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RESEARCH PAPER

Length Based Growth Estimation of Most Commercially Important Scombridae from Offshore Water of Pakistan Coast in the Arabian Sea

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Abstract

Seasonal growth pattern of skipjack tuna (*Katsuwonus pelamis*), longtail tuna (*Thunnus tonggol*), kawakawa (*Euthynnus affinis*) and king mackerel (*Scomberomorus guttatus*) were studied during five years period (between August 2006 and December 2011). Seasonal samplings of the species were collected from offshore water of Pakistan coast in the Arabian Sea. The weight - length relationships (WLRs) among the species except *E. affinis* demonstrated that the growth is allometric type (Pauly's *t* test, P < 0.005). The seasonal von Bertalanffy growth model parameters computed from seasonal length - frequency distributions, were estimated as L_∞ = 67.1 cm TL, K = 1.055 year^{-1}, C = 0.990 for *E. affinis*, as L_∞ = 66.8 cm TL, K = 1.378 year^{-1} and C = 0.950 for *K. pelamis*, as L_∞ = 71.7 cm TL, K = 0.916 year^{-1} and C = 0.849 for *T. tonggol*, as L_∞ = 55.7 cm TL, K = 1.049 year^{-1} and C = 0.980 for *S. guttatus*. The seasonal oscillation in growth rate was determined for the species (C > 0.8). The slowest period of growth corresponded to in September (WP = 0.7) for *E. affinis,* (WP = 0.6) in August for *K. pelamis*, (WP = 0.4) in May for *T. tonggol* and (WP = 0.0) in January for *S. guttatus*.

Keywords: **:** Scombridae, seasonal growth, LFDA, ELEFAN, Arabian Sea, Pakistan

Introduction

Gillnet is the main fishing gear used for catching tuna and other large pelagic fishes in many countries of the world including Pakistan (Moazzam and Nawaz, 2015). There are four main harbors and nine primary landing sites along the coast of Pakistan. The largest is Karachi fish harbor, which is used by approximately 80-90% of the industrial fishing fleet, almost exclusively shrimp trawlers and larger gillnetters (Hornby *et al*., 2014). The gillnets are the gear employed for catching tuna by these wooden-hulled vessels and about 500 gillnet fishing vessels are engaged in the inshore and offshore fishery for large pelagic species with most vessels ranging between 10 and 20 m (Hornby *et al*., 2014; Khan, 2012). Only about 30 vessels are between 20 to 30 m and have on board freezing compartments and dual registration to fish in Pakistan and Iran's exclusive economic zone, EEZ (Khan, 2012). Large pelagic species such as skipjack tuna, *Katsuwonus pelamis*, longtail tuna, *Thunnus tonggol*, kawakawa, *Euthynnus affinis*, king mackerel, *Scomberomorus guttatus* and narrow-barred Spanish mackerel, *Scomberomorus commerson* support some of the more important fisheries in Pakistan (FAO, 2015). According to FAO statistics for last four years between 2010 and 2013, total catch of these fish species was reported as between 28463 and 30520 ton (mean: 29710.8±490.29 ton), while total marine fish catch was between 294814 and 308167 ton (mean: 302826.6±6060.19 ton) from the Pakistan coast (FAO, 2015) in the Arabian Sea.

This means that Scombrids fish catches constitutes about 10% of the total marine fish catch in Pakistan.

The distribution of *K. pelamis* includes the offshore waters with temperature ranging from 14.7 to 30°C (circumglobal in seas warmer than 15°C) while larvae are mostly restricted to waters with surface temperatures of at least 25°C (van der Land *et al*., 2001; Collette *et al*., 2011a; Froese and Pauly, 2015). *T. tonggol* is Indo-Pacific species inhabiting from the Red Sea and East Africa to Papua New Guinea, north to Japan, and south to Australia (Collette *et al*., 2011b; Froese and Pauly, 2015). The distribution of *E. affinis* includes Indian and Western Pacific Ocean and occurs in open waters with temperatures ranging from 18°C to 29°C but always remains close to the shoreline (Collette and Nauen, 1983; Collette *et al*., 2011c; Froese and Pauly, 2015). The distribution areas of *S. guttatus* include Indo-Pacific from the

Persian Gulf, India and Sri Lanka to Southeast Asia, north to Hong Kong and Wakasa Bay, Sea of Japan (van der Land *et al*., 2001; Froese and Pauly, 2015). *S. commerson* is pelagic and oceanodromous and found in the Indo-West Pacific from the Red Sea and South Africa to Southeast Asia, north to China and Japan and south to southeast Australia, and to Fiji shrimps (Collette *et al*., 2011e; Froese and Pauly, 2015). These scomberids fish species feeds on a variety of fish, crustaceans, cephalopods, mollusks and spawns all year long in tropical waters and from spring to early fall in subtropical waters (Devaraj, 1998; van der Land *et al*., 2001; Collette *et al*., 2011a, b, c, d, e; Froese and Pauly, 2015).

Fish growth can be definite changes in fish length or weight over time and it is mostly rapid in early life most probably associated with the size at sexual maturity and slows with age (Von Bertalanffy, 1951). Growth is also considered to be the result of a counteraction of anabolism and catabolism of building materials and anabolic activities are in perpetuity greater than the catabolic activities for fish (Avşar, 2005). A number of environmental factors, such as temperature, oxygen concentration, salinity and photoperiod, influence the rate of growth. Nutrition, including the quality and quantity of food, also plays a significant role in growth regulation (Dutta, 1994). Fish exhibit a determinate type of growth in short-lived species of warmer regions and an indeterminate type in long-lived species of colder regions (Dutta, 1994). The most common type of animal growth is that growth rates continually decrease with time and finally the organism reaches a steady state in the adult (Von Bertalanffy, 1951). The growth of fish can also display seasonal oscillations, mainly due to fluctuations of temperature, food supply and investment of energy during spawning and maturity time.

