

## ASSESSMENT OF LIFE HISTORY TRAITS OF *CHANNA MARULIUS* FOR FISHERY MANAGEMENT IN PAKISTAN

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### ABSTRACT

This is the first attempt to investigate growth and mortality parameters of *Channa marulius* (Hamilton, 1822), a major murrel species, caught from the Indus River, Pakistan. Six research surveys were conducted at Chasma Barrage, located on the Indus River, during the months May-October, 2016. Length-weight and length frequency readings,  $n = 674$ , were collected and evaluated by using FiSAT II computer application. The observed length and weight ranged between 5-39 cm and 1-301 g correspondingly. The estimated values of  $b$ ,  $a$  and  $R^2$  remained 3.033, 0.006 and 0.987 respectively. Growth parameters,  $L_{\infty} = 40.95$  and  $K = 0.3 \text{ year}^{-1}$ , were evaluated by applying ELEFAN I routine via von Bertalanffy growth equation. The computed values, by employing LCCC, of  $Z$ ,  $M$ ,  $F$  and  $E$  remained  $1.18 \text{ year}^{-1}$ ,  $0.68 \text{ year}^{-1}$ ,  $0.5 \text{ year}^{-1}$  and  $0.42 \text{ year}^{-1}$  in that order. YPRA indicated that when  $t_c = 1$ , estimated values of  $F_{\max}$ ,  $F_{0.1}$  and  $F_{\text{current}}$  were  $0.9 \text{ year}^{-1}$ ,  $0.75 \text{ year}^{-1}$  and  $0.50 \text{ year}^{-1}$  correspondingly. LSVPA indicated the highest mortality rates were in the 29-32 cm length cohort. The lower value of  $F_{\text{current}}$ ,  $0.50 \text{ year}^{-1}$ , than Gulland BRP,  $M = F_{\text{opt}} = 0.68 \text{ year}^{-1}$ , suggests that this fishery resource is in a safe condition.

**Key words:** growth, mortality, *Channa marulius*, Indus River, Pakistan.

### INTRODUCTION

In order to maintain a fish stock, its assessment is essential which requires data collection, data evaluation and finally strategy selection involving stakeholders (FAO, 1997; Die, 2002). Fishery managers do not work blindly rather they get help from the reference points (RPs) or indicators computed for desired or targeted parameters e.g. growth and mortality. The estimation of RPs by using reliable data forms the basis of fish stock management (De La Mare, 1998). These, RPs act as signposts by depicting fish stock status and are used for making management strategies (Hoggarth *et al.*, 2006). Nowadays, a variety of RPs can be computed which indicate different population parameters (FAO, 1999). In 1992, for the first time, the idea of RPs was included into the fish stock assessment literature. Afterward, they were incorporated into FAO's code which was proposed to keep fisheries in a sustainable state (FAO, 1995).

This is an alarming fact that majority of the fish resources around the globe are overharvested. Though, there also exists, by luck or through proper management, sustainable fisheries. The condition of fisheries management in developing countries is worse where mostly the assessment of fish stock is absent. Hence, these areas are wasting privileges offered by fisheries management (Hoggarth *et al.*, 2006). Several scientific publications through light on the significance and model approach for fish stock assessment (Sparre and Venema, 1998; Cadima, 2003; Hilborn and Walters, 1992; Quinn

and Deriso, 1999; Haddon, 2010). Various fishery indicators have been computed with the use of these and other mathematical models by different researchers on self-designed spreadsheets or fishery specialized software. However, FAO's fishery stock assessment tool viz. FiSAT II software is preferred and is thought to confer benefits as compared to other alternatives. That is why this stock assessment tool is frequently used by fishery scientists (Hoggarth *et al.*, 2006).

*Channa marulius*, also called giant snakehead, is a fresh water native fish of Pakistan and is locally known as "Sol". It dwells in various aquatic bodies including lakes, canals, rivers etc. along with other members of the genus *Channa* (Kok, 1982). This fast growing fish has high demand in the local market and is among the major murrel fishes caught from the riverine waters. Published literature mostly documents population dynamics of various fish species such as *C. striatus* and *C. punctatus* related to genus *Channa* (Aliyu-Paiko *et al.*, 2010; Khan *et al.*, 2013). Only few studies have been conducted on *C. marulius* to evaluate its growth and mortality parameters (Dua and Kumar, 2006; Khan *et al.*, 2012; Khan and Khan, 2009). However, all of the previous research work is reported from India.

This is the first attempt to explore growth and mortality parameters of *C. marulius* inhabiting the Indus River, Pakistan. In order to compute RPs for growth and mortality parameters latest modeling approach by using FAO's fishery software viz. FiSAT II is used in this study. It is envisaged that this study shall not only help in

understanding the state of this fishery resource but also guide in formulating management strategies for the conservation of this precious aquatic creature.

## MATERIALS AND METHODS

**Data Collection:** For this study, six monthly research data collection surveys, May–October, 2016, were conducted at the landing site of the Chashma Barrage which is located on the Indus River, Pakistan. The Chashma Barrage is one of the six barrages located on the Indus River (Figure 1). It contributes significantly in the inland capture production of fish fauna. Data collection was done before fish sorting to ensure unbiasedness. The techniques used for fishing included gillnet, cast net and seine net. The length-weight and length frequency data of 674 *C. marulius* samples, pair wise data of both sexes combined were recorded by using portable balance and calibrated steel rod. Each individual was measured from snout (tip) to the middle caudal fin rays (end) i.e. fork length (FL) was taken. Individuals having length or weight below 1 cm or g, respectively, were not considered.

