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Age, Growth and Mortality of Brown Stripe Snapper *Lutjanus vitta* (Quoy and Gaimard 1824) from West Sulu Sea, Philippines

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Abstract

The age, growth and mortality parameters of brown stripe snapper *Lutjanus vitta* (Quoy and Gaimard 1824) from west Sulu Sea were investigated. Brown stripe snappers were sampled from small-scale bottom set longline landings from October 2012 until December 2013. The oldest recorded male was 11.71 years and female was 10.71 years, and measured 33.5 and 26.5 cm, respectively. Examination of sectioned otolith margins (n= 490) indicated annuli deposition in December and January which was closely related to the lowest water temperature in Sulu Sea. The von Bertalanffy growth parameters (male L_∞ = 32.5 cm, K= 0.34 year^{-1}, t_0 = -1.68 year; female L_∞= 27.1 cm, K = 0.53 year^{-1}, t_0 = -1.30 year) differed significantly between sexes (ARSS F= 6.33, d.f. =22, p< 0.05). The estimated total mortality rates were, 0.53 year^{-1} (male) and 0.50 year^{-1} (female). Linear relations between otolith weight and age implies continuous growth proportional to age and otolith weight and therefore, otolith weight may be used as proxy to predict age in future stock assessment.

Introduction

The brown stripe snapper *Lutjanus vitta* (Quoy and Gaimard 1824), is a medium-size, reef-dwelling snapper belonging to the family Lutjanidae. It is widely distributed throughout the Indo-west Pacific region extending from Seychelles in the Indian Ocean to New Caledonia and northward to Ryukyu Islands (Allen 1985). Brown stripe snapper inhabits waters between 40- 120 m depth with bigger fish observed in deeper areas (Davis and West 1992).

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Snappers of the genus *Lutjanus* form an important component of small-scale and commercial fisheries within the Indo-Pacific region (Davis and West 1992; Newman et al. 2000; Shimose and Tachihara 2005; Shimose and Nanami 2015). In the Philippines, snappers are important components in demersal fish catch. However, trends in catch and catch per unit effort had been declining due to the continuous increase in fishing effort that has led to overfishing of economically important species (Barut et al. 2004; Gonzales 2004). More recently, fish stock assessment conducted in Honda Bay in west Sulu Sea (WSS) suggested an overexploitation of many important species including *Lutjanus fulviflamma* (Forsskål 1775) and *Lutjanus vitta* (Quoy and Gaimard 1824) (Ramos et al. 2009).

Fish age determination using otoliths has long been practised in temperate countries for many important fish stocks such as cod and hake. This is because of high reading accuracy due to clear annuli formation attributed to temperature (Morales-Nin and Geffen 2015). In the tropics, length-frequency analysis has been the most popular method because it requires less time and effort and relatively cheap compared to the sectioned otolith method. However, various studies have recently claimed that sectioned otoliths method is the most accurate among others to determine fish age particularly for slow growing, long-lived species with low rate of natural mortality such as snappers (Fowler 2009; Newman et al. 2010; Holloway et al. 2015; Piddocke et al. 2015). In the Great Barrier Reef (GBR), Australia, annual growth increment of 14 species of snappers (including brown stripe snapper) was validated using mark and recapture method by injecting oxytetracycline (OTC) in fish (Cappo et al. 2000). This study has failed to draw conclusion for six species (including brown stripe snapper) due to inadequate sample size. However, according to Piddocke et al. (2015) wide range of studies using marginal increment analysis on *Lutjanus* species have strongly supported the annual increment deposition.

Available information concerning the life history of brown stripe snapper was restricted to the studies of Loubens (1980) in the waters of New Caledonia, Davis and West (1992) from the North West Shelf of Western Australia, Newman et al. (2000) from central GBR and Ramachandran et al. (2014) from southwest coast of India. Loubens (1980) and Newman et al. (2000) reported the age and growth of brown stripe snapper based on annuli counts in sectioned otoliths, Davis and West (1992) have used urohyals to determine age, growth and mortality while Ramachandran et al. (2014) determined the age, growth and mortality using length-frequency analysis. Among those studies reported, sectioned otolith method provided higher estimates of maximum age, while that of urohyal and length-frequency reported lower estimates.

The use of sectioned otoliths to determine age, growth, longevity and mortality of brown stripe snapper has never been reported in the northern hemisphere. This study was the first comprehensive investigation on the life history of brown stripe snapper using sectioned otoliths in WSS, Philippines. The objectives of this study were to determine the age, growth and mortality rates, length-at-age composition and establish the relationship between otolith weight and age of brown stripe snapper in WSS.

