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Length-weight relationships and condition factors of *Sardinella longiceps* (Valenciennes, 1847) from Seeb, Sultanate of Oman

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Decadal (from 1997 to 2009) comparative analysis of the length-weight relationship and condition factors of Indian Oil Sardine (*Sardinella longiceps*) of the Sultanate of Oman was studied for long-term management. The length-weight data were collected from Ministry of Agriculture, Fisheries and Water Resources, Sultanate of Oman. An isometric growth ($b = 3$) was seen in 1997, a positive allometric growth ($b > 3$) was observed between 2004 and 2009, and a negative allometric growth ($b < 3$) was observed in 2005, 2006 and 2007. Fulton's condition factor in the studied years were 0.857, 0.897, 0.911, 0.902, 0.885 and 0.900, respectively. The results of this study can be used as a valuable tool by fishery biologists, managers and conservationists to carry out *Sardinella longiceps* stock assessments along the coast of Sultanate of Oman and its neighbouring countries.

[**Keywords**: Allometric growth, Fisheries management, Growth coefficient, Indian Oil Sardine, Isometric growth]

Introduction

In fisheries science, Length-Weight Relationships (LWRs) are often applied to calculate quantitative measures of essential factors such as growth pattern, population dynamics[1], stock and biomass. The link between a fish's length and weight is used as a proxy for its condition, with the heavier the fish of a given length being in better condition[2]. The length and weight of a fish is of fundamental importance in fisheries sciences because it contributes not only to the mathematical relation between the two variables but also transforms one into another variable[3]. Habitat, season, sex, gonad maturity, stomach fullness, diet, and health may all have an impact on length-weight relationships[4,5]. Age, gender, season, food, reserved amount of fat and environmental circumstances can all influence the condition factor of a fish[5]. It is vital to examine both the human impact and the environmental forcing when studying the population response or, in general, the life history pattern of an economically important fish species[6]. Life history theory provides a viable paradigm for connecting demography to fundamental elements of species biology[7].

This study focuses on a commercially important coastal species, Indian Oil Sardine (*Sardinella longiceps*), is one of the vital fishes of Sultanate of Oman and is distributed throughout Sultanate of Oman coast. For the last three decades, *S. longiceps* landings contributed about 28 % to the total landings of the Sultanate of Oman's fisheries[8]. *Sardinella longiceps* are used in Sultanate of Oman for human consumption, in fertilizer industry and for livestock feed[9]. Besides, a significant portion is also exported. Traditional fishermen in Sultanate of Oman used to catch sardine by beach seines, gillnet and purse seines. These gears are very small since they can only work in waters with depths of up to 5 m[(ref. 9)].

The LWR study is fundamental in fisheries science. There are several studies on LWR and Condition Factor (CF) of *S. longiceps* throughout its geographically distributed areas like India[10-12], Pakistan[13,14], and Sultanate of Oman[9,15-17]. Aljufaili[9] calculated the LWR of *S. longiceps* along with Gonadosomatic Index and sex ratio; however, Zaki *et al.*[15,16], Jayabalan *et al.*[17] mainly focused on population dynamics of *S. longiceps*. There is no published research conducted on the decadal variations in LWR and CF on *S. longiceps* from the coast of Sultanate of Oman. This study will serve as a baseline for decision-making in order to ensure successful stock

management and conservation. The objectives of this paper are: 1) to compare the decadal LWR between 1997 and 2009 and 2) to analyze three different types of condition factors of *S. longiceps* considering various scenarios of management.

Materials and Methods

Length-weight data of *S. longiceps* were collected in 1997, 2004, 2005, 2006, 2007 and 2009 from the Seeb fish market (23°41'17.92" N, 58°10'36.04" E) of Muscat Governorate by the Ministry of Agriculture, Fisheries and Water Resources, Sultanate of Oman (Fig. 1).

