Growth and Mortality of *Sillago sihama* (Forsskål) from Karachi Coast, Pakistan

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Authors’ contributions

This work was carried out in collaboration among all authors. Author QL designed and correspond the study. Author AB performed the statistical analysis. Author BL wrote the protocol. Authors AB and HY wrote the first draft of the manuscript. Authors AW and IA managed the analyses of the study. Author ZQ managed the literature searches. All authors read and approved the final manuscript.

ABSTRACT

Length frequency data of silver sillago, *Sillago sihama* (Forsskål) were collected and measured from the fisherman catches using beach seines and handlines, at random, during 2012 from the Karachi coast of Pakistan. In this study, 1846 fish individuals (male and female combined) were collected ranging from 10 to 24 cm with dominant individuals ranged 12 to 16 cm (total length). Weight ranging was measured from 9 to 110 g. The above length-frequency data were analysed for the estimation of growth and mortality parameters. The power coefficient b of length-weight, the relationship was estimated at 2.9177. The estimated von Bertalanffy growth, function parameters of 25.20 cm (L∞) and 1.00 year⁻¹ (K) were calculated by ELEFAN method equipped on FiSAT computer package. With length-converted catch curve analysis, the total mortality rate (Z) and its 95% confidence interval were 2.42 (2.174-2.669) year⁻¹. The natural mortality rate (M) was 1.84 year⁻¹ calculated with Pauly’s equation (the annual average seawater temperature was 27°C).

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Therefore, the fishing mortality rate was $Z-M=\frac{0.578}{\text{year}^{-1}}$. The exploitation ratio ($E$) estimated as $F/Z=0.239$ which is less than biological reference point (0.5), therefore it indicates that the stock of *S. sihama* was exploited at managed.

**Keywords**: Pakistan; *Sillago sihama*; growth; mortality; FISAT.

1. **INTRODUCTION**

The fisheries sector is not only providing the cheap animal protein but also playing a significant role in the national economy, human development and welfare, such as in terms of providing employment, production and trade. Employment in the fisheries sector has grown more rapidly, especially in Asia, where over 85% of the world’s fisherfolk live [1]. The fishing industry of Pakistan has importance in the foreign exchange earnings and employment. The Pakistani coastal belt is about 1,120 km long from the southeast Indian border to the northwest Iranian border (Fig. 1) and an EEZ (exclusive economic zone) is 2,40,000 km$^2$ with an additional continental shelf area of about 50,270 km$^2$. There were about 250 commercially important demersal fishes, 50 small pelagic, 15 medium-sized pelagic and 20 large pelagic fish species from Pakistani water [2,3].

Family *Sillaginidae* is small to moderate-sized fishes and primarily inhabit inshore waters with the sandy substrate or estuarine areas of rivers [4]. Geographically the family is widely distributed throughout the Indian and Pacific Ocean [5]. Family *Sillaginidae* currently comprises in 34 species [6] in three genera [7,8,9] and three subgenera [10] of the genus *Sillago* [11,12].

*Sillago sihama* (Forskkål), locally known as Bhambor in Sindh province, is a coastal species, commonly along beaches, sandy substrates, mangroves; also in creeks and estuaries, in the depth ranging from 0 to 60 m, the maximum length is 30 cm while commonly 15 cm [13,14]. It feeds on copepods, polychaetes, Decapods, larvaceans and other small fishes [15].

*Sillago sihama* is a commercially important fish [16,17]. Some studies have been done from Indian waters such as on age and growth [18,19] on food and feeding on biochemical composition and caloric content [20] on eggs and early larvae [21] on maturation and spawning [22] on the reproductive biology. From the waters of Thailand work was done on feeding habits on reproductive biology [23]. Work is done at the length-weight relationship from Turkey [24]. From South Africa work done on the diet of juvenile and length-weight relationship [25]. Study on the effect of water temperature and photoperiod on the spawning cycle from Tokyo, Japan and on Isolation and characterization of microsatellite DNA loci from China. Work on morphological variation from Indonesia [26].

