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Population Dynamic Parameters of Rohu, *Labeo rohita* (Hamilton, 1822) in the Indus River, Sindh, Pakistan

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Key words
***Labeo rohita*, Sustainable management, Overfishing, BRPs, FiSAT**

ABSTRACT

The population dynamics of *Labeo rohita* in the Indus River of Pakistan were analyzed using monthly length frequency data from January 2013 to December 2013. The study focused on growth, mortality rates, exploitation, biological reference points (BRPs), yield per recruit, and growth performance index. A total of 720 fish samples ranging from 15 to 35cm in length (average length of 23±5.111cm) and weighing 50 to 700g (average weight of 225±144g) were collected. The relationship between length and weight was determined as $W= 0.025\ L^{2.844}$ with $R^2= 0.990$. The von Bertalanffy growth model parameters were $L_\infty= 36.75$cm and $K= 1.200\ yr^{-1}$, $t_0= -\ 0.904$ years and $R_n= 0.313$. The natural mortality rate was 1.662 yr^{-1}, total mortality was 2.06 yr^{-1} with $CI_{95\%}$ 1.65-2.46yr^{-1} ($r^2= 0.895$), fishing mortality was 0.398 yr^{-1}, and current exploitation ratio was 0.193. Growth performance indices for asymptotic length $\Phi'= 3.210$ yr^{-1} and asymptotic weight $\Phi= 1.979$ yr^{-1} were calculated. The Beverton-Holt yield per recruit model was done by FiSAT-II in which t_c was 1, F_{max} 3 yr^{-1} and $F_{0.1}$ 2.1 yr^{-1}. The current age at the first capture was approximately 1 year, $F_{current}$ 0.398 yr^{-1} was smaller than F_{max} and $F_{0.1}$ and current fishing mortality 0.398 yr^{-1} is smaller than the target biological reference point $F_{opt}= 1.662\ yr^{-1}$, F_{max} 3 yr^{-1} and $F_{0.1}$ 2.1 yr^{-1} indicating the stock of the *Labeo rohita* in Indus River is not overfished. The estimated parameters suggest that the fishery of *Labeo rohita* in the Indus River can be managed sustainably.

INTRODUCTION

The Indus River plays a crucial role as Pakistan's primary water route and a significant geographical element of the Indus civilization, which marked the early urbanization period in the Indian subcontinent between 2500 and 1900 BCE (Before Christ Era). Initially known as Sindhu, the river's name influenced the name of the Pakistani province of Sindh. The change from Sindhu to Indus is a minor phonetic alteration, and India derived its name from the Indus River (Indus River, 2012). The Indus River is the single most important natural resource in Pakistan and the Kotri Barrage is one of the most important fishing centres along the Sindh over the lower reaches of the river Indus (Bhatti, 1999). Kotri Barrage was built in 1955 (Mushtaq, 1975) and is located on the right bank of the Indus River. It lies at 25º 26' N and 68º 22' E and is the last barrage on the Indus River measuring about 0.575 miles (920 m) across the Indus River, near Hyderabad city in southern Pakistan; the river runs about 100 km below (Bhatti, 1999) before discharging into the Arabian Sea (Yu *et al*., 2013).

Pakistan has one of the largest integrated irrigation network systems in the world in the Indus Basin during the current century. It serves 34.5 million acres of contiguous cultivated land along with the Indus River and its major tributaries. The total length of the Indus River is 2900 km with a drainage area of about 966,000 sq. km. The system has three major storage reservoirs namely Tarbela and

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Chasma on the Indus River while the Mangla dam is on the Jhelum River. There are 19 Barrages/headwork, 12 link canals, 45 canal commands measuring 58,450 km in length and some 99,000 watercourses measuring 160,000 Km in length (Kahlown and Majeed, 2003).

The reported number of freshwater and marine water fish species is 193 and 326, respectively from water bodies of Pakistan (Rafique, 2007; Psomadakis *et al*., 2015). Similar to marine fisheries, inland fisheries of Pakistan have a tremendous capacity for holding aquatic animal diversity including fish, crustaceans and Molluscs. Pakistan has extensive inland water areas, which depend on the water type body that has much more potential for development both in inland fisheries and aquaculture. The Indus River is dominated by freshwater resources such as rivers, lakes, ponds and reservoirs (FAO, 2009).

The agricultural sector has remained an important element of Pakistan's economy. This agriculture sector accounts for 19.30% of the overall Gross Domestic Product (GDP) in Pakistan and this industry adds value to the economy by creating 45% of employment in rural areas (PES, 2019-20). In Pakistan, fishery plays an important role in the economy and is considered a reducing poverty tool towards the economic growth of the country. The fisheries industry made a 0.4% contribution to the GDP and brought in foreign exchange through exports totaling US $ 317.307 million (Rs 49,528 million) in the 2019-20 financial year (PES, 2019-20). Pakistan's export of fish and fishery products saw positive growth in 2019-20. A total of 133,226 metric tonnes were exported, with a value of $317.307 million (Rs 49,528 million). The main buyers of Pakistan's fish and fishery products were China, Thailand, Malaysia, the Middle East, Sri Lanka, and Japan. Comparing the export figures to the previous year 2018-19, there was a 2.7 per cent increase in quantity, an 8.0 percent increase in value, and a significant 26.2 percent increase in rupee terms. This indicates a successful performance in the export of fish and fishery products during the 2019-20 period. The provided text highlights the production of marine and inland fish during 2019-20. The total combined production of fish during this period was 701,726 metric tonnes. Out of this total, 474,025 metric tonnes were sourced from marine waters, while the remaining quantity came from inland waters (PES, 2019-20). Mainly more than 80% of the total inland fisheries production comes from rivers and reservoirs. Sindh province contains more than 100 natural lakes, which are good sources of fish fauna. The major contribution of the freshwater fishing system is the Indus River and its tributaries (FAO, 2009).

