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Research Article

Population dynamics of Rainbow Sardines, *Dussumieria acuta* (Valenciennes, 1847) from Pakistani waters

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Abstract

Length frequency data of Rainbow Sardines, *Dussumieria acuta* were collected and measured from the coast of Pakistan during 2015, ranging from 5 to 19 cm (total length). Weight ranges were measured from 2 to 64 g. The length frequency data were analysed for the estimation of population dynamics, so b was estimated at 2.70. The estimated von Bertalanffy growth function parameters of 19.95 cm (L_{∞}) and 0.730 year⁻¹ (K). The mortality rate $Z = 1.84$ year⁻¹, $M = 1.59$ year⁻¹, $F = 0.25$ year⁻¹ and $E = F/Z = 0.135$. The yield-per-recruit analysis indicated that when t_c was 1, F_{max} was 1 year⁻¹. Currently, the age at first capture is about 1 year and $F_{current}$ was 0.25 year⁻¹. Therefore, $F_{current}$ was smaller than F_{max} . With Gulland method, the biological reference point for fishery (F_{opt}) was estimated as 1.59 year⁻¹, which is also higher than current fish mortality. Therefore, the present study shows that the *Dussumieria acuta* fishery is safe in Pakistan.

Introduction

The growth in the world population has resulted an increase in the consumption of animal protein, and fishery products are important to overcome this demand for human populations [1]. Pakistan is endowed with marine fisheries resources which are not only to supply the valuable animal protein but also contribute to the national economy of the country, take part in human development and employment [2]. Pakistan exports fish and fisheries products in the form of chilled, frozen, cured, and canned to 47 countries of the world [3]. The exported fish and fishery products were 155,671 metric tons valued at 367,472 USD during 2013–2014 [4].

Pakistan has a long coastline of 1 120 km from the southeast Indian border to the northwest Iranian border (Figure 1). It has an EEZ (exclusive economic zone) of 2 40 000 km² with

a continental shelf area of about 50 270 km². Pakistani water has rich commercially important fisheries resources comprise of about 250 demersal fish species, 50 small pelagic species, 15 medium-sized pelagic species, and 20 large pelagic fish species [2].

Small pelagic fish are important in the food web of a marine ecosystem, playing a significant role in connecting the lower and upper trophic levels, because a substantial number of predatory fish, seabirds and marine mammals feed on them [5, 6, 7]. Fishes belong to family Dussumieriidae is commonly known as round herrings, are small pelagic fishes widely distributed in tropical and temperate seas, mainly in the Indo-Pacific region [8]. Family Dussumieriidae comprises 2 recognized genera and 9 species. Genus *Dussumieria* has two species *Dussumieria acuta* and *D. elopsoides* [9], but only *D. acuta* has been reported from Pakistani waters [10].

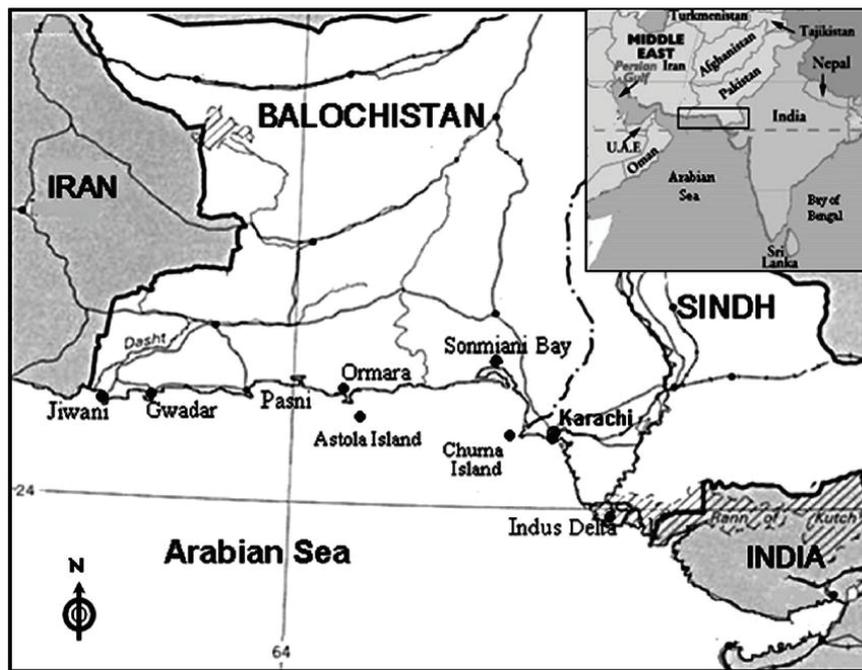


Figure 1: Map shows major sampling sites along the Pakistan coast.