Materials and Methods

The collecting site and sample collection

Specimens were collected monthly from October 2012 to December 2013 in Puerto Princesa City, Palawan, Philippines fish market. Only specimens caught from WSS were chosen as samples. To ensure that specimens came from WSS, regular interviews with fishers from fish landings and fish vendors in the market were conducted. In Puerto Princesa City, the fish vendors were also the traders who bought fish directly from fishers upon landing and sold immediately in the market which is an hour away by public transport. The brown stripe snappers were captured using small-scale bottom set longline at water depth between 40-130 m.

West Sulu Sea is situated along the east coast of mainland Palawan (Fig. 1). The Sulu Sea in particular is located at the southwestern Philippines bordered by the Philippine islands on the north, east and west and on the south by Borneo. It has an average depth of 4,400 m and is one of the major fishing grounds in the Philippines. It serves as a major nautical highway linking the Indo-Pacific to the Indian Ocean (WWF 2003).

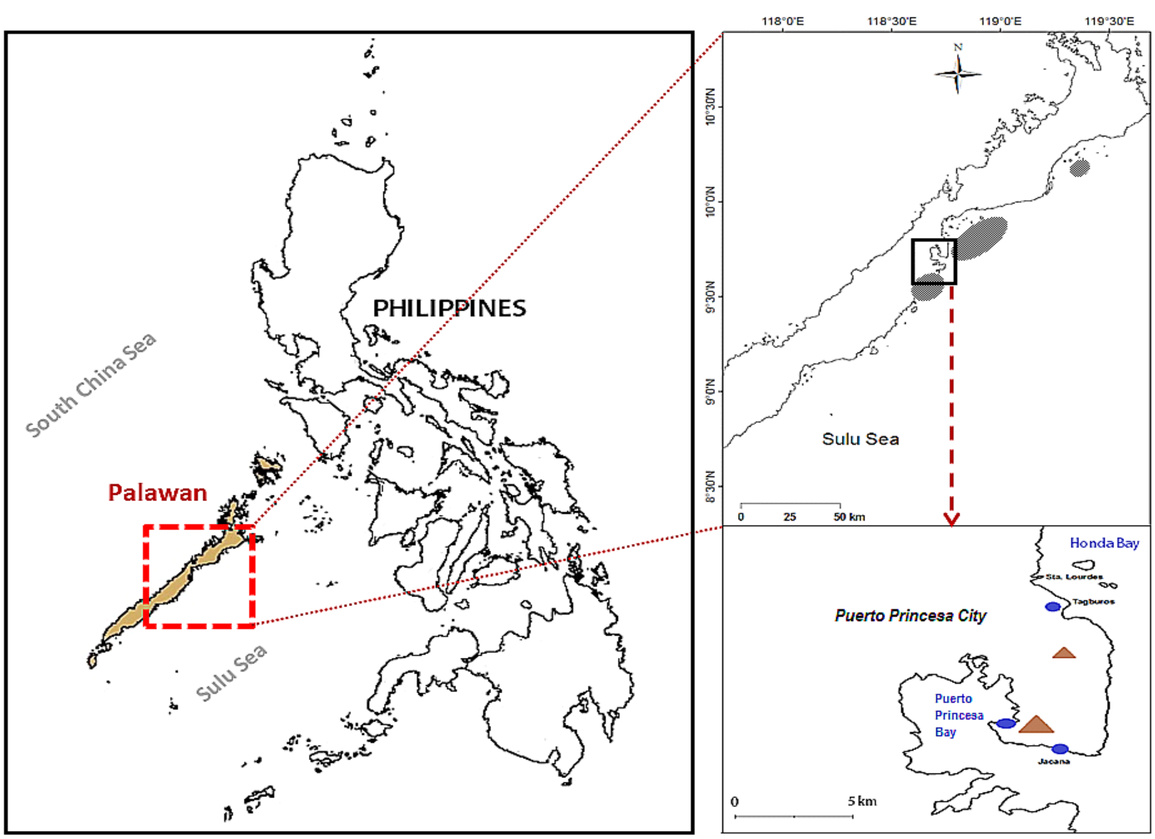

Fig. 1. Map of Palawan showing fish markets (▲) and fish landing sites (●) in Puerto Princesa City (inset), shaded area denotes fishing grounds in west Sulu Sea. Size of symbols and shades are proportional to the quantity of samples obtained.

