DOI: 10.2478/cjf-2020-0001

**CODEN RIBAEG ISSN 1330-061X (print)
1848-0586 (online)**

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BIOLOGICAL PARAMETERS AND FISHERIES INDICES OF BELUGA STURGEON *Huso Huso* IN THE SOUTHERN CASPIAN SEA

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ARTICLE INFO

Received: 26 July 2019
Accepted: 25 November 2019

Keywords:
Growth parameters
Maturity
Life history
Great sturgeon
Caspian Sea

ABSTRACT

There is a significant lack of data for the biological parameters of beluga or great sturgeon, the largest fish in the Caspian Sea. The age, growth and fisheries indices for the stock status of beluga was investigated in the south Caspian Basin of Iran between 1990 and 2011. Fork lengths ranged between 113-420 cm and weights from 8.0 to 725.0 kg. The growth parameters were L_∞ = 440 cm, K = 0.027 year^{-1}, t_0 = − 5.8 years. The age at first capture (t_c) was 13.1 years. The long-term age composition data showed age up to 63 years, and the ages 12-19 years comprised 76.7% of the total catch. The generation length was 33 years. The values of "*KF*" were close to 1 or >1, indicating that beluga sturgeon is in a favorable condition in the southern Caspian Sea. The length distribution showed that 24.2% of the catch is comprised of juveniles. Based on the age structure and age at first maturity, recruitment and growth overfishing occurred in beluga stocks. Therefore, increased length or age at first capture in future fishery policies should be implemented. The mega-spawners represented 4.4% of the fish captured and revealed an unhealthy population structure.

How to Cite

Fazli, H., Tavakoli, M., Behrouz Khoshghalb, M. R., Moghim, M. (2020): Biological parameters and fisheries indices of beluga sturgeon *Huso huso* in the southern Caspian Sea. Croatian Journal of Fisheries, 78, 1-10. DOI: 10.2478/cjf-2020-0001.

INTRODUCTION

Before damming the Volga River, fishing was the major factor affecting sturgeon populations, and after World War II (1950), fishing pressure on sturgeons was increased in the Volga Caspian Basin (Ruban and Khodorevskaya, 2011). According to Ruban et al. (2019), the natural reproduction of sturgeon species in the Volga Caspian Basin has declined substantially during the past six decades due to the impact of anthropogenic factors. All sturgeon species are especially vulnerable to overfishing because of commercial importance. Taghavi Motlagh (2001) reported that beluga is an overfished species in the Caspian Sea. During the past three decades, the anthropogenic invasive species, pollution and poaching influenced all components of the Caspian Sea (Pourang et al., 2016; Luttuada et al., 2019). Also, Beyraghdar Kashkooli et al. (2017) reported that the environment of the Caspian Sea is shifted to a new condition. Due to this undesirable ecosystem, all sturgeon species are listed under Acipeserides I or II CITES in the Caspian Sea (CITES and UNEP, 2017). Beluga or great sturgeon *Huso huso* (Linnaeus, 1758) is present in the Caspian and Black Seas and Sea of Azov (CITES, 2000). It is the largest fish species of the entire Caspian Sea Basin. Beluga sturgeon feed on crustaceans, mollusks, worms and fishes. In contrast to other sturgeon species, beluga sturgeon adults are pelagic predators (Coad, 2019). Due to delayed maturation, high fecundity and long life span, the populations of beluga sturgeon buffer from changes in environmental status and admeasures energy for growth, allowing beluga sturgeon to get a bigger size (Beamesderfer and Farr, 1997). Unfortunately, our knowledge on the ecological parameters of the beluga sturgeon population was limited to the age, growth, mortality and yield-per-recruit in the south of the Caspian Sea by using limited sample size (~1580 specimens collected during 1996-1999; Taghavi Motlagh, 2001). This information is vital due to several factors affecting the ecosystem structure and fish stocks. Also, age and growth studies have required the estimation of mortality rate, productivity and management purposes. The aim of this study is, therefore, to provide information on the basic biological parameters (age and growth), generation length and optimum length of beluga sturgeon based on the data collected during the years between 1990-2011. Fisheries indicators are described as a simple management strategy based on the min-max ranges of capture for the species in the Caspian Sea.

MATERIALS AND METHODS

The fish samples were collected from Iranian commercial fisheries (by gillnets and beach seines) between 1990 and 2011. In total, 7791 beluga sturgeon specimens were analyzed. During the sampling period, the fork length (*FL*) and total length (*TL*) were measured to the nearest 1 cm, body weight (*W*) to the nearest 100 g. The age of 5202 individuals was determined by pectoral fin ray sections (Table 1).