The Rainbow sardine, *D. acuta* is locally known as Tel-tampri, which is a small pelagic clupeoid fish [10]. It is an important commercial fish, distributed in Indo-Pacific: Persian Gulf (and perhaps south to Somalia), along the coasts of Pakistan, India, and Malaysia to Indonesia (Kalimantan) and the Philippines [9]. Its maximum size is 20 cm in Pakistani waters while the common length is about 15 cm. Caught with setnets, beach and purse seines, and shallow water trawls [10], in the depth range from 10 to 20 m [9].

Study of different population parameters like the asymptotic length (L_{∞}) and growth coefficient (K), mortalities (natural and fishing) rate, and exploitation level (E) are essential for the planning and management of marine resources. Lack of awareness of population structure and proper evaluation of the exploitation of marine resources emphasized the importance of a detailed study to facilitate better management of the resource. There are many tools for assessing the exploitation level and status of the stock. Of these, FiSAT (FAO-ICLARM Stock Assessment Tools, Gayanilo et al., 2003) has been commonly used for estimating population parameters of fishes [11-13], because primarily it requires only length-frequency data but also enables related analysis, of size-at-age, catch-at-age, selection, and other analysis. 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 [14]. 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 e.g. Beverton and Holt, 1957 [20]; Pauly, 1983, 1984 [19, 23]; Pitcher, 2002 [14].

Some studies are done on Rainbow sardine, *D. acuta* from Indian waters such as on length-weight relationship from Southern coast of Karnataka (Abdurahiman et al., 2004) on the age and growth rate from Mandapam area [15, 36] and on diurnal variation in feeding habits of *D. acuta* from the gulf of Mannar and the Palk bay [8] but there was no work done from Pakistani waters. The present work was designed to evaluate the population dynamics of *D. acuta* from Pakistani waters. We hope that it would be helpful for the proper management of the fisheries and the optimum utilization of the resources of Pakistan.

Materials and methods

A total of 1234 individuals of *D. acuta* were collected and measured from the fishermen catches using setnets and beach seines at random during 2015, from the 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.

The length frequency data of *D. acuta* during 2015 were analysed using computer software packages FiSAT-II (FAO-ICLARM stock assessment tool, Gayanilo et al., 2003) [16]. In this study, we estimated parameters such as length-weight relationship, growth, mortality rate, growth performance index, virtual population analysis (VPA), and biological reference point.



The relationship between length (L, cm-TL) and weight (W, g) of *D. acuta* was established by using a power equation [17]: $W=aL^b$

Where a = constant condition factor and b = an exponent slope or allometric growth parameter.

The growth parameters of *D. acuta* during 2015 was calculated by using von Bertalanffy growth function (VBGF) [18]: $L_t = L_\infty (1 - \exp^{-K(t-t_0)})$,

Where L_t was the length (TL-cm) at age t. L_∞ is the asymptotic length, K is the growth coefficient and t_0 was the hypothetical age at which length equal to zero (usually negative) and was calculated by empirical formula [19], as $\log_{10}(-t_0) = -0.3922 - 0.275 \log_{10} L_\infty - 1.038 \log_{10} K$.

From the estimated growth parameter values (L_∞ , K) of *D. acuta* during 2015, the total annual mortality (Z) were estimated using the length converted catch curve analysis method [19,20]: $\ln(N_t) = \ln(N_0) - Zt$

Where N_t is the population size at age t, N_0 is population size at age 0.

The natural mortality coefficient was obtained by

$$\log_{10} M = -0.006 - 0.279 \log_{10} L_\infty + 0.654 \log_{10} K + 0.6434 \log_{10} T,$$

Where T is the average annual sea surface temperature, which was 27 °C in Pakistani waters. The fishing mortality (F) was calculated by $F=Z-M$ and exploitation ratio (E) was calculated from $E=F/Z$.

Biological reference points of the optimum fishing mortality were calculated by Gulland method [21] as $F_{opt} = M$

The Beverton-Holt yield per recruit model was calculated by:

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

, where Y_w/R was the yield per recruitment, t_c was the mean age at first capture, t_r was the recruitment age, t_λ was the asymptotic age, Q_n was a constant and equals to 1, -3, 3 and -1 when n was 0, 1, 2 and 3, respectively [22].