Morphometric measurements

The total length (TL), and weight (W) of 916 specimens were measured to the nearest 0.1 cm and 0.1 g, respectively. Sex was determined based on macroscopic and microscopic characterisation of gonads.

Otolith preparation and age determination

The left and right sagittal otoliths were extracted from the otic bulla through the operculum. The extracted otoliths were cleaned, dried and weighed (OW) to the nearest 0.0001 g using Sartorius analytical balance. Age analysis followed that of Secor et al. (1992) and Newman and Dunk (2002). Only right otoliths were processed, since comparison of mean weight between left and right otolith did not significantly differ (t-test, $p > 0.05$, d.f.=914). Otoliths were embedded in transparent epoxy resin and sectioned transversely at the primordium using Buehler Isomet low-speed jewelry saw. Two thin sections (0.5-0.6 mm) were mounted on glass slides and coated with transparent nail enamel. Blind readings were initially undertaken to ensure accuracy of results. Counting of annuli was done under the stereo microscope at 10x and 50x magnifications using alternately transmitted and reflected lights with black background. Ages were determined by counting the opaque band from primordium towards the proximal of the ventral lobe. Birthdate was based on main spawning season determined for this species (Palla et al. unpubl. data) and corrected following Nanami et al. (2010). Each otolith was examined independently in three occasions by the primary author at one month interval. An agreement was made when readings on three different occasions were identical, otherwise the third reading was selected because by this time the reader had acquired adequate experience in annuli interpretation. Otoliths with indecipherable annuli were excluded from the analysis.

The precision of each estimate was calculated using the “index average percent error” (IAPE) of Beamish and Fournier (1981). The IAPE uses 5 as reference value, whereby values below 5 indicate high reading accuracy and values above denote otherwise. This was computed using the formula:

$$\mathrm{IAPE} = \frac{100}{N}\sum_{j=1}^{R}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}\right]$$

where: N = number of fish aged; R = number of readings; X_{ij} = mean age of jth fish at ith reading; and X_j = mean age calculated for the fish jth fish.

Growth models

Growth in length-at-age for both sexes after correction was fitted to von Bertalanffy growth function (VBGF) using the FISAT II software (Gayanilo et al. 2005) to estimate the size-at-age using non-linear least squares estimation procedures.

The VBGF is defined as;

$$L_t = L_\infty(1 - exp^{\{-K[t-t_0]\}})$$

where: L_t= is the length of fish at age t; L_∞= is the asymptotic length; K = is the growth coefficient and defines the growth rate towards L_∞; t = the age of fish and t_o= the hypothetical age at which a fish would have zero length if it had always grown in a manner described by the equation. A modified analysis of residual sum of squares (ARSS) (Chen et al. 1992) was used to compare the VBGF growth curve between sexes. This was derived from the linear model of Zar (1999). This modified model is one of the robust tools to compare the VBGF because of its non-linear formulation. It was computed using the formula:

$$F = \frac{\frac{RSS_P - RSS_S}{DF_{RSS_P} - DF_{RSS_S}}}{\frac{RSS_S}{DF_{RSS_S}}} = \frac{\frac{RSS_P - RSS_S}{3.(K-1)}}{\frac{RSS_S}{N-3.K}}$$

where: RSS_p = residual sum of square (RSS) of each VBGF fitted by pooled growth data; RSS_s = sum of the RSS of each VBGF fitted to growth data for each individual sample, N = total sample size, and K = number of samples in the comparison.

Estimation of mortality rate

The age-based catch curve was used to estimate the total mortality rate (Z) (Ricker 1975). The number of fish in each age class was log-transformed and regressed against the corresponding age. The negative slope (*b*) in the regression equation corresponded to Z. A t-test was used to compare if there exists a significant difference between sexes using the formula:

$$t = \frac{|b1 - b2|}{\sqrt{(S_{b1})^2 + (S_{b2})^2}}$$

where: *b* is the slope (-Z) and S_b is the standard error of slope.

Otolith weight-age relationship

Relationship between OW and age was fitted to the linear regression model to determine whether OW was significantly related to age. This was performed using the formula:

Age = *a* + *b* x OW

where: *b* is the constant (slope of regression line) and *a* constant (intercept).