Cyprinidae is an important family of freshwater fishes distributed all over the world in 371 genera with 3036 species (Eschmeyer and Fong, 2016). This family is represented by 74 species in Pakistan and considered as largest freshwater fish fauna family in terms of genera and species (Mirza, 2003). The genus *Labeo* is the largest genera in Pakistan and is represented by 15 species (Mirza, 1975). The species of this family have significance in aquaculture and high commercial importance in inland fish fauna species of Pakistan (Peter, 1999).

Labeo rohita is one of the most important species of the inland fisheries in Pakistan, which contributes around 35% of total stocking, and 23% of the total aquaculture production in the region (Ashraf and Zafar, 2013). This common freshwater teleost fish *Labeo rohita* (Hamilton, 1822) is commonly known as "Roho Labeo" and locally known as "Rohu" or "Dumbra" in Pakistan (Ali, 1999). It is an esteemed table fish, has high commercial and aquaculture importance, and is a geographically widespread species in tropical freshwater of India and adjacent countries with considerable variation in reproductive traits (Chondar, 1999). The natural resources of the fish are from the network of the Ganges, Sindh and Brahmaputra River systems in the north, and the east and west coast river systems flowing through south and central India (FAO, 2011). This freshwater fish species is naturally distributed well in the rivers, lakes and ponds of Pakistan, Bangladesh, India, and Myanmar (Talwar and Jhingran, 1991) and also reported from brackish-water systems (Riede, 2004). This is the column feeder fish and mostly feeds on phytoplankton and soft weeds. The fish *L. rohita* is one of the most important economic food fish in Pakistan and is considered as tastiest of all carp. This species breeds during summer (July-August) in naturally flooded riverine areas of Pakistan and grows up to a length of 1.2 m (Ali, 1999), while the maximum length of this fish is reported at 200 cm (Frimodt, 1995).

The relationship between humans and riverine is intricate and has developed over millions of years, showcasing our dependence on riverine fisheries for resources and climate regulations (WHO, 2018). Riverine fisheries play a crucial role in the cultural and economic aspects of many communities globally. These fisheries are essential for providing food security, livelihoods, and income, especially in developing nations (WHO, 2018). The significance of riverine fisheries cannot be understated, as they support millions of people and contribute to the overall well-being of these communities with inland water reserves spanning 8,563,820 hectares (Jarwar, 2008). Over 59 million people are likely linked to fisheries and aquaculture in 2018 highlighting its importance for both cultural and economic well-being, especially in developing countries according to the Food and Agriculture Organization (FAO, 2020).

For the management and conservation of wild populations of *L. rohita*, it is important to understand the parameters of population dynamics of this fish species in its natural environment. Previously some studies were reported on the population dynamics of *L. rohita* from the Sylhet basin by Amin *et al*. (2001); from Dhir Beel by Goswami and Devaraj (1995); from Ganga and the Yamuna by Gupta and Tyagi (1992); in the Paisuni River by Dwivedi (2009); in the Rivers of Vindhyan region, India by Dwivedi and Nautiyal (2012); from Mymensingh Basin and Sylhet basin, Bangladesh by Haroon *et al*. (2001) and (2002). Although, earlier reported work describes the population dynamics of some fish species from Pakistani waters (Mohsin *et al*., 2016; Memon *et al*., 2017a, b, 2022), however, no research work has been carried out on the population dynamics of *L. rohita*. This study is the first attempt to provide information on the parameters of growth and stock status of *L. rohita* from the natural population of the Indus River. The study focuses on analyzing the growth and mortality characteristics of teleost bony fish in the Indus River, specifically the *L. rohita* species. To investigate the stock status various aspects such as growth parameters, mortality rates, biological reference points, growth performance indices, and virtual population analysis were examined. The research also aimed to determine the rate of exploitation and relative yield per recruit. The main goal and objective were to gain insights into the stock position and population parameters for the successful development and management of *L. rohita* in the Indus River. This study provides valuable information that was previously lacking, shedding light on important aspects of the fish population dynamics of *L. rohita* species in the region and will be useful for fisheries conservationists and environmentalists for the successful development, management, production and preservation in the Indus River.

MATERIALS AND METHODS

Sampling

During the study period, the monthly samples of *L. rohita* were collected from the Indus River, at the site of Kotri Barrage (Ghulam Muhammad Barrage), Sindh, Pakistan (Fig. 1). A total of 720 fish specimens were used in the current study obtained from the fishermen's catch at small-scale centres from January 2013 to December 2013. All individual samples were registered in the total length (cm) and total weight (g) with an average total length of 23±5.11cm (Mean±SD) and total weight at an average of 225±144.14g.