Knowledge of different population parameters like the asymptotic length ($L_\infty$) and growth coefficient ($K$), mortalities (natural and fishing) rate and exploitation level ($E$) are essential for planning and management of marine resources. Lack of knowledge of population structure and proper evaluation of the exploitation of marine resource emphasized the importance of a detailed study to facilitate better management of the resource. There are many

![Fig. 1. Map shows major landing sites along the Pakistan coast](image-url)
tools for assessing the exploitation level and status of the stock. Of these, FiSAT (FAO-ICLARM Stock Assessment Tools) has been commonly used for estimating population parameters of fishes [27] because primarily it requires only length-frequency data. ELEFAN is a non-parametric method widely used in fish length-frequency analysis, which is an ad hoc and does not depend on estimating the parameters of cohort distributions directly. So it makes only weak assumptions about the distribution of sizes within the cohorts. The modal lengths of each cohort are fixed to lie upon a curve described by growth models such as von Bertalanffy growth model, thus it makes a strong assumption about growth [28]. These tools are especially appreciated for Pakistani marine resources and estimate parameters such as length-weight relationship, growth, mortality rate, biological reference points, growth performance index and virtual population analysis. There are abundant studies focused on length-based stock assessment [29].

*S. sihama* is in large numbers from creeks. The fishery mainly takes place from June to July. The catches reported range from 201 t (1999) to 413 (2009) with an average of 367. Some studies done from Pakistan are such as on maximum sustainable yield on observations on sex ratios and fecundity on food and feeding habits on morphometric studies from the Baluchistan coast of Pakistan [30]. But there was no work on growth and mortality rate, so in this study, the length-frequency data were collected during 2012 from Pakistan and analysed for growth and mortality rate of *S. sihama* which can be helpful for fishery management in Pakistan.

2. MATERIALS AND METHODS

2.1 Sample Collection

A total of 1846 fish samples of *S. sihama* were collected and measured from the fishermen catches using beach seines and handlines, at random, during 2012 from the Karachi coast of Pakistan. The total length (TL) of each fish was taken to the nearest 1.0 cm using the measuring board. The weight (W) of each fish was weighted to the nearest 1.0 g. The samples were male and female combined.

2.2 Analysis of Data

The length-frequency data of *S. sihama* during 2015 were analyzed using FiSAT-II. In this study, the following core population parameters such as length-weight relationship (LWR) mortality rate, growth, growth performance index, virtual population analysis (VPA) and biological reference point.

2.3 Length-weight relationship

The weight (W, g) relationship to the length (L, cm-TL) of *S. sihama* was established by using a power equation [31] \( W = aL^b \), where the weight of fish was represented by W in grams (g), constant condition factor was represented by intercept (a), L was indicted by the total length in (cm) and allometric growth parameter was represented by exponent or slope (b).

2.4 Growth Parameters

The parameters of growth for *S. sihama* was calculated by using von Bertalanffy growth function the von Bertalanffy equation for growth in length according to [32] is: \( L_t = L_\infty (1- \exp (-K (t- t_0))) \), where \( L_t \) was the length at the predicted time \( t \), \( L_\infty \) was the asymptotic length, \( K \) was the growth coefficient and \( t_0 \) was the hypothetical age or time where length was equal to zero. Additional estimated value of \( t_0 \) was obtained by the empirical equation by Pauly as: \( \log_{10} (t_0) = -0.3922 - 0.275 \log_{10} L_\infty - 1.038 \log_{10} K \).

2.5 Mortality Rate

The estimation of instantaneous total mortality (Z) for *S. sihama* during 2012, the length converted catch curve method by Pauly was used. Additional parameters of M and F (natural mortality and fishing mortality) were also calculated. The regression formula for Z is \( \text{Ln (N)} = \text{Ln (N)}_0 - \text{Ct} \), where \( N_0 \) is the population size at age 0, \( C \) is average mortality rate, \( t \) is age or time where length was equal to zero.

The total annual mortality (Z) can also be estimated by the Beverton and Holt’s method (Beverton and Holt, 1956).

\[
Z = K \frac{L_t - \bar{L}'}{L'_L - \bar{L}'}
\]

where \( \bar{L}'_L \) is the mean length of fish of length \( L' \) and larger where \( L' \) is a length such that all fish of that length and larger are fully selected by the fishery. The equation by Pauly 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 \( T = 27^\circ \text{C} \) was average annual sea surface temperature of Pakistani waters. The \( F \) (Fishing mortality) was estimated by using the relationship of subtracting \( F = Z - M \).
The exploitation ratio (E) was obtained by the relationship of Gulland [33]:

\[ E = \frac{F}{Z} = \frac{F}{F+M}. \]

### 2.6 Biological Reference Points

According to Gulland, the optimal fishing mortality rate \( F_{opt} = M \) was determined as the limit biological reference points for *S. sihama* during 2012 from the Karachi coast of Pakistan.