**Data Evaluation:** Collected data figures were evaluated by using Microsoft Excel spreadsheet 2007 and FiSAT II (FAO ICLARM stock assessment tool) fishery software (Gayanilo *et al.*, 2003). Various statistical designs were employed to evaluate the length-weight and length frequency data of *C. marulius* data for various parameters.

**Length-Weight Relationships (LWRs):** To estimate the length-weight relationships for *C. marulius* power function of  $W = aL^b$  was used. In this mathematical expression, W stands for total weight (g), a represents condition factor or the intercept while b indicates allometric growth parameter or the slope.

**Growth Parameters (GPs):** To calculate growth parameters, the value of K (growth constant) was computed initially by using  $L_\infty$  (asymptotic length) through ELEFAN-I method. Then growth coefficient was computed by using (the von Bertalanffy growth function). Haddon (2010) has defined VBGF equation as follow:

$$L_t = L_\infty (1 - \exp(-K(t - t_0)))$$

$L_t$ ,  $L_\infty$ , K and  $t_0$  represent predicted length at age t, asymptotic length, growth coefficient and hypothetical age at which length is equal to zero respectively. Where,  $t_0$  was calculated by using the following Pauly's (1983) equation:

$$\log_{10}(-t_0) = -0.3922 - 0.275 \log_{10} L_\infty - 1.038 \log_{10} K$$

FiSAT II allows the computing of growth performance index (GPI,  $\Phi$ ). To calculate this index, estimates of asymptotic  $L_\infty$  and  $W_\infty$  were used by using equations (Pauly and Munro, 1984) which are as follow:

$$\Phi' = \log_{10} K + 2 \log_{10} L_\infty$$

$$\Phi = \log_{10} K + 2/3 \log_{10} W_\infty$$

**Fishing Mortality Rates (FMRs):** LCCC (Length converted catch curve) technique was employed to evaluate various mortality rates such as Z, F and M which represent total mortality, fishing mortality and natural mortality correspondingly. Natural mortality rate (M) was computed by using Pauly's (1980) mathematical statement as given below:

$$\log_{10} M = 0.0066 - 0.279 \log_{10} L_\infty + 0.654 \log_{10} K + 0.4634 \log_{10} (T)$$

$L_\infty$  and K are the parameters of VBGF. T stands for average annual water surface temperature measured in degree Celsius (for the Indus River it is 23 °C). LCCC (Pauly, 1983) computed the total mortality (Z). The exploitation ratio was computed as equation,  $E = F / Z$ , where F represents fishing mortality and was estimated as  $F = Z - M$ . Z (total mortality) was also evaluated by using another method by Beverton and Holt (1957) from equation:

$$Z = K (L_\infty - L_{\text{mean}}) / (L_{\text{mean}} - L)$$

$L_\infty$  and K are the VBGF parameters and indicate asymptotic length and growth rate correspondingly.  $L_{\text{mean}}$  and L represent mean length and cut-off length respectively.

**Biological Reference Points (BRPs):** Gulland (1969) technique was employed to calculate biological reference points. It assumes  $F_{\text{opt}}$  (optimum fishing mortality) = M.

For this analysis, Beverton-Holt method (yield per recruit analysis) was used by using following equation:

$$Y_w / R = F W_\infty e^{-M(t_c - t_r)} \sum_{n=0}^3 \frac{Q_n e^{-nK(t_c - t_0)}}{F + M + nK} (1 - e^{-(F+M+nK)(t_\lambda - t_c)})$$

$Y_w/R$  represents yield per recruit,  $t_c$  indicate mean age of fish at first capture,  $t_r$  stands for recruitment age,  $t_\lambda$  was the asymptotic age, Q represents constant value and its value equals to 1, -3, 3 and -1 when n is 0, 1, 2 and 3 correspondingly (Pitcher and Hart, 1982).

**Length Structured Virtual Population Analysis (LSVPA):** LSVPA depicts reconstructed fishery population by highlighting survivors, exploited stock and fishing mortality in each length group. This routine is actually a tailored form of Jones and van Zalinge (1981). VPA was performed by inputting computed values of a, b,  $L_\infty$ , K,  $F_t$  and M into the user interface for VPA window.

## RESULTS

In total, 674 readings of the length-weight and length frequency data collected during six monthly research surveys from May to October 2016, was examined during this study. Pooled data showed that majority of fishes caught belonged to 20-25 cm length

cohort (32%) (Table 1). Summary of all the important parameters computed is given in Table 2.

**LWRs:** The length (FL) ranged from 5 (4.8) to 39 (38.9) cm while total weight (TW) varied from 1 to 301 g. The average length and weight remained 20 cm ( $\pm$  7.662) and 82 g ( $\pm$  65.397) correspondingly. The dominant length frequency peaks can be observed at 5, 20, 22 and 28 cm in that order (Figure 2). The computed length-weight relation was  $W = 0.006 * L^{3.033}$  i.e. the value of a i.e. intercept is 0.006 and slope (b) is 3.033 for n = 674 (Figure 3).

**GPs:** To estimate growth parameters, length frequency data comprising of 674 observations collected during research surveys was analyzed with ELEFAN I method (Figure 4). Estimated growth parameters for *C. marulius*, by using VBGF, were  $L_{\infty} = 40.95$  cm (FL) and  $K = 0.300$  year<sup>-1</sup>. The value of  $t_0$  was computed as -0.2928 year<sup>-1</sup> by applying Pauly's equation. The calculated value of goodness of fit ( $R_n$ ) was 0.458. The computed values of growth performance index by using asymptotic length and asymptotic weight were 2.702 and 1.224 correspondingly.

