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An Estimation of Growth Parameter, Mortality Rates and Yield-per-recruit for Beluga (*Huso huso*) Living in Caspian Sea

A. Taghavi Motlagh

Fisheries Affairs Dept., Iranian Fisheries Co., No. 250, West Fatemi Ave., Tehran, Iran

E-mail: s_taghavimotlagh@hotmail.com

Abstract: This paper presents the results of study on age, growth, mortality rates and yield-per-recruit of Beluga (*Huso huso*) living in Caspian Sea. The mean length of successive years, mortality rates and yield-per-recruit studies indicated that at present the resource is under heavy fishing pressure.

For the female Beluga growth was regarded as comprising of three stages, and the von Bertalanffy parameters were calculated for juveniles, for middle stanza (<8 to 24 years), and third stanza (>24 years). The value of K was the highest (0.065) for the first stanza, lower for the middle (0.029), and the lowest for the third one (0.023). Total mortality of female and male Beluga estimated from the descending limb of the catch curve using the combined data (1990-1994) were: for females, Z=0.48 per year, r=0.982, P<0.01 and for males, Z=0.38 per year, r=0.992, P<0.01. Natural mortality for female and male Beluga was estimated using Richter and Efanov's formula as 0.03 for females and 0.05 for males. Values of fishing mortality (F) were estimated from Z and M, using values of Z from catch curves and M estimated from Richter and Efanov's formula as 0.045 and 0.33 for female and male, respectively. Yield-per-recruit curve was produced for female and male Beluga. It was found that the maximum Y/R (Maximum sustainable yield-per-recruit) were produced at Fs =0.07, for female and Fs=0.16 for male. Inspection of the yield-per-recruit model for the Beluga in the Caspian Sea showed that the fishing mortality should be stopped for this species in the Caspian Sea. This result confirms the over-fishing of the sturgeon in Caspian Sea. Several other authors such as Smith (1990), Birstein (1993), Bemis and Findeis (1994), Dumount (1995) and current catch data, have confirmed the overfishing of the Beluga in the Caspian Sea.

KEY WORD: Growth parameter, Mortality rates, Caspian Sea, Fishing, Beluga

Introduction

The sturgeon population in southern sea declined as a result of increased riveriene and particularly marine catches between the end of the last century and 1913 (Barannikova, 1987). However, a further reduction of sturgeon stocks in Caspian and Azov seas occurred between 1930 and 1940 as a result of intensive marine fishing using automatic hook-and-line gear and gill nets. For instance, sturgeon catches from Caspian Sea were only 75,000 tones in 1940 as compared to 23,000 tones in 1910 (Barannikova, 1987). Other reductions of sturgeon catches in Caspian Sea have occurred since 1989 when the annual catches of sturgeon began to decrease. Later, there was a sharp reduction in the catches after the break up of the former Soviet Union.

The annual catches of sturgeon by Iran and Soviet Union started to decrease from 1983. The decrease from 1983 to 1988 was not large, but from 1989 the annual catches of sturgeon in Caspian Sea have sharply declined. For example, the sturgeon catches were 27,000 tones in 1982, but only 13,558 in 1991 (FAO, 1993). Since then, yearly decline has been recorded in Iranian side. The annual yield of caviar in southern Caspian from 1971 to 1989 (Iranian sides) varied between 191.5 tones to 304.5 tones (average 234.5 tones per year), but nowadays the annual caviar production is less than 100 tones per year. All of this evidence shows the concerning situation of sturgeon in Caspian Sea. For this period (1971-1988) stellate caviar was 48.8% (minimum in 1972 and maximum in 1980), Persian and Russian sturgeon caviar 26.4-45.4% (minimum in 1974 and maximum in 1980) and Beluga 18.8-1.2% (minimum in 1986 and maximum in 1972) of the total yield (Rezavni, 1989). The proportion of the Beluga caviar in 1998 and 1999 was 4% of total caviar production. This proportion of the Beluga caviar has decreased 14 times between 1971 and 1999.

Beluga is the largest sturgeon living in Caspian Sea, and reaches a length of up to 45 cm and weight of 725 kg. In the past, individuals were found to reach the age of 100 to 120 years, but the present life span does not exceed 50 to 55 years (Kosarev & Yablonkaya, 1994). At the beginning of the 20th century (1904-1913), it accounted for about 40% of the sturgeon catch. At the present, the catch is not more than 10%. In 1971, 18% of the Iranian caviar came from Beluga, at the present (1998 and 2000) it decreased to 4%.

The purpose of this paper is to estimate growth parameters, mortality rates and yield-per-recruit of Beluga (*Huso huso*) living in Caspian Sea in order to inform Iranian authorities and provide them with advice on the rational management of this valuable resources.

Material and methods

In the southern part of Caspian Sea, adjacent to the northern part of Iran, the Iranian Fisheries Company established two research centres and one international institute in the Guilan and Mazandaran provinces to undertake research projects in their respective areas. The most important assignment for these research centres was to investigate different aspects of the sturgeon population. From 1995 to 1999, sampling was conducted from *Huso huso* (Beluga) in the southern Caspian. Four fishing districts, two in each province were established for managing and organizing the sturgeon fisheries and each district has several fishing stations, from which the sturgeon captured by fishermen are delivered for processing caviar.

The sampling periods coincided with the fishing periods for the sturgeon in each area. Samples were obtained every day of fishing, except when the weather was not suitable. When the catch was high, part of the catch was taken randomly as a subsample. When the fish were transferred by the fishermen from sea to the processing station, technicians recorded all the necessary data, including total and fork lengths, weight, and weight of caviar; and the pectoral fin ray was removed for age determination. Females and males, sexed according to the gonads, were recorded separately. Ages of fish were later calculated from sections of the pectoral fin. All Beluga were routinely examined for spawning condition, mature individuals being distinguished by the degree of gonad development and differentiation of the gonads.

Sex, age, fork length and total weight data were supplied for each fish. The SPSS (version 6.0, 1993) program was used for the statistical analysis of the data. The analyses were conducted for each year separately and all combined, as well as for sexes separately. The von Bertalanffy growth parameters ($L\infty$, K and t_0) were then calculated.

Total mortality (Z) was estimated using linearized catch curves based on age and length composition data, and Beverton and Holt's Z-equations (Beverton & Holt, 1956) based on length and age data. Natural mortality (M) was estimated using Pauly's (1980b) empirical formula based on growth parameters and mean environmental temperature, and Richter and Efanov's formula (1976). Fishing mortality (F) was estimated from the difference, F=Z-M.

Finally, the yield-per-recruit curve (Beverton & Holt, 1957) was estimated, based on growth parameters and mortality rates, to provide advice for the management of the Beluga fishery in Caspian Sea.

Growth parameters

The method of estimating K and $L\infty$ from growth increments (Gulland & Holt, 1959; Gulland 1969) depends on the increment, declining with age as von Bertalanffy's (1934) model assumes. As the sample sizes for the older age classes tended to be very small, and it became apparent well off the growth curve predicted by the von Bertalanffy equation, parameter estimates utilized initially only the age classes (8-20), for which lengths were based on large samples. In circumstances in which the increments fluctuated greatly between years, the von Bertalanffy parameters were estimated using smoothed values of length and increment derived from the quadratic equation that best fitted the data. As in length at age sets for males, where the increment did not decrease over the ages covered by adequately sized samples, $L\infty$ was estimated from maximum observed length, L_{max}. The criterion for choosing the best L near L_{max} was that the generated von Bertalanffy curve should pass within ±1SD from all the annual mean lengths.

