.5 ± 0.5	5.9	4.6 ± 0.2	4.3	60.9 ± 8.2	13.5	43.3 - 81.8
7	226	8.9 ± 0.5	5.6	4.8 ± 0.3	6.3	70.0 ± 10.8	15.4	41.8 - 102.4
8	234	9.1 ± 0.5	5.5	4.9 ± 0.3	6.1	76.5 ± 12.6	16.5	51.4 - 120.8
9	212	9.3 ± 0.5	5.4	5.1 ± 0.2	3.9	82.9 ± 13.3	16.0	56.7 - 123.4
10	88	9.6 ± 0.6	6.3	5.2 ± 0.3	5.8	90.4 ± 16.2	17.9	54.1 - 127.9
11	39	9.8 ± 0.5	5.1	5.3 ± 0.2	3.8	101.2 ± 16.6	16.4	64.8 - 136.7
12	22	9.9 ± 0.6	6.1	5.5 ± 0.3	5.5	111.3 ± 21.9	19.7	69.4 - 142.0
13	12	10.3 ± 0.3	2.9	5.4 ± 0.3	5.6	115.5 ± 14.3	12.4	91.2 - 137.3
14	9	10.6 ± 0.5	4.7	5.7 ± 0.3	5.3	121.2 ± 15.8	13.0	97.6 - 143.1
15	5	10.7 ± 0.3	2.8	5.8 ± 0.3	5.2	130.5 ± 23.4	17.9	103.4 - 161.9
16	5	11.2 ± 0.3	2.7	5.8 ± 0.2	3.4	140.9 ± 12.6	8.9	129.7 - 140.9
18	1	11.0		6.1		154.4		

s.e.) from true age (0.48 ± 0.03 yr^{-1}) did not differ significantly from predicted age (0.44 ± 0.02 yr^{-1}) (Student's t = 1.203; d.f. = 25, $p > 0.05$).

DISCUSSION

Both otolith length and height exhibited decreased growth at age 12 years when the rate of increase in body length of blackspot snapper had began to decline (Kamukuru *et al.*, 2005). The Brody growth coefficient K, of von Bertalanffy growth function for the blackspot snapper obtained by length-at-age data (0.15 yr^{-1}) (Kamukuru *et al.*, 2005) is equal to that of otolith length-at-age (see Fig. 1 a) suggesting that otolith length grows in a similar fashion as fish length increases with age. Similar changes in otolith length and height to fish age have been described in other fish species (Boehlert, 1985; Anderson *et al.*, 1992).

Otolith weight increased with fish age throughout the life of blackspot snapper as shown in many previous studies for other fish species (e.g. Reznick *et al.*, 1989; Pawson, 1990; Wright *et al.*, 1990; Worthington *et al.*, 1995; Newman *et al.*, 1996; Araya *et al.*, 2000; Cardinale *et al.*, 2000; Cardinale & Arrhenius, 2004). This implies that otolith weight may provide a rapid and economic method of ageing, as suggested by some authors (Pawson, 1990; Wright *et al.*, 1990; Fletcher, 1991; Wilson *et al.*, 1991; Worthington *et al.*, 1995; Cardinale & Arrhenius, 2004). This notion emphasises that otolith weight in older fish continues to increase with fish age unlike other variables (e.g. fish length, fish weight, otolith length, otolith height and otolith width).

In this study, otolith weight explained 86% of the variation in age of blackspot snapper within the range commonly reported for the relationship between fish age and otolith weight (80-95%). However, Worthington *et al.* (1995) cautioned that the coefficient of determination is not the best index on which to assess the utility of otolith weight to estimate age. These authors suggested that more reliable estimates of age will be possible when there is little variation in otolith weight within age-classes and large variation among age-classes implying a tight fit of observations to a relationship with a higher steep. In the present study, the large overlap of otolith weight among age-classes and a lack of known-age individuals used for calibration, suggests that otolith weight alone cannot reliably be used to predict the age of blackspot snapper. For example, individuals with an otolith weight of approximately 79 mg were