### 2.7 Beverton-Holt Y/R Analysis

\[ Y/R = FW_e^{e^{-M(t-t_0)}} \sum_{n=0}^{\infty} Q_n e^{-nK(t-t_0)} (1-e^{-(F+M+K)(t-t_0)}), \]

The model used by [34] incorporated into the FAO FISAT-II program with the formula relative yield per recruitment (\( Y/R \)) values as a function of exploitation ratio (\( E \)) of *S. sihama* during 2012 from the Karachi coast Pakistan were estimated. Where \( Yw/R \) was yield per recruit, \( tc \) was the average age of the first capture, \( t_c \) was the age of recruitment, \( t_f \) was the asymptotical ages, was the constant and equal to 1, -3.3 and -1 when \( n \) was 0, 1, 2 and 3 correspondingly, \( e \) was the base of natural logarithms [35].

### 2.8 Growth Performance Index

The estimated growth parameters values of \( L_\infty \) (asymptotic length) and \( K \) (growth constant) *S. sihama* in 2012 were used to compute the growth performance index (Phi prime \( \Phi' \)). Following equations by [36] \( \Phi' = \log_{10} K + 2 \log_{10} L_\infty \) and \( \Phi = \log_{10} K + 2/3 \log_{10} W_\infty \) were used.

### 3. RESULTS

#### 3.1 Length-Weight Relationship

A total of 1846 individuals during 2012 of *S. sihama* were examined in this study. The shortest length was 10 cm and the longest was 24 cm and the dominant individuals are ranged 12 to 16 cm total length (TL). Weights were measured from 9 to 110 g. The LWR of male and female combined was: \( W = 0.0107 \times L^{2.9177} \) \( (R^2 = 0.96) \) (Figs 2 & 3).

#### 3.1.2 Mortality

Applying VBGF growth parameters (\( L_\infty, K \)) and using the (LCCA) length converted catch curve analysis, \( Z = 2.42 \) (2.174-2.669) years\(^{-1} \) (Fig. 5). While using Pauly’s (1980) equation \( M \) was calculated 1.84 year\(^{-1} \) (with \( L_\infty = 25.20, K = 0.440 \) year\(^{-1} \) and average annual sea surface temperature 27°C). The fishing mortality was calculated as \( F = Z-M = 0.578 \) year\(^{-1} \). While \( E = F/Z = 0.239 \) year\(^{-1} \).

**Fig. 2.** Length frequency distribution of *S. sihama* from Karachi coast of Pakistan
Fig. 3. Length-weight relationship of both sexes combined of *S. sihama* length and weight ranging from 10 to 24 cm (TL), 9 to 110 g respectively

\[ y = 0.0107x^{2.9177} \]
\[ R^2 = 0.9684 \]
Both sexes combined

Fig. 4. Length-frequency distribution data and the growth curves estimated using ELEFAN for *S. sihama* in Karachi coast of Pakistan in 2012

Fig. 5. A length-converted catch curve for *S. sihama* in Karachi in 2012 for the pooled data for one year (\( L_\infty = 25.20 \) cm and \( k=1.00 \) year\(^{-1} \))
Fig. 6. Yield per recruit contour map of *S. sihama* from Pakistani waters during 2012

Because $\mu = 17.614$ and $L^* = 15$, the total annual mortality estimated by the Beverton and Holt's method is: $Z = 2.90$ per year.

### 3.1.3 Biological reference points

The Gulland criterion of biological reference points (BRPs) was estimated at the optimum fishing mortality rate of 1.84 year$^{-1}$ for both years. The yield-per-recruit analysis (Fig. 6) indicated that when $t_c = 1$ and $F_{max} = 1$. Currently, the age at first capture is about 1 year and $F_{current} = 0.57$ years$^{-1}$. It is recommended that the present condition of *S. sihama* fishery in Pakistan is safe.

### 3.1.4 Growth performance index

Using VBGF growth parameters ($L_\infty$, $K$) the growth performance index ($\phi'$) for *S. sihama* was estimated 2.803 based on length-frequency data during 2012 from the Karachi coast of Pakistan.

