

Growth, mortality and exploitation rate of *Sardinella longiceps* (Valenciennes, 1847) from Pakistani waters based on length frequency distribution data

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The computer software FiSAT package was used to analyze the growth and mortality parameters of *S. longiceps*. Length weight relationship parameters of both sexes combined were at $W = 0.0179 \times b^{2.8583}$ ($R^2 = 0.819$). ELEFAN method was used to estimate the von Bertalanffy growth function (VBGF) parameters and were estimated as $L_{\infty} = 25.20$ cm (FL), $K = 1.4$ year⁻¹ and t_0 value was calculated by Pauly's formula as -0.929, hence the total mortality was estimated using length converted catch curve analysis as $Z = 4.84$ year⁻¹ at 95% confidential interval between (CI = 3.32-6.37). Natural mortality was calculated as $M = 2.255$ year⁻¹ using an average sea surface temperature of 26 °C from Pakistani waters, hence the fishing mortality was obtained by $F = Z - M = 2.560$ year⁻¹. Exploitation rate (E) was $E = F/Z = 0.534$ year⁻¹. Present study results indicate that the stock of *S. longiceps* from Pakistani waters is in overexploitation state.

[**Keywords:** Pakistan, *Sardinella longiceps*, growth, mortality, length frequency distribution data.]

Introduction

Pakistan coastline consists of 1100 km which starts from Indian to Iranian borders. From which 348 km is Sindh and 772 is the part of Balochistan coast and having an Exclusive Economic Zone (EEZ) of 250 000 km². The most of the fishing is done on the continental shelf area which is around 50 270 km². According to the FAO¹ report around 57% of fish landing was from the marine sector and export value was about US \$ 196 million in 2006¹. Sindh coastline is much diverse due to freshwater inflow from the Indus River which creates best nursery and protective ground for the many fish and shellfish species^{2,3}. Marine fisheries of Pakistan comprises of about 250 demersal fish species, 50 small pelagic, 20 large pelagic and 15 medium sized pelagic fish species¹.

Indian oil sardine is one of the small pelagic fishery resources of the Pakistani waters. This species is widely distributed along Sindh and Balochistan coast. Most of the catch caught from Balochistan coast which is favorable habitat for this species. In spite of commercially important fish species from Pakistani waters there is lack of research and management studies on this fish species. Some research work has been done from

other parts of the world, like from Omani waters^{4,5,6,7} and from Indian waters^{8,9,10,11}.

There is lack of studies available on the growth and mortality of *Sardinella longiceps* from Pakistani waters. In contrast there are different fish species stock assessment has been done from Pakistani waters such as, *Harpadon neherus*¹², *Saurida undosquamis*¹³, *S. tumbil*^{14,15}, *Nemipterus japonicas*¹⁶, *N. randalli*¹⁷, Indian squid^{18,19}, *Portunus pelagicus*^{20,21}, Ribbon fish²² and *Atrobuca alcocki*²³.

According to Marine Fisheries Statistics the yearly fish landing catch report, the exploitation history of *S. longiceps* during 1991 the catch was 30629 metric tons (mt) and decreased to 26937 mt during 2009. The average landing catch from 1991-2009 in Pakistani waters was 31374 metric tons (mt). Mostly the catch was from Balochistan coast²⁴. This fish species mostly exported to China and some Middle East countries. In Pakistan *S. longiceps* species is mostly used for fish meal processing specially in Balochistan coast²⁴. Indian oil sardine is fished throughout the year but the catch is dominant in the winter seasons. *S. longiceps* are found in the pelagic zone at a depth of 20-200 m from the shore. In a period