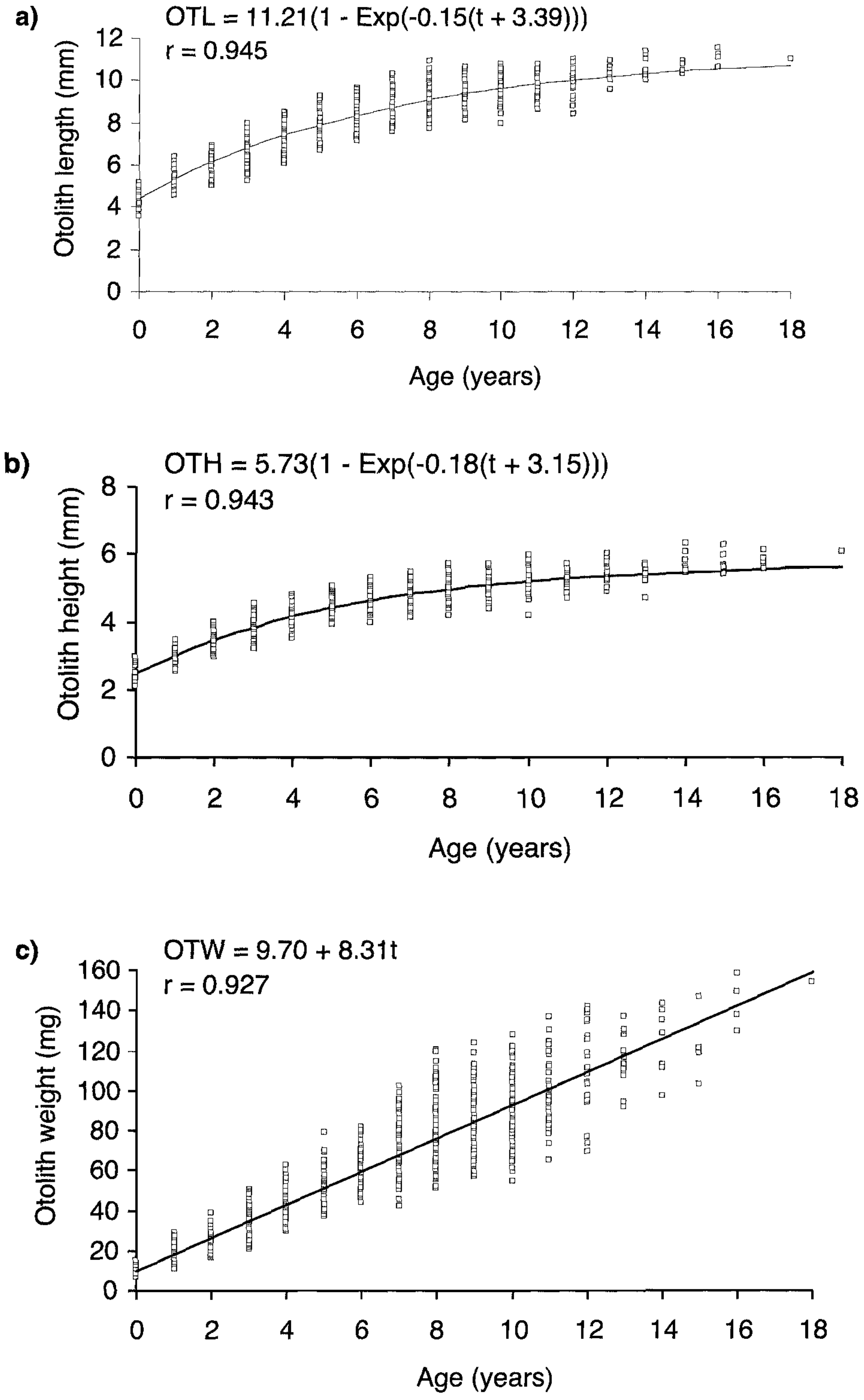

Fig. 1. Relationships between fish age and (a) otolith length (OTL), (b) otolith height (OTH) and (c) otolith weight (OTW) of *Lutjanus fulviflamma* (n = 2,320, t = age in years)