The estimation of L_∞ and K were used to calculate the growth performance index (ϕ') of *D. acuta* in 2015²³: $\phi' = \log_{10} K + 2 \log_{10} L_\infty$

Results

A total of 1234 individuals during 2015 of *D. acuta* were examined during this study. The minimum length was 5 cm and the maximum was 19 cm, and the dominant individuals are ranged 12 to 15 cm total length (TL) (Figure 2). Weights were measured from 2 to 64 g. The length-weight relationship of both sexes combined was: $W=0.0233x^{2.7044}$ ($R^2 = 0.995$) (Figure 3).

Growth parameters for *D. acuta* were estimated using the ELEFAN method in the FiSATII computer software package. The von Bertalanffy growth parameters for *D. acuta* were $L_\infty =$

19.95 (TL-cm) and $K=0.730 \text{ year}^{-1}$ (Figure. 4) with the goodness of fit model at $R_n = 0.168$. The t_0 values were calculated as -0.246 years.

Applying VBGF growth parameters (L_∞ , K) and using the length converted catch curve analysis, the total mortality rate (Z) were 1.84 year^{-1} (Figure 5) with Pauly empirical equation, natural mortality was calculated as $M = 1.59 \text{ year}^{-1}$ (with $L_\infty = 19.95 \text{ cm}$, $K=0.730 \text{ year}^{-1}$ and average annual sea surface temperature 27 °C). The fishing mortality was calculated as $F=Z-M= 0.25 \text{ year}^{-1}$.

The exploitation ratio (E) was calculated from $F/Z = 0.135 \text{ year}^{-1}$. Because $L_{L'} = 15.988 \text{ cm}$ and $L' = 15 \text{ cm}$, the total annual mortality estimated by the Beverton and Holt's method is: $Z = 2.92 \text{ per year}$.

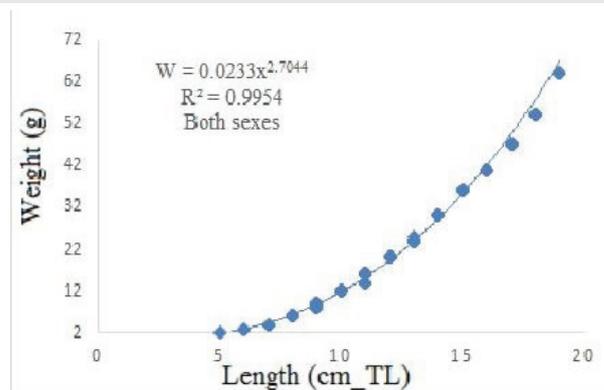


Figure 2: Length-weight relationship of both sexes combined with *D. acuta* length and weight ranging from 5 to 19 cm (TL), 2 to 64g respectively.

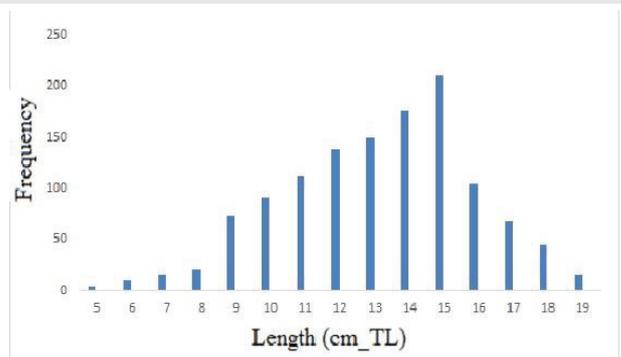


Figure 3: Length frequency distribution of *D. acuta* from the coast of Pakistan during 2015.

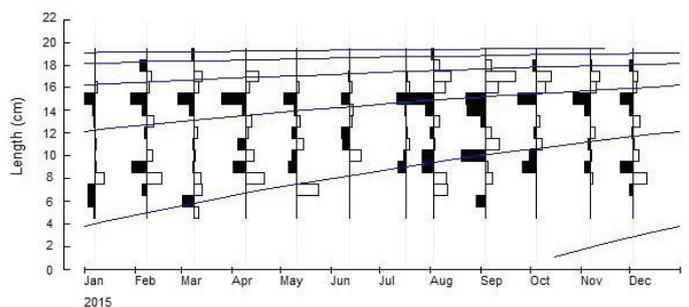


Figure 4: Length-frequency distribution data and the growth curves estimated using ELEFAN for *D. acuta* from Pakistani waters.