Results

Size structure

A total of 916 brown stripe snappers were examined with mean of 23.7±0.2 cm TL (meanSE), (range 11.5-37.2 cm) and mean W of 259.6±5.5 g (range 20.1-760.0 g). Otoliths with legible annuli comprised 63.2% of the total number of individuals examined. Mean size of males was 26.6±0.3 cm TL, and mean W was 307.7±9.1 g; females had mean of 24.1±0.2 cm TL and mean W 215.6±5.1 g and unknown or indeterminate sex had mean of 16.7±0.2 cm TL and mean W 63.9±1.9 g (Fig. 2). The dominant size classes were those between 24.0 and 32.0 cm or 78% for males and 22.0-28.0 cm or 80% for females. Individuals with undetermined sex which comprised the majority of juvenile cohorts were excluded in the analysis. Mean length and weight between sexes differed significantly (t-test, $p < 0.05$), which indicates that males are larger than females in this study.

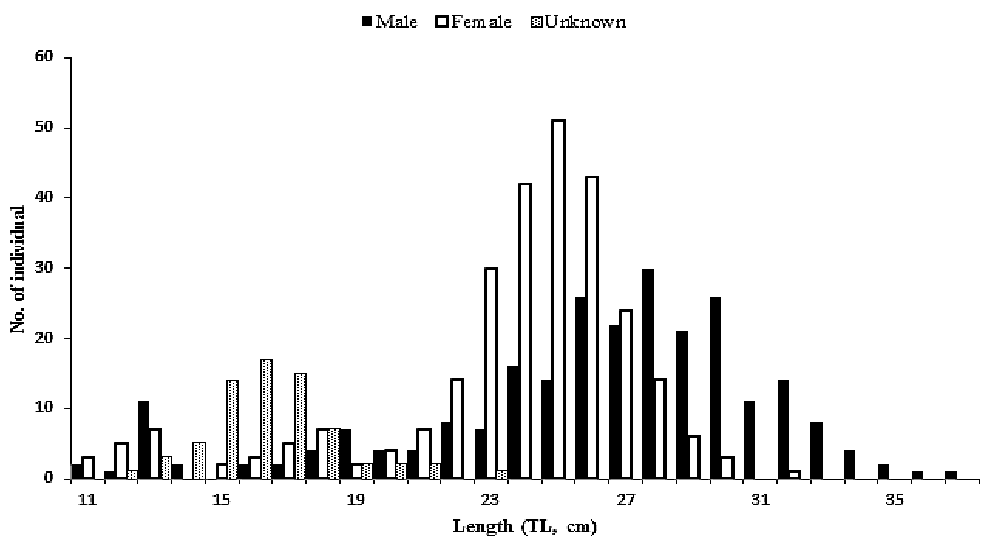

Fig. 2. Length-frequency distribution of *Lutjanus vitta* from West Sulu Sea (males = 250, females = 273, unknown, indeterminate sex = 69.

Otolith morphology and microstructure

The sagittal otoliths of brown stripe snapper were laterally compressed and concave along the distal surface (Fig. 3A). The sulcus formed longitudinally along the median of the proximal surface. The ratio of otolith depth to length ranged from 48-60%. Annuli of individuals between 2 years old and below displayed broad and diffused opaque bands, whereas, specimens between 4 years and older showed relatively clear annual rings with few checks, overlapping broad opaque and narrow translucent bands (Fig. 3B).

Annuli counts were mainly derived from ventral lobe near the lower edge of sulcus. Sagittal otolith of brown stripe snapper was characterised by hard calcified structure. Thus sectioning was restricted to 0.5-0.6 mm thick. The precision of otolith reading was low, with overall IAPE of 13.82%, n = 458. The IAPE of individuals between ages 0.71 and 2.71 years was higher (23.63%, n = 100) than ages between 3.71 and 11.71 years (11.01%, n = 358).