Historically, different methods have been applied to determine of growth of Scombrids fish obtained different area. These studies based on length frequency analysis (LFA), hard parts such as otolith, dorsal spines and vertebrata and tagging studies. Most of these studies were conducted based on LFA and for this two techniques were used as popularly. Firstly, the Electronic Length Frequency Analysis (ELEFAN) program has been used to fit the von Bertalanffy growth (VBG) curve on seasonal length-frequency distributions without considering the age composition. Secondly, length frequencies have been transformed to ages either by Petersen method or by standard statistical procedures such as Bhattacharya method and then the VBG curve has been fitted to modal lengths (mean length at age) to estimate the growth parameters (Wild and Hampton, 1994; Yesaki, 1994a,b; Siddeek, 1995).

Reviews of the biology and fisheries for *K. pelamis* from Pacific Ocean, *T. tonggol* and *E. affinis* from the indo-pacific region were reported by Wild and Hampton (1994), Yesaki (1994a) and Yesaki (1994b), respectively. Moreover, the VBG curve parameters (L_∞, K, t_0) mostly estimated based on the ELEFAN procedure for *E. affinis* were reported from different areas by different authors (Yesaki, 1994b; Khan, 2004; Ahmed *et al*., 2015). In the previously studies growth estimation using direct and indirect methods for *K. pelamis* were also reported from different geographical areas by different authors (Chi and Yang, 1973; Koya *et al*., 2012; Adams and Kerstetter, 2014). Studies concerning parameters estimation of VBG curve for *T. tonggol* from different geographical areas almost all of were based on otolith, modal progression analysis (MPA) and the ELEFAN were reported by Wilson (1981), Supongpan and Saikliang (1987), Yesaki, (1989), Prabhakar and Dubley (1989), Ghosh *et al*. (2010), Griffiths *et al*. (2010), Abdussamad *et al*. (2012) and Kaymaram *et al*. (2013). Length based growth estimation of *S. guttatus* were reported by Devaraj (1981) from the Palk Bay and the Mannar Gulf and by Rashid *et al*. (2010) from the Bay of Bengal off Bangladesh coast.

Various growth models have been proposed to explain the growth pattern of individuals for a particular species.Because organisms generally growth seasonally, a good description of the pattern of growth of an organism that lives for a number of years requires a seasonal adjustment to the growth rate (Henderson and Seaby, 2006). A modified von Bertalanffy growth model (five parameters model) has been developed to incorporate such a seasonal growth pattern (Somers, 1988). A seasonal growth pattern has recently been reported from different areas for different fish species. However, there is no detailed information on the seasonal growth rate of Scombrids fish from offshore water of Pakistan coast in the Arabian Sea. The aim of this study was to estimate the seasonal von Bertalanffy growth parameters using length frequency data for skipjack tuna (*K. pelamis*), longtail tuna (*T. tonggol*), kawakawa (*E. affinis*) and king mackerel (*S. guttatus*) during five years period (2006 - 2011) and also investigate the length weight relationships of these species from offshore water of pakistan coast in the Arabian Sea.

Materials and Methods

Study Area and Sampling

Scomberomorus commerson (n = 294), *Scomberomorus guttatus* (n = 278), *Euthynnus affinis* (n= 313), *Thunnus tonggol* (n = 300) and *Katsuwonus pelamis* (n = 325) were collected offshore water in exclusive economic zone (EEZ) of Pakistan coast in the Arabian Sea. Fishes were obtained from commercial fishermen engaged in fishing with gill nets on average 2500 m long, with a mesh size ranging between 13 cm to 17 cm (average 15 cm) and a depth of about 80 meshes during seasonal surveys. Seasons were grouped as winter (between December and February), spring (between March and May), summer (between June and August), and autumn (between September and November).

Weight - Length relationships (WLRs)

The length (*TL*) of the fish was measured from the tip of the anterior part of the mouth to the tip of caudal fin in (cm). Fish weight was measured after blot drying with a piece of clean towel. From the fresh samples were taken total length (*TL*) in (cm) and body weight (*W*) in (g) were measured to the nearest 0.1 cm and 0.01 g, respectively.

Least squares regression analysis with MS Excel software was used to calculate the weight length relationship parameters of all species. The weight length relationship was estimated as:

$$W = aTL^b;$$

where *W* is the body weight (g), *TL* is the total length (cm), *a* is the intercept, and *b* is the slope of the regression line.

Comparison of the difference of slope value from *b* = 3 (isometric growth) for all species, Pauly's *t*-test was performed (Pauly 1984). Pauly's *t*-test statistic was calculated as:

$$t = \frac{Sd_{\log TL}}{Sd_{\log W}} \frac{|b-3|}{\sqrt{1-r^2}} \sqrt{n-2}$$

where Sd_{logTL} is the standard deviation of the log *TL* values, Sd_{logW} is the standard deviation of the log *W* values, n is the number of specimens used in the computation. The value of *b* is different from *b* = 3 if *t* value is greater than the tabled *t* values for n-2 degrees of freedom (Pauly, 1984).

Von Bertalanffy Growth Parameter Estimation

Growth in length has been described using the von Bertalanffy (1938) growth equation, based on either observed or back calculated length at ages. The length frequency distribution analysis (LFDA) package is also a PC based computer package for estimating growth parameters from fish length frequency distributions. Version 5.0 of LFDA includes methods for estimating the parameters of both non seasonal and seasonal versions of the von Bertalanffy growth curve (Kirkwood *et al*., 2003).

The standard or non-seasonal von Bertalanffy (1938) growth function (VBGF) is:

$$L_t = L_\infty (1 - e^{-k(t-t_0)})$$

Seasonal growth or five parameter von Bertalanffy growth model (5 P VBGF) was described using the Somers's (1988) version of the VBG equation:

$$L_t = L_\infty \left[1 - e^{\left[-K(t-t_o) - \left(C\frac{K}{2\pi} \right) \sin 2\pi (t-t_S) + \left(C\frac{K}{2\pi} \right) \sin 2\pi (t_o - t_S) \right]} \right]$$

,

where, L_t is length at age t, L_∞ is the asymptotic length to which the fish growth, *K* is the growth-rate parameter, t_0 is the nominal age at which the length is zero, *C* is the relative amplitude ($0 \leq C \leq 1$) of the seasonal oscillations, t_S is the phase of the seasonal oscillations ($-0.5 \leq ts \leq 0.5$) denoting the time of year corresponding to the start of the convex segment of sinusoidal oscillation.