After visual sex determination, the maturity stages were distinguished according to the six-stage maturity scale based on macroscopic examination in the ovary, as described by Moghim et al. (2002). The difference between the length classes frequency in sexes was analyzed by the Kolmogorov–Smirnov (K–S) test.
The length-weight relation was estimated by exponential regression: $W= aFL^b$ (Ricker, 1975), where *a* and *b* are

Table 1. Average fork length and weight at age of *Huso huso* in Iranian waters of the Caspian Sea

Age	Frequency		Fork length (cm)		Weight (g)	
	N	%	Mean	SD	Mean	SD
7	3	0.06	133.7	4.93	20.00	2.83
8	11	0.21	142.1	3.05	29.88	7.94
9	29	0.56	157.4	8.00	36.17	6.71
10	127	2.44	167.1	12.34	44.09	11.21
11	230	4.42	174.1	11.49	49.83	10.60
12	389	7.48	177.8	12.31	54.12	12.42
13	498	9.57	181.5	14.74	58.50	15.11
14	722	13.88	185.1	15.02	63.44	17.15
15	688	13.23	189.7	15.08	69.58	19.76

Age	Frequency		Fork length (cm)		Weight (g)	
	N	%	Mean	SD	Mean	SD
16	600	11.53	197.1	20.37	78.60	28.58
17	488	9.38	199.7	22.84	85.68	34.91
18	329	6.32	200.6	23.41	86.54	34.82
19	278	5.34	205.7	22.93	93.37	36.11
20	186	3.58	216.0	24.17	110.53	39.88
21	88	1.69	226.0	30.61	126.09	55.72
22	79	1.52	228.7	27.49	131.64	48.60
23	65	1.25	233.6	30.46	144.23	64.35
24	61	1.17	234.4	29.69	140.47	57.28
25	63	1.21	233.3	25.63	142.29	52.08
26	62	1.19	249.1	28.94	172.20	68.41
27	48	0.92	250.3	27.42	174.50	53.74
28	32	0.62	259.3	28.57	195.05	72.41
29	20	0.38	266.1	24.78	206.90	67.78
30	19	0.37	257.6	18.48	194.05	49.65
31	12	0.23	286.1	34.19	278.58	94.70
32	5	0.10	290.2	24.53	253.00	44.08
33	10	0.19	292.7	25.30	269.30	51.41
34	7	0.13	269.9	24.42	225.87	69.72
35	7	0.13	288.3	40.33	279.00	118.63
36	10	0.19	303.9	43.18	326.20	112.41
37	6	0.12	299.3	39.13	276.50	129.67
38	6	0.12	296.5	43.98	323.43	115.03
39	10	0.19	299.0	45.09	320.50	115.14
40	6	0.12	318.3	24.01	333.67	55.10
42	1	0.02	320.0	-	432.00	-
43	1	0.02	367.0	-	492.00	-
44	1	0.02	306.0	-	357.00	-
45	3	0.06	366.3	46.80	547.00	172.31
46	1	0.02	343.0	-	458.00	-
63	1	0.02	379.0	-	545.00	-
Total	**5202**	**100**	**197.0**	**30.27**	**83.53**	**53.25**

parameters. Parameter estimation was conducted by least-squares linear regression on log-log transformed data: $log(W) = log(a) + b \times log(TL)$. The allometric growth values were compared with the expected $b = 3$ by Student's t-test. Further, *TL* and *FL* relationship was established by linear regression.

The condition factor (*KF*) was calculated based on the following equation (Froese, 2006):

$$KF = (W / FL^3) \times 100$$

The von Bertalanffy growth model was applied to the lengths at age, and growth performance index value (φ') was calculated as:

$$L_t = L_\infty(1-e^{-K(t-t_0)})$$

$$\varphi' = logK + 2logL_\infty$$

Where L_t is fork length at age *t*, *K* is growth coefficient, L_∞ is the theoretical maximum length, and t_0 is hypothetical age at $L_t = 0$. The natural mortality (*M*) was estimated on Bertalanffy growth parameters (Pauly, 1980) and habitat temperature set at 16.5°C (Nasrollahzadeh, 2013). The age at first capture (t_c, the age at which 50% of the fish are vulnerable to capture) was calculated by using the Pauly method, from length-converted catch curve with corresponding to age via growth equation (Pauly, 1984).

The generation length (*GL*, the average age of parents) was calculated according to the following equation (IUCN, 2017):

$$GL=(3/M)+A_{50}$$

Where *M* is adult natural mortality and A_{50} is the average age at first reproduction. According to Froese and Pauly (2019), the age of female sexual maturity of beluga sturgeon ranged between 14-20 years. In the present study, the median age of female maturity (17 years) was used as age at first reproduction. The beluga sturgeon stock status was assessed using three indicators based on length classes of catches (Froese, 2004): (I) percentage of mature individuals ($>L_{m50\%}$); (II) frequency of fish caught at ± 10% optimum length (L_{opt}). L_{opt} was calculated by using the growth parameters (using L_∞, *M*, and *K*) as (Beverton, 1992):

$$L_{opt} = L_\infty / ((3+(M/K))$$

(III) frequency of fish with length bigger L_{opt} plus 10% ($> 1.1\ L_{opt}$), assigned as mega-spawners (Froese, 2004).