### 4. DISCUSSION

#### 4.1 Length-Weight Relationship

The length-weight relationship is considered to be a useful measurement which makes easy for the estimations of metamorphosis, gonad maturity and rate of feeding of fish which is deliberated as a significant parameter in fishery biology and fish stock assessment [37]. In the present study, the value of slope “$b$” of *S. sihama* was estimated 2.9177 ($R^2 = 0.96$) from the Karachi coast of Pakistan in 2012, which indicates the negative allometric growth. Because, when the $b$ value is lower than 3 it determines the negative allometric growth, greater than 3 is positive allometric and when equal to 3 is isometric growth. The estimated value of slope $b$ was compared with the results obtained from the other areas of the world of the same species (Table 1), the $b$ values were 3.08 and 3.04 from Pulicat Lake and Goa of Indian waters respectively, which were greater than the present study. 2.88 was from India [38] and 2.73 from Northern Persian Gulf were closer to the present study. 3.355 and 3.064 [39] from E Mediterranean coast and NE Mediterranean Sea respectively from Turkey, 3.13 from New Caledonia [40] and 3.029 from South African waters which were greater from the present study. The differences among the slope values may be because of the changes in regions, seasonal fluctuations, environmental parameters and physical conditions of the fish at the time of sample collection, sex gonad development and nutritive conditions, sample size, different observed length ranges during the study etc. [41].

#### 4.2 Growth

VBGF parameters, i.e. asymptotic length $L_\infty$, growth rate $K$ and the hypothetical age $t_0$ were estimated from the length-frequency data from *S. sihama* from the Karachi coast of Pakistan and were compared with the results in previous studies from the different areas (Table 2).

In this study, the ELEFAN method in the FISATII computer software package was used to estimate the VBGF parameters ($L_\infty$ and $K$). $L_\infty$ was 25.20 cm and K was 1.00. The asymptotic length $L_\infty$ and growth rate $K$ was estimated at 406.82 mm and 0.2226 Pulicat lake [42], 519 mm and 0.2179 from Kawar waters 388 mm and 0.1526 from Goa, 510 mm and 0.1577 from Indian waters where the $L_\infty$ very high from the present study while $K$ was lower than the present study [43] .281 mm and 0.75 from Indian waters [44] and 260.89 mm and 0.6614 from Minnan-
Taiwan fishing ground were closer to the present study. 188.6 mm and 0.51 from Beibu Gulf were lower than the present study. Because FISHBASE (accessed on 26 May 2016) reported the maximum length of 30 cm, we would like to suggest that the very high L\(_\infty\) of about 50 cm and very low K of about 0.2 in [45] resulted from a non-representative data, i.e. their data maybe only for the young fish and missed old fish [44].

The \(t_0 = 0.2745\) from Pulicat lake [46] and \(t_0 = 0.08909\) from Kawar of Indian waters show positive \(t_0\) values. \(t_0 = -1.09\) and \(t_0 = -1.60\) from Goa from Indian waters were lower than the present study [47]. \(t_0 = -0.32\) from the Beibu Gulf and \(t_0 = -0.6158\) from Minnan-Taiwan fishing ground were closer to our present study (\(t_0 = -0.166\)). The differences between those values in Table 2. Maybe because of their different sampling strategies, data sets, estimation methods, life patterns and ecological characteristics [48].

### 4.3 Mortality

The present study used length-converted catch curve analysis for estimation of the mortality rate of S. sihama using input values of the VBGF growth parameter given above from the Karachi coast of Pakistan and which were compared with earlier studies from the same species but different countries of the world (Table 3).

Table 1. Comparison of value b of S. sihama with previous studies from different areas of the world to present study from Karachi coast, Pakistan during 2012

| Location                | Slope “b” | Sources                          |
|------------------------|-----------|----------------------------------|
| India                  | 2.88      | Radhakrishnan [49]               |
| Pulicat lake, India    | 3.08      | Krishnamurthy and Kaliyamurthy [50] |
| New Caledonia          | 3.13      | Letourneur et al. [51]           |
| South African waters   | 3.02      | Harrison [52]                    |
| E Mediterranean coast, Turkey | 3.35  | Taskavak and Bilecenoglu [53]    |
| NE Mediterranean Sea, Turkey | 3.06 | Erguden et al. [54]              |
| Goa, India             | 3.04      | Shamsan and Ansari [55]          |
| Northern Persian Gulf  | 2.73      | Daliri et al., [56]              |
| Karachi coast, Pakistan| 2.92      | Present study                    |