Analysis of data

The monthly length-frequency data of *L. rohita* was analyzed using the FISAT-II software (Gayanilo *et al*., 2005). Time-series data of size-frequency distributions at one 5cm intervals were obtained for each month (Table I). Following core population parameters such as growth, mortality rate, biological reference points, growth performance index, virtual population analysis and relative yield per recruit analysis were estimated in the present study.

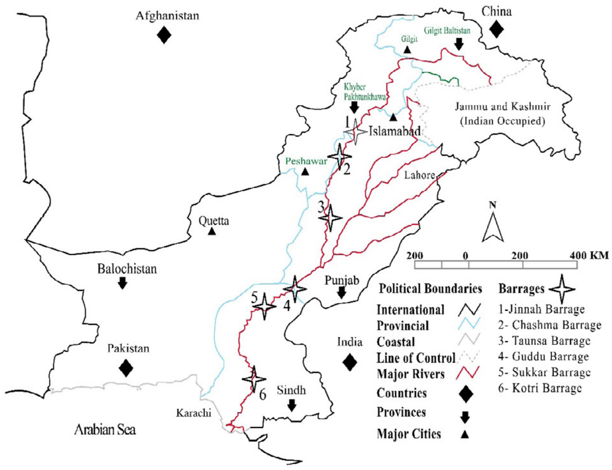

Fig. 1. Map showing the study area.

Length-weight relationship

The lengths and weights of 720 specimens of *L. rohita* were determine according to Le Cren (1951). The parameters *a* and *b* of the length-weight relationship were estimated by the power equation: $W = aL^b$, where the weight of fish was represented by *W* in grams (g), constant condition factor was represented by intercept (*a*), *L* was indicated by total length in (cm) and allometric growth parameter was represented by exponent or slope (*b*).

Table I. Length-frequency data of *L. rohita* from January 2013 to December 2013 in the Indus River, Pakistan.

Size classes	Jan.	Feb.	Mar.	Apr.	May	Aug.	Sep.	Oct.	Nov.	Dec.	Total	%
15-19.9	36	54	65	20	5	2	0	0	0	0	182	25.28
20-24.9	16	44	64	54	56	26	1	0	0	0	261	36.25
25-29.9	0	0	0	0	37	53	41	28	2	9	170	23.61
30-34.9	0	0	0	0	0	6	20	10	30	41	107	14.86
Total	52	98	129	74	98	87	62	38	32	50	720	100

Growth parameters

The von Bertalanffy growth function parameters of *L. rohita* were determined by using the method ELEFAN-I (Electronic Length Frequency Analysis) in this study, which makes direct use of size distributions to prepare an estimate of the growth parameters. The von Bertalanffy equation for growth in length according to Haddon (2011) is: $L_t = L_\infty (1 - \exp(-K(t - t_0)))$, where L_t was the length at the predicted time t, L_∞ was the asymptotic length, K was the growth coefficient and t_0 was the hypothetical age or time where length was equal to zero. An additional estimated value of t_0 was obtained by the empirical equation by Pauly (1983) as $log_{10}(-t_0) = -0.3922 - 0.275\ log_{10}L_\infty - 1.038\ log_{10}K$.

Mortalities rates

For the estimation of instantaneous total mortality (Z), the length-converted catch curve method by Pauly (1983) was used. Additional parameters of M and F (natural mortality and fishing mortality) were also calculated. The regression formula for Z is $\text{Ln}(N_t) = \text{Ln}(N_0) - Zt$, where N_t is the population size at age t and N_0 is the population size at 0 (Pauly, 1980). The equation by Pauly (1980) was used for natural mortality (M) from $log_{10}M = 0.0066 - 0.279\ log_{10}L_\infty + 0.654\ log_{10}K + 0.4634\ log_{10}T$. Where; $T = 21^{o}$C was the average annual surface temperature of the water was analyzed with the help of digital thermometer in the Indus River in which the stock of *L. rohita* occurs. The F (Fishing mortality) was estimated by using the relationship of subtracting $F = Z\text{-}M$. The exploitation ratio (E) was obtained by the relationship of Gulland (1971a): $E = F/Z = F/(F+M)$.

Virtual population analysis

According to Sparre and Venema (1992), the length structured virtual population analysis (VPA) of *L. rohita* was carried out with the input values of length-weight relationship parameters intercept (a), slope (b) and growth parameters values of asymptotic length (L_∞), growth coefficient (K) and mortality parameters values of natural mortality (M) and fishing mortality (F) to estimate the fishing mortalities per length class. The t_0 value was taken as zero.

Biological reference points

According to Gulland (1969), the optimal fishing mortality rate $F_{opt} = M$ was determined as the limit biological reference point for *L. rohita* in the Indus River.

