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Research Article

Population dynamics of stellate sturgeon *Acipenser stellatus* Pallas, 1771 in the southern Caspian Sea

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Abstract

In the last three decades, several ecological factors were changed and affected the most important commercial fish stocks in the Caspian Sea. This paper aims to assess the effects of these pressures on the population structure, stock status and the vulnerability risk of stock extinction of the stellate sturgeon (*Acipenser stellatus* Pallas, 1771) in the Southern Caspian Sea, in the years 1990-2011. For this period, we estimated growth parameters, the age structure of catch, sexual maturity, age at first capture, natural and fishing mortality, biomass and risk of stock extinction of stellate sturgeon by IUCN Red List categories. Fork lengths of individuals ranged from 82 to 206 cm and ages from 4 to 29 years. The growth parameters were L_∞=215.0 cm, K= 0.064 year^{-1}, t_0=−3.2 years. The majority of the catch (67.4-90.1%, averaged 80.0%) belonged to 9-13 years old. The biomass had a descending trend from 4983.5 mt in 1990-91 declined to 10.6 mt in 2011-12. The generation length was 16 years. Stock status indicators showed that 89% of catch were mature individuals, mature and optimum fish length comprised 74% and 10% of the fish captured comprise mega-spawners. This study revealed that the stock of the stellate sturgeon is being overfished for the whole years and critically endangered.

Keywords: Growth parameters, Biomass, Stock extinction, *Acipenser stellatus*, Caspian Sea

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Introduction

The Caspian Sea, with an area of about 380000 km^2, is the largest lake which can be divided into three parts: the northern, middle, and southern parts (Dumont, 1998). This great lake is a unique ecosystem known for its several aquatic (Karpinsky, 2005). About 130 rivers drain into the ecosystem which the Volga river is the biggest one, contributes more than 85% of the total inflow volume (Kosarev, 2005).

Stellate sturgeon distributes in the Caspian, Azov, and Black Seas. This species is anadromous in which the largest stock is concentrated in the Caspian Sea. This species is found in the whole basin of the Caspian Sea, but its main spawning occurs in the Volga, Ural, and Terek rivers (Berg, 1948). In Iranian waters, this highly valuable species was represented about 45% of the total sturgeon catch (Moghim *et al*., 2002; Florescu et al., 2019).

All sturgeon species such as stellate sturgeon *Acipenser stellatus* (Pallas, 1771) are especially vulnerable to overfishing because of commercial importance. Also, in the past two decades, the anthropogenic effects influenced all components of the Caspian Sea (Pourang *et al*., 2016). It is revealed that the environment of the Caspian Sea is shifted to a new condition (Beyraghdar Kashkooli *et al*. 2017), and Lattuada *et al*. (2019) reported that the invasive species are the most important anthropogenic pressure. All sturgeon species are collapsed and listed under Acipeserides I or II CITES due to pollution, poaching over the last decades, habitat destruction, overexploitation and illegal trade (Ivanov *et al*., 1999; Pourkazemi, 2006; Graham and Murphy, 2007; Khodorevskaya *et al*., 2009, 2014; Qiwei, 2010; CITES and UNEP, 2017; Tavakoli *et al*., 2019; Fazli *et al*., 2020). According to the Commission on Aquatic Bioresources, commercial fishing of sturgeons is banned since 2012.

Unfortunately, our knowledge of the population dynamics of the stellate sturgeon was limited to the length-weight relationships, growth parameters, and mortality (Bakhshalizadeh *et al*., 2012), and maturation (Bakhshalizadeh *et al*., 2017). This information is very important because of changes in the ecological structure of the Caspian Sea due to the impacts of several factors that affected all components of the ecosystem and fish stocks (Daskalov and Mamedov, 2007; Karimzadeh *et al*., 2010; Pourang *et al*., 2016; Tavakoli *et al*., 2019). Therefore, this study aims to fill the information gaps on the primary population biology parameters (length-weight relationship, growth, and maturity), explain the stock status and management, and provide quantitative methods for assessing vulnerability extinction of stellate sturgeon based on population size during 22 years, from 1990 to 2011.

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Materials and methods

Study area and sampling

The fish samples were collected from Iranian commercial fisheries (by gillnets and beach seines, Fig. 1) during 1990-2011. A total of 92980 specimens were sampled (Table 1). The fork length (*FL*) and body weight (*W*) were measured to the nearest centimeter and the nearest 100 g, respectively. After visual sex determination, the maturity stages were determined according to the six-stage maturity scale based on macroscopic examination in gonad development (Moghim *et al*., 2002). The age was determined by pectoral fin ray sections.