**FMRs:** Length-converted catch curve analysis (LCCCA) was used to estimate total mortality rate (Z) (Figure 5). The computed value of Z, 1.18, was obtained by putting

values of VBGF growth parameters viz.  $L_{\infty}$  (40.95 cm (FL)) and  $K$  (0.300 year<sup>-1</sup>) in LCCCA while its 95% confidence interval were estimated at 0.97 – 1.40. Value of natural mortality (M), 0.68, was estimated by using average annual water surface temperature which is 23 °C for the Indus River. F was estimated, 0.5, by using formula,  $F = Z - M$ . Whereas, E was estimated as  $F / Z = 0.42$  year<sup>-1</sup>.

**BRPs:** Figure 6 shows the YPRA output graph of *C. marulius*. For  $t_c = 1$ , estimated values of  $F_{max}$  and  $F_{0.1}$  were 0.9, 0.75 in that order. It is vivid that F is lower than  $F_{max}$  and  $F_{0.1}$ . According to Gulland (1971) BRP, the computed M (0.68) and  $F_{opt}$  are equal. Thus, F is lower than Gulland BRP further suggesting safe condition of this fishery stock at the Chashma Barrage, Pakistan.

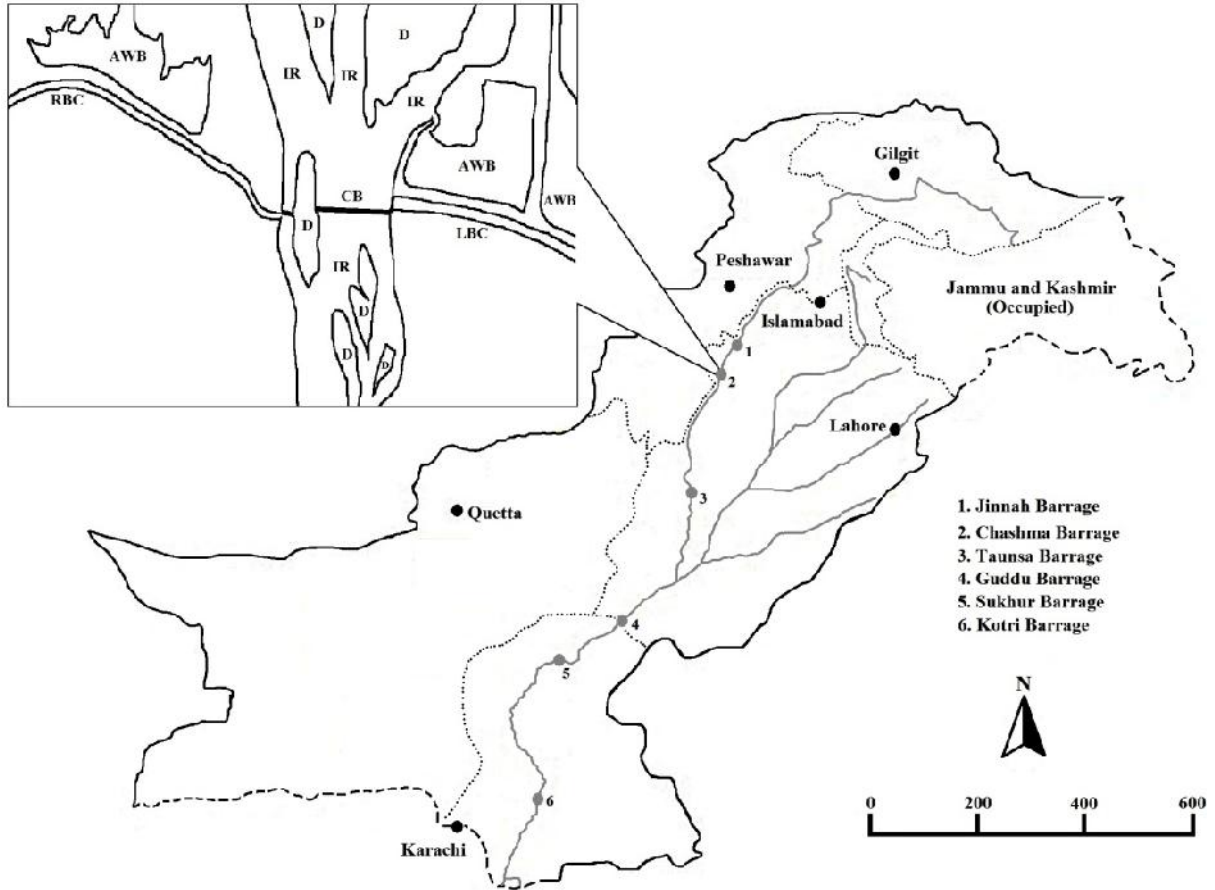
**LSVPA:** Figure 7 highlights the graphical representation of the output parameters computed by using LSVPA provided in FiSAT II fishery suit. LSVPA has revealed that higher mortalities were observed in 29 – 32 cm length group of *C. marulius* during the study period. On the other hand, length groups of 7 – 10 cm showed lowest mortality rates. The number of survivors and natural losses, within different length cohorts, show the decreasing trend with the increase in length.