As showed in yield-per-recruit contour map (Figure 6), when t_c was assumed to be 1, F_{max} was estimated as 1 year⁻¹. Because the current age at first capture is about 1 year and $F_{current}$ was 0.25 year⁻¹, therefore $F_{current}$ was smaller than F_{max} . This indicated that current fishing mortality is in manage condition. When using Gulland (1971) biological reference point, F_{opt} was equal to M (1.59 year⁻¹). The current fishing mortality rate of 0.25 year⁻¹ was lower than the target biological reference points (BRP). It is recommended that present condition of *D. acuta* fishery in Pakistan is safe.

The growth performance index (ϕ') was estimated at 2.463 based on the estimated growth parameters for *D. acuta* during 2015 from Pakistani waters.

The results of virtual population analysis (VPA) were analyzed from pooled data in 2015 and from the input of growth and length-weight relationship parameters (L_{∞} , K , a , b) given above. The output of the length structured VPA using FISAT for *D. acuta* is in Figure 7 and shows that the maximum fishing mortality was at 18 and 19cm (TL) length.

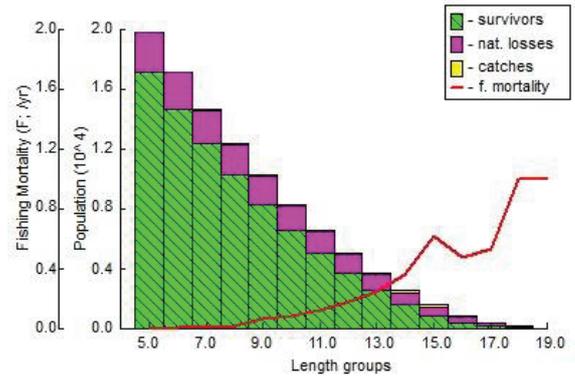


Figure 7: Length-structured virtual population analysis (VPA) of *D. acuta* from Pakistani waters during 2015.

Discussion

The length-weight relationship (LWR) is basic in the biological study of fishes and their stock assessments, which makes it easy for the estimations of metamorphosis, gonad maturity and rate of feeding of fish [23,24]. Methods to estimate the length-weight relationship of fishes are described by Pauly [19]. In the present study, the value of slope “b” of *D. acuta* was estimated at 2.704 ($R^2 = 0.995$) in 2015 from the Pakistani waters, which indicates the negative allometric growth [25]. Because when the b value is lower than 3 it determines the negative allometric growth when greater than 3 it is positive allometric and when it 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 2.938 for male and 2.894 for female from Indian waters [28]. The above values look closer to the present study. It was 3.228 (for pooled) from Kenyan waters [29], 3.536 from Indian waters [15], 3.142 from Indonesian waters [30], and 3.03 from Turkish waters by Taskavak and Bileenoglu (2001). These values were greater than the present study values.

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 range during the study etc [26,27,17].

In general, fish may grow faster when the population density is decreased or the habitat is improved. VBGF parameters, i.e. asymptotic length L_{∞} , growth rate K and the hypothetical age t_0 were estimated from the length frequency data of *D. acuta* during 2015 from the Pakistani waters and were compared with the results in previous studies from the other areas (Table 2). In this study the VBGF growth coefficient was estimated, using a non-parametric method usually used in length frequency analysis of fish, which is basically *ad hoc* and does not depend on estimating the parameters of cohort distribution directly. So it makes only weak assumption about the distribution of sizes within the cohorts. The model 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 [14].

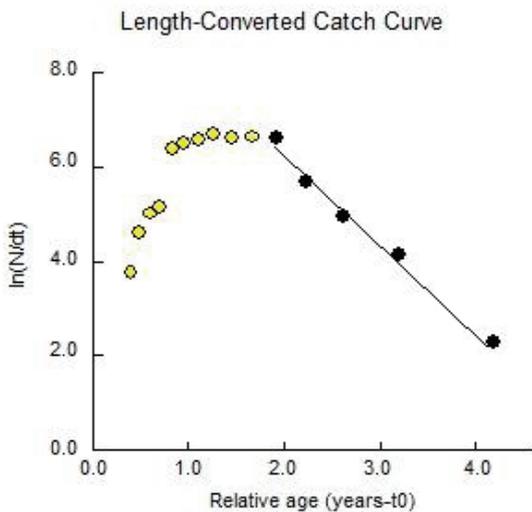


Figure 5: A length-converted catch curve for *D. acuta* in Pakistani waters for the pooled data of one year ($L_{\infty} = 19.95\text{cm}$ and $k=0.730\text{ year}^{-1}$).