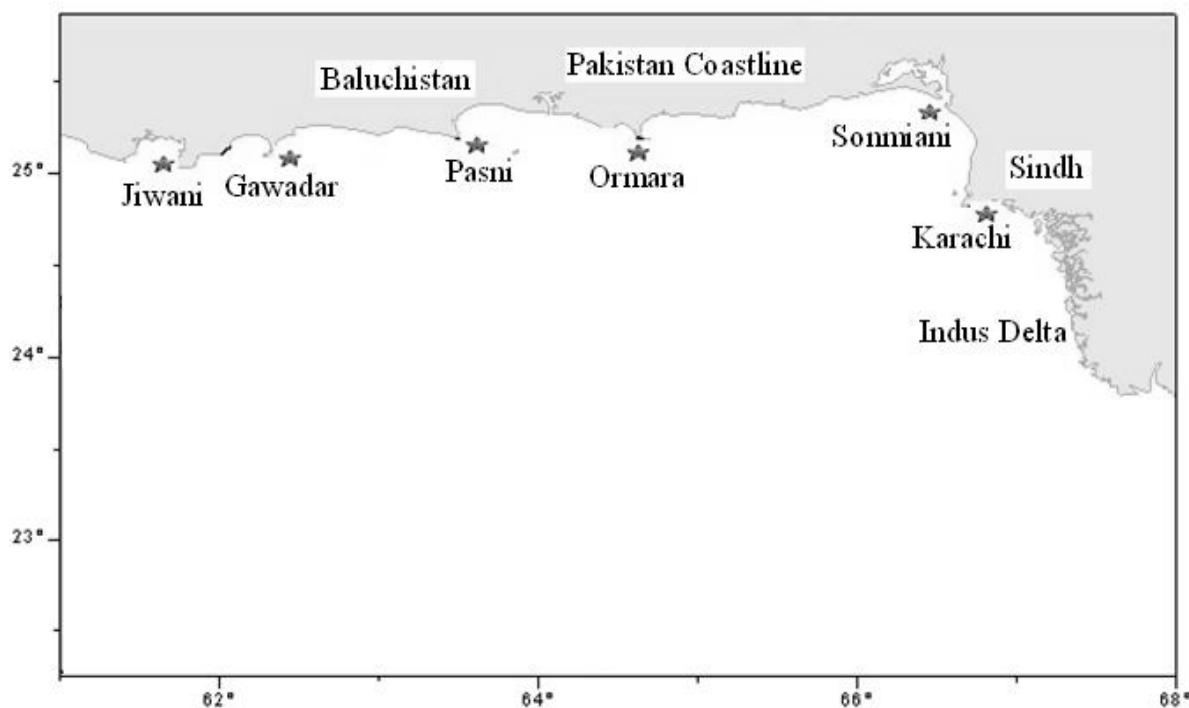


Fig 1— Pakistan coastline (* stars) showing different fish landing sites along the Sindh and Balochistan coast.

of one year at a length of 15 cm *S. longiceps* attain maturity^{25, 26, 27}.

Present study is focused on the growth, mortality and exploitation rate of *S. longiceps* from Pakistani waters. The length frequency distribution data collected from different fish landing sites was used for present study. This will be the basic contribution to biological study of this species and also can provide information to the fishery managers for better management.

Materials and Methods

Data collection

The fish samples of *S. longiceps* were collected from different fish landing sites of Pakistan coast (Fig. 1). The length frequency distribution and length-weight data on weekly basis were measured during January to November 2015. The fish samples were measured at nearest length in cm (TL) and weight in grams (g).

The total of 1990 length frequency distribution data were analyzed during 2015 as 216 in January, 167 in February, 250 in March, 211 in April, 185 in May, 158 in June, 154 in August, 198 in September, 236 in October and 215 in November 2015. The length-weight relationship data (n = 1825) of both sexes combine were also measured the in present study.

Length weight relationship analysis

The length weight relationship data of Indian oil sardine were calculated by the power function

of $W=aL^b$ ^{28, 29} where a is the condition factor and b is the allometric growth parameters or slope b .

Growth parameters

The von Bertalanffy growth function (VBGF) was used to estimate the growth parameters by the formula $L_t = L_\infty (1 - \exp(-k(t - t_0)))$ where L_t is the predicted length in the cm at the age t . L_∞ is the asymptotic length in cm (TL), K is the growth coefficient. The species having low K values have older age and bigger size at maturity and lower reproduction and longer life span and high asymptotic length³⁰ and t_0 is the hypothetical age at which the length of the fish equals to zero (usually negative)³¹. Biologically it has no meaning because when fish eggs hatch, that stage also has certain length and weight which may be estimated from the Pauly's equation³² as:

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

Mortality rate

The natural mortality rate (M) was calculated using Pauly's³² empirical formula $\log_{10}(M) = -0.006 - 0.279 \log_{10} L_\infty + 0.654 \log_{10}(K) + 0.6434 \log_{10}(T)$,

Where L_∞ and K are the VBGF parameters and T the annual average sea surface temperature taken in the degree Celsius (26 to 27 °C in Pakistani waters). The total mortality (Z) was estimated using length-converted catch curve analysis method³². The exploitation rate (E) was

calculated from equation: $E = F / Z$, where F is the fishing mortality which was calculated by $F = Z - M$.