RESULTS

The results showed that the fork length (*FL*) and weight (*W*) of beluga sturgeon ranged from 113 to 420 cm and from 8.0 to 725.0 kg, and averaged (±SD) 202.8 (±33.83) cm and 93.33 (±60.75) kg, respectively. The longest fish (*FL* = 420 cm and weight = 725.0 kg) was a female, with an age of 63 years and caviar (roe) weight of 98.2 kg. The mean *FL* and *W* of females and males were 209.5 ± 37.66 cm and 106.35 ± 70.35 kg, and 192.1 ± 22.89 cm and 72.57 ± 31.39 kg, respectively, the mean *FL* and *W* in females being significantly higher than in males ($t = 25.3$, $p < 0.001$ and $t = 28.9$, $p < 0.001$; for *FL* and *W*, respectively).

The annual length-frequency distribution of beluga sturgeon, by combined sexes, is shown in Fig. 1. In the length classes, male individuals smaller than 205 cm were predominant (Fig. 2), and the length classes of both sexes were markedly different ($K\text{–}S = 9.89$, $p < 0.001$).

The *FL-W* regression of the whole sample was: $W = 7.8^{-6}FL^{3.048}$ ($R^2 = 0.88$, S.E. of $b = 0.013$, n = 7791); for females $W=7.63^{-6}FL^{3.056}$ ($R^2= 0.89$, S.E. of $b = 0.016$, n= 4787) and for males $W=2.711^{-5}FL^{2.805}$ ($R^2= 0.79$, S.E. of $b = 0.027$, n = 3004). The slopes of the *FL-W* regressions were significantly different from 3 ($P<0.001$), indicating that males tend to grow slightly faster in length than in weight. In contrast, females and the whole population appear to grow slightly slower in length than in weight. The total length-fork length regression was TL = 11.3+1.0581×FL ($R^2= 0.98$, n = 2309).

Of the 7791 specimens, females predominated, representing 61.4% of the total sample. The male: female ratio (M: F) was 1:1.59.

The average (± *S.E.*) condition factors (*KF*) of females and males were 1.04 ± 0.003 and 0.98 ± 0.003, respectively, the mean *KF* in females being significantly greater than in males ($t = 132.5$, $p <0.001$). The annual *KF* of males ranged from 0.91 in 1990 to 1.06 in 2006. The annual *KF* of females had an increasing trend from 0.94 in 1990 to 1.16 in 2010 (Fig. 3). Average of the KF differed significantly among the years ($F = 10.6$; $P < 0.001$ for males and $F = 18.5$; $P < 0.001$ for females; Fig. 3).

Monthly *KF* average values of both sexes showed that the lowest values occurred in July (Fig. 4). Also, average of *KF* varied significantly among the months ($F = 5.2$; $P < 0.001$ for males and $F = 22.0$; $P < 0.001$ for females). Immature ovaries (maturity stage II) increased from 44-52% in January-April to 100% in July, then declined to the lowest level (29%) in December. During January-April and September-December, the proportion of maturity IV was more abundant, ranging between 44-53% and 53-66% of total individuals, respectively (Fig. 5).

Based on the fin ray section analysis, the growth parameters L_∞, *K*, and t_0 were 440 cm, 0.027 year^{-1}, and -5.8 years (Fig. 6), and the growth index was 3.72.

In the commercial catch composition, the age groups varied between 7 and 63. The age of 14 years was the largest age group which accounted for 13.9%, and the majority of the catch (76.7%) belonged to the age of 12-19 years. A noticeable gap was observed for ages 41 and 47-62, with no specimens recorded at these ages. The estimate of natural mortality for beluga sturgeon was 0.062 year^{-1}. The age at first capture (t_c) was 13.1 years (Fig. 7). The generation length by using age at first reproduction was 33 years. The juveniles of beluga sturgeon corresponded to 24.2% of the stock. Also, L_{opt} range comprised 20.0% of the fish, while mega-spawners obtained 4.4% of the total catch (Fig. 8).