The time of the year when the growth rate is slowest, known as the winter point (*WP*), was calculated as:

$WP = t_S + 0.5$.

Seasonal VBG curves were fitted to the length distributions after first indicating a range of values of L_∞ and *K* and reducing iteratively the range to maximize the goodness of fit (*Rn*) of the curves to the data. *Rn* was calculated as:

$$Rn = \frac{10^{\frac{ESP}{ASP}}}{10}$$

where ASP is the available sum of peaks, computed by adding the best values of the available peaks, and ESP is the explained sum of peaks, computed by summing all the peaks and troughs hit by the VBG curve. Analysis of the seasonal length data were fitted to length frequency distributions grouped in 2 cm total length size classes using the ELEFAN procedure in the PC-based computer package Version 5.0 of LFDA (Kirkwood *et al*. 2003).

The ELEFAN procedure firs restructures length frequencies and than fits a VBG curve to the restructured data. Both seasonal and non-seasonal VBG curves were fitted to the seasonal length distribution after providing a range of values for the parameters to be estimated and than iteratively reducing the range until the goodness of fit of the curve to the data is maximized. Attempts of growth estimation for *S. commerson* were not achieved at all due to length frequency distribution data and therefore, we performed LFDA procedure for *E. affinis*, *K. pelamis*, *S. guttatus* and *T. tonggol*. Because of the fact that significant differences of mean total length and size distribution were not determined between males and females, growth estimations were derived for combined sexes.

Growth performance comparisons were made using the growth performance index (*Φ*') which is preferred rather than using L_∞ and *K* individually (Pauly and Munro 1984) and is computed as:

$\Phi' = \log(K) + 2\log(L_\infty)$.

Results

A total of 1510 fish were sampled from 2006 to 2011 during fishing seasons. Mean total length of females and males for *E. affinis* (*t*-test: P=0.0575), *K. pelamis* (*t*-test: P=0.6046), *S. commerson* (*t*-test: P=0.0327), *S. guttatus* (*t*-test: P=0.6267) and *T. tonggol* (*t*-test: P=0.3687) were not significant different.

Size-frequency distribution between females and males for *E. affinis* (Kolmogorov-Smirnov two sample test: d = 0.1779, P=0.4298), *K. pelamis* (Kolmogorov-Smirnov two sample test: d = 0.1015, P=0.8981), *S. commerson* (Kolmogorov-Smirnov two sample test: d = 0.1241, P=0.3113), *S. guttatus* (Kolmogorov-Smirnov two sample test: d = 0.0699, P=0.9424) and *T. tonggol* (Kolmogorov-Smirnov two sample test: d = 0.1434, P=0.5162) were not significant different.

Weight - length relationships (WLRs)

The weight - length relationships of five species were showed in Table 1. WLRs was estimated as $W = 0.0076TL^{3.0882}$ (r^2 = 0.8110, n = 313, sd_{logTL} = 0.0218, sd_{logW} = 0.0750, Pauly's *t*-test = 0.9829, $P > 0.005$, isometric growth) for *E. affinis*, $W = 0.0016TL^{3.4571}$ (r^2 = 0.8595, n = 325, sd_{logTL} = 0.0237, sd_{logW} = 0.0885, Pauly's *t*-test = 5.8774, P<0.005, possitive allometric growth) for *K. pelamis*, $W = 0.1514TL^{2.1468}$ (r^2 = 0.7746, n = 278, sd_{logTL} = 0.0093, sd_{logW} = 0.0228, Pauly's *t*-test = 12.2398, P<0.005, negative allometric growth) for *S. guttatus*, $W = 0.1558TL^{2.1626}$ (r^2 = 0.8453, n = 294, sd_{logTL} = 0.0113, sd_{logW} = 0.0265, Pauly's *t*-test = 15.4678, P<0.005, negative allometric growth) for *S. commerson* and $W = 0.1011TL^{2.4606}$ (r^2 = 0.8387, n = 300, sd_{logTL} = 0.0228, sd_{logW} = 0.0613, Pauly's *t*-test = 8.6291, P<0.005, negative allometric growth) for *T. tonggol*.

The slope of WLRs regression lines for 5 species except for *E. affinis* were significantly different from the isometric growth curve slope (*b* = 3) (P<0.005). These results showed that *S. guttatus*, *S. commerson* and *T. tonggol* have negative allometric growth characteristics while *K. pelamis* exhibit positive allometric growth.

Von Bertalanffy Growth Parameters

The seasonal and non-seasonal von Bertalanffy growth parameters obtained from the LFDA for each species are summarized in Table 2. The Rn value of the non-seasonal growth curve for each species improved when a seasonal growth curve was fitted (Table 2), suggesting that, at least for our data, *E. affinis*, *K. pelamis*, *S. guttatus* and *T. tonggol* exhibit a seasonal growth pattern. This was also apparent in (Figure 1A, Figure 1B, Figure 2A, Figure 2B, Figure 3A, Figure 3B, Figure 4A, Figure 4B) where sinusoidal pattern could be observed in the seasonal von Bertalanffy growth curve. On the other hand, the *Rn* value of the non-seasonal VBG curve improved by 14% for *K. pelamis* (Figure 1B), 27% for *T. tonggol* (Figure 2B), 30% for *E. affinis* ((Figure 3B), 21% for

Table 1. Weight – length relationship parameters and growth types of five species. ns: non-significant, *a* is the intercept, and *b* is the slope of the regression line