Yield per recruit analysis

The yield per recruit were calculated from Beverton-Holt method by following formula

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

where Y_w / R is the yield per recruit, t_c is the average age of the fish at its first capture, t_r is the age when recruited, t_λ is the asymptotic age, Q is a constant value which is equal to 3, -3, 1 and -1 when n is 2, 1, 0 and 3 respectively³³.

Biological reference points

Gulland³⁴ method was used to analyze biological reference points (BRF), the optimum fishing mortality by $F_{opt} = M$.

Growth performance index

Growth performance index (ϕ') of this species was calculated based on equation given by Pauly and Munro³⁵: $\phi' = \log_{10} K + 2 \log_{10} L_\infty$ which is also available in computer software package by applying the VBGF growth parameters.

Virtual population analysis

The virtual population analysis (VPA) for the *S. longiceps* from Pakistani waters was estimated from input values of length-weight, growth, natural and fishing mortality into FiSAT computer software package.

Results

Length frequency distribution

Total 1990 length frequency distributions of *S. longiceps* were measured during present study from January to November 2015. The length ranges were from 10 to 24 cm (TL) from which the dominant length range were from 13 to 16 cm (TL) (Fig. 2).

Length weight relationship

The total 1825 pairs of length-weight relationship data of Indian oil Sardine were measured during the present study. The total length (cm) and total weight (grams) were examined which range from 10 to 24 (TL-cm) and 15 to 156 grams (g) respectively. The length weight relationship of *S.*

longiceps of combined sex were $W = 0.0179xL^{2.858}$ ($R^2 = 0.819$) (Fig. 3).

Growth parameters

The total 1990 length frequency distribution data were collected from fish landing sites to estimate the growth coefficient by applying ELEFAN method. The VBGF (von Bertalanffy growth parameters of *S. longiceps* were estimated at $L_\infty = 25.20$ cm (TL), $K = 1.4$ year⁻¹ (Fig. 4) and t_0 value were calculated by Pauly³² formula at -0.929 year⁻¹

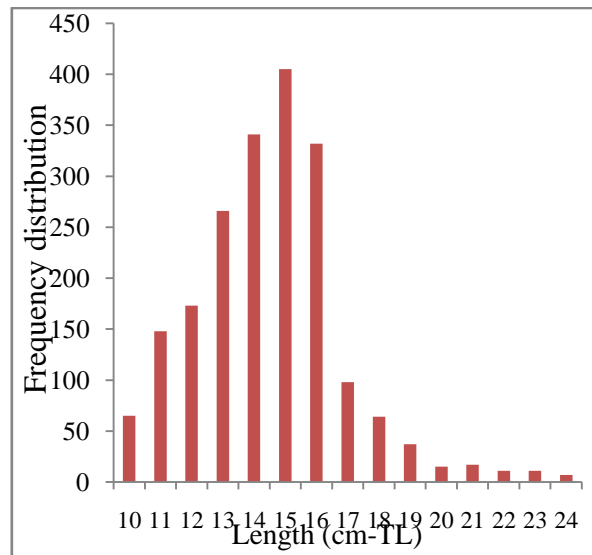


Fig 2 - Length frequency distribution of *S. longiceps* from Pakistani waters ranges from 10 to 24 cm (TL).