Beverton and holt yield per recruit model

Using the model of Beverton and Holt (1957) incorporated into the FAO FiSAT-II program (Gayanilo *et al*., 2005) with the formula relative yield per recruitment (Y/R) values as a function of exploitation ratio (E) of *L. rohita* were estimated. where Y_w/R was yield per recruit, t_c was the average age of first capture, t_r was the age of recruitment, t_λ was the asymptotic ages, Q_n was the constant and equal to 1, -3,3 and -1 when n was 0, 1, 2 and 3 correspondingly (Pitcher and Hart, 1982).

Growth performance indices

The estimated growth parameters values of L_∞ (asymptotic length) and K (growth constant) were used to compute the growth performance index (Phi prime Φ') following equations by Pauly and Munro (1984) $\Phi' = log_{10} K + 2log_{10}L_\infty$ and $\Phi = log_{10}K + 2/3\ log_{10}W_\infty$ were used.

RESULTS

Length-weight relationship

720 specimens of *L. rohita* were collected from the Indus River at Kotri Barrage during the period January 2013 to December 2013. The total length ranged between 15 and 35cm at an average length of 23 cm with SD±5.111cm, while total individual weight varied between 50 to 700g with an average of 225±144.14 (Mean±SD) g (Fig. 2). The length-weight relationship parameters a and b for *L. rohita* were described by the power equation as: $W = 0.025\ L^{2.844}$, $R^2 = 0.990$ (n=720). The maximum and minimum number of individual species was found at 20cm (n= 77) and while least was at 15cm (n= 5) respectively (Table I). Dominant length and weight of *L. rohita* were observed at ranges between 17 to 23cm (Fig. 3) and 65 to 150g, respectively.

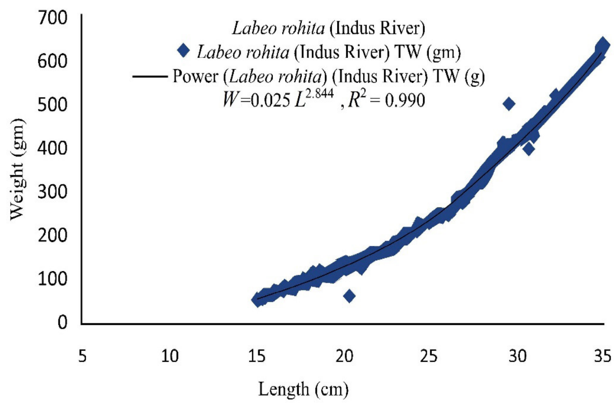

Fig. 2. Length-weight relationship of *L. rohita* (n= 720) from Indus River.

Growth parameters

The procedure of K-scan was computed to estimate the L_∞ (asymptotic length) and K (growth coefficient) through the method of ELEFAN-I. The monthly length frequency size distribution of *L. rohita* was arranged at 5cm intervals shown in Table I. The estimated values of L_∞ and K were obtained as L_∞= 36.75cm and K= 1.200 yr^{-1}, respectively. The score of the goodness fit index of the ELEFAN-I routine (R_n= 0.313) was constructed by the total sum of observations in this function. Hypothetical age at zero length was estimated as t_0= -0.904 years. The graphical representations of these output VBGF curves are shown in Figure 4.

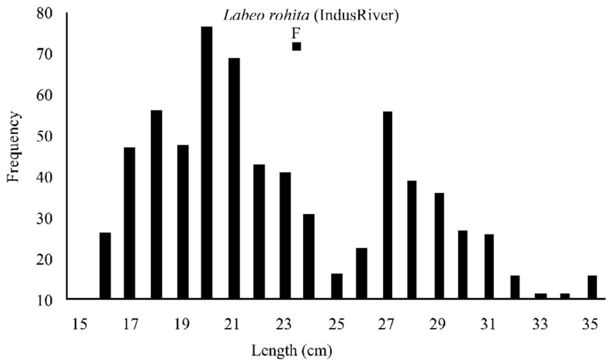

Fig. 3. Length frequency distribution of *L. rohita* from the Indus River.

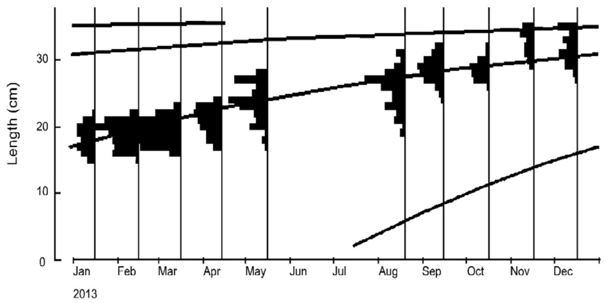

Fig. 4. Computed growth curves for *L. rohita* with model of von Bertalanffy growth function (VBGF) *L_∞= 36.75cm total length and K= 1.200 yr^{-1} from Indus River.

Mortality and exploitation ratio

The value of instantaneous total mortality for *L. rohita* in Indus River Z= 2.06 yr^{-1} with $CI_{95\%}$ of 1.65-2.46 (r^2 = 0.895) was constructed from the input values of VBGF growth parameters (L_∞ and K) in the length converted catch curve model described by Pauly (1983) (Fig. 5 and Table II). At the same time, the value of natural mortality was M= 1.662 yr^{-1} using Pauly's (1980) equation. Fishing mortality (F= 0.398 yr^{-1}) was obtained by subtracting Z from M and the exploitation ratio (E= 0.193) was achieved from the Gulland (1971a): E= F/Z= 0.398/ (0.398+1.662).