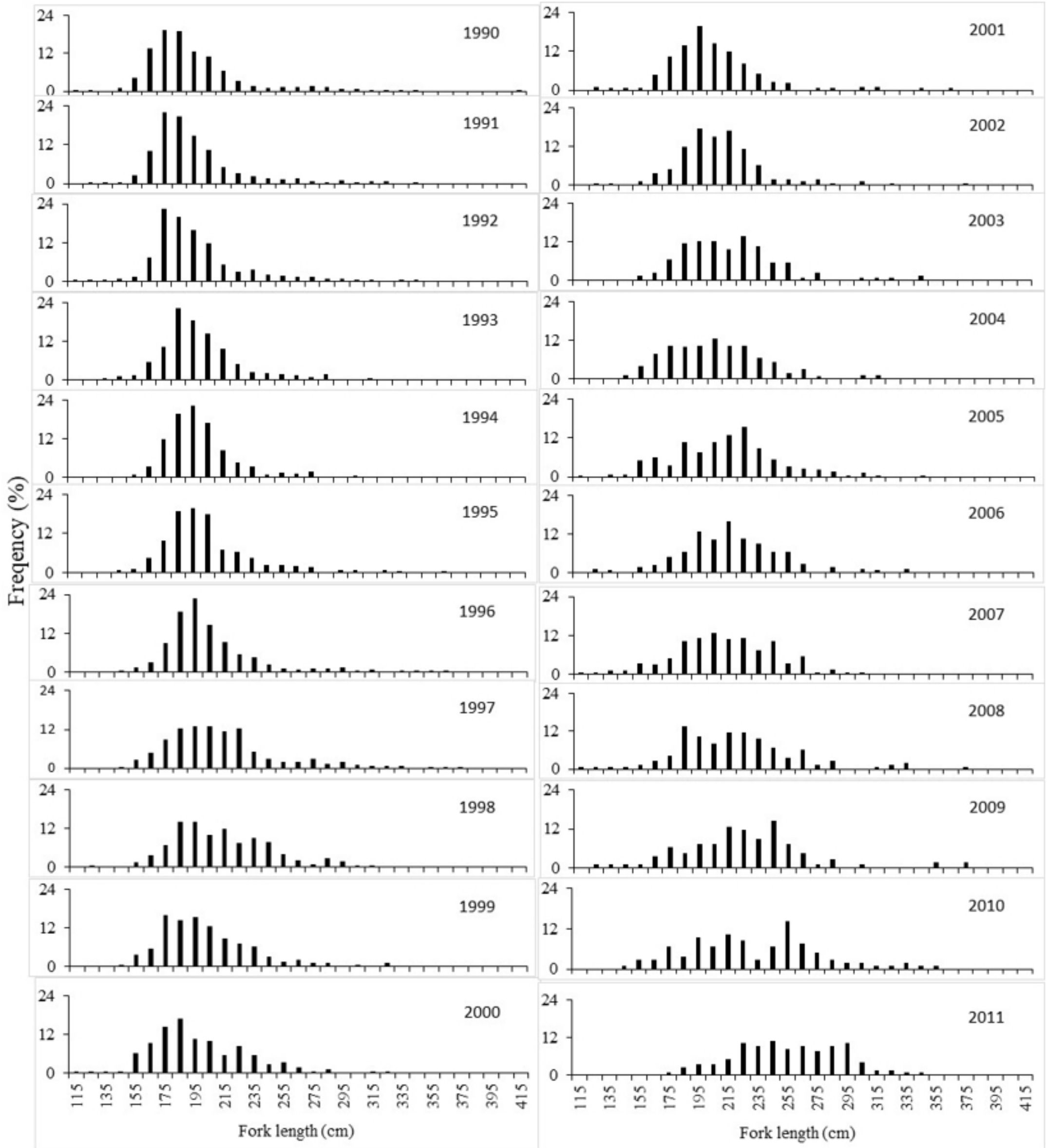

Fig 1. Length frequency distribution of *Huso huso* in Iranian waters of the Caspian Sea during 1990–2011

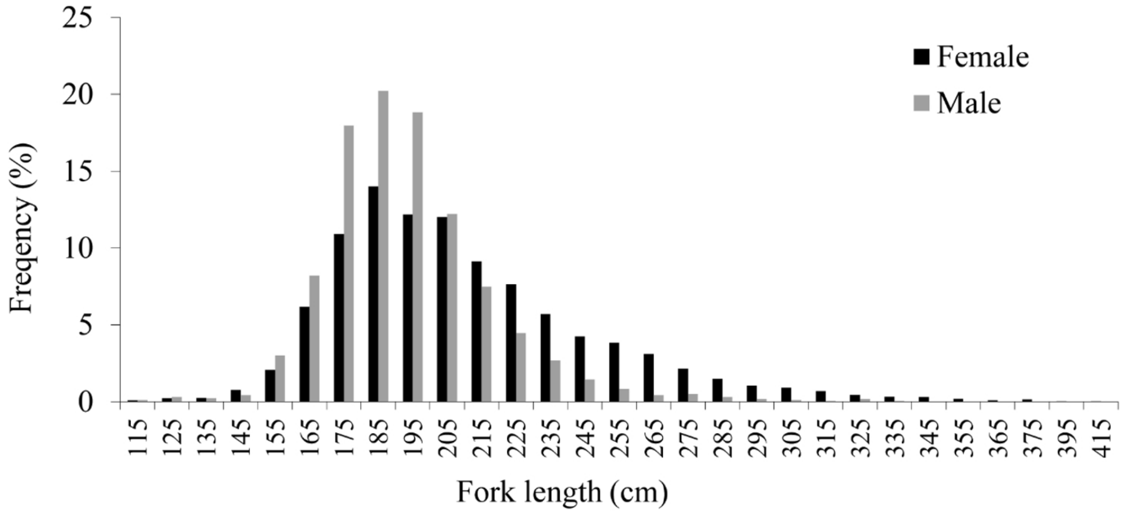

Fig 2. Length frequency distributions of females and males of *Huso huso* in Iranian waters of the Caspian Sea