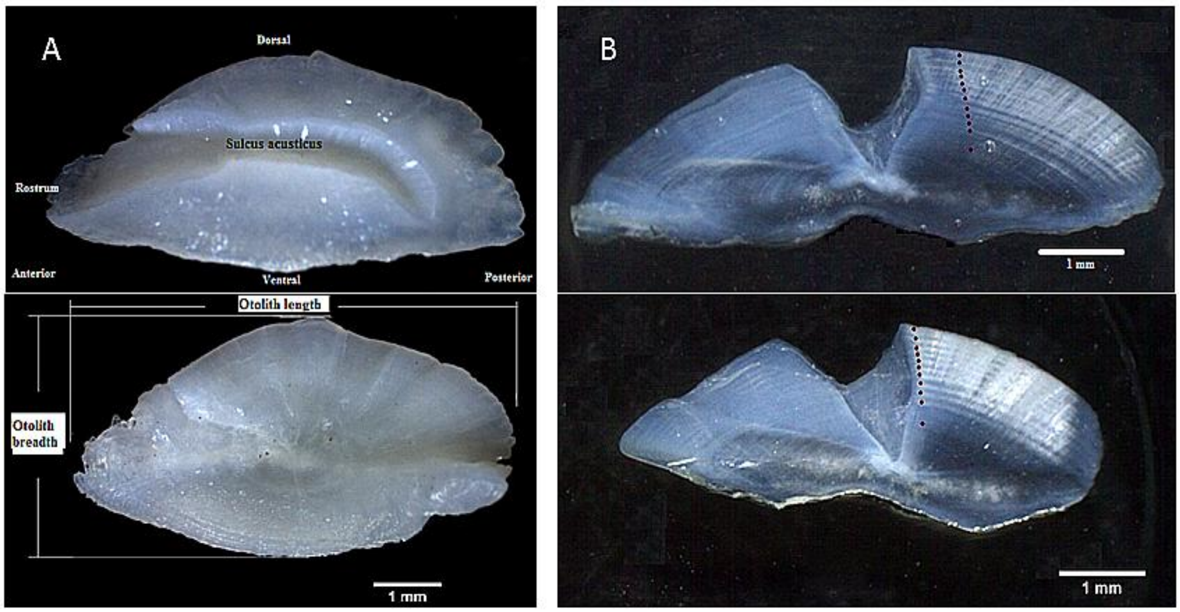

Fig. 3. (A) Right otolith (34.2 cm, TL) showing proximal side (above) and left otolith distal side and dimensions (below), and (B) photomicrograph of transverse section of male otolith 34.2 cm TL, 11.71 years old (above) and female 26.5 cm TL, 10.71 years old (below) of *Lutjanus vitta* from west Sulu Sea, Philippines.

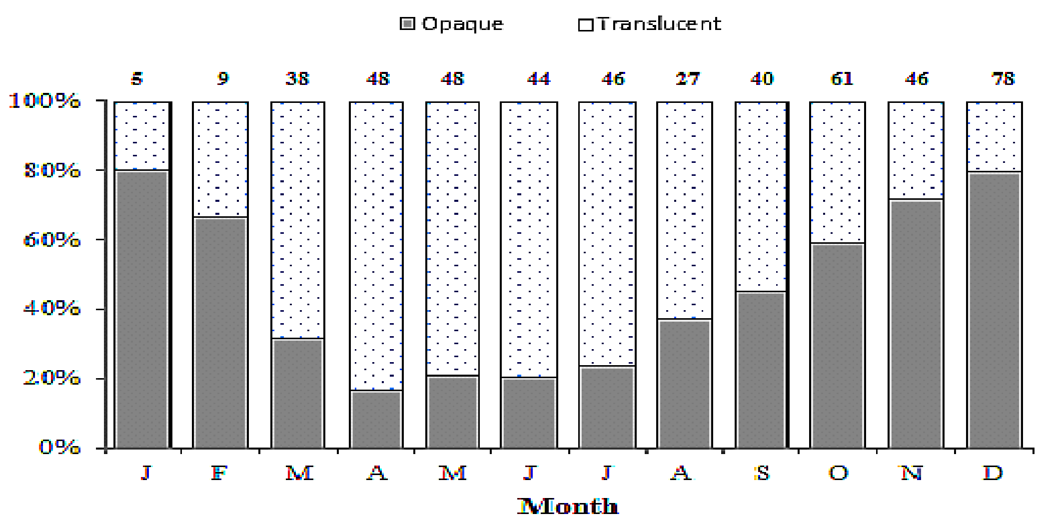

Fig. 4. Percentage composition of opaque and translucent bands at the otolith margins of *Lutjanus vitta* from west Sulu Sea, Philippines. Numbers above bars denote sample size.

Analysis of otolith margin was performed on 490 samples. The proportion of otoliths with highest (>50%) opaque margins was recorded from October to February with peaks in December and January, while for otolith with translucent margins was from March to September (Fig. 4).

Age structure and longevity

Based on the main spawning season in April, the age was corrected to the fraction of time in year from April to December and January. This gave the average of 0.71 year for the first annulus, 1.71 years for the second and so on. The recorded age for males ranged from 0-11.71 years with dominant age class of 4.71 years (25 %) while that of females ranged from 0-10.71 years with dominant age class of 3.71 years (19%) or 1 year lower than that of males (Fig. 5).