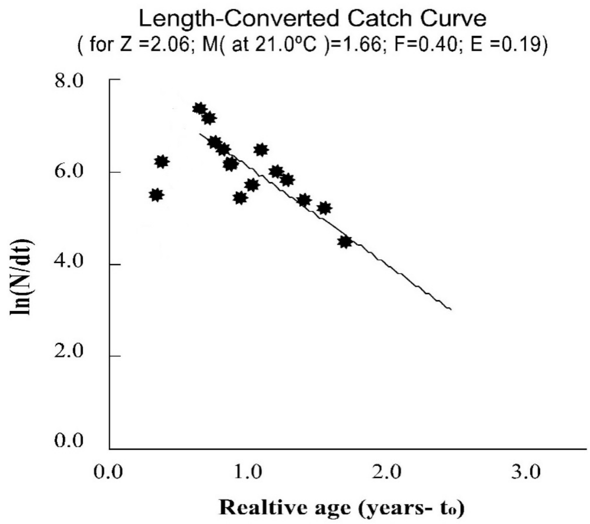

Fig. 5. Length converted catch curve for *L. rohita* from the Indus River.

Table II. Estimated key parameters of growth, mortality, exploitation and yield of *L. rohita* from the Indus River in 2013.

Population parameters	*Labeo rohita* from the River Indus
Intercept (*a*)	0.025
Exponent (*b*)	2.844
Coefficient of determination (R^2)	0.99
Asymptotic length (L_∞)	36.75cm
Growth coefficient (K)	1.200 yr^{-1}
Theoretical age (t) at zero length (t_0)	- 0.904 years
Goodness of fit (R_n)	0.313
Total mortality (Z)	2.06 yr^{-1} at $CI_{95\%}$ to 1.65 – 2.46
Mean annual water temperature of the Indus River	21°C
Natural mortality (M)	1.662 yr^{-1}
Fishing mortality (F) $F= Z-M$	0.398 yr^{-1}
Exploitation rate (E) $E= F/Z$	0.193
GPI Φ' (L_∞)	3.210
GPI Φ (W_∞)	1.979
Length range (*cm*)	15-35cm
Sample number (*n*)	720

Virtual population analysis

The input value of von Bertalanffy growth function of the growth parameters (L_∞ and K), mortality parameters

(M and F) and length-weight relationship parameters (a and b) were used to build the length structured virtual population analysis (LVPA) for the *L. rohita* in the Indus River. Cohort analysis to output graphics for LVPA was done by FiSAT-II (Fig. 6). The length of the high fishing mortality was observed in the 26.0 to 31.0cm range.

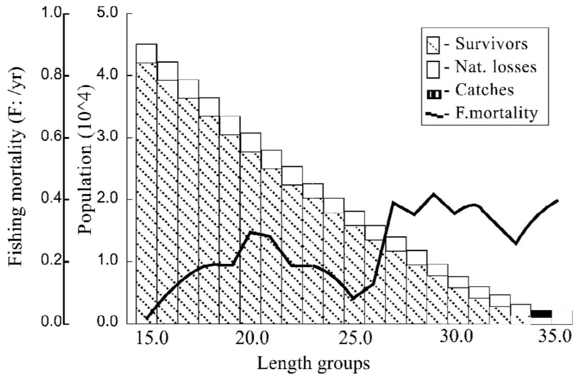

Fig. 6. LVPA analysis cohort for the *L. rohita* in the Indus River.

Biological reference points

The relative yield per recruitment for *L. rohita* was analyzed by the model of Beverton-Holt yield per recruit with the knife edge selection in FiSAT-II (Fig. 7). When t_c was 1 the F_{max} was estimated at 3 yr^{-1} and $F_{0.1}$ to 2.1 yr^{-1}. Since the current age at the first capture was approximately 1 year and $F_{current}$ was 0.398, the $F_{current}$ was smaller than F_{max} and $F_{0.1}$ indicating the stock of *L. rohita* in the Indus River is by the situation of the holding exploitation state. Biological reference point F_{opt} was equal to (M= 1.662). The current fishing mortality rate of 0.398 yr^{-1} was below the biological reference point target benchmark.

Growth performance index (GPI)

The von Bertalanffy growth parameters of L_∞ and K were used for the estimation of growth performance indices (phi prime or index Φ') for *L. rohita* in the Indus River as Φ'= 3.210 and Φ= 1.979.

DISCUSSION

Freshwater fish in Pakistan are not only important for food security but also the livelihoods of those involved in commercial fishing, especially in inland waterlogged areas. However, studies in Pakistan have mainly focused on freshwater species diversity and composition, rather than key characteristics like fish population dynamics and conservation status of economically important freshwater fish species (Sheikh *et al*., 2017). The decline in the population of certain commercially significant freshwater fish species can be attributed to factors such as overexploitation, pollution, and habitat disintegration (Memon *et al*., 2017a). This highlights the need for further research and conservation efforts to protect these economically and commercially important species and sustain the livelihoods of fishing communities. The main purpose of fisheries stock assessment is to assist in fishery management (Gayanilo and Pauly, 1997). Length composition data is used to assess the current status of fish stocks. It is observed that fishing not only reduces the population of fish but also affects the relationships between different species (Sheikh *et al*., 2017). Analyzing the length frequency distribution of fish stocks is an important method for evaluating resources and managing fish populations that helps to prevent fragmentation within the fisheries sector (Maunder *et al*., 2016).