Since, $\ln [(L\infty - L_t) / L\infty] = - K (t - t_0)$, the initial estimates of K and $L\infty$ were refined by plotting $- \ln [(L\infty - L_t) / L\infty]$ against age, t (Bertalanffy, 1934), relationship of which should be linear, with slope K and X-axis intercept t_0. However, as t increases, the values of $\ln [(L\infty - L_t) / L\infty]$ become increasingly sensitive to inaccuracy in the initial estimate of $L\infty$, so that the line becomes curved. The correct values of K and t_0 are obtained when, by iteration, the exact value of $L\infty$ is found, which produces a straight line. Goodness of fit is assessed by the product-moment correlation coefficient (r). The correct $L\infty$ is the one that produces the highest value of r (for highest correlation r = 1).

It was found that, even for female fish, the parameter estimates produced curves that fitted only the earlier age groups in data sets (based on large sample sizes), which had been used in the Gulland plots. To find the values that approximated to the entire length at age data sets, it was necessary, by iteration, to alter the values of K and $L\infty$, even though this meant accepting much lower r-values for the most reliable part of the curve. Such derived curves tended to have unrealistic values for t_0. It is realized that the initial pre-recruit growth of Beluga is relatively high, and an appropriate, steeper line had to be fitted by eyes.

The growth parameters were also estimated by a program called "Fishery Science Application System" (FSAS) by S. B. Saila, C. W. Recksiek and M. H. Prager. To obtain the von Bertalanffy growth parameters of Beluga from this program, it was necessary to force the curve through zero (i.e., put zero for the first row of the data sets, i.e. age, mean length).

Two growth stanzas (second and third) were recognized during the sampling period for the female Beluga, with a separation at age about t=24. Table 1. shows the input data for estimation of female Beluga growth parameters.

For female Beluga, the following procedures were employed:

(1) The best-fit line was determined. This is shown in Fig.1, with actual means (±1SD) superimposed.

(2) Increments were plotted against mean length (Gulled & Holt 1959), ignoring 'rogue' points, to derive first estimates of $L\infty$ and K. There was great scatter (Fig2).

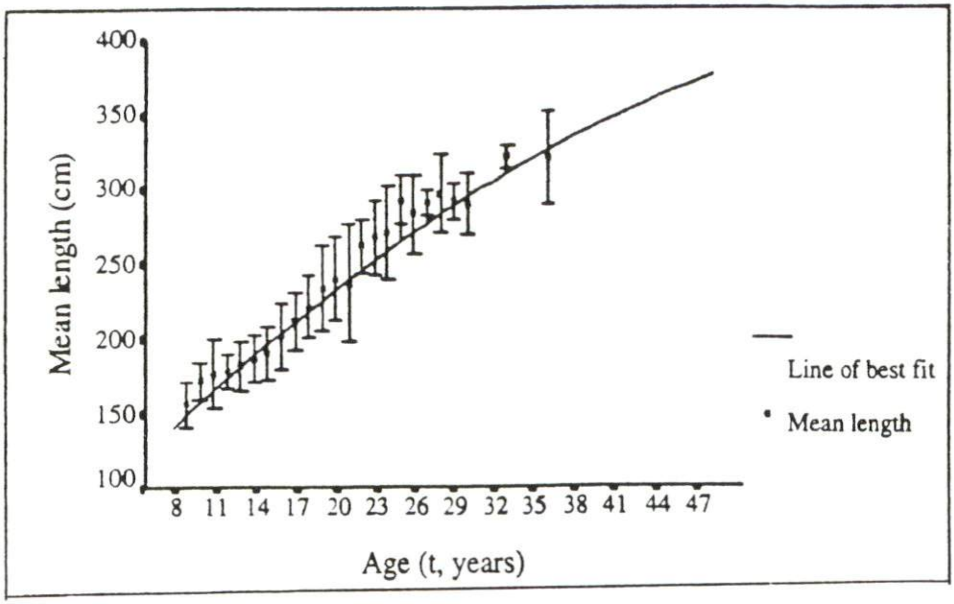

Fig. 1: Plot of mean length ±1SD against age of the female Beluga with line of best fit (quadratic plot)

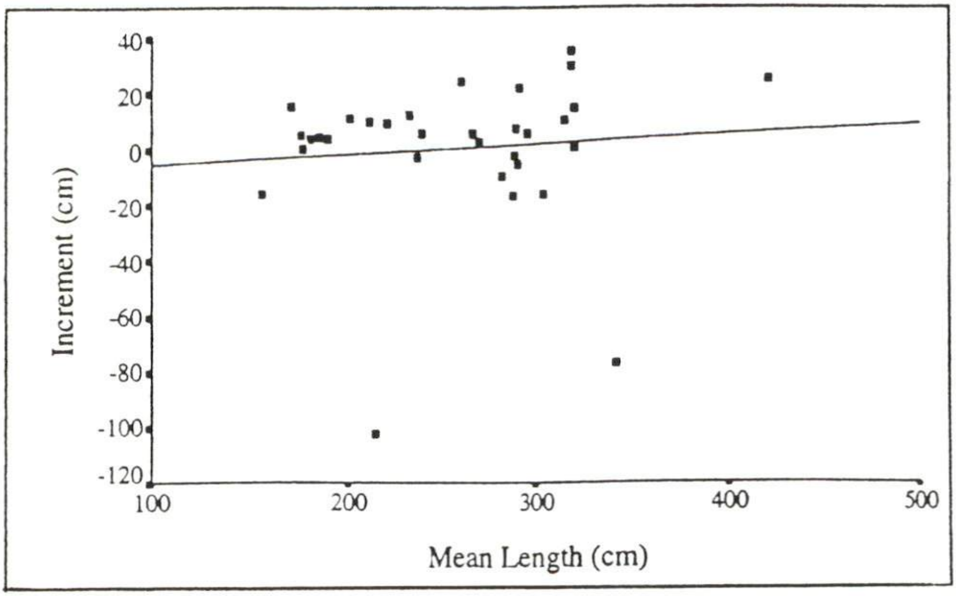

Fig. 2: Female Beluga: Gulland plot using all data and annual mean length

(3) Another plot was created using the estimated increment and mean length from (1) above. Since the line of best fit was not a von Bertalanffy curve, the points did not fall as a straight line (Fig.3). This confirms that a simply derived Von Bertalanffy model cannot fit the data sets.

(4) Plot (3) was repeated, using only points of the middle stanza, which contained the largest samples. This provided estimates of $L_\infty = 666$ cm and K=0.016, with an r = 0.999. However, an L_∞ of 666 cm is manifestly too high (literature estimates of L_{max} are 490-600 cm total length), and the projected curve is far above the data points for the older year classes. However, these values were used in the von Bertalanffy plot of $-\ln[(L_\infty - L_t) / L_\infty]$ vs. age, t (Fig.4), substituting a series of values for L_∞ that were closer to the L_{max}. Thus:

$L_\infty = 666$ cm, $K = 0.016$, $t_0 = -7.0747$, $r = 1.000$ (Fig.5)
$L_\infty = 550$ cm, $K = 0.021$, $t_0 = -6.1452$, $r = 0.9993$ (Fig.6)
$L_\infty = 450$ cm, $K = 0.029$, $t_0 = -4.8705$, $r = 0.9991$ (Fig.7)

From the above estimations, three growth curves of female Beluga for the middle stanza were drawn (Fig.8). Even though more realistic curves are obtained with lower (though still high) values of r, the curves remain well within ±1SD.