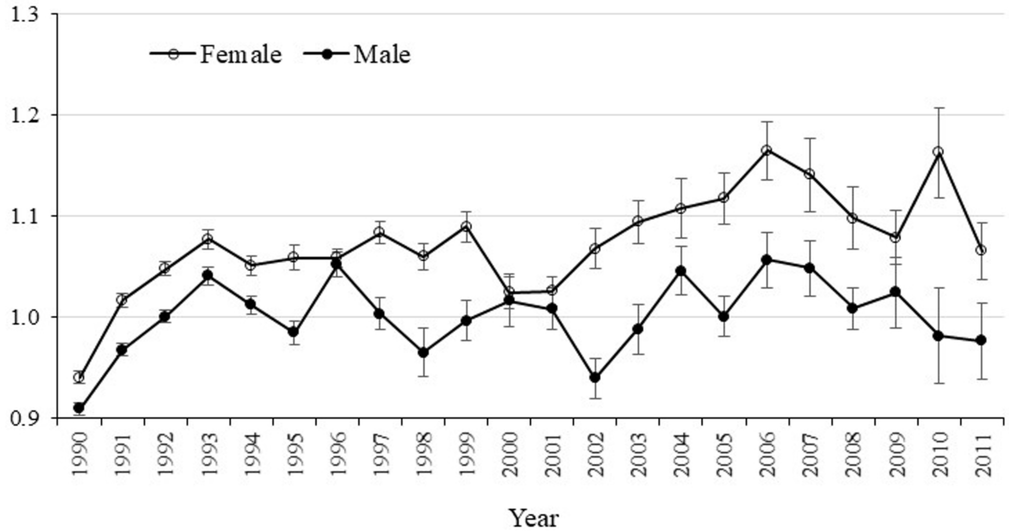

Fig 3. Condition factor (mean±S.E.) of *Huso huso* in Iranian waters of the Caspian Sea during 1990–2011

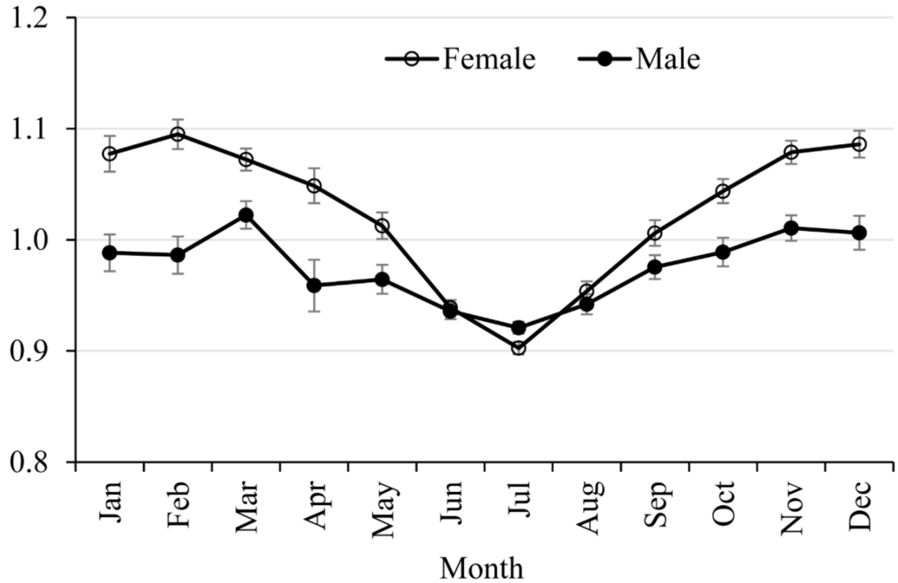

Fig 4. Monthly condition factor (mean±S.E.) of *Huso huso* in Iranian waters of the Caspian Sea

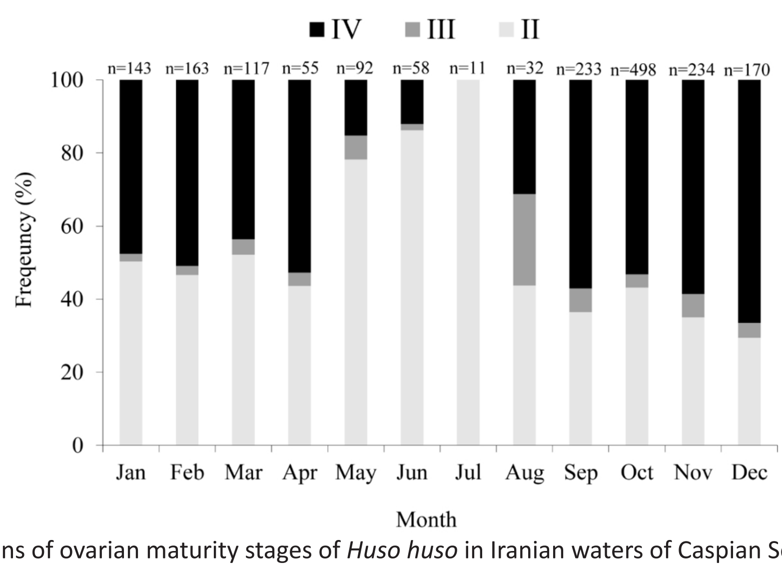

Fig 5. Monthly variations of ovarian maturity stages of *Huso huso* in Iranian waters of Caspian Sea (stage II = immature; stage III = maturing; stage IV= fully mature)