Species	*a*	*b*	r^2	*n*	Pauly's *t*-test	*P*	Growth type
K. pelamis	0.0016	3.4571	0.8595	325	5.8774	P<0.005	positive allometric
T. tonggol	0.1011	2.4606	0.8387	300	8.6291	P<0.005	negative allometric
E. affinis	0.0076	3.0882	0.8110	313	0.9829	ns	isometric
S. guttatus	0.1514	2.1468	0.7746	278	12.2398	P<0.005	negative allometric
S. commerson	0.1558	2.1626	0.8453	294	15.4678	P<0.005	negative allometric

Table 2. Seasonal and non-seasonal von Bertalanffy growth function parameters. L_∞ is the asymptotic length to which the fish growth, *K* is the growth-rate parameter, t_0 is the nominal age at which the length is zero, *C* is the relative amplitude of the seasonal oscillations, t_S is the phase of the seasonal oscillations, *WP* is winter point, *Rn* is the goodness of fit, φ' is growth performance index

Growth Curve	Species	Parameters					*WP*	*Rn*	φ'
		L_∞ (cm)	K (year^{-1})	t_0 (year)	t_s	*C*			
Hoenig seasonal	*K. pelamis*	66.8	1.378	-0.05	0.11	0.950	0.6	0.503	3.789
	T. tonggol	71.7	0.916	-0.99	-0.06	0.849	0.4	0.679	3.673
	E. affinis	67.1	1.055	-0.84	0.16	0.990	0.7	0.633	3.677
	S. guttatus	55.7	1.049	-0.42	-0.50	0.980	0.0	0.779	3.512
Non seasonal	*K. pelamis*	66.3	1.223	-0.45				0.443	3.730
	T. tonggol	69.9	0.934	-0.09				0.536	3.659
	E. affinis	66.3	0.927	-0.23				0.486	3.610
	S. guttatus	55.8	1.081	-0.27				0.644	3.527

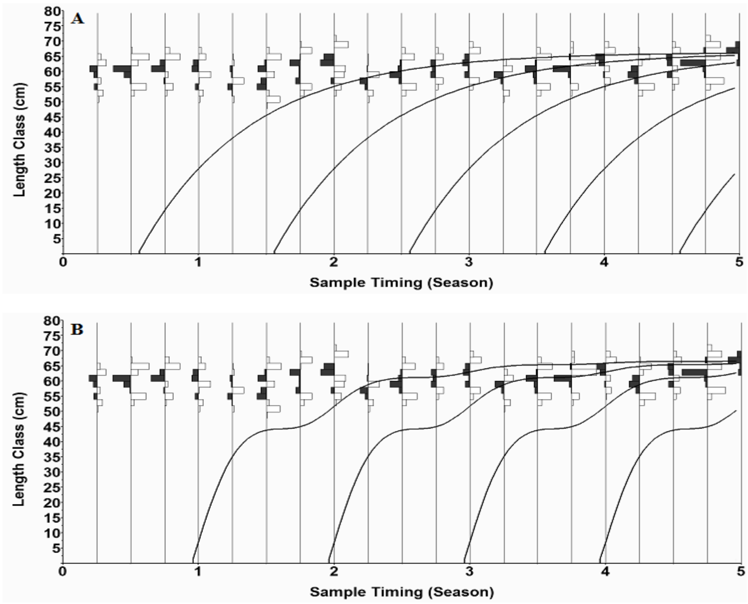

Figure 1. Non-seasonal (A) and Hoenig seasonal (B) von Bertalanffy Growth Function (VBGF) curves of *Katsuwonus pelamis*.

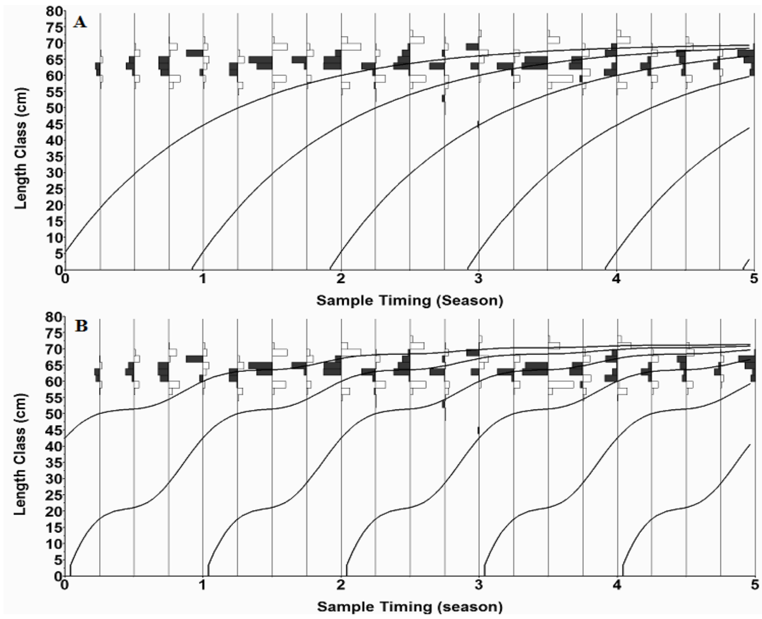

Figure 2. Non-seasonal (A) and seasonal (B) von Bertalanffy Growth Function (VBGF) curves of *Thunnus tonggol*.

S. guttatus (Figure 4B), and after fitting a seasonal VBG curve (Table 2).

Stronger seasonal variation of growth was determined for *E. affinis* (C = 0.990), *K. pelamis* (C = 0.950), *S. guttatus* (C = 0.980) and *T. tonggol* (C = 0.849). The start of slow growth period was in September (WP = 0.7) for *E. affinis*, in early August for *K. pelamis* (WP = 0.6), in early January for *S. guttatus* (WP = 0.0) and the slow growth period started in May (WP = 0.4) for *T. tonggol* (Table 2). Calculated growth performance indices (Φ'; Table 2) of seasonal growth were a bit greater than it was for non-seasonal.