(5) At this stage, the Gulland plot was repeated only for the older fish, again using estimates from the line of best fit (final stanza, Fig.9).

(6) The estimates of L_∞ and K from (5) were then used in the von Bertalanffy plot (Fig.10), $L_\infty = 533$ cm, $K = 0.023$ and $t_0 = -4.033$, $r = 0.9981$. Figure 11 illustrates the growth of female Beluga, showing annual means ±1SD (where $n \geq 2$) and the calculated von Bertalanffy curve for $L_\infty = 533$ cm, which is regarded realistic for females. The fit to annual means is not as close for the middle stanza, but the line is still almost invariably within ±1SD.

(7) Assuming that the Beluga larva measured about 10 mm at hatching (11 mm hatching length according to Ghazel 1987), by trial and error, von Bertalanffy parameters were calculated for the juvenile stanza, so that a curve from 10 mm at t = 0 joined the main curve at about t=0. The parameters then obtained were: $L_\infty = 320$, $K = 0.065$, $t_0 = -0.05$, $r = 0.997$.

Figure 12 illustrates the growth curves for female Beluga showing the three stanzas.

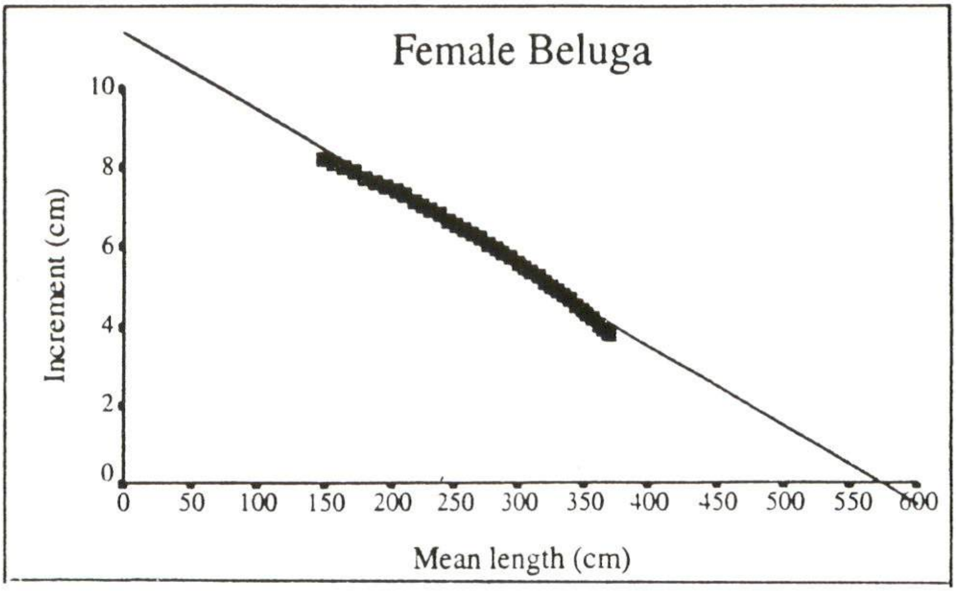

Fig. 3: Gulland plot using annual mean lengths estimated from line of best fit ($L\infty$=575cm, K=0.0159, r=0.995)

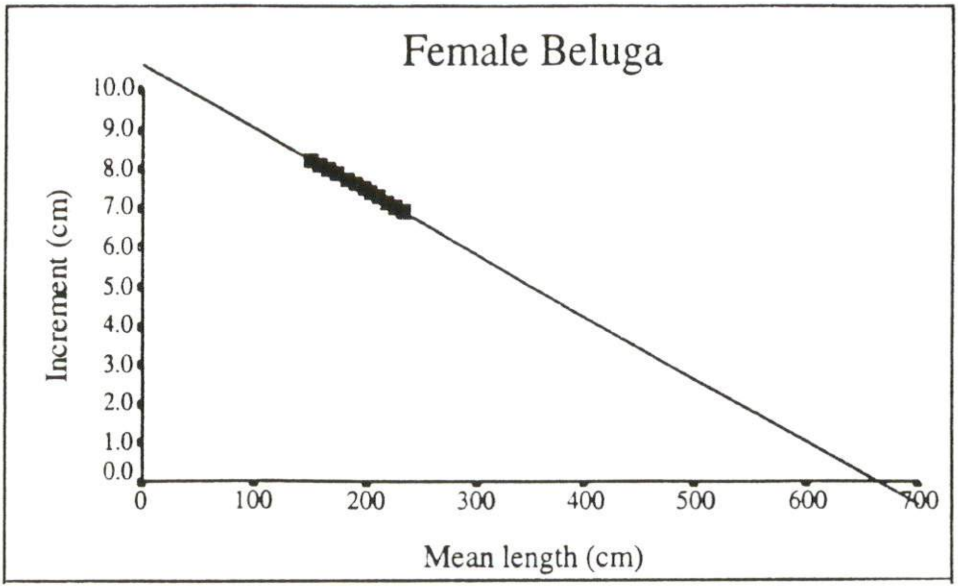

Fig. 4: Gulland plot using annual mean lengths obtained from the line of best fit middle stanza ($L\infty$=666cm, K=0.0158, r=0.999)

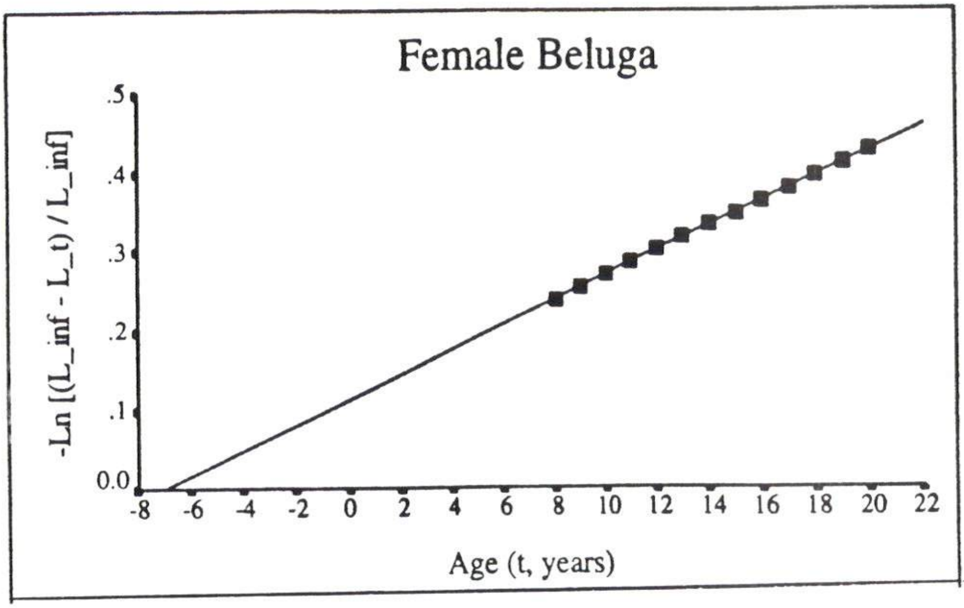

Fig. 5: Middle stanza: estimation of Von Bertalanffy parameters using annual lengths obtained from the line of best fit L_t=666[(1-exp(-0.0158(t+7.075)