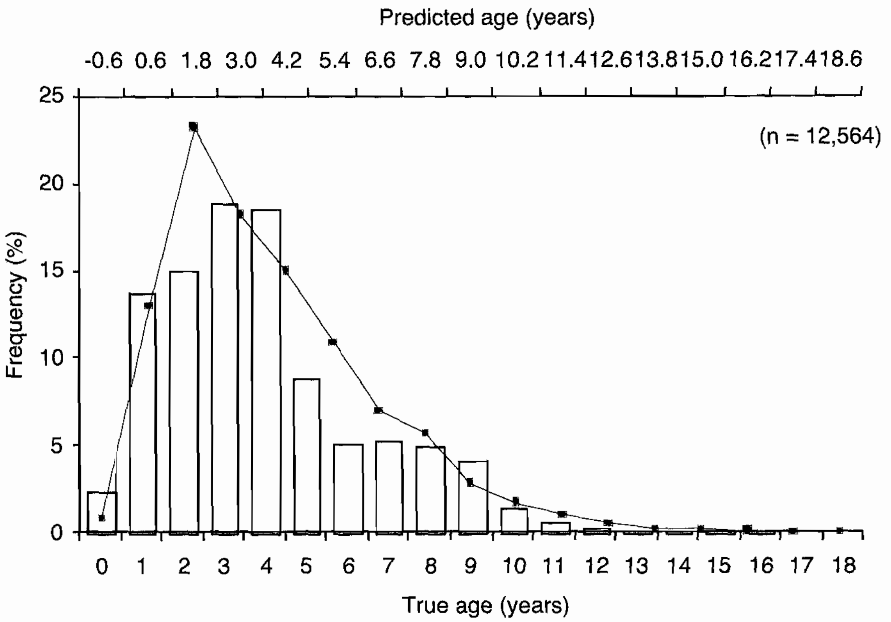

Fig. 2. Age structures of *Lutjanus fulviflamma* sampled from Mafia Island between May 1999 and April 2001. Bars show true age structure determined from annuli in sectioned otolith and line shows estimated age structure from the relationship between fish age and otolith weight

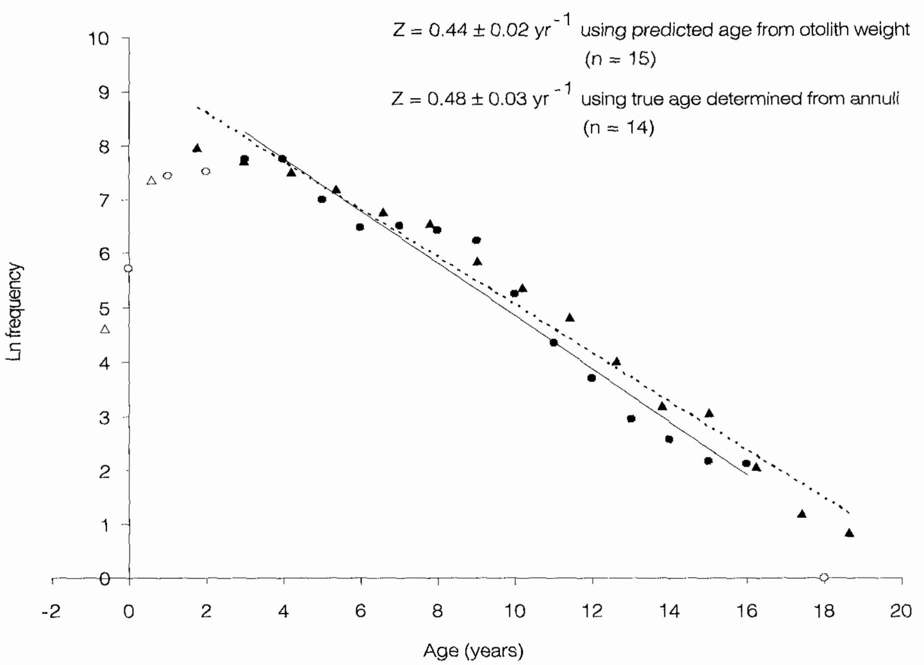

Fig. 3. Estimated instantaneous total annual mortality (Z) of *Lutjanus fulviflamma* determined from descending slopes of linearized catch curves. Solid circles and triangles show true age and predicted age points respectively used in least-squares regression analysis (note that open circles and triangles represent age groups not fully recruited)

found in age-classes from 5 to 12 years. Nevertheless, if traditional techniques (i.e. annuli reading in sectioned otoliths) could be combined with more accurate, expensive and time consuming techniques (e.g. image analysers and scanning electron microscope) (Welleman & Storbeck, 1995) there could be an increase in the accuracy of linear calibration thus, establishing a model that could be routinely used in estimating fish age. Furthermore, Worthington *et al.* (1995) and Cardinale & Arrhenius (2004) suggested that the use of known-age fish for calibration could greatly increase the reliability of using otolith weight to determine fish age with subsequent estimation of total mortality.

Currently, as a result of high-intensity fishing, most tropical reef fish stocks are seriously fished (Munro & Williams, 1985). Consequently, fisheries managers will require fish age data for routine fish stock assessment. Results of this study are promising and potentially useful to managers since they confirm that otolith weight can reliably be used to determine age structure of populations and instantaneous total annual mortality of blackspot snapper, with the same level of accuracy as that of true age determined from annuli reading in sectioned otoliths. Worthington *et al.* (1995) recommended the use of otolith weight for monitoring the age structure of populations and estimation of rates of mortality from catch curves of exploited fish species.

In conclusion, the use of otolith weight could present an optimal method (cheap, quick, and of equal accuracy as annuli counting technique) to determine the age structure of fish populations and estimations of total annual mortality (Z). In addition, the ability to age larger samples of fish using otolith weight could increase accuracy of estimates of the age structure of a population for species that are difficult to age using annuli, provided an initial calibration equation can be determined from a few individuals.

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