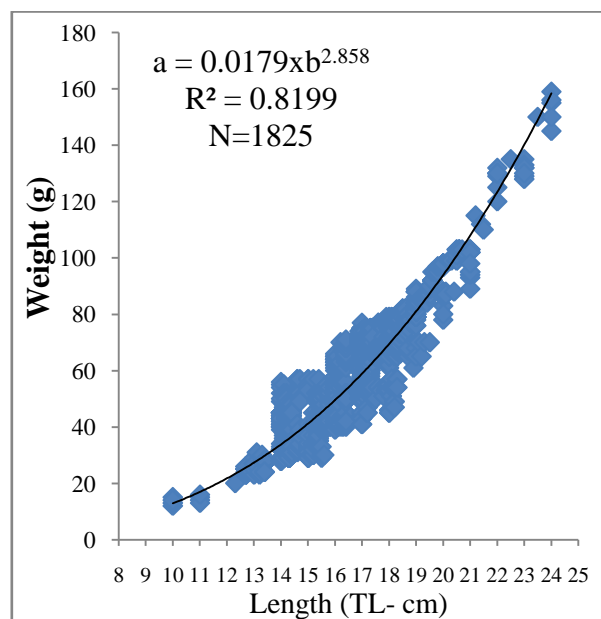


Fig 3 - Length weight relationship of *S. longiceps* from Pakistani waters during 2015.

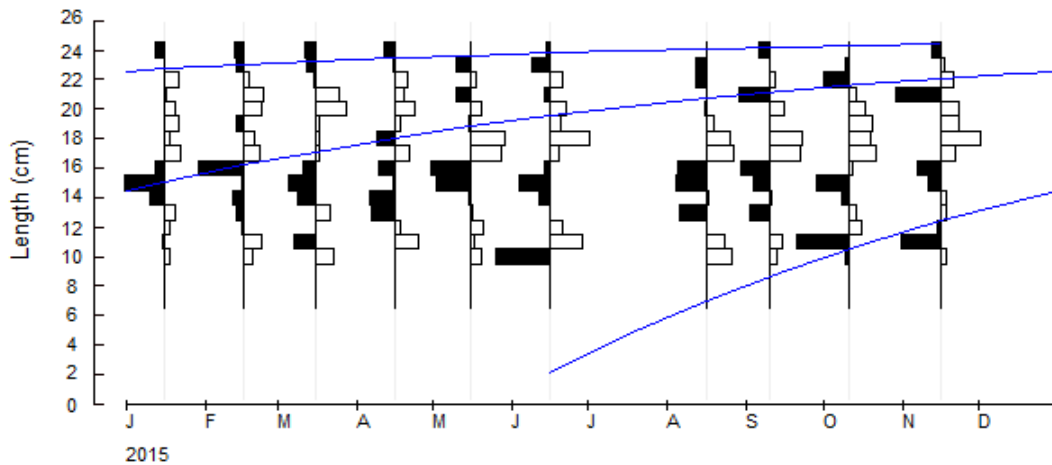


Fig 4- Length frequency distribution data (n = 1990) of both sexes combined of *S. longiceps* fitted with growth curve and estimated at were estimated at $L_{\infty} = 25.20$ cm (TL), $K = 1.4$ year⁻¹ from Pakistani waters during 2015.

Mortality rate parameters

The length converted catch curve method was used to estimate the total mortality of *S. longiceps* which were as $Z = 4.84$ year⁻¹ at 95% confidential interval of total mortality rate showing variation difference of (CI = 3.32-6.37) (Fig.5). The input values of growth coefficient parameters ($L_{\infty} = 25.20$ cm (TL), $K = 1.4$ K year⁻¹).

Only the black dots were included to calculate the total mortality because smaller size (yellow dots) must be not included and large size fish have only few samples so must be excluded from mortality calculation. The natural mortality were calculated at $M = 2.255$ year⁻¹ using an average sea surface temperature of 26 °C, hence the fishing mortality was obtained by $F = Z - M = 2.560$ year⁻¹, the exploitation rate (E) were $E = F/Z = 0.534$ year⁻¹

Yield per recruit analysis (YPR)

The contour map of yield per recruit analysis shows (Fig. 6) that when age of fish at first capture was assumed to be 2, F_{max} was estimated at 2.4 and $F_{0.1}$ were at 3 year⁻¹, and when age of the fish at the first capture (t_c). Currently the fishing mortality was $F_{current} = 2.60$ year⁻¹, therefore, results indicates that $F_{current}$ was greater than F_{max} which shows that the *S. longiceps* fishery from Pakistani waters is an overexploitation state. Furthermore, applying Gulland³⁶ biological reference points (BRF) F_{opt} were equal to M (2.55 year⁻¹) the current fishing mortality rate is

2.60 year⁻¹ which is greater than the current biological reference points.

Growth performance index

The growth performance index (ϕ') of the Indian oil sardine was calculated at 2.95 during present study.