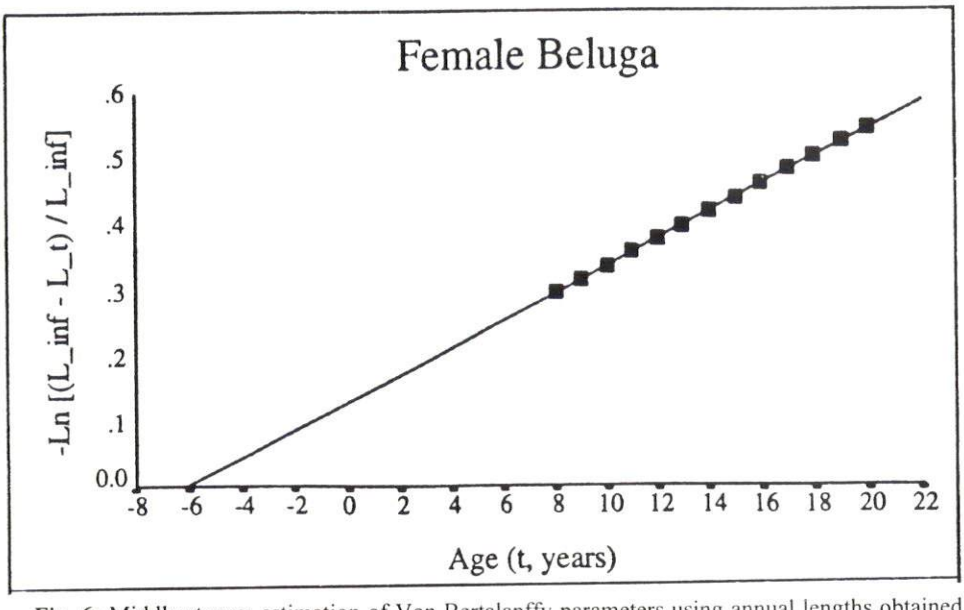

Fig. 6: Middle stanza: estimation of Von Bertalanffy parameters using annual lengths obtained from the line of best fit L_t=550[(1-exp(-0.0209(t+6.153)

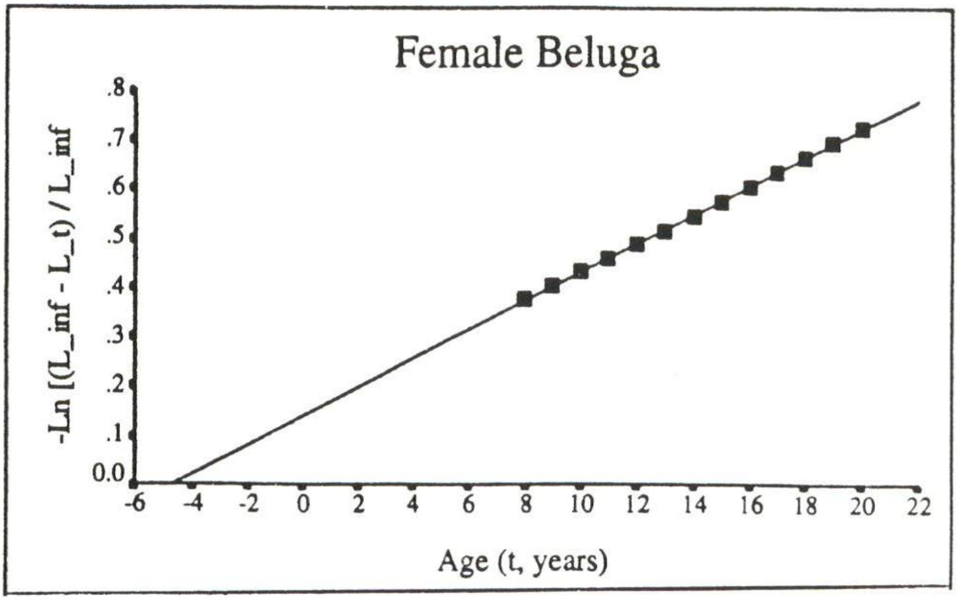

Fig. 7: Middle stanza: estimation of Von Bertalanfy parameters using annual lengths obtained from the line of best fit. L_t=450[(1-exp(-0.029(t+4.87)

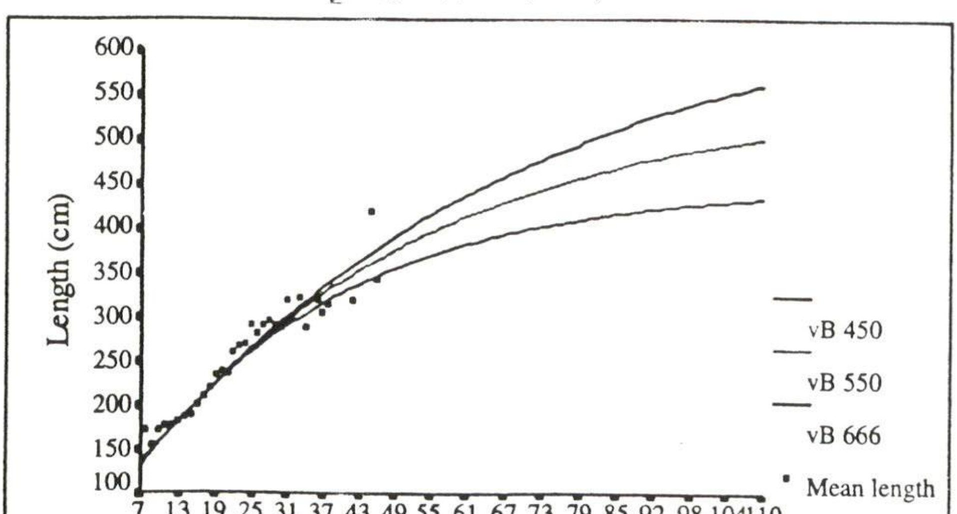

Fig. 8: Growth of female Beluga showing annual mean length for the middle stanza, with three fitted growth curves

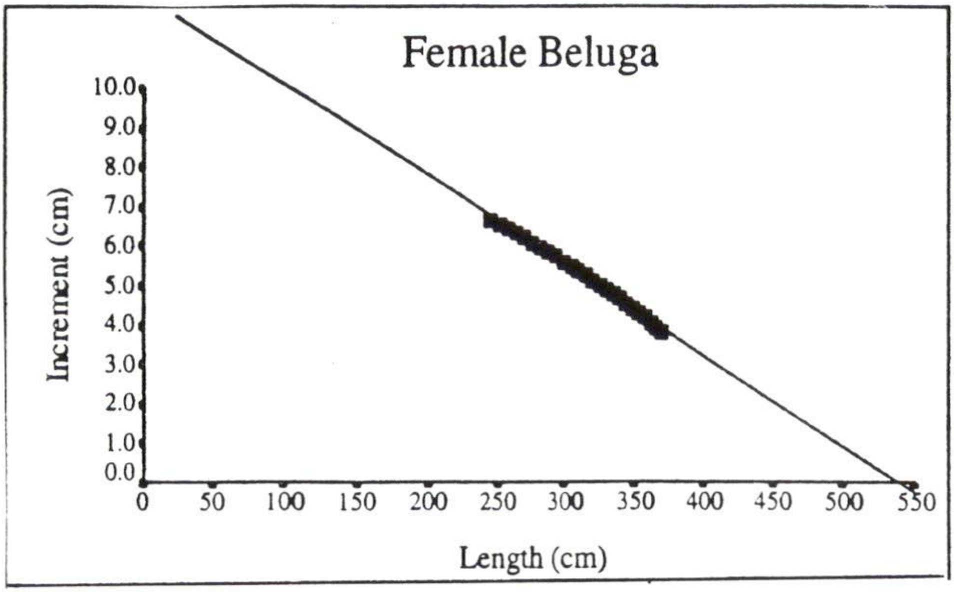

Fig. 9: Gulland Plot for older fish using annual lengths estimated from line of best fit

