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Age Determination and Growth Parameters of *Lutjanus bohar* (Forsskal, 1775) in Jeddah Fisheries, Saudi Arabia

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Abstract. Age-based life history parameters: the asymptotic length (L_∞), the growth coefficient (K) and the hypothetical age at zero length (t_0), for *Lutjanus bohar* in Jeddah fisheries were estimated. Scales were used for age determination and measurements, and the back-calculated lengths-at-ages were calculated using the body proportional formula (BPH). The growth of *L. bohar* is isometric where the length-weight relationship could be described by the power equation: $W = 0.0125\ L^{3.05}$ ($R^2 = 0.99$) for males, $W = 0.01571\ L^{3.00}$ ($R^2 = 0.98$) for females, and $W = 0.0142\ L^{3.04}$ ($R^2 = 0.99$) for combined sexes. The Scale radius (S) total length (L) relationship could be described by the linear form: $L = 5.52\ S - 0.41$ ($R^2 = 0.953$) for males, $L = 5.64\ S - 0.85$ ($R^2 = 0.945$) for females, and $L = 5.60\ S - 0.39$ ($R^2 = 0.948$) for combined sexes. The growth parameters were estimated to be: $L_\infty = 89.38$ cm, $K = 0.123$ year^{-1}, and $t_o = -1.04$ year for males; $L_\infty = 90.68$ cm, $K = 0.121$ year^{-1}, and $t_o = -1.05$ year for females; and $L_\infty = 90.17$ cm, $K = 0.122$ year^{-1}, and $t_o = -1.04$ year for pooled data. The performance index of growth in length ' Φ' ' was found to be 3.0 for both males and females. The maximum age (life span) was estimated to be 23.8 year for females and 22.8 year for males, which indicate that *L. bohar* is a long-lived species.

Keywords: *Lutjanus bohar*, Age determination, Growth parameters, Life span, Jeddah fisheries.

1. Introduction

Snappers are the fish species belonging to the Family Lutjanidae. Nelson (2006) reported that there are about 105 species in 17 genera belonging to four subfamilies in this family. They inhabit tropical and subtropical regions of all oceans (Allen, 1985). The majority of snappers are active carnivores, feeding on crustaceans and fishes. Many species of this family are valued food fish, and one of them is the two-spot red snapper, *Lutjanus bohar* (Forsskal, 1775). It is a large piscivorous Lutjanid species that is an important target species for artisanal fishermen in the small-scale fisheries in the coral reef ecosystems in the Indo- Pacific region, including the Red Sea (Allen 1985; Wright *et al*., 1986).

The effect of fishing on coral reef fish ecology can be determined by investigating the life history characteristics of these fishes and how they respond to their exploitation (Jennings *et al.,* 2001). However, age-based studies are usually used to investigate the life history traits of coral reef fishes (Choat and Robertson, 2002), which are necessary in stock assessments (Grandcourt, 2005).

Biological aspects of the two-spot red snapper, *Lutjanus bohar* have been studied by different authors at different localities (Wheeler and Ommanney, 1953, in the Seychelles; Talbot, 1960 in East Africa; Loubens, 1980, in New Caledonia; Wright *et al.*, 1986, in Papua New Guinea; Marriott *et al*., 2007, in Great Barrier Reef, Australia; Fortaleza and Nanola, 2017, in Davao Gulf, Philippines). Large differences have been reported in these studies regarding the estimates of maximum age, ranging from 9 years (Wheeler & Ommanney, 1953) to 55 years (Marriott *et al.,* 2007). However, these markedly different results could lead to markedly different management decisions (Marriott *et al*., 2007).

Although this species is one of the important food fish caught in hook and line, gillnet and pot fishing in the Red Sea artisanal fisheries of Saudi Arabia, there is no even one study available concerning any biological aspects of *L. bohar* in the Red Sea. Thus, the aim of the present study is to determine ages, estimate growth rates and parameters of the two-spot red snapper in Jeddah fisheries.

2. Materials and Methods

Monthly specimens of *Lutjanus bohar* were collected from the different landing sites of Jeddah during the daily fish auction that occurs for the fresh catch of local artisanal fishermen, during the period from January 2018 to January 2019. Fish total length (L) was measured to the nearest 0.1 cm and the total body weight (W) was recorded to the nearest 0.1 g. The length -weight relationship was described by the power equation: $W = a L^b$ (Le Cren, 1951) where a and b are the intercept and the slope, respectively. The constants a and b could be estimated by transforming the power form into the following the linearized form and carrying out the linear regression analysis: $\ln W = \ln a + b \ln L$. The t-test of Pauly (1984) was used to check for differences from the isometric growth (the slope 'b' equal to 3 or not).