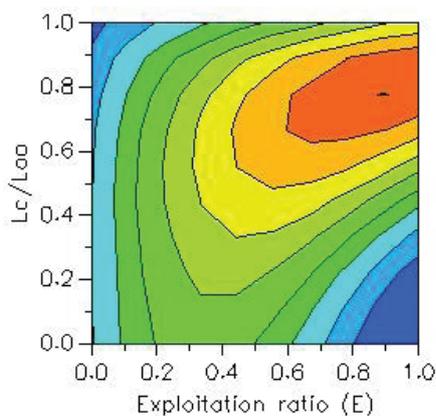


Figure 6: Yield per recruit contour map of *D. acuta* from Pakistani waters during 2015.



Table 1: Comparison of value *b* of *D. acuta* with the previous studies from different areas of the world with the present study from the coast of Pakistani during 2015.

Location		A	b	Sources
India	Male	0.009	2.938	[36]
	Female	0.01	2.894	
Kenya		-4.093	3.228	[29]
India		-6.2011	3.536	Nair, 1991
Indonesia		0.0056	3.142	[30]
Turkey		0.00001	3.03	Taskavak and Bileenoglu, 2001
Pakistan		0.0233	2.7044	The present study

'a' is the regression intercept and 'b' is the regression slope.

Table 2: Comparison of growth parameters of *D. acuta* from the present study with those from previous studies.

Location	L_{∞} (cm)	K	t_0	Sources
India	19.1	0.20701	-1.34	Nair, 1991
Pakistan	19.95	0.73	-0.246	The present study

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

In the present study, the ELEFAN (Electronic length frequency analysis) method in the FiSATII computer software package was used to estimate the VBGF parameters (L_{∞} and K). L_{∞} was 19.95 cm and K was 0.730. The asymptotic length L_{∞} was estimated at 19.20 cm and K was 0.20701 from Indian waters¹⁵ which were closer to the present study. The $t_0 = -1.34$ from Indian waters which is lower than the present study $t_0 = -0.16491$. The differences of those values in Table 2 maybe because of their different sampling strategies, data sets, estimation methods, life patterns and ecological characteristics [31].

The present study used length-converted catch curve analysis for estimation of the mortality rate of *D. acuta* in 2015 using input values of the VBGF growth parameters given above from the Pakistani waters.

The mortality values in this study (total mortality Z, natural mortality M and fishing mortality F) were 1.84, 1.59 and 0.25 $year^{-1}$ respectively in 2015. The exploitation ratio (E) was calculated from $E = F/Z = 0.135$. There was no work done found on mortality from other areas to compare with the present study. However, the difference among values from different areas are because of unfavorable 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 [32]. However, in the present study, the fishing mortalities (0.25) are lower than natural mortality (1.59) which indicates that the stock of *D. acuta* is in managing the condition in Pakistan.

The total annual mortality estimated by the Beverton and Holt's method was 2.92 per year for 2015, which was greater than the results of length-converted catch curve analysis. Because the length converted catch curve analysis is more commonly used, so we chose Z=1.84 as our final result.

The definition and widespread use of BRPs (Biological reference points) have greatly benefitted fisheries management. For each managed fish stock, the fishing mortality- and biomass-based BRPs can be combined as a "control law" to specify fishing mortality rates as a function of stock biomass [33,34]. BRPs are broadly used to describe safe levels of harvesting for marine fish populations i.e. Either minimum acceptable biomass levels or maximum fishing mortality rates [35].

The yield-per-recruit analysis (Figure 6) indicated that when t_c was 1, F_{max} was 1 $year^{-1}$. Because the current age at first capture is about 1 year and $F_{current}$ was 0.25 $year^{-1}$ which indicated that the current fishing mortality is low. Also the current fishing mortality rate estimated here is lower than the Gulland (1969) target biological reference point (F_{opt} , 1.59 $year^{-1}$). Therefore, we may suggest that the *D. acuta* fishery is in manage condition in Pakistani waters. However, because the information available is limited, it is very difficult to compare the life history parameters estimated in this study with those from other studies, especially what ecological/biological process contributes to such differences as well as the spatial differences and/or temporal differences which can influence the life history parameter estimates.

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