($L\infty$=533cm, K=0.023, r=0.998)

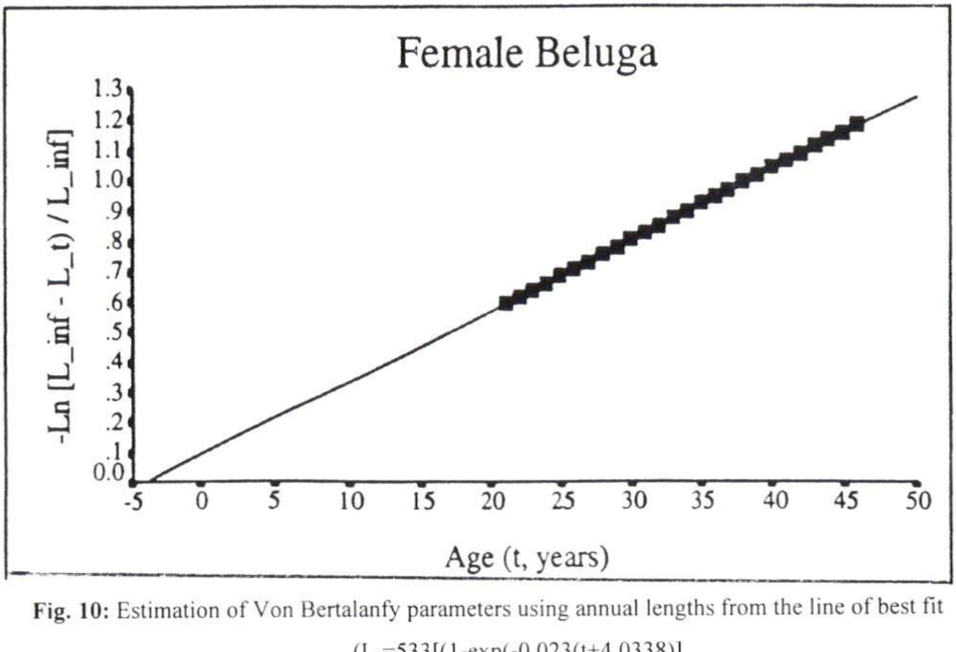

Fig. 10: Estimation of Von Bertalanfy parameters using annual lengths from the line of best fit

(L_t=533[(1-exp(-0.023(t+4.0338)]

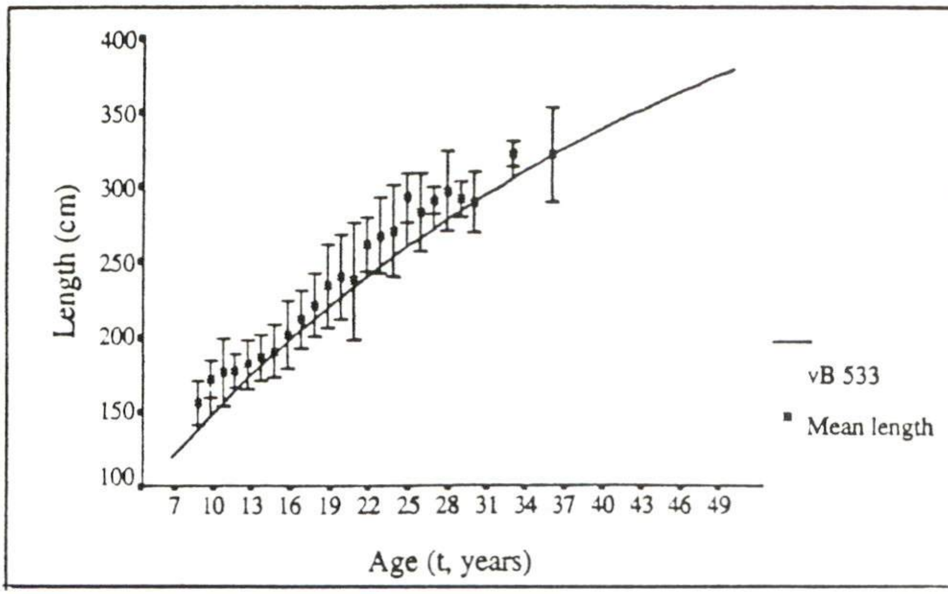

Fig. 11: Growth of female Beluga showing annual mean1SD (where n≥2) and calculated Von Bertalanfy curve for L∞=533cm

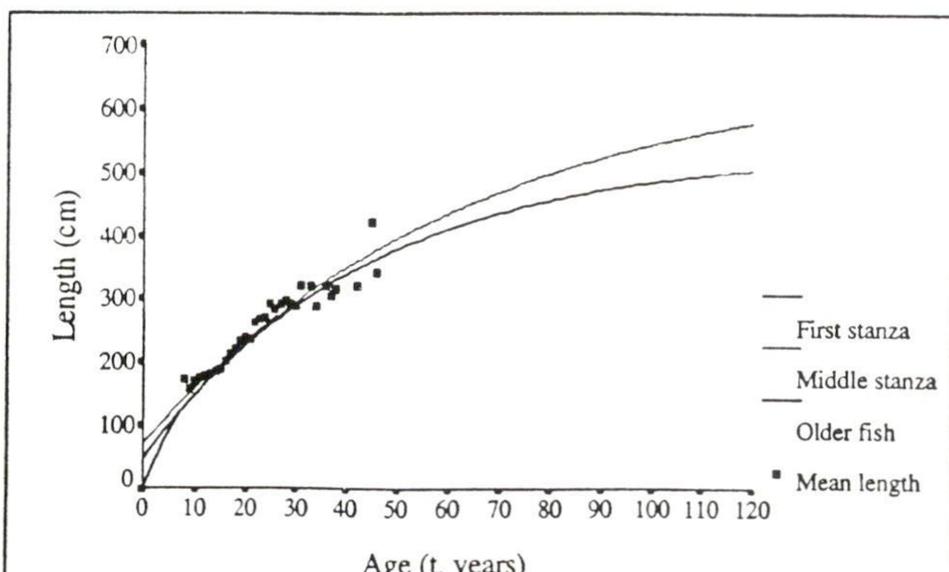

Fig. 12: Growth curves for female Beluga showing three stanza

Growth parameters of female Beluga were also estimated using FSAS program from the complete sets of mean length of the original data (Table 1) and are as follows:

$L\infty = 370$, $K = 0.052$, $t_0 = -0.354$, $r = 0.933$. Figure 13 indicates the growth curve for female Beluga based on FSAS estimation. The $L\infty$ estimated by this program is much lower than the maximum length observed (420 cm) in the original data, which shows that this program underestimates $L\infty$.