The total number of *S. longiceps* specimens measured during the study period were 1606 in the year 1997, 369 in 2004, 350 in 2005, 201 in 2006, 393 in 2007 and 590 in 2009, respectively by a metric scale and a digital weighing machine (providing a maximum measuring capacity of 5 kg and with an accuracy of 0.5 g). To estimate the LWR, the total length (TL) from the upper jaw to the tip of the tail was measured in millimeter (mm) by laying down the fish normally (*i.e.* without any stretching)[18,19] and the weight is measured in grams (g). The equation provided by Le Cren[3] was used to compute the LWR:

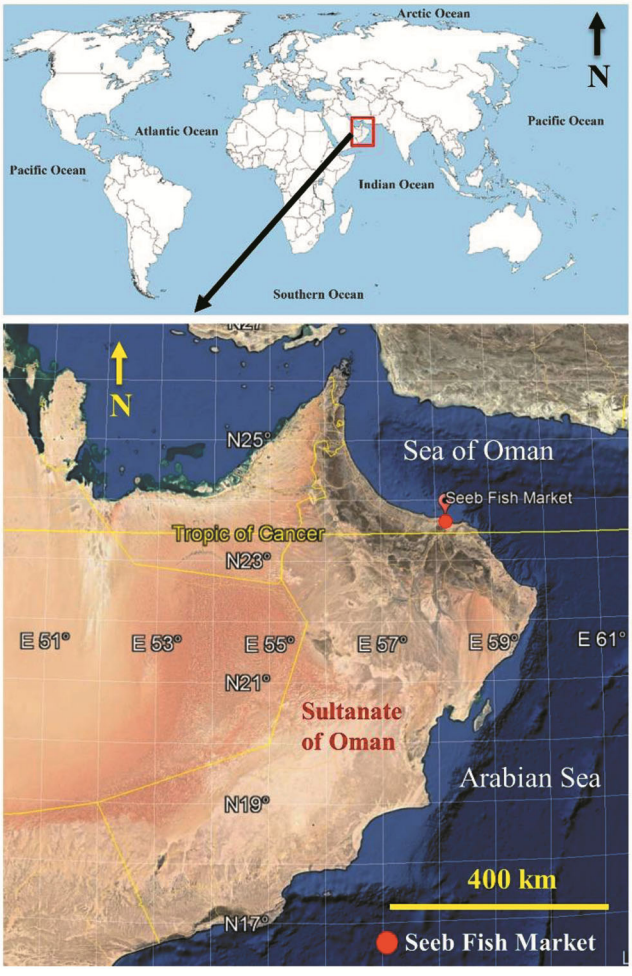

Fig. 1 — The sampling location, the Seeb fish market of Sultanate of Oman

$$W = aL^b ,$$

Where, W is the weight of the fish in g, L is the total length of the fish in mm, b is the exponent describing the rate of variation in weight with respect to length, and a denotes the coefficient of the LWR. $LogW = Loga+bLogL$ is a linear representation of the equation $W = aL^b$. The least square regression approach was used to estimate the values of 'b' and '$Log\ a$' in the equation. To see if the values of b obtained in the linear regressions were significantly different from the isometric value of 95 %, ($\alpha = 0.05$) was used, represented as t_s = (b-3) / s_b, where t_s is the t-test value, b is the slope, and s_b is the standard error of the slope (b), according to Sokal and Rohlf[20]. The statistical significance of the values of b was determined by comparing the resultant t-test values with the relevant tabulated critical values. As a result, either the isometric range ($b = 3$) or the allometric range (negative allometric; $b < 3$ or positive allometric; $b > 3$) is included.

Fulton's condition factor (C)[21] was calculated using the following formula:

$$K = 100 \times (W/L^3),$$

Where, W is the total weight, and L is the length in centimeter (cm). The scaling factor of 100 was used to bring the K_F close to unit.

The allometric condition factor (K_A) was calculated following the equation of Tesch[22] as:

$$K_A = W/L^b,$$

Where, W is the total weight, L is the length in cm, and b is the parameter of length-weight relationship (LWR).

The relative condition factor (K_R) was assessed by the equation of Le Cren[3]:

$$K_R = W/(a \times L^b),$$

Where, W denotes the total weight, L is the length in cm, and a and b are LWR's parameters. A relative $CF > 1$ indicates the fish weighs more than expected for its length; a relative $CF < 1$ means the fish weights is less than expected for its length.

All the analyses were performed in R.4.0.3 (R Core Team, 2020) considering 5 % ($p < 0.05$) significance level.