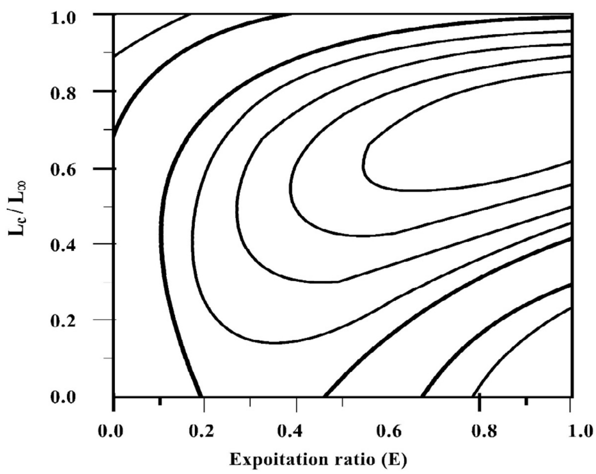

Fig. 7. Contour map of relative yield per recruitment model with the knife edge selection option for *L. rohita* from the Indus River.

The study involved measuring the overall length of *L. rohita* specimens, ranging from 15.0 to 35.0 cm, and their weight, ranging from 50 to 700g. A total of 720 specimens were analyzed to study the length-weight relationship (LWR). The LWR parameters for *L. rohita* can be found in Table II. A high R^2 value of 0.990 indicated a strong correlation between the length and weight of *L. rohita*. The exponent b value revealed a negative allometric growth pattern. In cases of isometric growth, the b value is 3, signifying that the fish maintains the same body shape throughout its life (Wootton, 1990; Pauly and Gayanilo, 1997). However, a b value greater or less than 3 indicates allometric growth, resulting in changes in the fish dimensions.

Table III. Comparison of estimated growth parameters of *L. rohita* in the Indus River with the other estimated growth parameters from the different countries.

Location	L_∞(cm)	K (yr^{-1})	t_0	Φ'	Reference
Dhirbeel of Assam, India	135.29	1.2	-	-	Goswami and Devaraj (1995)
Sylhet basin, Bangladesh (1998)	80.31	0.41	-	-	Haroon *et al.* (2002)
Sylhet basin, Bangladesh (1999)	51.74	0.8	-	-	
Mymensingh basin, Bangladesh (1998)	74.36	0.74	-	-	Harron*et al.* (2001)
Mymensingh basin, Bangladesh (1999)	97	0.7	-	-	
Sylhet basin, Bangladesh	80.2	0.41	-	-	Amin *et al.* (2001)
Govindgarh Lake, India	91.2	0.38	-0.13	3.5	Prakash and Gupta (1986)
Aligarh Waters, India	102	0.28	-0.33	3.46	Khan and Jhingran (1975)
Paisuni river, India	833 (mm)	0.56	-	-	Dwivedi (2009)
River Ken	946 (mm)	0.4	-	-	Dwivedi and Nautiyal (2012)
River Paisuni	833 (mm)	0.56	-	-	
River Tons	962 (mm)	0.42	-	-	
Indus River, Pakistan	36.75	1.2	-0.904	3.21	Present study

Our study found a b value of 2.844 for *L. rohita*, demonstrating a negative allometric growth pattern. This aligns with the findings of Pauly and Gayanilo (1997), who suggested that b values typically range between 2.5 and 3.5.

This relationship helps in assessing the health and sustainability of fish stocks, which is vital for effective fisheries management. Overall, the LWR is a fundamental tool in fisheries science that aids in comprehending the biology and dynamics of fish populations. The fluctuations in the length-weight relationship (LWR) within the same species across different areas can be attributed to ecological and environmental conditions, habitat changes, or physiological factors (Le Cren, 1951). The provided text presents various studies documenting the b values for different fish species in different locations. Bhat (2011) found a b value of 2.97 for *L. rohita* fish in Phuj Reservoir, Jhansi, India. Choudhury *et al*. (1982) reported negative allometric growth (b= 2.347) in the Brahmaputra River, Assam, India. Khan and Jhingran (1975) reported b values of 2.533 in Panchet Reservoir, Damodar Valley, India, 2.698 in Tilaya Reservoir, Damodar Valley, India, and 2.808 in the Konar Reservoir, Damodar Valley, India. Garcia (2010) obtained a b value of 2.920 in Pampanga River, Candaba, Philippines. However, Khan and Jhingran (1975) observed a b value of 3.014 in the Ganges River, India. Ahmed and Saha (1996) reported a b value of 3.149 in Kaptai Lake, Bangladesh. Jhingran (1952) reported a b value of 3.0 in a moat and spring in Calcutta, India. Sarkar *et al*. (1999) observed b values of 3.306 and 3.125, respectively from Bundh and Hatchery-bred.