Table 1: Input data and regression for the von Bertalanffy plots of the female Beluga

Age (t)	Number	Mean length ±1SD	Length estimated from line of best fit	increment	$-\ln[(L_\infty - L_t)/L_\infty]$ $L_\infty = 666$ cm	$-\ln[(L_\infty - L_t)/L_\infty]$ $L_\infty = 550$ cm	$-\ln[(L_\infty - L_t)/L_\infty]$ $L_\infty = 450$ cm
8	1	172.0 ±0.00	141.4		.24	.30	.38
9	9	156.2 ± 14.9	149.6	8.2	.25	.32	.40
10	29	171.6 ± 12.5	157.7	8.1	.27	.34	.43
11	43	176.8 ± 22.6	165.7	8.0	.29	.36	.46
12	93	177.3 ± 11.5	173.5	7.9	.30	.38	.49
13	137	181.6 ± 16.2	181.3	7.7	.32	.40	.52
14	251	186.3 ± 15.6	188.9	7.6	.33	.42	.54
15	247	190.2 ± 17.5	196.4	7.5	.35	.44	.57
16	205	201.6 ± 22.7	203.8	7.4	.37	.46	.60
17	124	211.5 ± 19.1	211.0	7.3	.38	.48	.63
18	61	221.1 ± 21.0	218.2	7.1	.40	.51	.66
19	32	233.6 ± 28.1	225.2	7.0	.41	.53	.69
20	23	239.7 ± 28.1	232.1	6.9	.43	.55	.73
21	10	237.1 ± 38.8					
22	9	261.7 ± 18.0					
23	11	267.6 ± 25.1					
24	8	270.6 ± 30.9					
25	5	292.6 ± 16.4					
26	10	283.1 ± 26.1					
27	3	290.7 ± 9.00					
28	6	296.7 ± 26.5					
29	2	291.5 ±12.1					
30	2	289.5 ± 20.5					
31	2	320.0 ± 0.00					
32	0	000.0 ±0.00					
33	2	321.5 ±5.00					
34	2	289.0 ± 8.50					
35	0	000.0 ±0.00					
36	3	321.0 ± 31.5					
37	1	305.0 ± 0.00					
38	1	316.0 ± 0.00					
39	1	214.0 ± 0.00					
40	0	000.0 ±0.00					
41	1	320.0 ± 0.00					
42	0	000.0 ±0.00					
43	0	000.0 ±0.00					
44	1	420.0 ± 0.00					
45	0	000.0 ±0.00					
46	1	343.0 ± 0.00					

For male Beluga, the difficulty in estimating the von Bertalanffy parameters was greater. First, the sample sizes were smaller in all years; and secondly, the trend of growth indicated by annual means was more irregular in comparison with females. Therefore, the curve did not approximate to the von Bertalanffy, even when all the years are combined. However, by examining every year separately, it was found that some part of the data for the year 1997 could be used for a von Bertalanffy plot. Different values of $L\infty$ (270, 274 and 284 cm) near L_{max} were used, and the best one was found to be 270cm. Figure 14 indicates the von Bertalanffy plot for estimation of growth parameters:

$$L\infty = 270 \text{ cm}, K = 0.086, t0 = -0.259, r = 0.9099, P<0.01.$$

Figure 15 demonstrates the growth curve for male Beluga showing annual means ±1SD (where n≥2) and the calculated von Bertalanffy curve for $L\infty$= 270cm.

From the FSAS program, using combined years' mean length and forcing the curve through zero, the growth parameters of male Beluga were estimated as: $L\infty = 302$ cm, $K = 0.072$, $t_0 = -0.574$, $r = 0.9679$. Figure 16 shows the growth curve of males based on FSAS estimation.

Table 2: Male Beluga input data for estimation of von Bertalanffy growth parameters

Age (t, years)	Number	Mean length ±SD	-ln [(L∞ - Lt) / L∞]
8	1	177.0 ±0.00	
10	2	159.5 ±2.10	0.89
11	9	173.3 ±6.20	1.03
12	40	177.0 ±7.10	1.07
13	57	184.1 ±7.60	1.15
14	58	184.1 ±13.5	1.15
15	41	192.7 ±14.2	1.25
16	24	197.5 ±8.60	1.31
17	7	199.1 ±11.6	1.34
18	1	225.0 ±0.00	1.79
19	1	173.0 ±0.00	
20	1	238.0 ±0.00	
22	1	235.0 ±0.00	

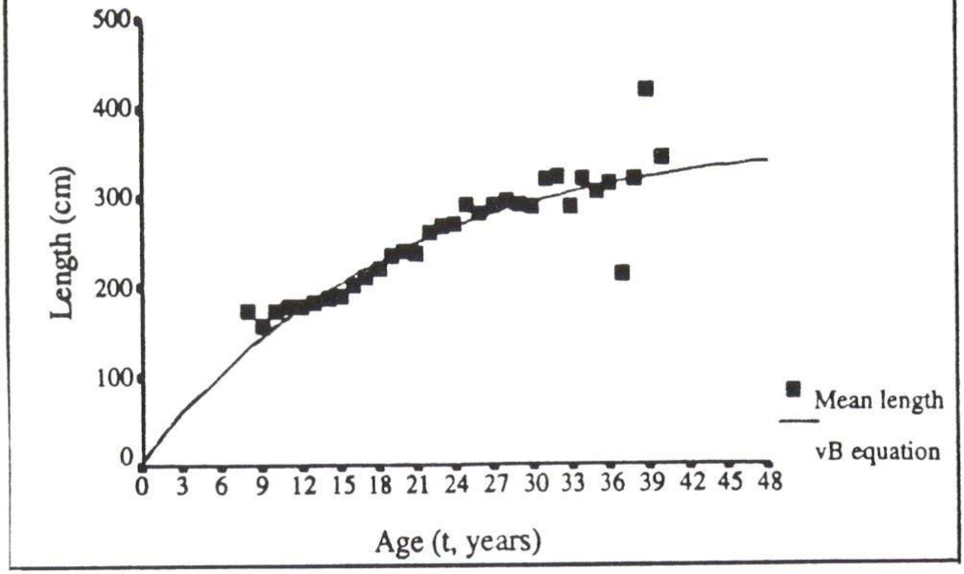

Fig. 13: Growth curve for female Beluga, estimated by FSAS program for L∞=369.6 cm

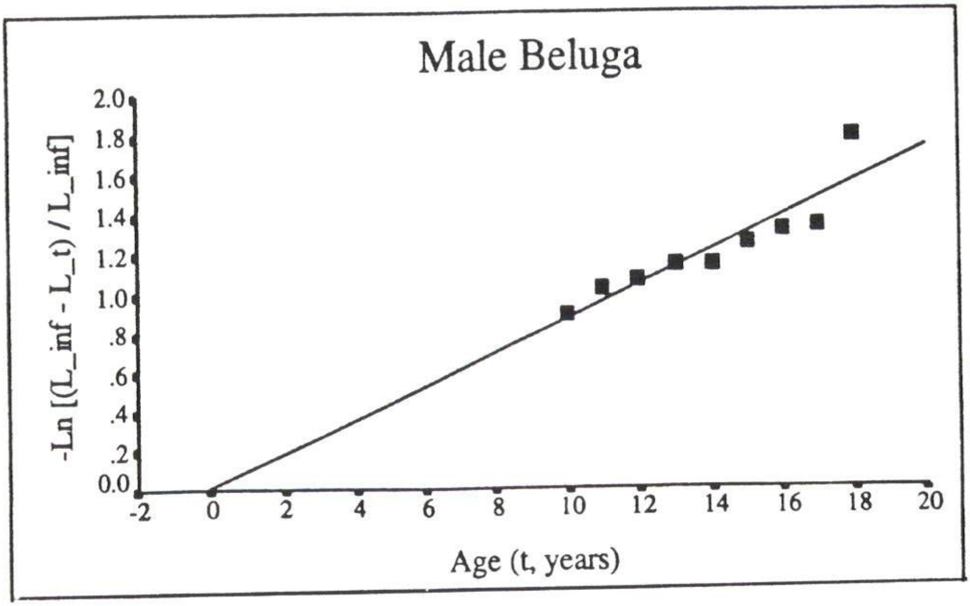

Fig. 14: Estimation of Von Bertalanffy parameters using mean length of year 1992.