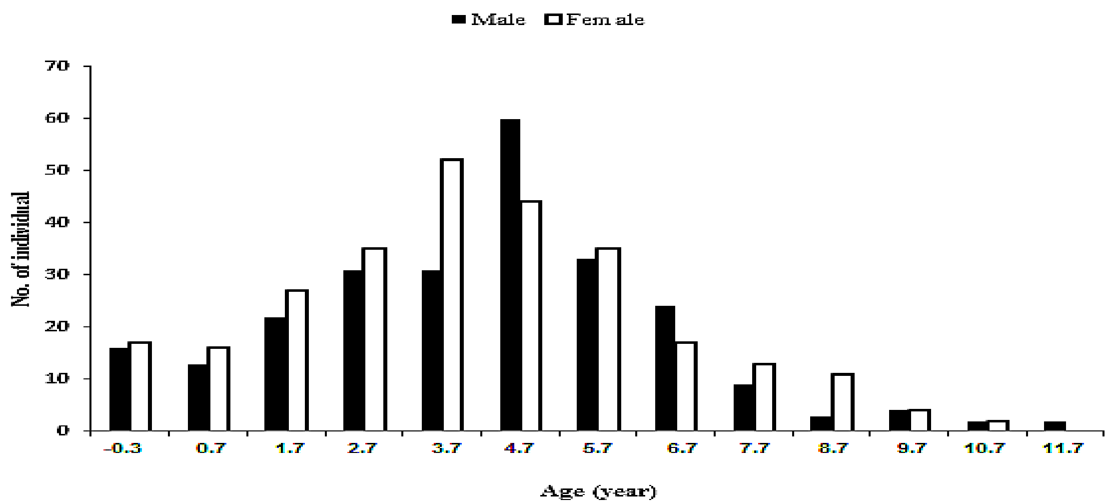

Fig. 5. Age-frequency distribution of *Lutjanus vitta* from west Sulu Sea, Philippines (males = 250, females = 273).

Growth and mortality parameters

The corrected length-at-age data were fitted with von Bertalanffy growth curve separately for each sex (Table 1, Fig. 6). The estimated length infinity was higher for males than females, while the growth constant (K) was the opposite. Initial rapid growth pattern was observed during the first 2 years for both sexes. Differential and faster growth rates were observed for males from age 1.71 onwards. Growth was much slower upon reaching age 6.71 for males and age 4.71 for females. Fifty percent of asymptotic length was attained before reaching age 1 for both sexes. Length-at-age between sexes was significantly different (ARSS, F= 6.33, d.f.= 22, p< 0.05,). The catch curve method considers samples within the full recruitment age. This could be determined by visual inspection of the points lying close to the regression line. Samples away from the regression line were excluded on the premise that they have not yet entered the fishery or perhaps not well-represented as in the case of larger individuals.

The full recruitment age for both sexes was at 4.71 years. The estimated mortality rates ranged from 50-53% which could be translated to nearly 50% survival rate of brown stripe snapper in WSS. The estimated total mortalities rates between sexes (Table 1) were not significantly different (t-test, $p > 0.05$).

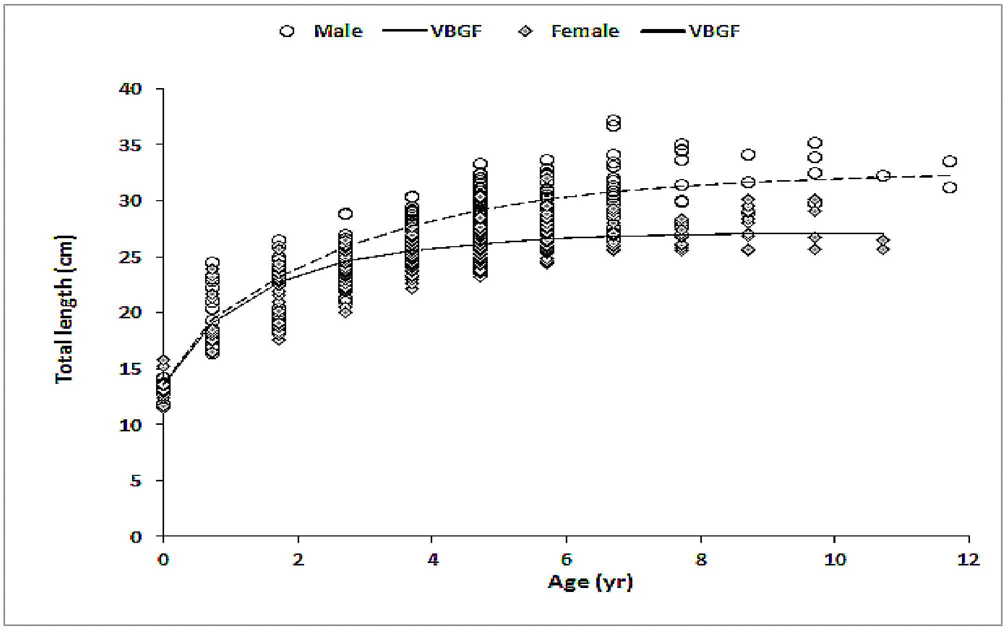

Fig. 6. Corrected length–at-age values and fitted von Bertalanffy growth curve of males and females *Lutjanus vitta* from west Sulu Sea, Philippines.