**Table 1. Description of Lengthwise Size Classes (cm) Observed in the Population of *C. marulius*.**

Size classes	May	June	July	August	September	October	%
01–04.9	0	0	0	0	0	0	00.00
05–09.9	72	5	0	0	0	0	11.41
10–14.9	0	71	1	0	0	0	10.68
15–19.9	0	27	57	18	2	0	15.43
20–24.9	0	6	59	57	57	38	32.20
25–29.9	0	0	1	28	37	73	20.62
30–34.5	0	1	0	0	32	22	08.17
35–39.9	0	0	0	0	1	9	01.49
Total	72	110	118	103	129	142	674/100

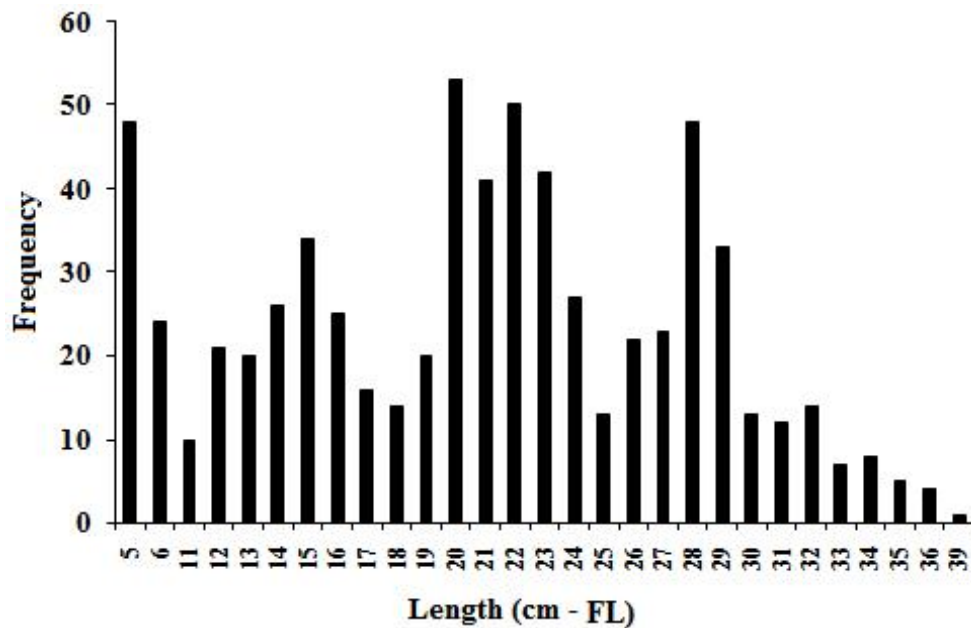
**Table 2. Estimated Growth and Mortality Parameters of *C. marulius*.**

Parameter	a	B	$L_{\infty}$	K	Z	M	F	E	$F_{max}$	$F_{0.1}$	$\Phi'$	$\Phi$
Estimated value	0.006	3.033	40.95	0.3	1.18	0.68	0.5	0.42	0.9	0.75	2.702	1.224



**Figure 1. Map of Pakistan showing Location of various Barrages on the Indus River.**

Note: Square represents the Chashma Barrage as viewed from 200 feet above ground; CB, Chashma Barrage; IR, Indus River; D, Delta; AWB, Attached water body; RBC, Right bank canal; LBC, Left bank canal.



**Figure 2. Length Frequency distribution of *C. marulius* (both sexes combined) at the Chashma Barrage, Pakistan during 2016.**

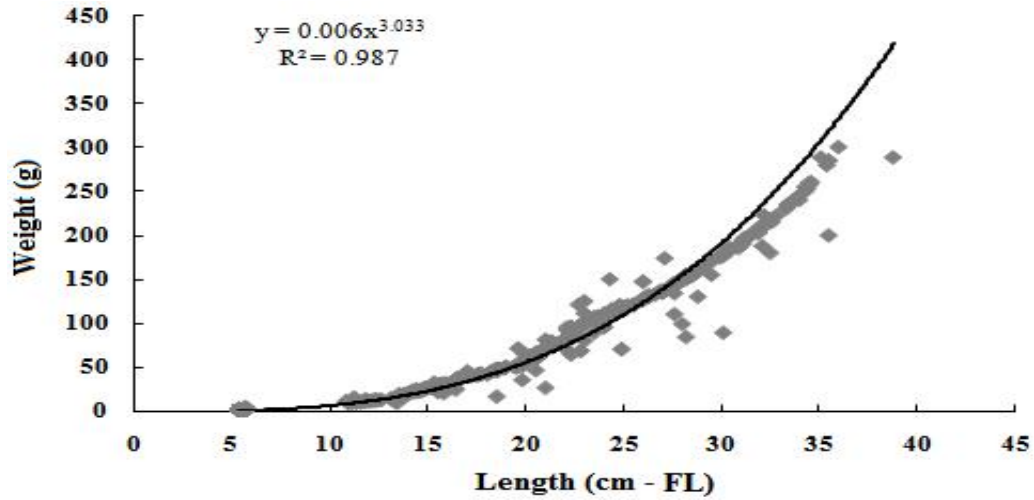


Figure 3. Length-weight relationship of *C. marulius* (both sexes combined) at the Chashma Barrage, Pakistan during 2016.

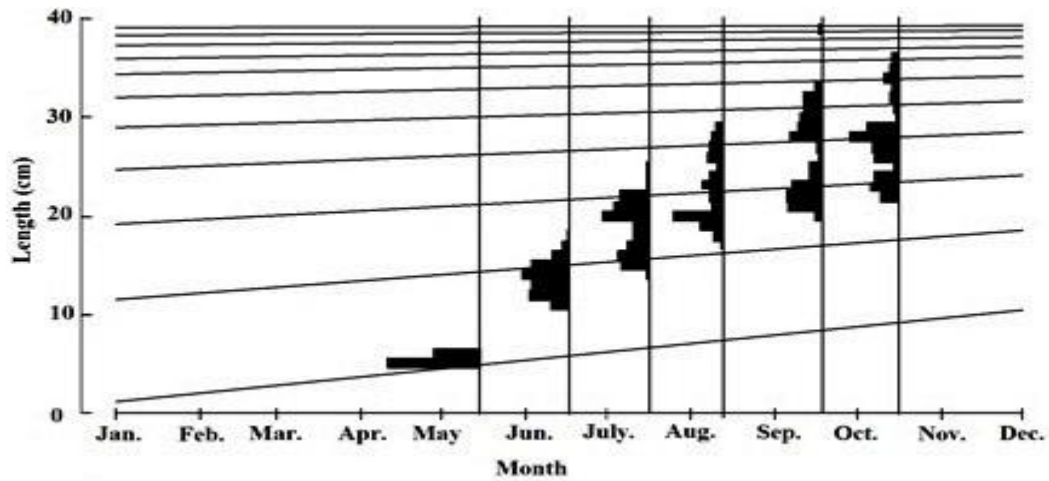


Figure 4. Representation of Growth Performance of *C. marulius* computed by using ELEFAN method.