Scales were collected, cleaned in water then dried and mounted between two microscopic glass slides to be examined under a stereo-zoom microscope (AmScope) using a digital video camera (AmScape18 MP) connected to a computer, where pictures were captured and saved to measure and record scale measurements.

The relationship between the body length (L) and scale radius (S) was described using two linear regression analyses. The first one is the linear regression of total length (L) on the scale radius (S) according to the linear form: $L = c + d S$ where 'c' is the intercept, and 'd' is the slope. The second is the regression analysis between S and L according to the linear form: $S = e + f L$ where 'e' is the intercept, and 'f' is the slope. The back-calculated lengths-at-ages were estimated using three back-calculation methods as recommended by Francis (1990):

Fraser-Lee equation (Lee, 1920):

$$L_i = c + (L - c) (S_i / S)$$

Body proportional hypothesis (BPH):

$$L_i = [(c + dS_i) / (c + dS)] L$$

Scale proportional hypothesis (SPH):

$$L_i = -(e/f) + [L + (e/f)] (S_i / S)$$

where, L_i is the back-calculated length at the time of annulus ' i ' formation, S_i is the radius of the annulus ' i'. The mean calculated lengths at ages estimated by the three methods were compared using a one-way analysis of variance (ANOVA) test.

Ford (1933) and Walford (1946) method was used to estimate the growth parameters of von Bertalanffy (1938) growth equation (VBGE): $L_t = L_\infty [1- e^{-K (t-t0)}]$: The

asymptotic length (L_∞) and the growth coefficient (K) by fitting the method to the average back-calculated lengths-at-ages for males, females and sexes combined. The hypothetical age at zero length (t_0) was estimated using the following empirical equation suggested by Pauly (1980):

$$\text{Log } (-to) = -0.3922 - 0.2752 \log L\infty - 1.038 \log K$$

The following formula suggested by Pauly and Munro (1984): $\Phi' = \text{Log } K + 2 \text{ Log } L_\infty$ was used to estimate the performance index of growth in length (phi-prime, Φ') for this species in Jeddah fisheries. This index is based on length and considered the most precise and flexible index of growth performance used to compare wild and cultured fish growth (Mathews and Samuel, 1990).

The maximum life span of *L. bohar* was estimated using the following form: $t_{max} = t_0 + 3 / K$, following Taylor (1958), considering it is the age of fish having a length equal to 95% of L_∞.

3. Results and Discussion

3.1 Length-Weight Relationship

For the total number of 165 specimens collected, the total fish length ranged from 15.0 – 70.0 cm, and the total body weight ranged from 60 – 5352 gm. The observed and predicted weights corresponding to fish lengths for *L. bohar* (combined sexes) in Jeddah fisheries are represented in Fig. 1. The relationship between body length and body weight for males, females and combined sexes could be described by the following equations:

$$W = 0.0125\ L^{3.06} \quad (R^2 = 0.992,\ n = 75 \text{ males})$$

$$W = 0.0157\ L^{3.00} \quad (R^2 = 0.984,\ n = 90 \text{ females})$$

$$W = 0.0142\ L^{3.03} \quad (R^2 = 0.988,\ n = 165 \text{ combined sexes})$$

The results indicated that the exponent 'b' values for males, females and combined sexes were not significantly different from the value '3' of the isometric growth (for males: t = 1.754, critical t = 2.0 for *P* = 0.05; for females: t = 0.049, critical t = 2.0 for *P* = 0.05; for combined sexes: t = 1.147, critical t = 2.0 for *P* = 0.05). Hence, the growth of *L. bohar* in Jeddah fisheries is isometric. However, these results are in agreement with other research by different authors on the same species in different localities as presented in Table 1 (Fortaleza and Nanola, 2017; Kulbicki *et al*., 2005; Letourneur *et al*., 1998).

3.2 Age Determination

The scales were used for age determination of *L. bohar* in Jeddah fisheries, depending upon the characteristic pattern recognized on the scales (Fig. 2) and the annual time scale (Williams and Bedford, 1974) assigned for each pair of alternative opaque and hyaline bands (annulus) as confirmed in previous studies on scales (Talbot, 1960) and on otoliths (Loubens, 1980; Marriott *et al*., 2007) of this species. The number of annuli formed on the scales was counted and the age (in years) could be assigned to each specimen. Twelve age groups (0-11) and 10 age groups (0-9) were determined for females and males, respectively.