Results

Length-weight relationship (LWR)

The descriptive statistics of length and weight such as mean, standard deviation, minimum and maximum, and the LWR parameters (coefficient of determination (r^2), intercept (a), growth coefficient (b), t-value, 95 % confidence interval of b are listed in Table 1. In this present study, LWR of *S. longiceps* is calculated for the years 1997, 2004, 2005, 2006, 2007 and 2009. An isometric growth (b = 3, t = -0.23, p = 0.82) was seen in 1997; however, a positive allometric growth (b > 3) was observed during 2004 (b = 3.18, t = 5.89, p < 0.001) and 2009 (b = 3.25, t = 4.87, p < 0.001), and a negative allometric growth (b < 3) was observed during 2005 (b = 2.81, t = -3.48, p < 0.001) and 2006 (b = 2.76, t = -5.65, p < 0.001), 2007 (b = 2.85, t = -3.45, p < 0.001) in Indian Oil Sardine (*S. longiceps*) population.

Figure 2 shows the LWR and variation in a (intercept) and b (slope) values of *S. longiceps* for different studied years, indicating a clear picture of the average growth condition. The coefficient of determination (r^2) values illustrated the proper fit of the growth model. The r^2 of *S. longiceps* was 0.97 in both 1997 and 2004, indicating proper fitness, while it was low (0.87) in 2009.

Condition factor

In this present study, three different types of condition factors namely Fulton's condition factor, relative condition factor and allometric condition factor were estimated in *S. longiceps* population from the Sultanate of Oman coast (Fig. 3). The mean, standard deviation, minimum, maximum, and 95 % confidence interval of these three different types of condition factors are listed in Table 2. There was a significant variation (t = 114.4, df = 5, p<0.001) in

Table 1 — Descriptive statistics and estimated parameters of LWR ($W = aL^b$) of Indian Oil Sardine (*Sardinella longiceps*) in the Sultanate of Oman

Year	Sample size	Length (mm)			Weight (g)			Regression parameter		95 % CL of b	r^2	t_s	Growth
		Minimum	Maximum	Mean±SD	Minimum	Maximum	Mean±SD	a	b				
1997	1606	106	213	161.88±21.24	10.12	91.00	38.24±15.02	0.0063	3.00	2.97 - 3.02	0.97	-0.233	A
2004	369	135	220	167.07±21.91	21.80	94.60	44.50±20.35	0.0043	3.18	3.12 - 3.24	0.97	5.894	+A
2005	350	140	182	160.50±8.91	24.20	58.40	37.96±6.33	0.0097	2.81	2.71 - 2.92	0.89	-3.485	-A
2006	201	153	211	184.19±17.36	30.47	89.70	57.47±15.32	0.011	2.76	2.67 - 2.84	0.95	-5.649	-A
2007	393	123	220	163.42±15.72	19.50	83.60	39.58±11.64	0.0087	2.85	2.77 - 2.94	0.92	-3.453	-A
2009	590	135	220	177.62±17.34	20.00	108.00	52.34±18.34	0.0036	3.25	3.15- 3.36	0.87	4.867	+A

SD = standard deviation; a = intercept; b = slope; CL = confidence limits; r^2 = coefficient of determination; t_s = t-test value, growth type- A = isometric; +A = positive allometric; -A = negative allometric; parentheses indicate the range of a mean value.