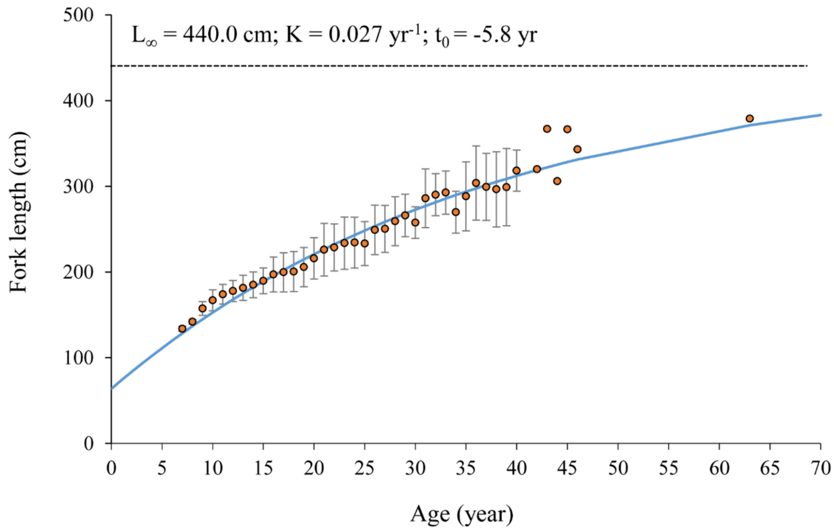

Fig 6. Theoretical growth curve for fork length of *Huso huso* in the southern Caspian Sea

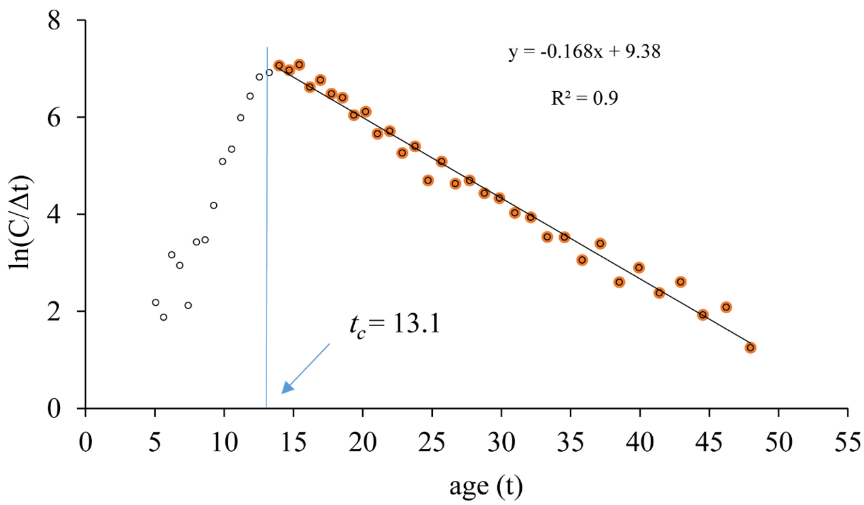

Fig 7. Estimation of the selection ogive of *Huso huso* from length converted catch curve analysis using the Pauly (1984) method