3.3 Scale Measurements and Back-Calculations

The distance from the focus to the scale margin was measured as the scale radius (S) and the distance from the focus to the margin of each annulus was measured as the annulus radius (s_1, s_2, s_3, …...s_i) as shown in Fig. 1. The relationship between the total fish length and scale radius was found to be linear, as shown in Fig. 3-A, and the best fit for this relationship was the model of linear regression of L on S, where the plot of the regression residuals against predicted lengths showed a random scattering around zero line (Fig. 3-B). The following two linear equations describing the relationship between fish length and scale

radius of *L. bohar* (sexes combined) in Jeddah fisheries were used for back-calculations:

$L = 5.6\ S - 0.39$ (regression of L on S, $R^2 = 0.948$)

$S = 0.48 + 0.17\ L$ (regression of S on L, $R^2 = 0.948$)

The average back-calculated lengths at ages that estimated by the three back-calculation formulae used in this study are listed in Table 2 and represented in Fig. 4. There is no significant difference between the average lengths at ages that estimated by the three back-calculation methods for *L. bohar* (ANOVA: F=0.00049, *P*=0.99998). Also, the average calculated lengths at corresponding ages that estimated by the body proportional hypothesis (BPH) formula for males were not significantly different from those for females (ANOVA: F=0.00027, *P*=0.987). This indicates that both sexes of *L. bohar* in Jedda fisheries have the same growth pattern, which is in agreement with previous studies on *L bohar* in East Africa (Talbot, 1960) and in the Great Barrier Reef, Australia (Marriott *et. al.*, 2007).

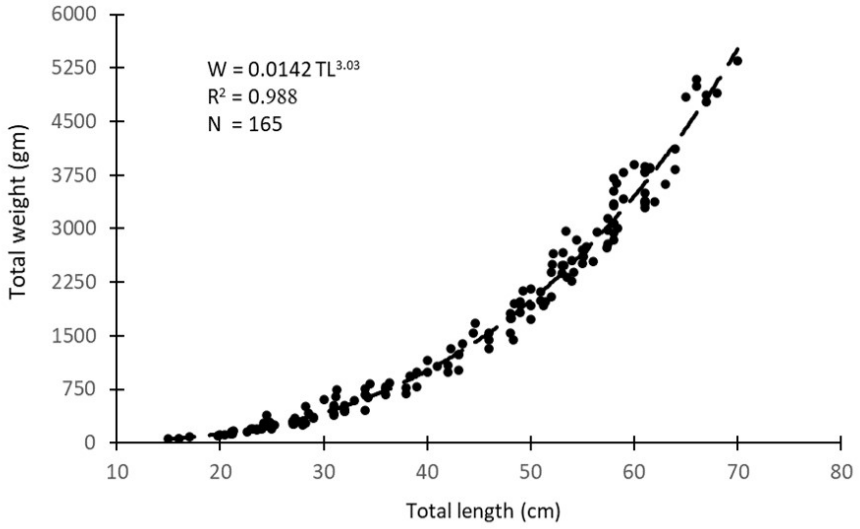

Fig. 1. Length-weight relationship of *Lutjanus bohar* (sexes combined) in Jeddah fisheries.

Table 1. Length-weight relationship parameters of Lutjanus bohar in the Red Sea estimated by different Authors.

Authors	Sex	a	b	R^2	N	Size range (cm)
The present study (Red Sea- Jeddah)	M	0.0125	3.06	0.992	67	16.0 – 64.0 TL
	F	0.0157	3.00	0.984	90	15.0 – 70.0 TL
	C	0.0142	3.03	0.988	157	15.0 – 70.0 TL
Fortaleza and Nanola (2017) (Davao Gulf, Philippines)	C	0.00002	3.002	0.986	NA	13.4 – 30.4 TL
Ralston (1988) (North Marianas)	C	0.0121	3.12	0.990	31	26.0 – 75.0 FL
Kulbicki *et al.*, (2005) (New Caledonia)	C	0.0156	3.059	0.994	510	4.0 – 75.0 FL
Letourneur *et al*., (1998) (New Caledonia)	C	0.0170	3.035	0.982	479	4.0 – 75.0 FL

M is Male, F is Female, C is Combined sexes, TL is the Total Length, FL is the Fork Length.