$L=270[(1-\exp(-0.0855(t+0.259)$

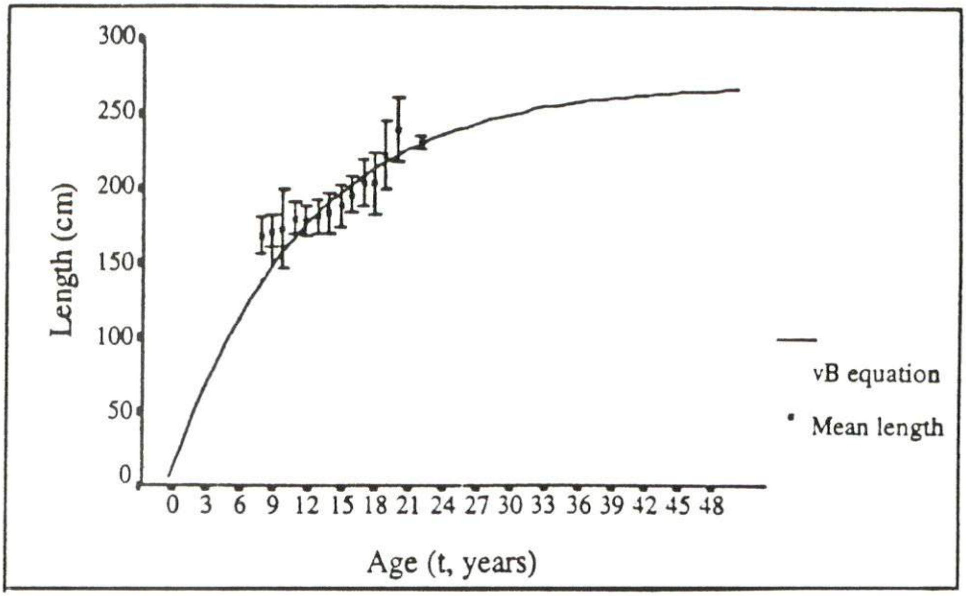

Fig. 15: Growth curve for male Beluga for L∞=270 cm

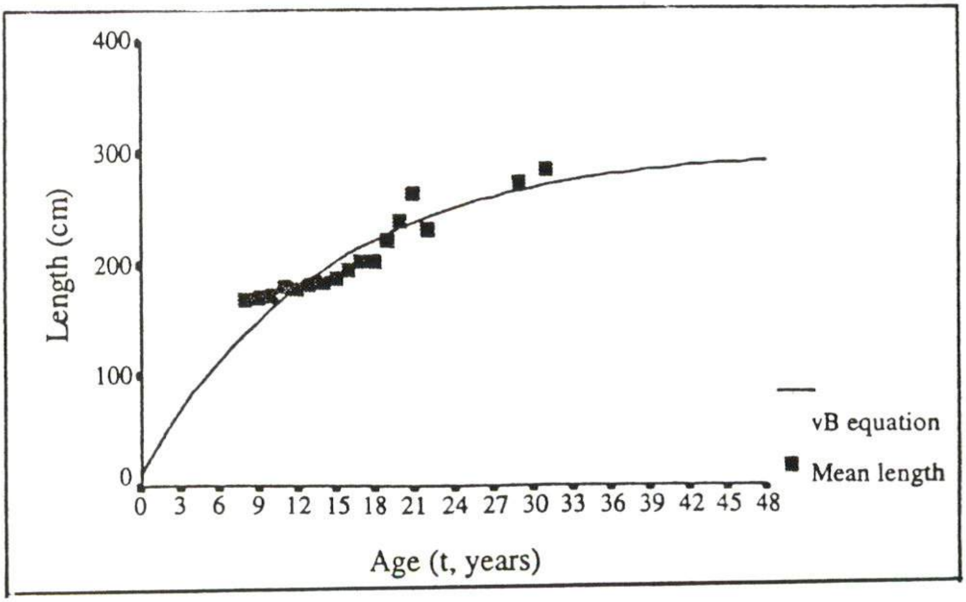

Fig. 16: Growth curve for male Beluga, estimated by FSAS program for L∞=301.8 cm

Mortality rates

Total mortalities of male and female Beluga estimated by different methods are shown in Table 3. As can be seen, the same values of total mortalities were derived from age-based and length-based catch curves for female Beluga. The value of Z estimated for males from age-based catch curves was much higher than that for females, the steeper slope reflecting the smaller numbers of males in the older (>16) age groups. Table 4 indicates the estimation of natural moralities by different formula.

Table 3: Total mortalities of female and male Beluga for combined years (n=1335 for females and 859 for males)

Sex	**Females**				**Males**			
Method	Catch curve (age)	Catch curve (length)	B&H Length	B&H Age	Catch curve (age)	Catch curve (length)	B&H length	B&H age
Z	0.48	0.48	0.21	0.67	0.67	0.38	0.22	0.75
R	0.982	0.984			0.992	0.981		
P	P<0.01	P<0.01			P<0.01	P<0.01		

B&H= Beverton and Holt

Table 4: Natural mortality of the Beluga estimated from Pauly's empirical formula and Richter and Efanov's formula

Pauly's empirical formula			Richter and Evanov's Formula		
Sex	**Female**	**Male**	**Sex**	**Female**	**Male**
L_∞ (cm) by FSAS	370	302	T_{m50} (year)	18	16
K	0.05	0.07	M	0.03	0.05
M	0.08	0.11			
L_∞ (cm) by L_{max}	533	270			
K	0.02	0.09			
M	0.04				

Fishing Mortality (F)

Once the values of total and natural mortality were calculated or estimated, the value of fishing mortality could be derived by splitting total mortality into natural mortality and fishing mortality as follows: F = Z-M

Table 5: Fishing mortalities of female and male Beluga in south of Caspian Sea

Sex	Female	Male
Z	0.48	0.38
M	0.03	0.05
F	0.45	0.33

Yield –Per-Recruit

Recruitment is the process of entry to a fishery, i.e. fishes first become liable to capture and thus enter the exploited phase of the population. Whether or not the fishing gear in use retains newly recruited fish, depends on its selectivite features and size of the fish (Beverton & Holt, 1957). Fishing mortality can vary, due to recruitment or selection, over a range of ages (or sizes), but for purposes of discussion and analysis it is easier, and often acceptable in practice, to treat recruitment or selection as being abrupt or knife-edged. That is, no fish enter the fishery until they reach an age T_r, but all fish of age T_r and older are fully recruited. Similarly, selection may be supposed to act so that fishing mortality is zero until the fish reach the mean selection age T_c, and then undergo the full, constant fishing mortality (Gulland, 1983).

Because of fluctuations in recruitment, yield is often expressed as yield per recruit. The yield per recruit model (Beverton & Holt, 1957) is in principle a model describing the state of the stock and the yield in a situation when the fishing pattern has been the same for such a long time that all living fish have been exposed to it since they recruited. Yield-per-recruit is greatly influenced by fishing mortality, and the shape of the yield curve depends greatly on growth parameters and natural mortality. Where K and M are low, the highest yields will be obtained at low F, simply because the fish will have the chance to grow bigger.

Yield-per-recruit curve for the Beluga, estimated based on growth parameters and mortality rates, to provide advice for Beluga fishery managements in Caspian Sea, in terms of yield-per-recruit and the fishing mortality ('F_S') is necessary to achieve the maximum sustainable yield, MSY.