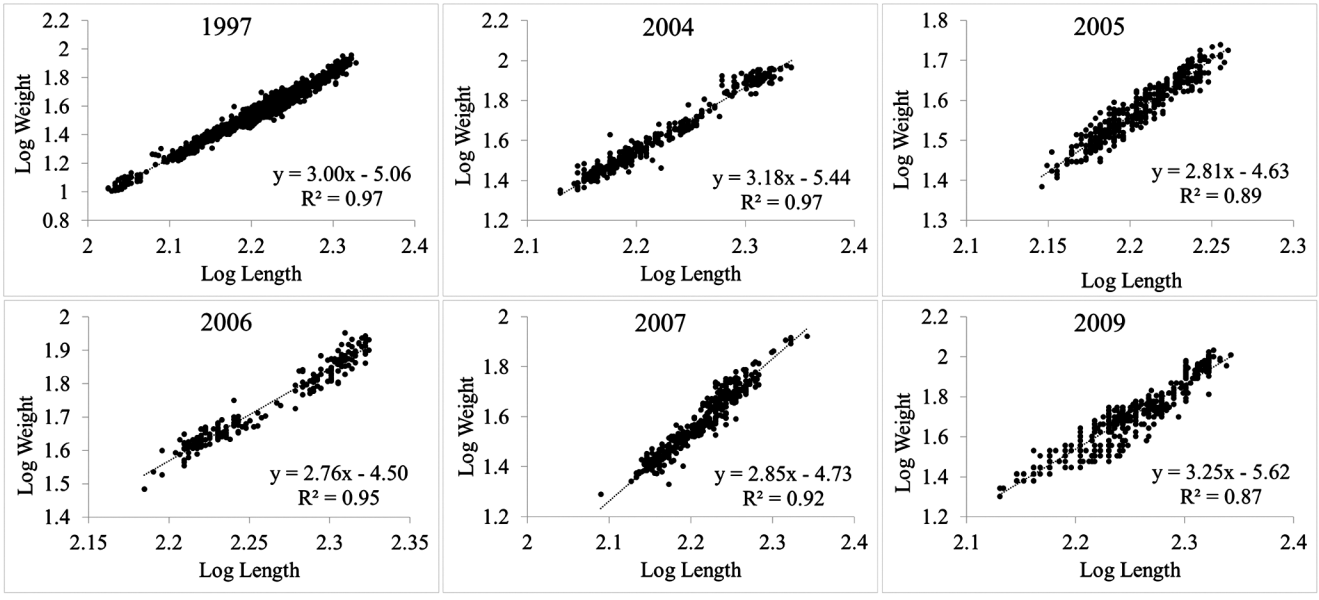

Fig. 2 — Year-wise LWR of *Sardinella longiceps* from Sultanate of Oman coast

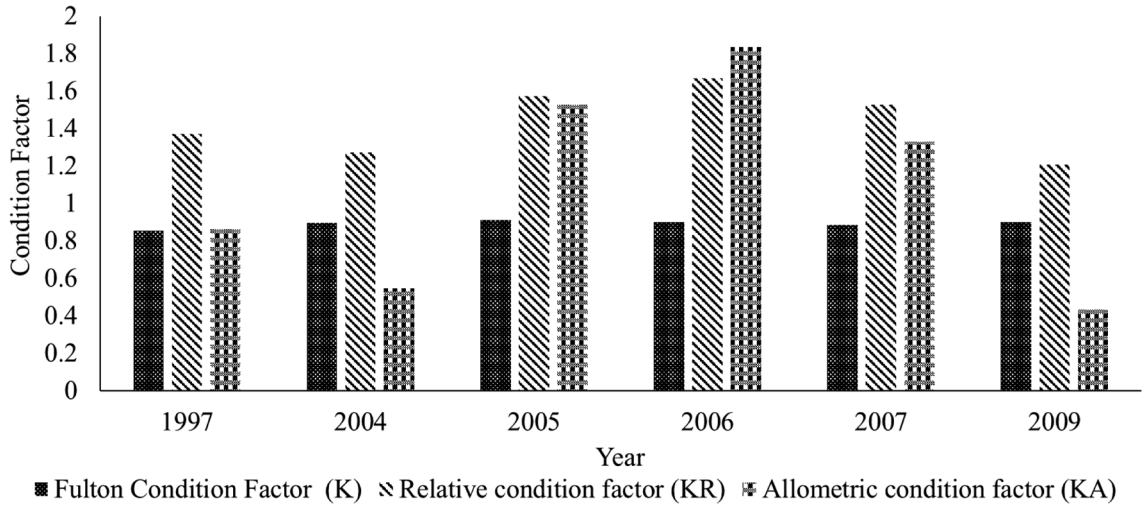

Fig. 3 — Year-wise variations in examined condition factors of *Sardinella longiceps* from Sultanate of Oman coast

Table 2 — Fulton's Condition factor (*K*); Allometric condition factor (K_A) and Relative condition factor (K_R) for *Sardinella longiceps* from Sultanate of Oman coast

	Condition factors	N	Minimum	Maximum	Mean±SD	95 % CL
1997	K	1606	0.649	1.149	0.857 ± 0.057	0.003
	K_R		1.040	1.838	1.372 ± 0.091	0.004
	K_A		0.655	1.158	0.864 ± 0.057	0.003
2004	K	369	0.623	1.259	0.897 ± 0.070	0.007
	K_R		0.882	1.817	1.272 ± 0.094	0.010
	K_A		0.379	0.781	0.547 ± 0.040	0.004
2005	K	350	0.744	1.060	0.911 ± 0.055	0.006
	K_R		1.277	1.840	1.574 ± 0.093	0.010
	K_A		1.238	1.785	1.527 ± 0.090	0.009
2006	K	201	0.640	1.260	0.902 ± 0.067	0.009
	K_R		1.188	2.277	1.667 ± 0.117	0.016
	K_A		1.307	2.505	1.834 ± 0.129	0.018
2007	K	393	0.616	1.115	0.885 ± 0.073	0.007
	K_R		1.084	1.958	1.529 ± 0.125	0.012
	K_A		0.943	1.703	1.330 ± 0.109	0.011
2009	K	590	0.607	1.200	0.900 ± 0.110	0.009
	K_R		0.811	1.575	1.209 ± 0.144	0.012
	K_A		0.292	0.567	0.435 ± 0.052	0.004