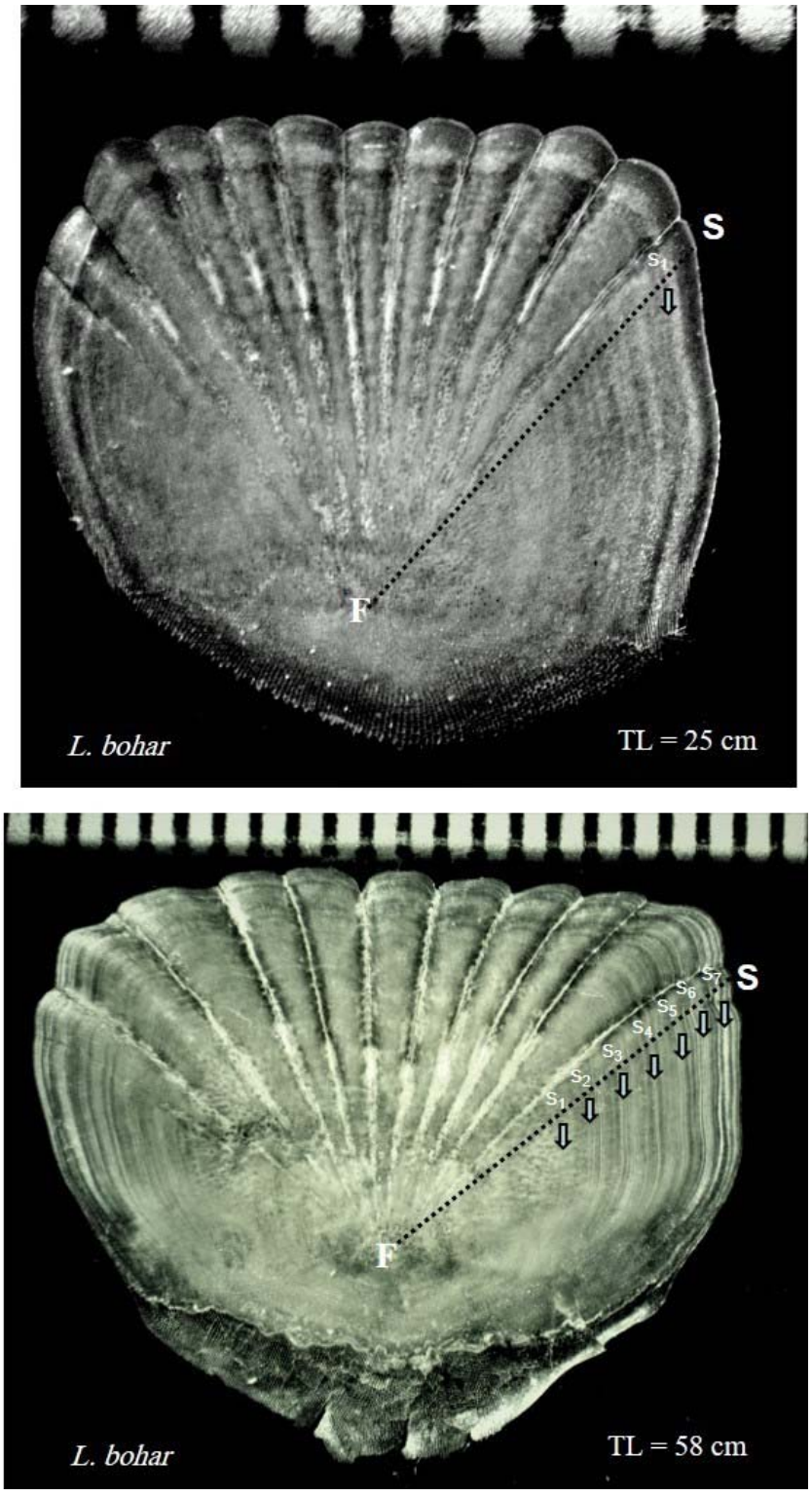

Fig. 2. A scale of 25 cm (top) and 58 cm (bottom) total length specimens of *Lutjanus bohar* in Jeddah fisheries showing the annual check marks ($s_1 – s_7$) (F is the focus, and S is the scale radius).