Table 2. Comparison of growth parameters of S. sihama from the present study with those from another part of the world

| Location                    | \(L_\infty\) (mm) | K     | \(t_0\) | \(\phi\) | Sources                      |
|-----------------------------|-------------------|-------|---------|--------|-------------------------------|
| India                       | 281               | 0.75  | -       | 2.77   | Banerji and Krishnan [57]     |
| Pulicat lake, India         | 406.82            | 0.22  | -0.27   | -      | Krishnamurthy and Kaliyamurthy [50] |
| India                       | 510               | 0.15  | -1.09   | -      | Gowda [58]                    |
| Kawar waters, India         | 519               | 0.21  | -0.08   | -      | Reddy and Neelakantan [45]    |
| Minnan-Taiwan fishing ground| 260.89            | 0.66  | -0.61   | 2.65   | CAO et al. [59]               |
| Beibu Gulf                  | 188.6             | 0.51  | -0.32   | 2.25   | Liu et al. [60]               |
| Goa, India                  | 388               | 0.15  | -1.6    | -      | Shamsan and Ansari [55]       |
| Karachi coast, Pakistan     | 252               | 0.44  | -0.16   | 2.8    | Present study                 |

\(L_\infty = \) asymptotic length (mm-TL); \(K = \) growth rate year\(^{-1}\); \(\phi = \) growth performance index; \(t_0 = \) hypothetical age at which length of the fish is equal to zero

Table 3. Mortality rates of S. sihama from Karachi coast of Pakistan were compared with the other studies from different areas

| Area                                | Z    | M    | F    | E    | Sources |
|-------------------------------------|------|------|------|------|---------|
| Minnan-Taiwan fishing ground        | 2.77 | 1.3  | 1.47 | 0.5  | CAO et al. [59] |
| Beibu Gulf                          | 2.58 | 1.21 | 1.36 | 0.5  | Liu et al. [60] |
| Karachi coast, Pakistan             | 2.42 | 1.84 | 0.57 | 0.2  | Present study |

\(Z = \) total mortality, \(M = \) natural mortality, \(F = \) fishing mortality, \(E = \) exploitation ratio
The mortality values in this study (total mortality $Z$, natural mortality $M$ and fishing mortality $F$) were 2.42, 1.841 and 0.5787 years$^{-1}$ respectively and the exploitation ratio $E$ was 0.239. The $Z$ was 2.7728, $M$ was 1.3004 and $F$ was 1.4724 while the exploitation ratio was 0.531 from Minnan-Taiwan fishing ground. The values of $Z$, $M$ and $F$ were 2.58, 1.217 and 1.36 respectively, and $E$ was 0.527 from the Beibu Gulf [61]. In the earlier studies, the values of total mortality in fishing mortality and exploitation ratio were higher than the present study and the values of natural mortality were lower than our study. The different values from different areas of the world were because of unfavourable environmental conditions or commercial demand, which increased fishing efforts in that region. There are many causes for the mortality rates, such as fishing, pollution, diseases, predation and old age in the fish community [62]. Predation is a big cause of natural mortality for $S. \text{sihama}$. However, in the present study, the fishing mortality ($0.5787$) is lower than natural mortality ($1.841$) which indicate that the stock of $S. \text{sihama}$ is in managing the condition in Pakistan.

The total annual mortality estimated by the Beverton and Holt’s method is: $Z = 2.90$ per year, which is similar to the results of catch curve analysis. Because the length converted catch curve analysis is more commonly used, we chose $Z = 2.42$ as our final result.

### 4.4 Growth Performance Index

The growth performance index ($q^1$) is usually estimated from the VBGF parameters ($a$, (asymptotic length) and $K$ (growth rate). If the value is higher it indicates faster and larger growth of the fish [63]. In this study, the growth performance index is 2.803. It was 2.772 from Indian water and 2.653 from Minnan-Taiwan fishing ground which were closer to the present study. It was 2.259 from the Beibu Gulf [64] which is lower, but closer to the present study values. Ecological and environmental changes may cause differences among the values of the growth performance index [65].

### 5. CONCLUSION

In the present study of mortality and growth parameters of $Sillago \text{sihama}$ from the Karachi coast of Pakistan has indicated that the fishery is in a safe condition because the current exploitation ratio (0.239) of this species is lower than the biological reference point (0.5). The growth rate and the growth performance index of this species were found to be good in Karachi coast, Pakistan.

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### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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