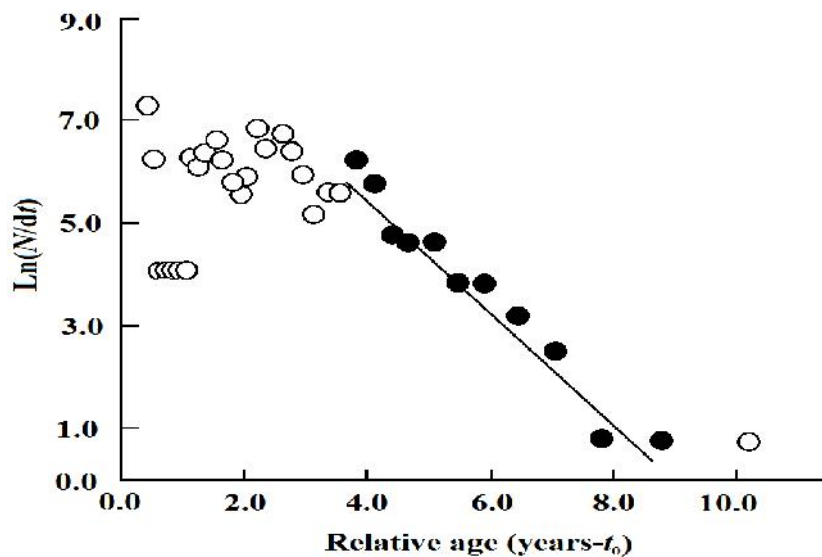


Figure 5. Computed Length Converted Catch Curve of *C. marulius*.

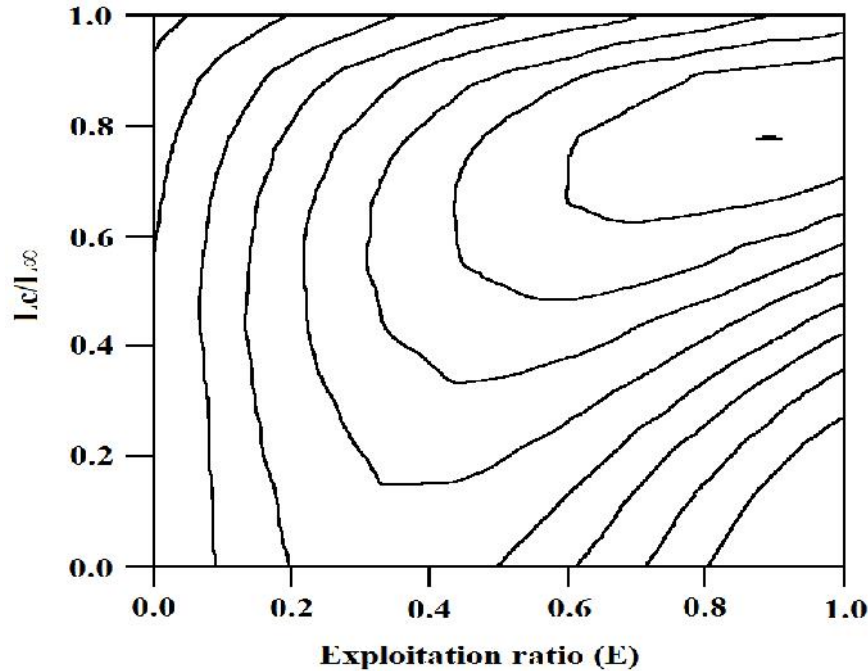


Figure 6. Estimated Yield Per Recruit Map of *C. marulius*.

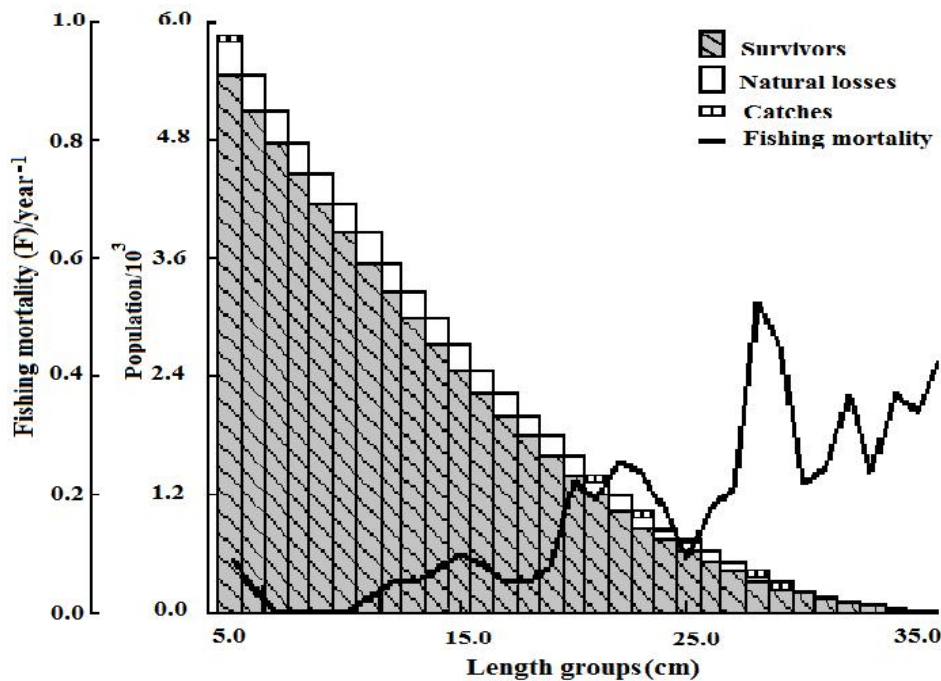


Figure 7. Length based Length Structured Virtual Population Analysis of *C. marulius*.