Virtual population analysis

The length frequency distribution data were used to calculate the virtual population analysis which shows that the fishing mortality ranges from 13 to 18 cm (TL). The results were obtained with input values of length-weight relationship and growth parameters. The input method is available in FiSAT program (Fig.7).

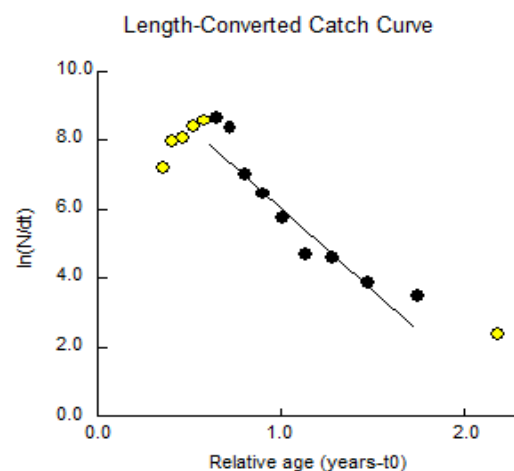


Fig. 5- The length converted catch curve analysis method were used to estimate the total mortality with input values of VBGF ($L_{\infty} = 25.20$ cm (TL), $K = 1.4$ year⁻¹) hence, total mortality were estimated at ($Z = 4.84$ at 95% confidential interval between (CI = 3.32-6.37) during present study.

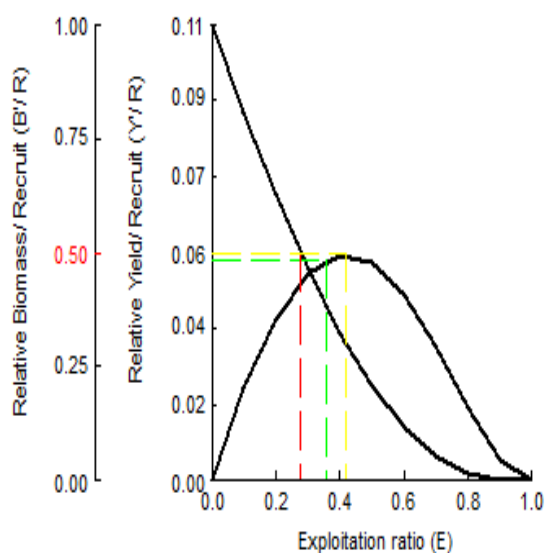


Fig 6 - Yield per recruit analysis of *S. longiceps* during present study 2015.

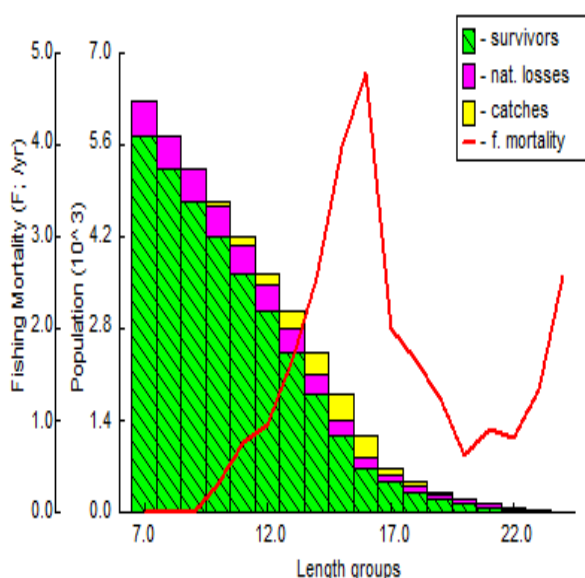


Fig 7 - Virtual population analysis shows the maximum pressure of fishing on the length class of 13 to 18 cm (TL) fish species from Pakistani waters during 2015.

Discussion

Length weight relationship

Length-weight relationship (LWR) parameters are mostly used for fish growth and stock assessment which is basic a parameter for the stock assessment to understand the fish growth like isometric or allometric^{37,38}. LWR also helps to indicate the metamorphosis, development of gonads and fish feeding rate³⁹. The normal range of length-weight relationship is from 2.5 to 3.5, but when the *b* values higher than 3 it means

the fish has isometric growth and when value *b* less than 3 the fish growth shows the allometric growth²⁹.