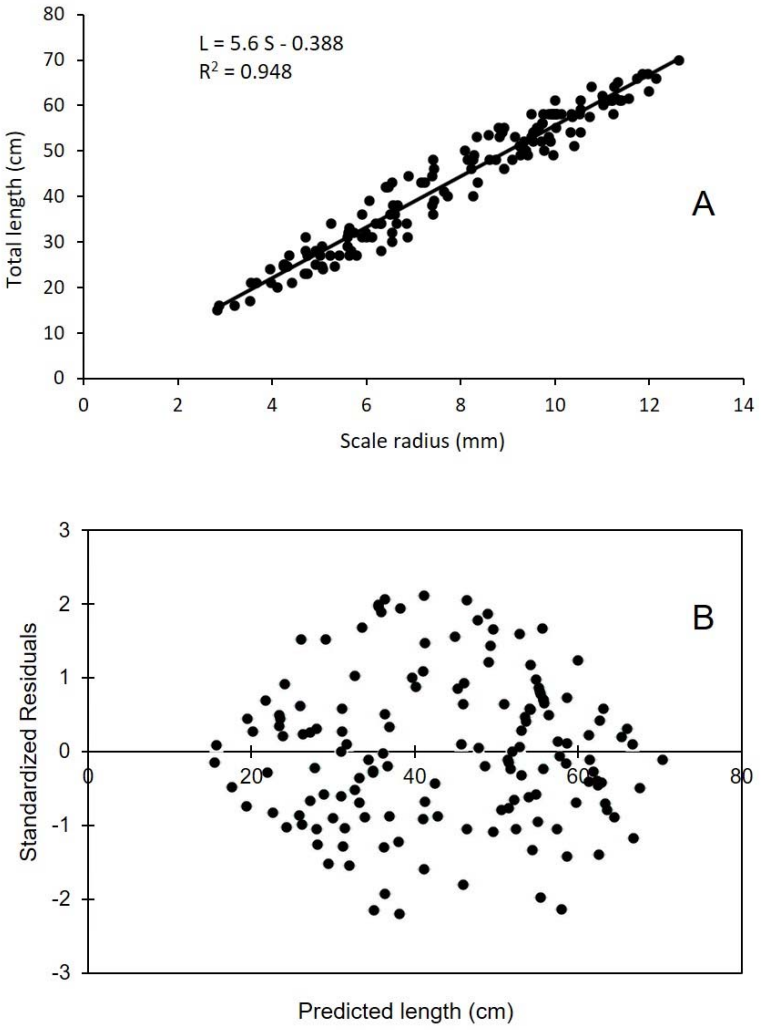

Fig. 3. Total length–Scale radius relationship (A) and residuals plot (B) of Lutjanus bohar (sexes combined) in Jeddah fisheries.

Table 2. The mean back-calculated lengths at ages estimated by three methods: Fraser -Lee, Body proportional hypothesis (BPH) and Scale proportional hypothesis (SPH) for Lutjanus bohar collected from Jeddah fisheries.

Age	Fraser-Lee (pooled)	BPH			SPH (pooled)
		Males	Females	pooled	
1	19.88	20.31	19.92	19.88	19.97
2	27.00	27.49	26.70	27.00	27.02
3	34.90	34.31	34.62	34.90	34.87
4	41.52	41.27	41.77	41.52	41.47
5	47.08	46.97	47.19	47.08	47.00
6	52.41	52.43	52.39	52.41	52.30
7	57.42	57.57	57.30	57.42	57.30
8	60.82	60.73	60.85	60.82	60.70
9	64.16	63.50	64.38	64.16	64.04
10	67.00	-	66.99	67.00	66.89
11	69.30	-	69.29	69.30	69.16

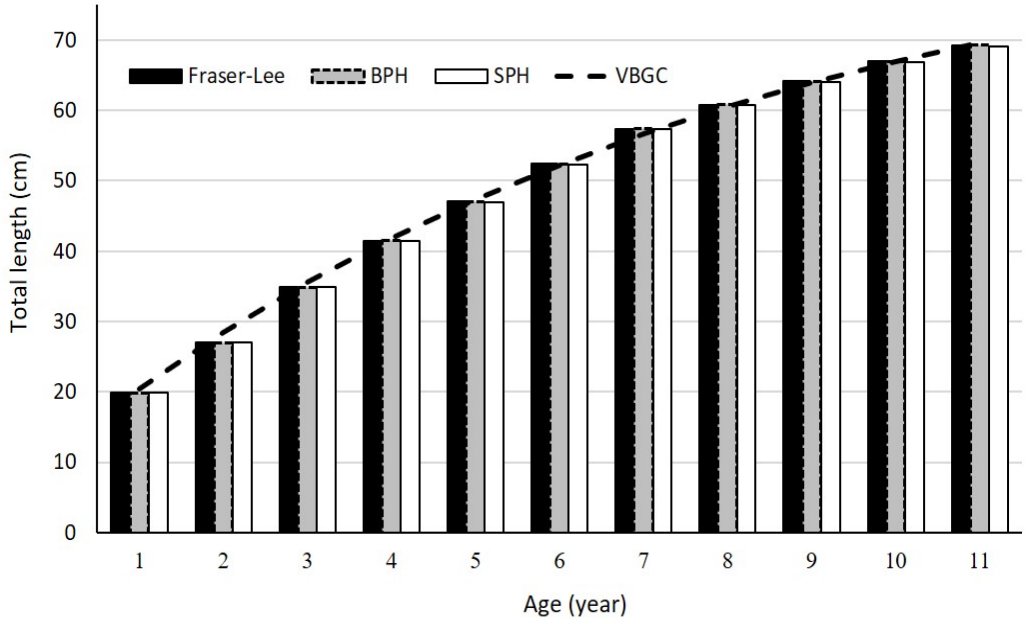

Fig. 4. Mean back-calculated lengths at ages (estimated by three different methods) and von Bertalanffy growth curve for *Lutjanus bohar* in Jeddah fisheries.