### DISCUSSION

LWRs are very important and basic indicators used in fishery science (Abdurahiman *et al.*, 2004). They can be used to compute other parameters such as rate of fish feeding, development of gonads and metamorphosis (Le Cren, 1951). Value of *b* speaks off about the growth

pattern of the fish. When *b* is equal to 3, it means isometric growth and if not then allometric growth is indicated. Earlier reported work on LWRs of *C. marulius* of Ganga River, India by Khan *et al.* (2012) also documents isometric growth in this fish species. Value of *b* estimated by these researchers is 3 which is almost same as obtained during this study i.e. 3.033 representing isometric growth. However, in another study conducted

by Johal *et al.* (1983) at Ghagger, India computed value was lower,  $b = 2.86$ , than our estimated value representing allometric growth. The difference in the value of  $b$ , reported from different locations depends upon several factors. These factors include gonads development, feeding conditions, physicochemical characters of the local environment etc (Biswas, 1993; Froese, 2006).

The estimated values of  $L_{\infty}$  and  $K$  during this study were 40.95 cm and 0.3 respectively. Only one previous study, Devaraj, 1973, documents on these parameters of *C. marulius*. According to this research work, the values of  $L_{\infty}$  and  $K$  are 113 cm and 0.23 in that order. It has been found that  $L_{\infty}$  and  $K$  are inversely interrelated. The higher value of one parameter usually corresponds with the lower value of the other (Pauly and Moragn, 1987). The variation in the parameter values of  $L_{\infty}$  and  $K$  is due to the difference in the fish life history, ecological patterns and sampling techniques used (Adam, 1980).

Growth parameters,  $L_{\infty}$  and  $K$ , were further used to compute  $t_0$  value.  $t_0$  value is an indicator of juvenile growth. If  $t_0$  is positive it means juvenile growth is slow, on the other hand, negative value indicates rapid growth rate in juveniles as compared to the adult fish (King, 2013; Sparre and Venema, 1998). The estimated value of  $t_0$  in this study is  $-0.2928 \text{ year}^{-1}$  which represents growth is faster at juvenile stage as compared to the adult one. Usually,  $R^2$  is used to determine the goodness of fit and its value ranges between 0 to 1. The higher is the value the better is the fit. However,  $R_n$  score computed by ELEFAN method may be represented by any value. We obtained  $R_n = 0.458$ . It is supposed that  $R_n$  value computed for our input data reflects better fitting. FiSAT II computer package has the capacity to compute  $Z$  by using confidence intervals. However, it does not use CI while computing growth parameters.

It is expected that data used in this study represent all the fish length classes occurring in the Indus River waters. Thus, used data satisfy the requirement of the ELEFAN method. ELEFAN is basically a non-parametric or *ad hoc* method which means that it does not use cohort distribution patterns for its estimation of various parameters. This method is used to compute VBGF growth rates. ELEFAN method coupled with von Bertalanffy growth model make it very good assessment tool for growth study (Pitcher, 2002). The presented differences in the asymptotic length are due to the various sampling techniques employed and physicochemical differences (Biswas, 1993).

Our estimates of mortality parameters are  $Z = 1.18$ ,  $M = 0.68$ ,  $F = 0.5$  and  $E = 0.42$ . We could not find mortality parameters estimation for *C. marulius* in already stock assessment published literature. However, published literature shows difference in mortality rates from different stations for a specific fish. The diversity in

the mortality value around the globe may be due to the increasing capture fisheries coupled with ecological changes. Estimated growth curve, through Beverton and Holt method, has significant effect on the estimation of fishing death rates (Issac, 1990; Sparre, 1990; Pauly *et al.*, 1995). Beverton and Holt method (1957) requires the selection of at least three readings indicated by circles (Fig. 5). Due to the temporal and spatial distribution of the young fish stock, it is assumed that only small percentage of stock is vulnerable to gears used for sampling. Moreover, it is further supposed that representation of adult fish stock in the collected sample is partial.

Several factors are responsible for fishing mortality e.g. disease, pollution, capture fisheries, predation and death of old fishes (Nikolsky, 1969). However, among these factors predation is frequently on the top of the list (Brandt *et al.*, 1987; Laevastu and Favorite, 1988). Deaths in the fish stock, particularly in juveniles, by predation usually supersede natural mortality. It is not possible to witness deaths caused naturally in the fish stock since they can't be witnessed (Quinn and Deriso, 1999). Fishing mortality is directly related to capture fisheries. Higher is the capture fishery higher is the mortality and vice versa. On the other hand, natural mortality is difficult to compute and its value varies in waters with diversified temperatures.

Exploitation rate indicates exploitation state of the fish stock. If the value of exploitation rate is higher than 0.5, the fish stock is assumed to be in over-exploited state (Gulland, 1971). Whereas its value equal to 0.5 or lower corresponds to stable and under-exploited states respectively. However, the value of 0.5 is not fixed. Some scientists declare fish stock over-exploited even with exploitation ratio of 0.4 (Patterson, 1992). However, usually the value of exploitation ratio is compared with the biological reference point before asserting fishery stock status.