The estimated slope *b* value of *S. longiceps* in present study of both sexes combined were (*b* =2.858) which shows that the fish has isometric growth from Pakistani waters. The present values were within the range which were reported from different parts of the world^{40,41,42,43,44} (Table 1). Some studies values are lower and some are higher than present study (Table 1). The overall slope *b* values of both sexes combined show that *S. longiceps* has isometric growth. The overall results were close to present study which shows that the fish samples collected in present study fully represent the length-weight relation from Pakistani waters. The little difference within the values are because of some physical, chemical parameters and food nutrients availability in the water body with other environmental factors affect the length-weight relationship parameters^{29,50,51}.

Growth parameters

Using the ELEFAN method, the growth parameters were estimated at L_{∞} =25.20 cm (TL), $K = 1.4\text{year}^{-1}$).

The growth rates of the present study were compared with previous studies (Table 2)^{52,53,40,48,54,55,56,6}. The higher L_{∞} values usually have lower *K* values and vice versa. The lower *K* values describe the fish has long life and higher *K* values species has shorter like span^{57, 58}. The positive t_0 values show that the fish juvenile grows slower than the negative value^{57, 58}

Growth performance index indicates that higher growth rate values show better and faster growth curve. The growth performance index from present study was estimated at 2.950 which were close to previous studies showing in Table 2. It shows that Pakistani waters are suitable habitat for *S. longiceps* fishery.

It was observed that some values are lower, few are higher and few are same with present study (Table 2). The different is maybe because of different localities and different factors affecting on the growth parameters and measurement of data analysis. Some other ecological and environmental parameters also affect the growth rate of fish^{59, 60}. The different growth rate of fish stock shows the stock separation between the different areas of water bodies⁶¹. The compared results with other studies shows that the samples collected from present study fully represent the length class of *S. longiceps* from Pakistani waters.

Table 1. Comparison of intercept (*a*), Slope (*b*) and correlation coefficient (R^2) for the length-weight relationship of *S. longiceps* of current studies with the previous studies around the world.

<i>a</i>	<i>b</i>	R^2	Country	References
-6.4662	3.212	-	Mangalore, India	45
-6.6172	3.189	-	Karwar, India	46
0.0000135	2.927	-	Calicut, India	40,
-4.378	2.682	0.955	Saurashtra coast, India	41
3.47E-06	3.164	-	West coast of India	47
0.0321	2.5225	-	Ratnagiri, India	42
0.0126	2.903	-	East coast of India	42
0.8002	2.228	0.990	Ratnagiri, India	43
0.0059	3.141	0.822	Kochi India	44
0.0261	2.545	0.849	Chennai India	44
0.01189	2.86	-	Mangalore-Malpe	48
0.0000083	3.00	-	Al-Seeb Oman	49
0.0179	2.858	0.82	Pakistan*	Present study

*First time study conducted from Pakistani water, - data were not present in research articles.

Mortality rate

The population of a stock surrounds distinctive dynamic features which are not shared by individuals, for instance: death rates, birth rates, age structure etc. The "life history"⁶⁹ concept of a stock optimally includes a widespread description of the several stages through which the individuals in a population pass, i.e. from birth to the maturity stage. This comprises survival, mortality rate, fecundity and expectation of life span duration connected to the general environmental conditions. The full set of this information will provide not only a complete description of the population ecology but also enable one to deduce the controlling factors that determine its population dynamics. The key parameters which are used to describe death are termed the mortality rates. The mortality rate, is one of the other things being equal, closely interrelated to the predictability of the environment. The first thing to identify the mortality is that the measures which cause distinction in the year-class strength in the fishing occur during the first year of life, because it is the youngest stage that suffers most of the mortality⁷⁰.

In tropical waters where age structure data are not easy to determined, then length converted

catch curve method are frequently used with the help of length frequency distribution data. In present study the total (Z), natural (M) and fishing mortality (F) were estimated at (4.84, 2.255 and 2.560 $year^{-1}$) respectively and exploitation rate were $E=0.534year^{-1}$.

The mortality parameters of the same species from other parts of the world were shown in (Table 3) ^{71,53,67,63,56,72}. It was observed that overall values were close to the present study.