Discussion

The WLRs are important and have many applications in fish stock assessments, biomass estimations, ecological studies and modeling aquatic ecosystems. The WLRs are also provides valuable information on the habitat where the fish lives, condition, reproduction history, life cycle and the general health of fish species (Froese, 2006; Froese *et al*., 2011). Our results about the WLRs of five scomberids are not new, but provide current information on the species. In this study, four species showed allometric growth pattern, while one species

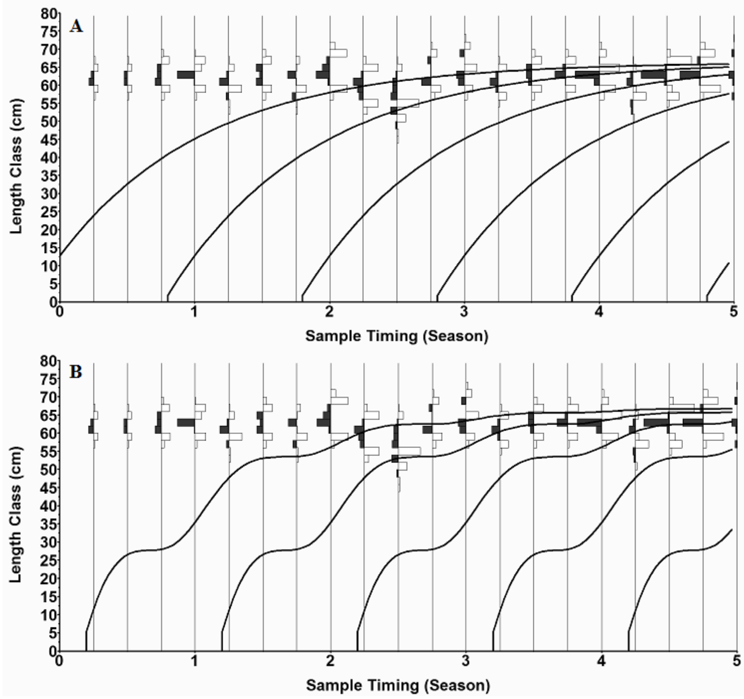

Figure 3. Non-seasonal (A) and Hoenig seasonal (B) von Bertalanffy Growth Function (VBGF) curves of *Euthynus affinis*.

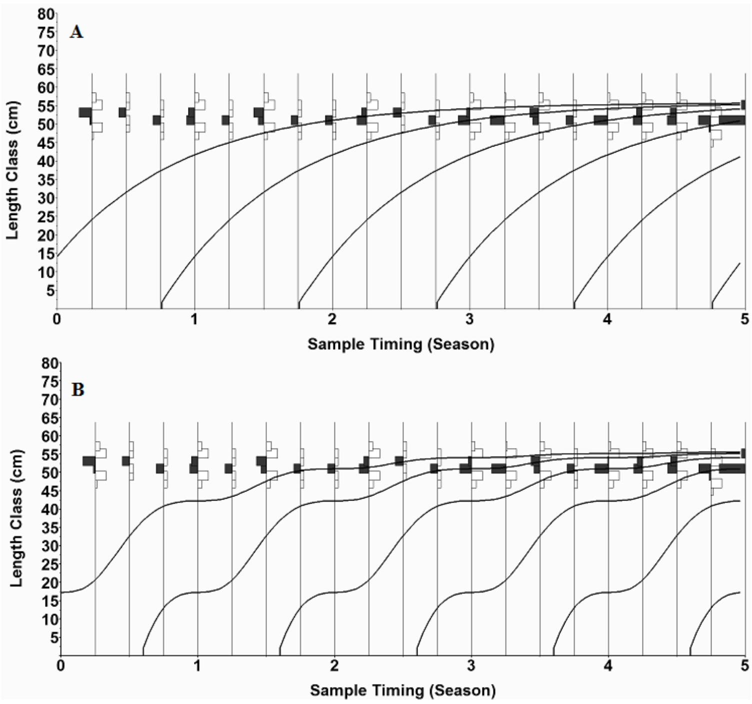

Figure 4. Non-seasonal (A) and Hoenig seasonal (B) von Bertalanffy Growth Function (VBGF) curves of *Scomberomorus guttatus*.

showed isometric growth.

Jin *et al*. (2015) reported *b* values of WLRs for *K. pelamis* when fork length was >60 cm were significantly less than 3 (negative allometric growth), but when fork length was <60 cm they were significantly greater than 3 (positive allometric growth). In the present study, *b* value (3.4571) of *K. pelamis* was estimated as positive allometric growth (length ranged between 52 and 68 cm). In generally, reported *b* values of *K. pelamis* are similar (allometric growth) to the previous studies (Table 3). The WLRs was also showed that *T. tonggol* exhibited negative allometric growth (b = 2.4606, P<0.005). Similar *b* value of 2.515 for *T. tonggol* (length ranged between 30.0 and 97.9 cm) was reported from Veraval waters (Ghosh *et al*., 2010). However, contrary to present study, *b* values for *T. tonggol* were reported by Kaymaram *et al*. (2013) as *b*=2.848 (isometric) in the Persian Gulf, Oman Sea and by Abdussamad *et al*. (2012) as *b*=3.000 (isometric) in the Indian coasts (Table 4). In the present study, isometric growth pattern was only determined for *E. affinis* (*b* = 3.0882, P>0.5). Similar *b* value of 3.056 for *E. affinis* (length ranged between 26.0 and 69.9 cm) was reported from Veraval waters (Ghosh *et al*., 2010). However, contrary to the present study, *b* values for *E. affinis* were reported from other studies as isometric (Table 5). The WLRs showed that *S. guttatus* exhibited negative allometric growth (*b*=2.1468, P<0.005). Similarly, negative allometric growth for *S. guttatus* (*b*=2.862; length ranged between 25 and 70 cm) was reported from Bay of Bengal off Bengladesh coats (Rashid *et al*. 2010) and from Palk Bay and Mannar Gulf (*b*=2.860; length ranged between 36.9 and 70.5 cm) (Devaraj, 1981) (Table 6). The WLRs of the other scombrids fish species, *S. commerson*, was also determined as negative allometric growth (*b* = 2.1626, length range = 45.8 and 51 cm) in the study area. These variations are probably due to factors related to ecosystem and biological condition like spawning time, sexual maturity, feeding behavior and competition for food (Ghosh *et al*., 2010). The variation in the exponent (*b*) of the WLRs of fish species could be also affected by geographic locations, sampling area, seasons, size range and ecological factors such as temperature (Frose, 2006; Frose *et al*., 2011).