Understanding fish populations and effectively managing fisheries requires a thorough understanding of growth parameters (Quinn and Deriso, 1999). These parameters provide valuable insights into the growth rates, mortality rates, and recruitment patterns of fish populations (Hilborn and Walters, 1992; Hoggarth, 2006; Maunder *et al*., 2016). By analyzing these parameters, fisheries managers can make informed decisions to ensure sustainable fishing practices and conservation efforts (Hilborn and Walters, 1992; Hoggarth, 2006; Maunder *et al*., 2016). The study by Moreau *et al*. (1986) emphasizes that the estimated L_∞ parameter of the von Bertalanffy growth function should closely correspond with the maximum length of the fish observed during the sample, with t_0 being less than zero to ensure a positive length at zero age. In this study, the estimated asymptotic length L_∞= 36.75 cm falls within the acceptable range of the total length of 35.00cm for *L. rohita*. The K and L_∞ values for *L. rohita* are provided in Table II. The length-frequency data for *L. rohita* is displayed in a 5cm class interval (Table I) using the ELEFAN-I method, where the length range of 20.0-24.9cm accounted for over 36% (261 fishes) of the *L. rohita* fishery. The t_0 value was determined as t_0= -0.13 year for *L. rohita* in Govindgarh Lake, India by Prakash and Gupta (1986), while Khan and Jhingran (1975) discovered t_0= -0.33 year for the same species in Aligarh waters, India (Table III). The t_0 value acts as an indicator of growth rate in adults and adolescents, with negative values indicating a higher proportion of juveniles compared to the anticipated growth curve for adults, while positive t_0 values suggest slower growth (King, 1997). Table III presents a comparison of the estimated growth parameters of *L. rohita* in the Indus River with those of other countries. In this particular study, the asymptotic length value for *L. rohita* was determined to be L_∞= 36.75cm, which is lower than previous estimates. However, the growth coefficient value obtained, K= 1.200 yr^{-1}, was found to be higher compared to findings from other regions. Hence, the current research conducted in the Indus River suggests that the growth of *L. rohita* may be superior to that observed in other studies.

The fish mortality parameter is a crucial parameter in fisheries population dynamics, accounting for the loss of fish within a fish stock due to death (Owen *et al*., 2023; Maunder *et al*., 2023). The natural mortality coefficient (M) is a critical factor in fisheries stock assessment but is also one of the least understood and most difficult to estimate due to unavailable direct data (Punt, 2023; Beverton and Holt, 1957; Gayanilo *et al*., 2005). The natural mortality coefficient (M) M is a key component in mathematical models used to study fish stock dynamics (Ping *et al*., 2018), with fishery scientists continuously striving to obtain precise estimates of M to enhance their understanding of fish populations and promote sustainable fisheries management practices for ensuring assessment outcomes accuracy and shaping fisheries management strategies (Maunder *et al*., 2023). Fishery scientists have been working to obtain reliable estimates of M to enhance their understanding of fish populations and establish a more scientific approach to fisheries management and sustainable development. This study focuses on one method for estimating the instantaneous rate of natural mortality in fish stocks and relies on the strong correlation between M with indirect methods of other life history parameters, such as maximum observed age, age at reproductive maturity, asymptotic fish length, and growth rate. The Pauly empirical equation (Pauly, 1980) is commonly used to assess *L. rohita* fisheries in Pakistan, playing a vital role in offering insights into fish population dynamics and guiding effective fisheries management practices.

The mortality rates and exploitation values of *L. rohita* were compared with those from other studies, as presented in Table IV. In this study, the total mortality (Z) was found to be slightly lower or higher than in previous studies. In this research, the calculation of the natural mortality (M) of *L. rohita* from the Indus River is determined using Pauly's equation and was notably higher compared to reported values worldwide. Consequently, our estimated natural mortality rate indicates its reliability and validity. Additionally, the fishing mortality (F) rate was moderately lower in this study compared to others. Similarly, the exploitation ratio was also found to be the lowest in this study compared to values observed in other regions around the world. The M/K ratio, which is commonly observed for various fish species, has been documented to range from 1.12 to 2.50 (Beverton and Holt, 1957). Interestingly, our study reveals that the M/K ratio of 1.385 falls within this established range. The natural mortality rate is influenced by various factors, including old age, predation, environmental stress, and parasitic diseases (King, 1997). The exploitation ratio is a measure used to determine the extent of fishery utilization. The ideal level of utilization is achieved when the fishing mortality rate matches the natural mortality rate. The natural mortality rate is 1.662 yr^{-1}, which is higher than the current estimated fishing mortality rate of 0.398 yr^{-1}. Based on the research, the exploitation ratio is 0.193, indicating that the *L. rohita* stock is in a secure state. This meets the guideline set by Gulland (1971b) that the exploitation rate should not exceed 0.5.

Table IV. Comparison of estimated mortality parameters and exploitation rate of *L. rohita* in the Indus River with the other estimated mortality parameters and exploitation rate from the different countries.