When the exploitation rate (E) is greater than 0.5 than it could be assumed that the fish stock from the area is overexploited^{36, 73}. While the exploitation rate equals to 0.4 than it shows that fish stock is under stress and overexploitation state⁷⁴ and should be maintained at $E = 0.4$ level per year⁷⁴. According to the present results ($E = 0.534$) the stock of *S. longiceps* from Pakistani waters is under threat and overexploited state. Based on the present study we may suggest that fishery managers should take some serious and management steps to maintain the fish stock of Indian oil sardine from Pakistani waters.

Now a day's fisheries resource management is turning out to be a big challenge for Pakistan government to manage the fish stock for the present generation as well as its posterity.

Pakistan marine fisheries have been tremendously affected not only by fishing but also by the environmental and climate factors. Marine pollution is main factor which effect on marine biodiversity. Pakistan marine fishery is based on small proportion industry with an outsized number of different smaller and larger fishing boats with different gears and large number of

fishermen. Most of the small fishing boats throughout Pakistani coast were not registered so the statistical system of fishing did not work accurately. The catch effort data is not completely accessible. Research over fish population parameters can give us good knowledge for better fish stock management.

Table 2. VBGF growth rate and growth performance index, comparison with previous studies from different areas of the world

L_{∞} (cm)	K (yr ⁻¹)	t_0	Φ'	Area	References
19.7	0.986	-	-	Oman (Muscat)	6
23.8	0.97	0.70	2.74	Gulf of Aden	62
21	1.10	-	-	Philippines	55
20.66	0.4	-	-	India	63
20	0.5	-	-	India	64
21	1.4	-	-	India	53
22.1	0.75	-	-	India	47
19.7	1.006	-	-	India	40
21	0.8	-	-	Indonesia	65
20	2.1	-	-	India	66
16.3	2.77	-0.03	2.87	Sri Lanka	67
26	0.086	-	-	Philippines	60
20.4	1.6	-	-	India	68
22.8	0.90	-	-	India	48
21.6	1.5	-	-	India	68
14.5	5.63	-0.03	3.07	Gulf of Aden	67
21	0.60	-	-	India	64
20.7	0.53	-	-	India	52
26	0.86	-	-	Philippines	59
25.20	1.40	-0.929	2.95	Pakistan*	Present study

*first time reported from Pakistani water, L_{∞} , K, t_0 and Φ' are growth parameters, - data were not present in research papers

Table 3. Comparison of the mortality rate parameters with previous studies from different regions of the world

Country	M	F	Z	E	Reference
India	0.67	-	-	-	75
India	0.75	1.4	2.15	0.65	71
Indonesia	2.25	4.32	6.57	-	76
Indonesia	1.95	2.44	4.39	-	76
Indonesia	1.72	0.52	2.24	-	76
Philippines	2.1	3.42	5.52	0.62	63
Philippines	2.1	5.72	7.37	0.72	55
Oman	1.3	0.95	0.35	-	77
Philippines	7.37	2.1	-	0.72	55
India	4.2	2.2	2.2	0.52	53
India	2.2	1.3	0.9	0.41	47
Indonesia	3.1	1.3	1.8	0.6	65
Philippines	3.65	1.68	1.97	0.54	56
India	6.34	1.43	4.91	0.78	68
India	2.74	1.51	0.93	0.34	48
Oman	4.11	2.21	1.91	0.46	72
Pakistan*	2.255	2.560	4.84	0.534	Present study

M = Natural mortality, F = Fishing mortality, Z = total mortality and E = exploitation rate. *First time reported

Conclusion

The present study shows that the stock of Indian oil sardine from Pakistani waters is in overexploitation state. The fishery managers should take some management steps to maintain the stock of Indian oil sardine from Pakistani waters. We could recommend that the marine protected areas (MPAs) should be declared specifically at the nursery grounds of the finfish and shellfish to secure the juveniles. It could be helpful to protect the small fishes by trawling in those areas where there are no juveniles and let them grow until they can breed once in their life time. The management determines of fishing license, use of proper gear types, suitable mesh size also the fishing methods, non-seasonal fishing must be banned. The control and coast guard surveillance system is necessary to protect fisheries sector for future to create a better understanding. Fisheries research institutions and the fisheries stockholders have to work together to understand the resources for better management which can lead us to an effective control and management.

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