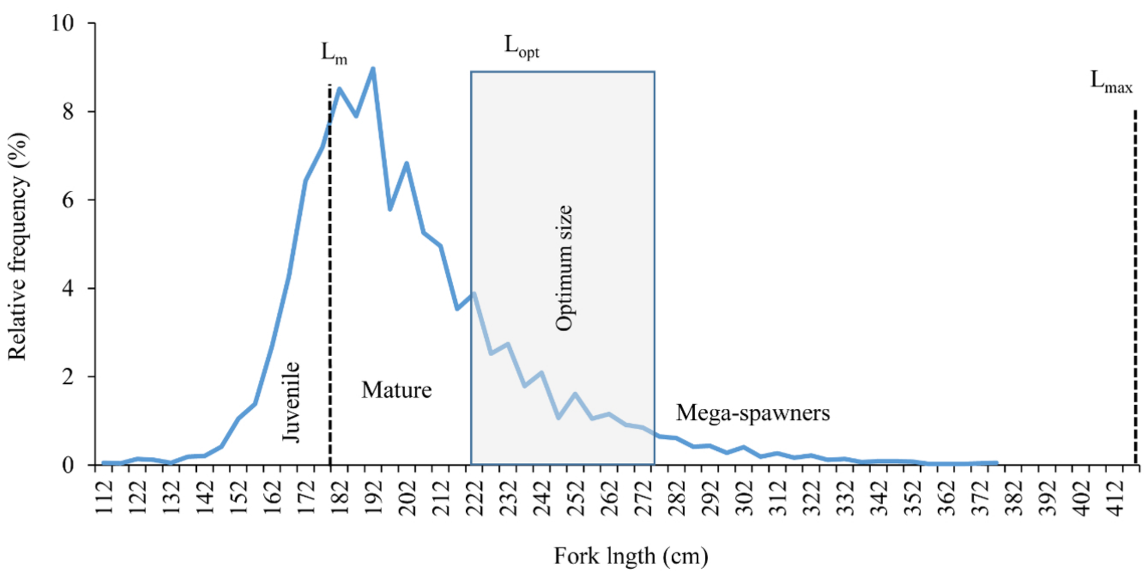

Fig 8. Length–frequency of *Huso huso* in landings between 1990 and 2011 in the southern Caspian Sea. L_m indicates length at first maturity, L_{opt} indicates the length range where optimum yield could be obtained and L_{max} is the maximum recorded size.

DISCUSSION

In this study, new information on the parameters of the beluga sturgeon population scattered in the southern Caspian Sea were presented. Monthly variations of ovarian maturity stages revealed that the proportion of maturity stage IV was more than 44% during January-April and September-December (Fig. 4). To our knowledge, the roe from ovaries maturity stage IV has the highest quality. Therefore, if the fishery would be reopened, the fishing season should be closed during September-December. The annual length-frequency distribution of beluga sturgeon (Fig. 1) showed that the sizes lower than 200 cm were prevailing during the years 1991-2002, comprising more than 50% of total individuals. After the year 2002, the modal length increased and demonstrated a shift towards bigger fish with lengths of more than 200 cm.

The *b* values of the *FL-W* relationship for males, females and whole samples remained within the expected range from 2.50 to 3.50 for all species, similar to those reported by Froese (2006). The *b* value for males showed negative allometric growth, suggesting that the size (i.e. growth) of males was not isometric compared to their weight. Conversely, the *b* values for females indicate positive allometric growth. The difference of *b* values can be attributed to the combination of factors such as sex, growth phase, stomach contents, gonad development (Leunda et al., 2006), biological and environmental conditions, and geographical, temporal and sampling factors (Froese, 2006). Condition factor reflects information on physiological states of fish welfare (Kumolu and Ndimele, 2010), and high condition factor values show suitable environmental conditions (Blackwell et al., 2000). The values of "*KF*" were close to 1 (for males) or > 1 (for females; Fig. 3), indicating that the southern Caspian Sea provides a suitable environment for beluga sturgeon. Also, the monthly average in *KF* of both sexes showed that the lowest values occurred in July, which can be explained by the lack of mature individuals in the sample in this month.

The longest fish (*FL* = 420 cm and *W* = 725.0 kg) was a female, with an age of 63 years and caviar (roe) weight of 98.2 kg. In Europe, beluga is capable of reaching a length of 6 meters and a weight of >1300 kilograms, being the largest freshwater fish (Pikitch et al., 2005). In comparison to other sturgeon species, beluga sturgeon gets a larger size and longevity due to later maturity (Beamesderfer and Farr, 1997). This species is the slowest-in-growth and greatest-in-longevity fish in the Caspian Sea. Based on the growth curve (Fig. 6), initial rapid growth occurred in the first ten years of the fish life. The maximum reported age for this species was 118 years (Babushkin et al., 1964, cited in CITES, 2000). Kosarev and Yablonkaya (1994) reported lower ages, not exceeding 50 to 55 years.

In our study, the long-term age composition of the catch data in the Caspian Sea (1990-2011) showed that the majority of the catch (76.7%) belonged to 12-19 years (Table 1). A noticeable gap was observed for ages 41 and 47-62 years, which might be due to either the absence of large size classes or fishing gear selectivity. The current age at first capture (t_c) was 13.1 years, slightly below the sexual maturity that is reportedly attained between 14-20 years (Froese and Pauly, 2019). A severe biological problem is the increase in beluga sturgeon overfishing which has depleted young individuals before they have reached their full biological and economic potential (Ottersen, 2008). Based on the age structure and age at first maturity, the recruitment and increase in catch resulting in overfishing occurred in beluga sturgeon stock. Therefore, increased length or age at first capture in future fishery policies should be implemented.

The present study showed that the estimated value of L_∞ (440.0 cm) was higher than observed L_{max} (420 cm), in line with $L_{max} \approx 0.95L_\infty$ (Mathews and Samuel, 1990). In contrast, Froese and Pauly (2019) reported a lower L_∞ in the Sea of Azov. In the Caspian Sea and Volga River Basin, L_∞ varied between 400 and 608 cm. The L_∞ estimated in the present study was intermediate of these reported values (Table 2). The growth coefficient (*K*) performance index (φ') of beluga was lower than the previous one estimated in the Sea of Azov and higher than that in the southern Caspian Sea (Taghavi Motlagh, 2001) and Volga River (Froese and Pauly, 2019; Table 2).