The VBG curve parameters (L_∞ and *K*) of different *K. pelamis* stocks were showed great variability (Table 3). In the literature, values of L_∞ were reported from 60 cm FL in Eastern Atlantic, Cap Vert (Cayré *et al*., 1986) to 127.8 cm FL in the Western Pacific (Chi and Yang, 1973). On the other hand, values of growth rate parameter (*K*) of *K. pelamis* stocks were reported between 0.14 year^{-1} in the Eastern Atlantic South of 10º N latitude (Gaertner *et al*., 2008) and 2.08 year^{-1} in the Eastern Atlantic, Senegal (Cayré *et al*., 1986). This variability may be due to particular characteristics of sampling region such as biotic and abiotic factors, state of the different exploited stocks, different length ranges and differences of growth estimation methods such as otolith, dorsal spine, vertebrae, tagging and length frequency analysis. In the present study, we estimated seasonal VBG curve parameters of *K. pelamis* first time. Estimated L_∞ (66.8 cm) and *K* (1.378 year^{-1}) values were between the values specified in the early studies (Table 2) and pointed out that *K. pelamis* was rapid growth species in the study area. The relative amplitude of the seasonal oscillations (*C* = 0.950) was also implied that *K. pelamis* showed strong seasonality in growth and the lowest growth time was corresponding to early August (*WP* = 0.6) offshore water of Pakistan coast in the Arabian Sea. *K. pelamis* mature and spawn round the year in Indian waters with a peak from December to March and a minor one during June – August (Koya *et al*., 2012). It was also observed that this species spawn almost round the year with one major peak during late winter and a minor peak during the south-west monsoon (Koya *et al*., 2012). Moreover, *K. pelamis* known as spawn multiple times in areas (e.g. eastern Pacific Ocean) where the surface temperature is equal to or higher than 24°C (Buňag, 1956; Schaefer, 2001). The reproduction of *K. pelamis* in tropical areas is also reported as continuous over the year and a seasonal component in the spawning appears if the studied area is far from the equator (Andrade and Santos, 2004; Andrade and Kinas, 2004). Reproduction time of *K. pelamis* in the tropical western and central Pacific Ocean was reported as evidence of spawning activity throughout the year without a clear seasonal pattern (Ashida *et al*., 2010). Several biotic and abiotic factors, especially sea water temperature and more of the energy spent for gonadal growth could increase on reproduction activity in the spawning time (mentioned above) probably cause decrease of somatic growth (to early August) of *K. pelamis* in the study area. In addition to these, amount and quality of prey occurrence and seasonal variation food availability in stomach in *K. pelamis* could be attributed mainly to the seasonal variation in growth (Al-Zibdah and Odat, 2007).

In the previous studies (Table 4), L_∞ values for *T. tonggol* were reported between 58.2 cm FL in Gulf of Thailand, South China Sea (Supongpan and Saikliang, 1987) and 133.7 cm FL in the Sea of Oman (Kaymaram *et al*., 2013). On the other hand, values of growth rate parameters (*K*) for *T. tonggol* stocks were reported from 0.18 year^{-1} in Veraval waters (Ghosh *et al*., 2010) to 1.44 year^{-1} in Gulf of Thailand, South China Sea (Supongpan and Saikliang, 1987). The VBG curve parameters recorded in the present study were different from other studies of *T. tonggol* in other geographical region. Namely, the L_∞ value (71.7 cm) obtained in this study was relatively smaller than in other studies, but the *K* value (0.916 year^{-1}) obtained in this study was calculated to be higher than the other studies. This is probably due to range of length used to growth calculation for *T. tonggol*. Size range of *T. tonggol* individuals used for growth analyzes in this study was smaller and narrower size range (43 – 69 cm) than in other studies. For example, length ranges and L_∞ values for *T. tonggol* were reported as length range: 30 – 97.9 cm, L_∞ = 107.4 cm by Ghosh *et al*. (2010), length range: 23.8 – 125 cm, L_∞ = 99.7 cm by Griffiths *et al*. (2010), length range: 26 – 125 cm, L_∞ = 133.7 cm by Kaymaram *et al*. (2013), length range: 23 – 111 cm, L_∞ = 123.5 cm by Abdussamad *et al*. (2012).

In the literature, values of L_∞ for *E. affinis* stocks were reported from 55.1 cm FL in the Thailand Gulf, South China Sea (Supongpan and Saikliang, 1987) to 117.8 cm FL in the Northwestern Hawaiian Islands (Uchiyama, 1980). Similarly, values of growth rate parameter (*K*) of *E. affinis* stocks were reported

Table 3. Von Bertalanffy growth parameters, length range, *b* values and growth performance index (*φ′*) of *Katsuwonus pelamis*. FL: fork length (cm), TL: total length (cm), MPA: Modal progression analyzes, ELEFAN: Electronic length frequency analyzes,* cited by Wild and Hampton (1994). *φ′* calculated by 2*log(L_∞)+log(K) equation.