Table 1. Growth and mortality parameters derived from von Bertalanffy growth function and age-based catch curve for *Lutjanus vitta* from west Sulu Sea, Philippines. (- standard error of mean)

Parameters	**Male**	**Female**
L_∞(cm)	32.5±0.8	27.1±0.2
K (yr^{-1})	0.34±0.03	0.53±0.05
t_0 (yr)	-1.68±0.19	-1.30 ± 0.12
Z(yr^{-1})	0.53 ($r^2 = 0.93$)	0.50 ($r^2 = 0.95$)
n	250	273

Otolith weight- age relationship

The relationships between OW and age for males and females were as follows: Males (Age = (39.59 x OW) – 0.7493), ($R^2 = 0.8223$); Females (Age = (48.54 x OW) – 1.4514), ($R^2 = 0.8005$).

Otolith weight was chosen among other otolith dimensions because it is widely used as a robust predictor of age (Newman et al. 2000; Fowler 2009; Williams et al. 2015). The present study suggests that OW is directly related to age.

Discussion

The mean TL for brown stripe snapper from WSS was found to differ significantly between sexes. The males were relatively larger than females, a result which is consistent with the findings by Newman et al. (2000) for the same species from the GBR.

As to the structure of annuli of brown stripe snapper from WSS, it closely resembled those from GBR with an IAPE of 13.8 % but higher than those obtained by Newman et al. (2000) in the GBR (IAPE =13.1%). While this needs further studies, it is likely that annuli structure of brown stripe snapper in these two regions is similar. In contrast, otoliths of brown stripe snapper from waters of Okinawa, Japan (Hayashida and Tachihara unpubl. data) showed a very well-defined annuli structure which is relatively easy to interpret. Such defined annuli structure could be attributed to seasonal differences in temperatures between latitudes wherein the range of seawater temperature during winter is higher in Okinawa (subtropical) than in lower latitude such as the Philippines and GBR. In this study, when the IAPE of the samples within the 3.71- 11.71 years cohorts were computed, it decreased to 11.1% which indicates that older individuals have more legible annuli.

In the examination of margin edge, the opaque band was observed to form in December and January, when water temperatures in WSS ranged from 27-31 ^{o}C. Wang et al. (2006) have demonstrated that the strong northeast monsoon from November until February in the Sulu Sea drives the mixing of cold and nutrient rich deep water to the surface layers resulting in low surface temperature (27.1 ^{o}C) and high primary production (Chl-a 0.4 g.m^{-3}). Analysis of reproductive period using gonado-somatic index (GSI) showed no relationship to annuli formation (Palla et al. unpubl. data). The peaks of spawning were recorded in April and October. The present study corroborates the findings that relate annuli deposition to temperature (Newman et al. 2000). Moreover, linear regression between OW and age was significant suggesting the proportion of growth as fish grows older. Likewise in Okinawa, opaque band formation has been related to reproductive period rather than temperature (Shimose and Tachihara 2005; Shimose and Nanami 2015).

The longevity observed in association with size for both sexes suggest that male lives longer and grows bigger than female. Similar to many *Lutjanus* species, the male brown stripe snapper attained longer asymptotic length and lower growth coefficient than female. The longevity estimated from this study lies within the range of those reported in the literatures (Loubens 1980, Newman et al. 2000) and unpublished data of Hayashida and Tachihara on Okinawa (Table 2).

The longevity reported using methods other than sectioned otolith provided underestimates (e.g. Davis and West 1992; Ramachandran et al. 2014).The relatively faster growth rate of brown stripe snapper during the first two years for both sexes is in consonance with the findings of Newman et al. (2000) from GBR. This difference in growth rate between sexes upon reaching age 2 is associated with sexual maturity (Newman et al. 2000). Accordingly, Palla et al. (unpubl. data) estimated an earlier sexual maturity for females (1.8 years) than males (2.2 years). However, Shimose and Nanami (2015) emphasized that the cause for sexual dimorphism with size for snappers is yet to be understood. A similar observation was also reported by Davis and West (1992) from Western Australia.