3.4 Growth in Length

The annual increment (growth rate) in length of *L. bohar* in Jeddah fisheries was calculated from the back-calculated lengths at ages that estimated based on the BPH formula applied on pooled data (combined sexes). The growth rates in total length were estimated and the results are represented in Fig. 5. The maximum growth rate in length was found in the first year (19.88 cm) and the second year (7.1 cm) of life, where the sum of growth rates during the first and the second year of life (27.0 cm) was estimated to be equivalent to 40% of the maximum observed length (70 cm); a result supported with the observations of Legendre and Albaret (1991) on the relation between the maximum observed length and growth rates in the first and second year of life of wild fish populations. Then, there was a gradual decrease in the growth rate of length occurred through the next years of life to reach its minimum in the last recorded year (2.3 cm during the 11^{th} year). These results indicate that the growth rate of *L. bohar* in Jeddah fisheries is relatively rapid in the first five years of life, where fish attain almost half (47.08 cm) of the asymptotic length (90.17 cm), then followed by a slow growth over the coming years of life, which is consistent with the observations of Marriott *et al*., (2007) on the same species..

3.5 The Growth Model and Performance Index

Since the von bertalanffy growth equation (VBGE) describes well the growth of most fish species and its parameters have been utilized considerably in life history studies (Jennings *et al.,* 2005), it is used in the present study to describe the growth of *L. bohar* in Jeddah fisheries. The Ford (1933) and Walford (1946) method was applied to the mean lengths-at-ages to estimate the growth parameters: L_{∞}, K and then the value of t_0 was determined. Thus, the VBGE for describing the growth in length of *L. bohar* in Jeddah fisheries could be written as follows:

$L_t = 90.17\ [1- e^{-0.122\ (t+0.1.04)}]$, and the von bertalanffy growth curve is shown in Fig. 6**.** The growth in length performance index (phi-prime, Φ') of the two-spot red snapper in Jeddah fisheries was estimated to be 3.0 for males and females. These results are compared with other previous studies on the same species at different locations as shown in Table 3. However, growth parameters showed considerable variability, which might be due to using different methods and techniques to determine age and estimate back-calculated lengths at ages. Carlander (1982) and Hirschhorn and Small (1987) indicated that poor representation of all size groups, different sites of scales used, and scales measuring at different angles can result in a wide variation in the regression analyses parameters used in the back-calculation methods. In addition, Taylor *et al*., (2020) observed declines in the maximum observed age, the asymptotic length and the life span with decreasing latitudes. This also is a major source of variability in growth parameters and performance index of this species.

3.6 Growth in Weight

To estimate the growth in weight for *L. bohar* in Jeddah fisheries, the weights-at-ages corresponding to the length-at-ages were calculated by using the equation describing the length - weight relationship for this species. The growth in weight could be estimated and the results are represented in Figure 7. The maximum growth rate in fish weight was recorded in the seventh year of life for both males (757 gm) and females (702 gm). The maximum asymptotic fish weight was estimated to be 11.676 kg for males, 11.810 kg for females, and 11.916 kg for combined sexes.

3.7 Maximum Age (Life Span)

Considering the maximum life span (longevity) is the age of fish having a length equal to 95% of the maximum asymptotic length L_{∞}, Taylor (1958) suggested the following form: $t_{max} = t_0 + 3 / K$, to estimate the maximum life span of fish. Thus, we used this form to estimate the maximum life span for males and females of *Lutjanus bohar* in Jeddah fisheries. The life span for females (23.8 years) was longer than that of males by one year (22.8). As reported in previous studies that fish having a life span of more than 20 years are considered to be long-lived species (King and McFarlane, 2003; Martinez-Andrade, 2003; Newman *et al*., 2016), Accordingly, and based on the results obtained in the present study, *L. bohar* in Jeddah fisheries is a long-lived species, which is in agreement with previous studies on the same species (Marriott *et al*., 2007; Taylor *et al*., 2020). However, the estimated life span in the present study using scales for age determination, is shorter than that reported by Marriott *et al*., 2007 (56 years) and by Taylor *et al*., 2020 (> 60 years), who used transverse otolith sections for age determinations. In the near future, we are trying to get equipment to use otolith sections for age determination of this species in comparison with age determination using scales.