For female Beluga, a yield per recruit curve was produced as a function of F for the following parameter values:

K = 0.0524	T_c = 14.0 year	t_0 = -0.354 year
M = 0.03	T_r = 9.0 year	$W\infty$ = 497.0 kg

It was found that F = 0.07 gives the maximum Y/R, the "maximum sustainable yield per recruit: MSY/R=107.5 kg per recruit, which corresponds to the optimum fishing mortality: F_S = 0.07 per year.

For male Beluga, was Y/R calculated using the following parameter values:

K = 0.072	T_c = 13.0 year	t_0 = - 0.754 year
M = 0.05	T_r = 8.0	$W\infty$ = 247.3 kg

The optimum value of fishing mortality for male Beluga was found to be F_S= 0.16, which gives the maximum sustainable yield of MSY/R = 57.6 kg per recruit.

Discussion

Sturgeon stocks have been depressed throughout the world because of demand for their highly valued flesh and caviar produced from their eggs. Human activities in watersheds, where sturgeon live have, affected their habitat. At the present, the population of sturgeon in Caspian Sea depends on both natural and artificial reproduction. The efficiency of natural reproduction is determined by flow in rivers as well as other environmental factors.

The population age structure was found to lack older fish: for Beluga more than one half of the potential age groups were absent.

The results of the present study suggest that growth of Beluga can be divided into three distinct stanzas, characterized by different values of the von Bertalanffy parameters, during the life of this sturgeon. Initially, before they enter the fishery, growth rate is high; between ages of about 9 to 21. In classes that dominate in the fishery, growth rate is intermediate that appears to be slower from about 24 onwards. The results also show that, because of the variation in growth rates, using Gulland and Holt plot cannot derive Von Bertalanffy parameters simply. Although the parameters were estimated using FSAS (Fishery Science Application System) computer program, by forcing the curve through zero, it appeared that this program underestimated $L\infty$ for the whole life span of the Beluga, as there were many specimens in the annual catches that were larger than the estimated $L\infty$. Table 6 shows the values of $L\infty$ and K estimated by both methods.

Table 6: $L\infty$ and K estimated for Beluga by two methods

Species	**Sexes**	**By using L_{max}** **L_{∞}, K**	**by FSAS program** **L_{∞}, K**
Beluga	**Female**	533 cm, 0.023	370 cm, 0.052

Note: L_{max} was not used for estimation of L_{∞} and K for the female Beluga.

Since Beluga is a long-lived, late maturing species, the change in growth rate, which appears to occur at about age 19-25, may be a consequence of maturity though the first maturity of Beluga tends to be sooner (perhaps 15-18). It may be that the relationship between fecundity and body weight differs between the first and subsequent maturations, as Raspopov (1987) noted a lower fecundity for the first time spawning Beluga. Thereafter, the females are believed to mature and spawn every 3-5 years. Thus, for female Beluga, the best way of calculating von Bertalanffy parameters was to regard the growth as comprising three stages, and the von Bertalanffy parameters were estimated for juveniles, for middle stanza, and for older fish separately. The value of L∞ for the female Beluga was estimated 320 cm for the juveniles, 450-666 cm for the middle stanza, and 533 cm for the older fish.

The value of K for the female Beluga was estimated as 0.065 for the juveniles, 0.029-0.016 for the middle stanza, and 0.023 for the older fish. Total mortalities (Z) were estimated using different methods of estimation. The preferred values of Z were 0.48 and 0.38 for female and male Beluga, respectively.

According to Sparre *et al.* (1989), when estimating the value of Z from the catch curve, any points which are systematically deviating from the straight line are excluded. However, it is difficult to give a general rule for when this deviation is sufficiently large to justify the exclusion of the point. In sturgeons, because of the large range of age groups in the catches, choosing which points to exclude is especially difficult. For Beluga, some older age groups were excluded because of their very small numbers in the sample. As the older age groups are progressively less represented in the catch, the estimates of the total mortality are almost certainly too high, especially for the male.

There are no other data available on total mortality of Beluga in Caspian Sea. Semakula and Larkin (1986) used catch data from commercial fisheries and estimated total mortality (Z= 0.219) of white sturgeon (*A. transmontanus*) of the Fraser River from the descending axis of the gill net selectivity curve. Total mortality (Z) for *A. brevirostrum* in St John River Estuary was estimated by Dadswell (1979) as 0.12-0.15. These values are much lower than those of Caspian Sea species as they are less exploited.

Natural mortality (M) was estimated using Pauly's empirical formula (1980b) and Richter and Efanov's formula (1976). As expected for long-lived species (Beverton & Holt, 1959), natural mortality estimates were low. The preferred values of M were, 0.03 and 0.05 for female and male Beluga.

There are no other data available on estimation of natural mortality of Beluga in Caspian Sea. The values of natural mortality are 0.01 for *A. fulvescens* in Wisconsin, USA (Beverton & Holt, 1959), 0.05 for *A. transmontanus* in the Fraser River, Canada, (Semakula and Larkin, 1969) and 0.03 for *A. medirostris* in the Gulf of California (Pycha, 1956).

Current fishing mortalities (F) were estimated by subtracting natural mortality from total mortality, both for females and males (Table 5). The averaged fishing mortalities for females and males together were 0.39. All parameters estimated for Beluga are summarized in Table 7.

Table 7: Growth parameters, total, natural and current fishing mortalities and optimum fishing mortalities (F_S) for Beluga.

Species	Sex	Using L_{max} L_∞, K	FSAS program L_∞, K	Z from different methods	M from different methods	Fishing mortality	F_s
	Female Juvenile	320 cm, 0.065					
Beluga	Female middle stanza	666 cm, 0.016 550 cm, 0.021 450 cm, 0.029	370 cm, 0.052	0.21-0.67	0.03-0.04	0.45	0.07
	Female older fish	533 cm, 0.023					
	Male	270 cm, 0.086	302 cm, 0.072	0.22-0.75	0.05-0.11	0.33	0.16

During the current years, a sharp decline in sturgeon catches has been observed. For example, catches in the Caspian basin were as much as 27,000 tones in 1982, but they were only 12,442 tones in 1992 and 7,274 tones in 1993. In addition, analysis of age composition shows that most of the specimens of Beluga (southern basin) are now less than 20 years old.

Inspection of the yield-per-recruit model for Beluga in Caspian Sea indicates that fishing mortality should be stopped for this species in Caspian Sea. This result proves over-fishing of sturgeon in Caspian Sea. Several other authors such as Smith (1990), Birstein (1993), Bemis and Findeis (1994), Dumont (1995) and current catch data, have reached the same conclusion on over fishing of Beluga in Caspian Sea.

Thus, to improve the present situation of Caspian Sea, it is necessary to reduce the fishing mortality (legal and illegal). The non-observance of fishery regulations after the break-up of the Soviet Union contributed to a drastic decline in the number of sturgeons. It seems that the population of Beluga, probably because of the higher quality of its caviar, is more depleted than others, and the number and quality of spawners have been negatively affected. Therefore, in order to maintain the spawning stock, the harvesting of Beluga (except for artificial propagation) should be restricted for a period of several years, as Iranian Fisheries authority has started this program several years ago. The sturgeon stock in the sea currently multiplies through a combination of natural and artificial reproduction. Fortunately, the artificial propagation of sturgeon is well developed and every year many fingerlings are released in the sea, but the environmental conditions of Caspian Sea should also be taken into consideration as determining factor in their survival and growth.

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