N = sample size; SD = standard deviation; *CL* = confidence limits; K = Fulton Condition Factor; K_R = Relative condition factor; K_A = Allometric condition factor

Fulton's condition factor in the studied years, whereas the relative condition factor and the allometric condition factor were high in 2005 to 2007 (Fig. 2). There is a significant variation (P = 0.042) among the three condition factors.

Discussion

The LWR of fish is significant in studying the population growth, gonadal development and overall well-being[3] and for comparing life history of fishes from different locations[23]. The growth coefficient, *i.e.*, *b*-values lies between 2.5 and 3.5 in *S. longiceps* studied in present study which conforms the findings of Carlander[24] and Froese[19]. These shifts in *b*-value(s) could be because of environmental factors, overfishing, food scarcity and the ecosystem's ability to support the fish population. During 2005 to 2007, the growth of *S. longiceps* was negative allometric, whereas in 2004 and 2009 the growth was positive allometric in this present study. Aljufaili[9] estimated isometric growth (b = 3) in *S. longiceps* from the Sultanate of Oman coast. Jayabalan *et al.*[17] figured out negative allometric growth (b = 2.91) during September 2007 and September 2009 from the

Arabian Sea coast of Sultanate of Oman. Shah *et al.*[11] calculated the LWR ($W = 0.000054L^{2.645}$) and Coefficient of correlation (r) (0.74) for pooled data of *S. longiceps* from Ratnagiri coast of Maharashtra, India indicating a negative allometric growth. Rohit & Bhat[25] estimated the b-value in *S. longiceps* as 2.86 from the Mangalore coast of India. Further, Zaki *et al.*[16] estimated isometric growth ($b = 3$) in sexed pooled population of *S. longiceps* between October 2007 and September 2009 from the Salalah coast of Sultanate of Oman. They concluded that *S. longiceps* in Sultanate of Oman's waters are heavier for their length than in Indian waters. This may also be due to the differences in the stock characteristics or could be due to genetic factors or environmental factors such as temperature, salinity, and food availability[26]. Morphological variations in Indian Oil Sardine can also result from adaptive specialization to optimize fitness to a particular environment and optimize the utilization of habitat[27].

A fish's condition is a common metric for determining survival, reproduction, maturity, and health[3]. It's a useful indicator of water quality or the overall health of fish populations in specific habitats or ecosystems[28]. A condition factor of 1 or above indicates that the fish is in good shape, while a value of less than 1 suggests that it is in poor shape[29]. On the other hand, the Fulton condition factor (K) assumes that the weight of the fish is proportionate to the cube of the length $K = 100(W / L^3)$, so that b exponents are constant in the Fulton equation. The assumption of isometric growth in fish is one of the drawbacks of Fulton's condition factor. But the allometric condition factor uses the b-value of LWR instead of a constant isometric b-value. The relative condition factor (K_R) introduced by Le Cren[3] offsets change in length in shape or condition and it is possible to determine whether the individual is in better ($K_R > 1$) or worse ($K_R < 1$) status than the average individual of the same length. A better condition ($K_R > 1$) was observed of *Sardinella longiceps* population in the studied period. Elahi *et al.*[13] estimated that the mean condition factor of *S. logiceps* from the Balochistan coast is 1.09. The results of this study can be used as a valuable tool by fishery biologists, managers and conservationists to carry out *Sardinella longiceps* stock assessments in coastal Sultanate of Oman and neighbouring countries. In addition to allowing the weight of individuals to be determined based on their length, the length-weight relationship helps give essential information for population dynamics, fish stock management, and ecosystem monitoring.

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Conflict of Interest

The authors declare no conflict of interests.

Author Contributions

SD: Conceptualization, methodology, software, formal analysis, and writing-original draft preparation. SMAJ: Conceptualization, investigation, writing-review & editing. ISAA: Writing-review & editing.

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