Table 2. Von Bertalanffy growth function parameters from other geographic regions with the present study.

Locality	Sex	L_∞	K	t_0	Length type	References
New Caledonia	M	28.0	0.32	-	SL	Loubens 1980
	F	24.0	0.30	-	SL	
Central Great Barrier	M	24.4	0.98	-0.08	FL	Newman et al. 2000
Reef, Australia	F	24.2	0.81	-0.10	FL	
Okinawa, Japan	M	27.0	0.34	-1.15	SL	Hayashida and
	F	21.7	0.69	-0.49	SL	Tachihara unpbl. data
West Sulu Sea,	**M**	**32.5**	**0.34**	**-1.68**	**TL**	**Present study**
Philippines	**F**	**27.1**	**0.53**	**-1.30**	**TL**	

The mortality rate of brown stripe snapper was not significantly different between sexes. The recorded mortality rate in this study will serve as baseline data for WSS. The present result is not comparable with those from the GBR because of different catching methods and the varying status of fish stock between these two areas. The main fishing method employed in the GBR was fish trap and it was indicated that brown stripe snapper from the GBR was unexploited by commercial fisheries (Newman et al. 2000). Moreover, this study can neither confirm nor disprove the earlier report of overexploitation in WSS because the previous study had employed the length-based method which was known to underestimate the longevity (Ramachandran et al. 2014). Finally, it should be noted that age-based catch curve method considers only a steady-state population and it was originally designed for temperate fish stocks. Accordingly, this method has the assumption of "constant parameter system" which means that parameters such as recruitment and mortality are constant throughout the year and by age classes which is not the case in this study.

In the context of OW to age relationship, the coefficient of determination for both sexes implies that 82% and 80% of variability is accounted for by age for male and female, respectively. In addition, the significant correlation between OW and age indicates that OW continues to increase even if the fish has reached its maximum length (Kamukuru et al. 2005). The linear regression models for both sexes were tested to estimate the predicted age using mean otolith weight for each age class (Appendix A). On the average, the difference between predicted age and observed age ranges from 0.52±0.07 year (males) to 0.66±0.12 year (females). Hence, it is suggested that OW is a good proxy of age in the absence of standard otolith processing tools. However, in doing so one must be cautious because of the inherent influence of environmental condition on the growth of the species concerned.

Conclusion

This study was able to determine the ages of brown stripe snappers in WSS. The maximum age attained was similar to those reported in Australia and New Caledonia but 1 year lower than those in Okinawa, Japan, suggesting that longevity is not strictly latitude specific. Evaluation of otolith margins suggests that annuli deposition maybe related to low water temperature as opposed to reproductive period. Furthermore, growth rate was fast during the first 2 years before reaching sexual maturity. The recorded mortality rates for both sexes can be translated into nearly 50% survival. Consequently, these estimates on mortality rates are incomparable with the other results because of the inherent bias in methods. This study has afforded accurate information that is useful in the development of a model for sustainable management of this species in WSS.

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Appendix A. Predicted age derived from linear regression model between Age and Otolith Weight (OW). Males (Age = (39.59 x OW) – 0.7493); Females (Age = (48.54 x OW) – 1.4514).

Male				**Female**			
OW (g)	**Age (observed)**	**Age (predicted)**	**Difference (yr)**	**OW (g)**	**Age (observed)**	**Age (predicted)**	**Difference (yr)**
0.06	0.71	1.54	0.83	**0.06**	0.71	1.41	0.70
0.08	1.71	2.32	0.61	**0.08**	1.71	2.36	0.65
0.10	2.71	3.20	0.49	**0.10**	2.71	3.34	0.63
0.13	3.71	4.52	0.81	**0.12**	3.71	4.29	0.58
0.15	4.71	5.04	0.33	**0.13**	4.71	5.06	0.35
0.15	5.71	5.36	0.35	**0.14**	5.71	5.57	0.14
0.17	6.71	6.02	0.69	**0.17**	6.71	6.72	0.01
0.21	7.71	7.45	0.26	**0.17**	7.71	6.80	0.91
0.24	8.71	8.74	0.03	**0.19**	8.71	8.01	0.70
0.28	9.71	10.32	0.61	**0.21**	9.71	8.66	1.05
0.30	10.71	11.23	0.52	**0.22**	10.71	9.14	1.57
0.33	11.71	12.41	0.70				
Mean			**0.52**				**0.66**
Standard error			**0.07**				**0.12**