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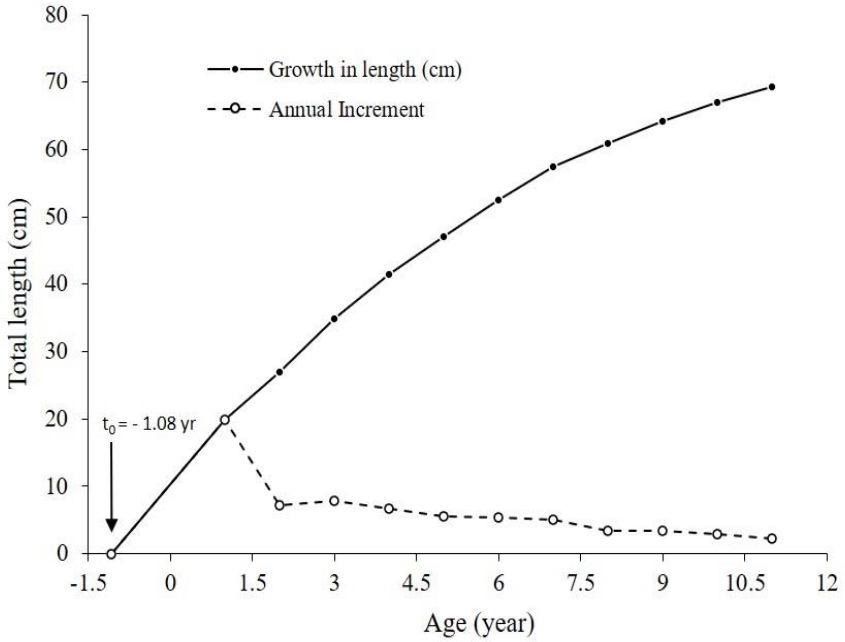

Fig. 5. Growth in length and annual increment of *Lutjanus bohar* in Jeddah fisheries.

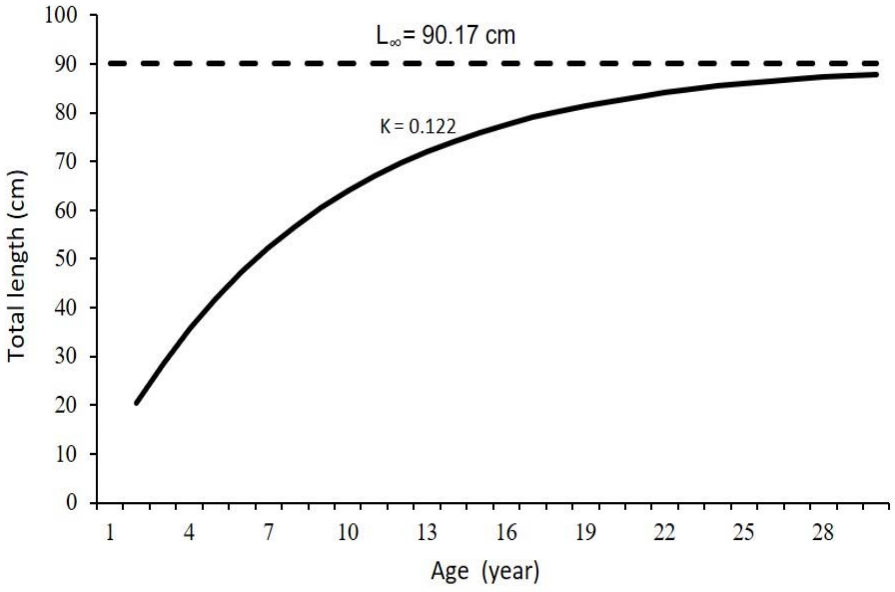

Fig. 6. von Bertalanffy growth curve for *Lutjanus bohar* (sexes combined) in Jeddah fisheries.

Table 3. Growth parameters and Growth performance index (Φ') of *Lutjanus bohar* at different locations estimated by different authors.

Author (Locality)	Method	Sex	L_∞ (cm)	K (year $^{-1}$)	t_o (year)	Φ'
The present study (Red Sea- Jeddah)	Scales TL	Males	89.35	0.126	-1.01	3.00
		Females	90.68	0.121	-1.05	3.00
		Combined	90.17	0.122	-1.04	3.00
Wheeler & Ommanney (1953) (Seychelles)	Length frequency TL	Combined	66.0	0.33	-0.404	3.16*
Talbot (1960) (East Africa)	Scales TL	Males	66.0	0.27	-0.498	3.07*
		Females	66.0	0.27	-0.498	3.07*
Loubens (1980) (New Caledonia)	Otoliths SL	Combined	52.0	0.11	-1.287	2.63
Wright *et al.*, (1986) (Papua New Guinea)	Length frequency FL	Combined	81.7	0.27	0.013	3.26*
Froese & Pauly (2000) (Pooled data)	Combined TL	Combined	92.7	0.17	-0.73	3.16*
Martinez-Andrade (2003) (comparison)	Combined TL	Combined	73.2	0.237	-0.567	3.10*
Marriott *et al.*, (2007) (Great Barrier Reef, Australia)	Otoliths FL	Combined	63.0	0.10	-3.05	2.60
Fortaleza and Nanola (2017) (Davao Gulf, Philippines)	Otoliths TL	Combined	28.9	0.81	NA	2.83