In the field of fishery management science RPs are computed which serve as a signpost for the fishery managers.  $F_{0.1}$ , rate of fishing mortality which corresponds to 10% increase in YPR, and  $F_{max}$ , rate of fishing mortality giving highest YPR, are the two very important fishery management reference points (Deriso, 1987; Hilborn and Walters, 1992; Caddy, 1998).

During this study estimated values by using YPRA are  $F_{max} = 0.9$  and  $F_{0.1} = 0.75$ . The value of  $F$  is less than  $F_{max}$  which means that the fishery stock of *C. marulius* at the study site is in safe condition. Gulland (1971) proposes  $M = F_{opt}$  thus  $F_{opt} = 0.68$ . Since the value of  $F$  is lower than Gulland BRP which further states stock of *C. marulius* under safe condition.

LSVPA assumes recruitment and fishing mortality rates at a constant state for all the length classes (Gulland and Rosenberg, 1992). LSVPA technique gives detailed and significant results which can be used for

fishery management simulation (Hoggarth *et al.*, 2006). LSVAP routine is applied to know about the total catch composition of the fishery stock. This finding is further used to find a correlation between ensuing recruitment pattern and spawning fish biomass for the evaluation of fishing mortalities (Hoggarth *et al.*, 2006; Wakeford *et al.*, 2004). Obtained results show that smaller fishes dominate fishery stock of *C. marulius* as predicted for any naturally occurring fish population. Fishing mortality is on the move with the passage of time as the length of cohort increases. It is worthwhile to note that fishing mortality is increasing despite of decreased number due to natural losses. Obviously, aging is in action however capture fisheries is also playing its part. It is necessary to mention that the capture fishing must be kept at current level to stop fishing mortality to increase in future.

This study of the population dynamics for *C. marulius* collected from the Indus River indicates that the stock is not damaged. The current results i.e. lower fishing mortality rate ( $F_{\text{current}} = 0.50 \text{ year}^{-1}$ ) than the biological reference points ( $F_{\text{opt}} = 0.68 \text{ year}^{-1}$ ) and the revealed exploitation ratio ( $E = 0.42 \text{ year}^{-1}$ ) for *C. marulius* represent that this species is in safe condition and has future perspective economic value in Pakistan.

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## REFERENCES

- Abdurahiman, K.P., T. Harishnayak, P.U. Zacharia, and K.S. Mohamed, (2004). Length-weight relationship of commercially important marine fishes and shellfishes of the southern coast of Karnataka, India. *NAGA, WorldFish Cent. Quart.* 27: 9-14.
- Adam, P.B. (1980). Life history pattern in marine fishes and their consequences for fisheries management. *Fish. B-NOAA.* 78: 1-12.
- Aliyu-Paiko, M., R. Hashim, and A.C. Shu-Chien, (2010). Influence of dietary lipid/protein ratio on survival, growth, body indices and digestive lipase activity in Snakehead (*Channa striatus*, Bloch 1793) fry reared in re-circulating water system. *Aquacult. Nutr.* 16: 466-474.
- Beverton, R.J.H., and S.J. Holt (1957). On the dynamics of exploited fish populations, fishery investigations series-II. Ministry of Agriculture, Fisheries and Food, London, 533 p.
- Biswas, S.P. (1993). Manual of Methods in Fish Biology. New Delhi, India: South Asia Publishers.
- Brandt, S.B., D.M. Mason, D.B. Macneill, T. Coates, and J.E. Gannon (1987). Predation by alewives on larvae of yellow perch in Lake Ontario. *T. Am. Fish. Soc.* 116: 641-645.
- Caddy, J. (1998). A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper. FAO, Rome, Italy, 379 p.
- Cadima, E.L. (2003). Fish stock assessment manual. FAO Fisheries Technical Paper No. 393. FAO, Rome, Italy.
- De La Mare, W.K. (1998). Tidier fisheries management requires a new MOP (management oriented paradigm). *Rev. Fish Biol. Fisheries.* 8: 349-356.
- Deriso, R.B. (1987). Optimal F 0.1 criteria and their relationship to maximum sustainable yield. *Can. J. Fish. Aquat. Sci.* 44: 339-348.
- Devaraj, M. (1973). Biology of the large snakehead *Ophicephalus marulius* (Ham.) in Bhavanisagar waters. *Indian J. Fish.* 20: 139-147.
- Die, D. (2002). Chapter 9. Design and implementation of management plans. Pp. 205-220 In: Cochrane, K.L., (ed). A fishery manager’s guidebook. Management measures and their application. FAO Fisheries Technical Paper No. 424. FAO, Rome, Italy, 231 p.
- Dua, A. and K. Kumar, (2006). Age and growth patterns in *Channa marulius* from Harike Wetland (A Ramsar site), Punjab, India. *J. Environ. Biol.* 27: 377-380.
- FAO (1995). Code of Conduct for Responsible Fisheries. FAO, Rome, Italy, 41 p.
- FAO (1997). Fisheries management. FAO Technical Guidelines for Responsible Fisheries No. 4. FAO, Rome, Italy, 82 p.
- FAO (1999). Indicators for sustainable development of marine capture fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 8. FAO, Rome, Italy, 68 p.
- Froese, R. (2006). Cube law, condition factor and weight-length relationships history, meta-analysis and recommendations. *J. Appl. Ichthyol.* 22: 241-253.
- Gayanilo, F.C., P. Sparre, and D. Pauly, (2003). FiSAT II User’s Guide. FAO Computerized Information Series Fisheries, 266 Rome, Italy: FAO-ICLARM.
- Gulland, J.A. (1969). Manual of Methods for Fish Stock Assessment. Part 1. FAO, Rome, Italy.
- Gulland, J.A. (1971). Fish resources of the ocean. FAO Fisheries Technical Paper No. 97. West Byfleet, Survey, Fishing news Books Ltd., 425 p.
- Gulland, J.A. and A.A. Rosenberg, (1992). A review of the length based approaches to assessing fish