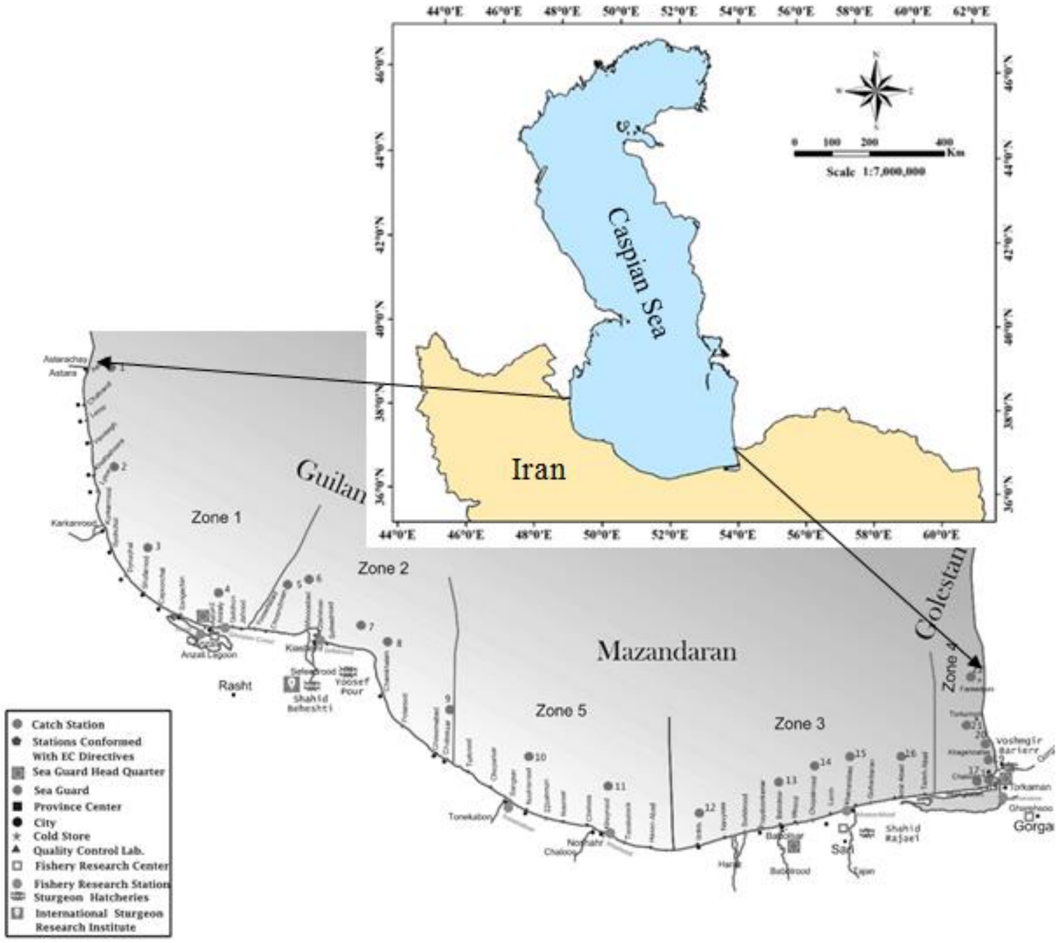

Figure 1: Map showing the fish landings and sampling locations in the Iranian waters of Caspian Sea.

Growth parameters and length at maturity

A log-log transformed data used to estimate length-weight relationships (Ricker, 1975). The non-linear von Bertalanffy growth model was fitted to the observed lengths at age data.

Length at maturity ($L_{m50\%}$) was estimated for individuals sampled during March and April with maturity classified into stage IV. The parameters were estimated using non-linear regression of Saila *et al*. (1988):

$$P = \frac{1}{1 + e^{(-r(L - Lm))}}$$

Where P is the ratio of mature individuals in each length group, r is a parameter, and Lm $Lm = a/r$ is an intercept.

Mortality and age at first capture

The natural mortality (M) was calculated as (Pauly, 1980):

$$\ln(M) = -0.0152 - 0.279\ln(L_\infty) + 0.6543\ln(K) + 0.463\ln(T)$$

Where T is the mean habitat temperature 16.5 °C (Nasrollahzadeh, 2013).

The catch curve method (Ricker, 1975) was applied to calculate the survival rate (S) by using the age compositions to catch the years from 2008 to 2011. The total mortality (Z) and terminal fishing mortalities (F_T) calculated as:

$$Z = -\ln S$$

$$F_T = Z - M$$

The Pauly length-converted catch curve method was used to calculate age at first capture (Pauly, 1984).