Locality	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	E	Reference
Sylhet basin, Bangladesh (1998)	1.56	0.73	0.83	0.52	Haroon *et al.* (2002)
Sylhet basin, Bangladesh (1999)	1.70	0.77	0.93	0.55	
Mymensingh basin, Bangladesh (1998)	3.09	1.12	1.97	0.64	Haroon *et al.* (2001)
Mymensingh basin, Bangladesh (1999)	2.64	0.99	1.65	0.62	
Sylhet basin, Bangladesh	1.56	0.73	0.83	-	Amin *et al.* (2001)
Paisuni river, India	3.67	0.94	2.73	-	Dwivedi (2009)
River Ken	3.2	0.74	3.67	0.94	Dwivedi and Nautiyal (2012)
River Paisuni	4.19	1.84	2.46	0.77	
River Tons	2.73	0.74	2.33	0.56	
Ganga River, Allahabad, India	0.74	0.30	0.44	0.59	Gupta and Tyagi (1992)
Indus River, Pakistan	2.06	1.662	0.398	0.193	Present study

The growth performance index (GPI) is determined by two VBGF parameters, K and L_∞, as mentioned in Gatabu's (1992) research. Phi prime (Φ') is a specific parameter that indicates the lack of reliability in the estimated growth parameters of the same or related species within a particular stock, as described in Adedolapo's (2007) study. The similarity of Φ' with related species in different tropical regions serves as a measure of the calculated growth parameter's reliability in the conducted study. GPI allows for the comparison of growth performance among fish species from different populations, whether they belong to the same or different environmental fish populations, as highlighted in Baijot and Moreau's (1997) and Pauly and Munro's (1984) studies. In this particular study, the GPI of the pooled data of *L. rohita* was determined to be 3.210, which aligns with some of the values obtained from different tropical fish. Prakash and Gupta (1986), reported a GPI of 3.50 for *L. rohita* from Govindgarh Lake, India, while Khan and Jhingran (1975) reported a GPI of 3.46 for *L. rohita* from Aligarh Waters, India. This index is also supported by the von Bertalanffy growth parameters (L_∞ and K) as it facilitates the comparison of species growth, as stated in Pauly and Munro's (1984) study. The growth rate (K) and asymptotic size (L_∞) are influenced by multiple factors, making the comparison of growth rates a complex matter. Phi prime (Φ') serves as a reliable indicator that effectively responds to these criteria and can help identify slight differences when compared to other indicators (Etim *et al*., 1999). The mean value of Φ' for some significant fish species in Africa ranges from 2.65 to 3.32. Therefore, the Indus River fish *L. rohita* can be considered to have slow growth, as its Φ' value of 3.210 was calculated to be lower. The lower growth performance of *L. rohita* in the Indus River may be due to genetic structure, overfishing, dietary patterns, and excess utilization.

Biological reference points are commonly used in the management and conservation of fisheries resources today (Haddon, 2011). These reference points, or BRPs, are defined as levels of fishing mortality and/or biomass. The two most well-known reference points are $F_{0.1}$ and F_{max}, which are widely used in fisheries management (Hilborn and Walters, 1992). F_{max} is the target biological reference point and is considered as a function of fishing mortality (F) for a specific exploitation pattern against the maximum value of yield per recruit (Y/P). F_{max} represents only the value of F that allows for the possible maximum yield per recruit from the cohort. On the other hand, $F_{0.1}$ is another target reference point that is a function of the fishing mortality coefficient (F). When F=0, the yield per recruit is at its highest, and when $F=F_{max}$, the yield per recruit decreases. $F_{0.1}$ refers to the point at which F has a value that results in a 10% increase in yield per recruit when it is maximized (Hilborn and Walters, 1992). During our investigation, the biological reference point (BRP) was determined by Patterson (1992) as F_{opt}, which equals 0.5 M (0.831) and F_{limit}, which equals 2/3 M (1.108). These BRPs were lower than the criterion of F_{opt}=M set by Gulland (1969). The Beverton and Holt model with knife-edge selection in FiSAT-II to analyze the contour map of relative yield per recruit for *L. rohita* was used. The contour map (Fig. 7) showed that F_{max} and $F_{0.1}$ were estimated at 3 yr^{-1} and 2.1 yr^{-1}, respectively, when t_c was 1. Since the age of the first capture during the current study was approximately one year, the current fishing mortality rate ($F_{current}$) of 0.398 yr^{-1} was lower than the baseline of biological reference points of F_{max} and $F_{0.1}$ indicating that the stock of *L. rohita* is stable in the downstream of Indus River.

CONCLUSION

Based on the current results of our study, it appears that the *L. rohita* species in Pakistan is in a safe state. The mortality rate of the species $F_{current}$= 0.398 yr^{-1} is lower than the biological reference point F_{opt}= 1.662 yr^{-1} as determined by Gulland (1971). This suggests that the stock is stable in the Indus River. Our study has provided baseline information about the *L. rohita* fish and confirms the hypothesis that fishing pressure above current levels may endanger the stock of *L. rohita* in the Indus River.

DECLARATIONS

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Ethical statement

All the individuals in this research work were handled carefully, we neither harmed nor damaged the animal. The study was conducted following the Declaration of the Ocean University of China, and the protocol was approved by the Ethics Committee of OUC (No. 201022001).

Statement of conflict of interest

The authors have declared no conflict of interest.

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