These size differences could be due to environmental factors such as productivity, availability of food and fishing gear and selectivity, and/or exploitation levels (Gulland and Rosenberg, 1992; Frédou and Ferreira, 2005). In the present study, the data was collected from commercial catches by gillnets and beach seines. Therefore, the size distribution of samples could be affected by fishing gear selectivity. According to Froese (2004), based on indicator I, 100% of the fish caught should be from mature individuals. Based on this study, only 75.8% catch of beluga sturgeon were mature fish, meaning that a quarter of the catch is comprised of juveniles. Based on Indicator II, 71.4% of individuals were mature and of optimum fish length. According to Froese (2004), the entire catch should comprise optimum fish length. For beluga sturgeon, fish with fork length between 180 and 275 cm should represent 100% of the catches. At last, 4.4% of the fish captured compose mega-spawners. Froese (2004) reported that the regions where there is no upper size limit for captures (such as beluga sturgeon in the Caspian Sea), with 30–40% of mega-spawners indicating an unhealthy population structure.

Recovering stocks of beluga sturgeon depend on generation length and anthropogenic activities. The generation length is > 30 years. If all bordering countries would decide to have rational management by controlling the current anthropogenic threatened factors and increasing the level of artificial propagation for restocking and stock enhancement, at least three decades would be needed to recover the stocks of beluga sturgeon in the Caspian Sea.

Table 2. Comparison of growth parameters of *Huso huso* between the previous and present study

Study area	L_∞ (cm)	Sex	K ($year^{-1}$)	t_0 (year)	φ'	Author (s)
Southern Caspian Sea	533.0 FL	Female	0.023	-4.03	3.81	Taghavi Motlagh, 2001
Sea of Azov	235.4 TL 211.8 FL	-	0.110	-0.86	3.79	Froese and Pauly, 2019
Sea of Azov	249.0 TL 244.6 FL*	-	0.097	-	3.78	Froese and Pauly, 2019
Southern Caspian Sea	434.9 TL 400.3 FL*	Male	0.020	-	3.58	Froese and Pauly, 2019
Volga River	468.6 TL 432.2 FL*	Male	0.019	-	3.62	Froese and Pauly, 2019
Volga River	481.6 TL 444.5 FL*	Female	0.021	-	3.69	Froese and Pauly, 2019
Southern Caspian Sea	501.5 TL 463.3 FL*	Female	0.020	-	3.70	Froese and Pauly, 2019
Volga river	655.2 TL 608.5 FL*	Female	0.012	-	3.71	Froese and Pauly, 2019
Caspian Sea	440.0 FL	-	0.027	-5.8	3.72	Present study

*TL converted to FL by using TL = 11.3+1.0581×FL (present study)

ACKNOWLEDGEMENTS

This research was funded by the Iranian Fisheries Science Research Institute (IFSRI) and International Sturgeon Research Institute (ISRI). We wish to thank Dr. Deniz Cukur for improving English of the draft manuscript and for providing pertinent comments.

BIOLOŠKI PARAMETRI I INDEKSI RASTA MORUNE *Huso huso* U JUŽNOM KASPIJSKOM MORU

Postoji značajan nedostatak podataka o biološkim parametrima morune *Huso huso*, najveće ribe u Kaspijskom moru. Ovim istraživanjem određivala se dob i indeksi rasta morune u svrhu procjene stanja njenog fonda u južnom Kaspijskom bazenu Irana od 1990. do 2011. Duljina vilice kretala se u rasponu između 113-420 cm, a masa od 8,0 do 725,0 kg. Parametri rasta bili su L_∞ = 440 cm, K = 0,027 godina^{-1}, t_0 = - 5,8 godina. Dob pri prvom ulovu (t_c) bila je 13,1 godina. Podaci o dugoročnoj strukturi dobi morune ukazali su na dob do 63 godine, a jedinke u dobi od 12-19 godina sačinjavale su 76,7% ukupnog ulova. Dužina generacije bila je 33 godine. Vrijednosti KF indeksa bile su blizu 1 ili > 1, što ukazuje da je moruna u povoljnom kondicijskom stanju u južnom Kaspijskom moru. Raspodjela vrijednosti dužine morune ukazala je kako 24,2% ulova čine juvenilni primjerci. Na temelju dobne strukture i dobi pri spolnom sazrijevanju, novačenje i prekomjerni ribolov utjecali su na zalihe morune. Ovim se, u budućim ribarstvenim politikama, preporuća povećati dužinu ili starost morune pri ribolovu. Mega-mrijesni primjerci morune su predstavljali 4,4% ulovljene ribe, što ukazuje na neujednačenu strukturu populacije.

Ključne riječi: pokazatelji rasta, zrelost, povijest, moruna, Kaspijsko more

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