Species		L_∞ (cm)	K (year^{-1})	t_o (year)	φ'	b	$L_{min\text{-}max}$ (cm)	Methods	Area	References
K. pelamis	TL					2.972	56-75		Aqaba Gulf, Red Sea	Al-Zibdah and Odat 2007
K. pelamis	FL					3.293	35-85		South Atlantic	Andrade and Campos 2002
K. pelamis	FL	66.9	0.24	-3.80	3.03	3.430	47-74	Otolith	Western Atlantic, S. Brazil, in 2004	Garbin and Castello 2014
K. pelamis	FL	85.4	0.15	-3.90	3.04			Otolith	Western Atlantic, S. Brazil, in 2007	Garbin and Castello 2014
K. pelamis	FL	72.5	0.33	-1.20	3.24	3.440	49-62	Otolith	Western Atlantic, S. Brazil, in 2008	Garbin and Castello 2014
K. pelamis	FL	112.8	0.24	-1.70	3.48		29-78	Otolith	South Florida waters (USA)	Adams and Kerstetter 2014
K. pelamis	FL	102.0	0.55	-0.02	3.76		30-82	Otolith	Central Pacific	Uchiyama and Struhsaker 1981
K. pelamis	FL	92.5	0.16	-2.90	3.14			Bhattacharya	Western Atlantic, S. Brazil,	Garbin and Castello 2014
K. pelamis	FL	74.8	0.51		3.46		30-74	MPA	Central Pacific, Papua New Guine	Wankowski 1981
K. pelamis	FL	92.0	0.50		3.63	3.147	12-82	ELEFAN	Indian waters	Koya et al. 2012
K. pelamis	FL	97.3	0.25		3.38			Tagging	Senegalese, north of Mauritania	Hallier and Gaertner 2006
K. pelamis	FL	61.3	1.25		3.67			Tagging	West Pacific	Sibert et al. 1983
K. pelamis	FL	75.5	0.77		3.64			Tagging	East Pacific	Sibert et al. 1983
K. pelamis	FL	112.3	0.14		3.25		42-60	Tagging	Eastern Atlantic Sout of 10ºN lat.	Gaertner et al., 2008
K. pelamis	FL	89.4	0.38		3.48		36-62	Tagging	Eastern Atlantic North of 10ºN lat.	Gaertner et al. 2008
K. pelamis	FL	62.0	2.08		3.90			Tagging	Eastern Atlantic, Senegal	Cayré et al. 1986*
K. pelamis	FL	60.0	1.54		3.74			Tagging	Eastern Atlantic, Cap Vert	Cayré et al. 1986*
K. pelamis	FL	86.7	0.31	-0.32	3.36		35-74	Dorsal spine	Atlantic, Guine Gulf	Chur and Zharov 1983*
K. pelamis	FL	103.6	0.30	-0.02	3.51		27-65	Vertebrae	Western Pacific	Chi and Yang 1973*

Table 4. von Bertalanffy growth parameters, length range and *b* values and growth performance index (*φ′*) of *Thunnus tonggol*. FL: fork length, TL: total length, LF: length frequency, ELEFAN: Electronic length frequency analyzes, MPA: Modal progression analyzes. *: cited by Yesaki (1994a). *φ′* calculated by 2*log(L_∞)+log(K) equation.

Species		L_∞ (cm)	K (year^{-1})	t_o (year)	φ'	b	$L_{min\text{-}max}$ (cm)	Methods	Area	References
T. tonggol	FL	107.4	0.18	-0.07	3.32	2.515	30-97.9	ELEFAN	Veraval, Arabian Sea	Ghosh et al. 2010
T. tonggol	FL	99.7	0.23	-1.50	3.36	2.826	23.8-125	Otolith	Australia,Carpentaria Gulf - Iluka	Griffiths et al. 2010
T. tonggol	FL	133.7	0.35		3.80	2.840	26-125	ELEFAN	Persian Gulf, Oman Sea	Kaymaram et al. 2013
T. tonggol	FL	123.5	0.51	-0.03	3.89	3.000	23-111	ELEFAN	Indian coast	Abdussamad et al. 2012
T. tonggol	FL	108.0	0.55		3.81			MPA	Thailand Gulf, South China Sea	Yesaki 1989*
T. tonggol	FL	58.2	1.44		3.69			MPA	Thailand Gulf, South China Sea	Supongpan and Saikliang 1987*
T. tonggol	FL	133.6	0.23		3.61			ELEFAN	Oman	Prabhakar and Dubley 1989*
T. tonggol	FL	131.8	0.40	-0.04	3.84		45-111	Otolith	Papua Gulf	Wilson 1981*

Table 5. von Bertalanffy growth parameters, length range and *b* values and growth performance index (φ') of *Euthynnus affinis*. FL: fork length (cm), TL: total length (cm), LF: length frequency, ELEFAN: Electronic length frequency analyzes, MPA: Modal progression analyzes. * cited by Yesaki (1994b). φ' calculated by $2*\log(L_\infty)+\log(K)$ equation.

Species		L_∞ (cm)	K (year^{-1})	t_o (year)	φ'	b	$L_{min-max}$ (cm)	Methods	Area	References
E. affinis	FL	81.7	0.79		3.72	2.786	26-73	ELEFAN	Maharashtra	Khan 2004
E. affinis	FL	87.7	0.51	-0.23	3.59		41-73	ELEFAN	Persian Gulf and Sea of Oman	Taghavi et al. 2010
E. affinis	FL	81.9	0.56	0.03	3.57	2.889	48-72	ELEFAN	Karachi, Arabian Sea	Ahmed et al. 2015
E. affinis	FL	64.6	1.00	-0.13	3.62		23.5-61.5	ELEFAN	Indian Ocean, Northwest Sumatera	Sulistyaningsih et al. 2014
E. affinis	FL	81.9	0.56	0.03	3.57	2.889	14-80	ELEFAN	Indian waters	Rohit et al. 2012
E. affinis	FL	72.5	0.56	-0.03	3.47	3.056	26-69.9	ELEFAN	Veraval, Arabian Sea	Ghosh et al. 2010
E. affinis	FL	95.1	0.67		3.78	2.870	28-88	ELEFAN	Persian Gulf and Sea of Oman	Kaymaram and Darvishi 2012
E. affinis	FL	55.1	2.23	-0.02	3.83			MPA	Thailand Gulf, South China Sea	Supongpan and Saikliang 1987*
E. affinis	FL	76.0	0.96		3.74			MPA	Thailand Gulf, South China Sea	Yesaki 1989*
E. affinis	FL	117.8	0.42	-0.03	3.77			Otolith	Northwestern Hawaiian Islands	Uchiyama 1980*
E. affinis	TL					3.140	46-64		Aqaba Gulf, Red Sea	Al-Zibdah and Odat 2007

Table 6. von Bertalanffy growth parameters, length range and *b* values and growth performance index (φ') of *Scomberomorus guttatus*. TL: total length, ELEFAN: Electronic length frequency analyzes. φ' calculated by $2*\log(L_\infty)+\log(K)$ equation.