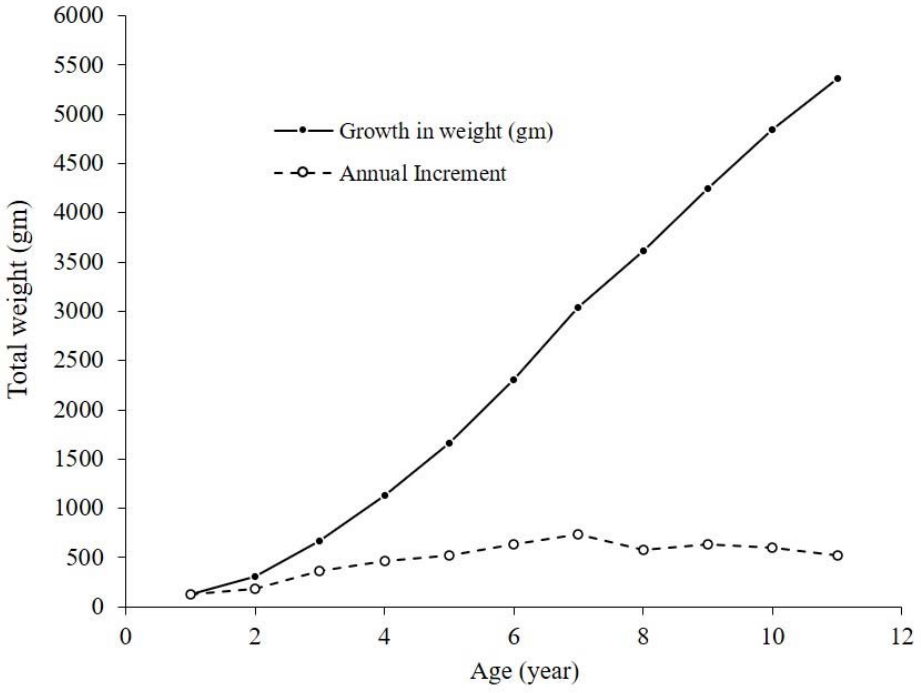

Fig. 7. Growth in weight and annual increment of Lutjanus bohar (sexes combined) in Jeddah fisheries.

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تحديد العمر ومعاملات النمو لأسماك البهار *Lutjanus bohar* في مصايد جدة بالسعودية

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المستخلص. فى هذه الدراسة تم حساب معاملات تاريخ الحياة: الطول الأقصى L_∞ ومعامل النمو K، والعمر الافتراضي عند الطول صفر t_o لأسماك البهار *Lutjanus bohar* في مصايد جدة. واستخدمت القشور لتحديد العمر وأخذ القياسات، وتم احتساب الأطوال المقابلة للأعمار باستخدام العلاقة التناسبية للجسم (BPH). ووجد أن نمو أسماك البهار في مصايد جدة هو نمو مثالى، إذ أمكن وصف العلاقة بين الطول الكلى والوزن الكلى للسمكة بمعادلة القوة: $\mathbf{W} = 0.0125\ \mathbf{L}^{3.05}$ ($R^2 = 0.99$) للذكور، $\mathbf{W} = 0.0157\ \mathbf{L}^{3.00}$ ($R^2 = 0.98$) للإناث، و $\mathbf{W} = 0.0142\ \mathbf{L}^{3.04}$ ($R^2 = 0.99$) للجنسين معًا. وأمكن وصف العلاقة بين نصف قطر القشرة (S) والطول الكلى (L) بالعلاقة الخطية: $\mathbf{L} = 5.52\ \mathbf{S} - 0.41$ ($R^2 = 0.953$) للذكور، $\mathbf{L} = 5.64\ \mathbf{S} - 0.85$ ($R^2 = 0.945$) للإناث، و$\mathbf{L} = 5.60\ \mathbf{S} - 0.39$ ($R^2 = 0.948$) للجنسين معًا. وتم حساب معاملات النمو، إذ كانت $L_\infty = 89.35$ سم، $K = 0.126$ فى السنة، و $t_o = -1.01$ سنة للذكور، و $L_\infty = 90.68$ سم، $K = 0.121$ فى السنة، و $t_o = -1.05$ سنة للإناث، و $L_\infty = 90.17$ سم، $K = 0.122$ في السنة، و $t_o = -1.04$ سنة للجنسين معًا. ووجد أن مؤشر الأداء للنمو في الطول $\Phi' = 3,0$ لكل من الذكور والإناث. وتم حساب أطول عمر (مدى الحياة) بـ 23,8 سنة للإناث و22,8 سنة للذكور، مما يدل على أن أسماك البهار من الأنواع المعمرة.

الكلمات المفتاحية: *Lutjanus bohar*، تحديد العمر، معاملات النمو، مدى الحياة، مصايد جدة.