- stocks, FAO Fisheries Technical Paper No. 323. FAO, Rome, Italy. 100 p.
- Haddon, M. (2010). Modelling and quantitative methods in fisheries. UK: Chapman & Hall, CRC.
- Hilborn, R. and C.J. Walters, (1992). Quantitative fisheries stock assessment: choice, dynamics and uncertainty. *Rev. Fish Biol. Fisheries.* 2: 177-178.
- Hoggarth, D.D., S. Abeyasekera, R.I. Arthur, J.R. Beddington, R.W. Burn, A.S. Halls, G.P. Kirkwood, M. McAllister, P. Medley, C.C. Mees, G.B. Parkes, G.M. Pilling, R.C. Wakeford, and R.L. Welcomme, (2006). Stock Assessment for Fishery Management - A Framework Guide to the Stock Assessment Tools of the Fisheries Management Science Programme. FAO Fisheries Technical Paper 487. FAO, Rome, Italy. 261P. CEDA download page: <https://www.mrag.co.uk/resources/fisheries-assessment-software>.
- Issac, V.J. (1990). The accuracy of some length-based methods for fish population studies. *ICLARM Tech. Report.*, 27: 81.
- Johal, M.S., L. Hanel, and O. Oliva, (1983). Note on the growth of *Ophicephalus marulius* (Pisces: Ophicephaliformes). *Vest. Cs. Spolec. Zool.* 47: 81-86.
- Jones, R. and N.P. Van Zalinge, (1981). Estimations of mortality rate and population size for shrimp in Kuwait waters. *Kuwait B. Mar. Sci.* 2: 273-288.
- Khan, M.A. and S. Khan, (2009). Comparison of age estimates from scale, opercular bone, otolith, vertebrae and dorsal fin ray in *Labeo rohita* (Hamilton), *Catla catla* (Hamilton) and *Channa marulius* (Hamilton). *Fish. Res.* 100: 255-259.
- Khan, M.A., S. Khan, and K. Miyan, (2012). Length-weight relationship of giant snakehead, *Channa marulius* and stinging catfish, *Heteropneustes fossilis* from the River Ganga, India. *J. Appl. Ichthyol.* 28: 154-155.
- Khan, M.A., K. Miyan, and S. Khan, (2013). Morphometric variation of snakehead fish, *Channa punctatus*, populations from three Indian rivers. *J. Appl. Ichthyol.* 29: 637-642.
- King, M. (2013). Fisheries biology, assessment and management. London, UK: John Wiley & Sons.
- Kok, K.L. (1982). Snakeheads-the biology and culture. In: Muir, J.F. and Roberts, R.J., editors. Recent Advances in Aquaculture. London, UK: Croom Helm Ltd., 179-213.
- Laevastu, T. and F. Favorite, (1988). Fishing and stock fluctuations. London, UK: Fishing News Books.
- Le Cren, E.D. (1951). The length-weight relationship and seasonal cycle in gonad weight and condition in the Perch (*Perca fluviatilis*). *J. Anim. Ecol.* 20: 201-219.
- Nikolskii, G.V. (1969). Theory of fish population dynamics as the background for rational exploitation and management of fishery resources. Edinburgh, UK: Oliver and Boyd.
- Patterson, K. (1992). Fisheries for small pelagic species: An empirical approach to management targets. *Rev. Fish Biol. Fisheries.* 2: 321-338.
- Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *ICES J. Mar. Sci.* 39: 175-192.
- Pauly, D. (1983). Some simple methods for the assessment of tropical fish stocks. FAO Fisheries Technical Paper 234. FAO, Rome, Italy.
- Pauly, D., J. Moreau, and N. Abad, (1995). Comparison of age-structured and length-converted catch curves of brown trout *Salmo trutta* in 2 French rivers. *Fish. Res.* 22: 197-204.
- Pauly, D. and G.R. Morgan, (1987). Length-based methods in fisheries research. Manila, Philippines: WorldFish.
- Pauly, D. and J.L. Munro, (1984). Once more on the comparison of growth in fish and invertebrates. *Fishbyte.* 2: 21-23.
- Pitcher, T.J. and P.J.B. Hart, (1982). Fisheries Ecology. London: UK: Croom Helm.
- Pitcher, T.J. (2002). A bumpy old road: size-base methods in fisheries assessment. In: Hart, P.J.B. and Reynold, J.D., editors. Handbook of Fish Biology and Fisheries. 2. Oxford, UK: Blackwell Publishing, 189-210 p.
- Quinn, T.J. and R.B. Deriso, (1999). Quantitative Fish Dynamics. Oxford, UK: Oxford University Press.
- Sparre, P. (1990). Can we use traditional length-based fish stock assessment when growth seasonal? *Fishbyte.* 8: 29-32.
- Sparre, P. and S.C. Venema, (1998). Introduction to tropical fish stock assessment—Part 1: Manual. FAO Fisheries Technical Report, 306. FAO, Rome, Italy. 407 p.
- Wakeford, R.C., G.M. Pilling, C.J. O'Neill, and A. Hine, (2004). Investigations of the implications of different reef fish life history strategies on fisheries management. Final Technical Report, FMSP Project R7835. MRAG, London, 123 p.