Species		L_∞ (cm)	K (year^{-1})	t_o (year)	φ'	b	$L_{min-max}$ (cm)	Methods	Area	References
S. guttatus	TL	127.8	0.18	-0.47	3.47	2.860	36.9-70.5	Petersen	Palk Bay, Mannar Gulf	Devaraj 1981
S. guttatus	TL	73.5	0.60		3.51	2.862	25-70	ELEFAN	Bay of Bengal off Bangladesh coast	Rashid et al. 2010

between 0.42 $year^{-1}$ in the Northwestern Hawaiian Islands (Uchiyama, 1980) and 2.23 $year^{-1}$ in the Thailand Gulf, South China Sea (Supongpan and Saikliang, 1987). In the present study area *E. affinis* growth parameters (L_∞ = 67.1 cm, K = 1.055 $year^{-1}$) were found similar to growth parameters values (L_∞ = 64.6 cm, K = 1.00 $year^{-1}$) for *E. affinis* in the Indian Ocean (Sulistyaningsih *et al*., 2014). In addition to these results, soma authors were reported different L_∞ and K values for *E. affinis* from the other geographical areas (Table 5). This could be due to the differences in the environmental parameters, availability and competition for food. Different L_∞ and K could be associated with variation in fishing intensity and differences in the environmental parameters and availability and competition for food. Moreover, these differences in growth parameters among the geographical area and different sampling years may be due to sampling error and the differences of the methods (such as length based and age based growth estimates) used to calculate the growth parameters. In the literature, there is no research concerning seasonal growth of *E. affinis*. This species showed seasonal variation in growth (C = 0.990) and *Rn* value of the non-seasonal VBG curve improved by 30% when seasonal VBG growth was applied. The start of slow growth period of *E. affinis* was corresponding to September (*WP* = 0.7). Al-Zibdah and Odat (2007) reported that food composition of *K. pelamis* and *E. affinis* suggests that the fish compete for the same food items. These are the fish *Atherinomorous lacunosus*, crustacean and molluscans. Prey occurrence in stomachs of two fish species is attributed mainly to the seasonal availability of food and this could be considered one of the causes of seasonal growth of *E. affinis* in the study area. Moreover, this seasonality in growth for *E. affinis* is possibly due to factors related to ecosystem and biological condition like reproductive activities such as gonad maturity stages (Al-Zibdah and Odat, 2007; Ghosh *et al*., 2010). Namely, the highest percentage of maturing females was observed during September - April off the west coast of Thailand (Yesaki, 1982). Moreover, Yesaki (1994b) reported that there are two spawning seasons for *E. affinis* in the equatorial regions. In the northern hemisphere, the principal spawning season generally occurs during the first half of the year (from October to May) and the secondary spawning season during the latter half. At higher latitudes of the tropical zone, there appears to be only one spawning season near the middle (during June - August) of the year. Besides the aforementioned reasons, another reason for the seasonal growth of *E. affinis* is probably thought to results from differences in different seasonal oceanography parameters such as temperature, current and salinity.

There are two previous studies based on length data have been completed to determine the growth of *S. guttatus* (Table 6). L_∞ value (L_∞ = 127.8 cm, K = 0.18 $year^{-1}$) reported by Devaraj (1981) was much higher than the value (L_∞ = 73.5 cm, K = 0.6 $year^{-1}$) reported by Rashid *et al*. (2010) whereas the K value reported by Devaraj (1981) was much lower. The von Bertalanffy growth parameters obtained this study (L_∞ = 55.7 cm, K = 1.049 $year^{-1}$) were lowest L_∞ value and highest K value than the others (Devaraj, 1981; Rashid *et al*., 2010). We studied first time to describe of seasonal von Bertalanffy growth parameters for *S. guttatus*. Seasonal variation of growth (C = 0.980) was determined and the start of slow growth period corresponding to early January (*WP* = 0.0). Moreover, the *Rn* value of the non-seasonal VBG curves for *S. guttatus* improved by 21% after fitting a seasonal VBG curve. Seasonal changes in fish growth mostly caused by differences in water temperature and reproductive activities affecting fish feeding mechanism (Bilgin *et al*., 2012; Bilgin *et al*., 2013). In the literature, reproduction time was reported during June and July in the Bay of Bengal (Rashid *et al*., 2010), from January to August, with a peak in April and May off the south coast of India (Devaraj, 1987), from April to July around Rameswaram Island between India and Sri Lanka (Collette and Nauen, 1983). As will be understood from these studies, start of reproduction activity time (between April and July) is not in agreement with the start of slow growth time (winter point =January). So, water temperature, and may be other biotic and abiotic parameters such as current, salinity, food and feeding habits could be considered mostly effecting the seasonal growth of *S. guttatus* in the study area. Moreover, Food and feeding habits of *S. guttatus* was studied by Deveraj (1998) from the northern Gulf of Mannar and Palk Bay along the southeast coast of India between July 1967 and July 1969. Deveraj (1998) reported that *S. guttatus* feeds on a limited number of about five species, of which the sardinella was the most important item of in the food in August and it was absent in the diet in from August through January in 1967 - 68 and in during January in 1968 – 69. The start of slow feeding period of *S. guttatus* was corresponding to more or less January and this period was in agreement with the start of slow growth time of *S. guttatus* (*WP* = 0, January).

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