Stock assessment

According to cohort analysis (Zhang and Sullivan, 1988), the annual biomass (B) and fishing mortality (F) of stellate sturgeon were estimated. The biomass of the last year and the last age-class (B_t) was:

$$B_t = \frac{C_t(F_t + M - G_t)}{F_t(1 - e^{-(F_t + M - G_t)})}$$

for others:

$$B_{ij} = B_{i+1j+1}e^{(M - G_j)} + C_{ij}e^{(M - G_j)/2}$$

The fishing mortality was calculated as:

$$F_{ij} = \ln(\frac{B_{ij}}{B_{i+1j+1}}) - M + G_j$$

Where C_t is the catch in weight, G_j is the instantaneous coefficient of growth at age j, B_{i+1j+1} is the biomass at age j+1 in year i+1 and C_{ij}, B_{ij} and F_{ij} are the biomass, catch in weight and fishing mortality at age j in year i, respectively. G_j was estimated as the following:

$$G_j = \ln(\frac{W_{j+1}}{W_j})$$

Where W_j and W_{j+1} are the weight of fish at age j and j+1, respectively.

Stock status

The exploitation rate (E) was calculated as (King, 2007):

$$E = \frac{F}{Z}$$

The stock status assessed using three indicators based on the length of fish in the catches (Froese 2004): (I) percentage of mature individuals ($>L_{m50\%}$); (II) frequency of fish at ± 10% optimum length (L_{opt}). L_{opt} calculated by using the growth parameters (using L_∞, M, and K) as:

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

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

The nine IUCN Red List categories and criteria utilized to consider the extinction risk of the sturgeon. The criteria related to population reduction (criteria *A*) was applied to categorize the risk of extinction (IUCN, 2017).

In general, in many taxa of marine fish species, the reproductive potential is closely related to body size. As biomass is 'an index of abundance' (IUCN, 2017), therefore the biomass of mature individuals of stellate sturgeon is used to apply criterion *A*, and complex pattern decline is used to explain the stock reduction.

The proportional rate of population mature biomass declines (Reduction=*R*) was calculated as:

$$R = 1 - (\frac{B2}{B1})$$

Where *B2* is the biomass of mature individuals for the last year (2011) and *B*1 is the biomass of mature individuals before overexploitation. We assumed that the decline of the population before overexploitation to be zero. An exponential regression was applied to explain the reduction of the population of stellate sturgeon.

The generation length (the average age of parents of the current cohort) was calculated (IUCN, 2017):

$$G = \frac{1}{AM} + AFC$$

Where the *AM* is adult mortality and *AFC* is the age at first reproduction.

Results

Length and weight

In the years 1990-2011, the fork length and weight of stellate sturgeon fluctuated between 82 and 206 cm; 3.0 to 66.0 kg, and averaged (±SD) 126.3 (±11.8) cm and 10.15 (±3.22) kg, respectively. The mean length and weight of females and males were 129.2±11.2 cm, 10.98±3.12 kg, and 117.3±9.6 cm, 7.46±2.44 kg, respectively, the values in females is significantly higher than in males (t=164.2, $p<0.001$ and t=186.7, $p<0.001$; for length and weight, respectively). In the length classes, female and male individuals between 110-150 and 100-135 cm were predominant and accounted for 92.3% and 94.2% of total samples (Fig. 2). The fork length-weight relationship was: $W=0.0038FL^{3.049}$ ($R^2=0.80$, standard error of b=0.005, $a=9.4^{-5}$ and n=92980).

Age and growth

The fin ray section analysis showed that the ages varied between 4 and 29 year (Table 1), the earliest growth occurred during the first 4 yr of life (Fig. 3). The L_∞, K, and t_0 were 215.0 cm ± 9.3 SE, 0.064 year^{-1} ± 0.010 SE, and -3.2 year ± 0.94 SE, respectively.

The total catch decreased from 1067.0 mt in 1990 to 917.8 mt in 1992 and sharply declined to 29.7 mt in 2004. The lowest value occurred in 2011 (about 4 mt; Fig. 4). The age 11 was the largest age group (except the years 1990 and 2002) and accounted for 23.4-29.8% of catches (Fig. 4). Age 12 was the largest age group in the other years and represented 22.1-25.6% of catches. In general, during 1990-2011, the majority of the catch (67.4-90.1%, averaged 80.0%) belonged to 9-13 years old.

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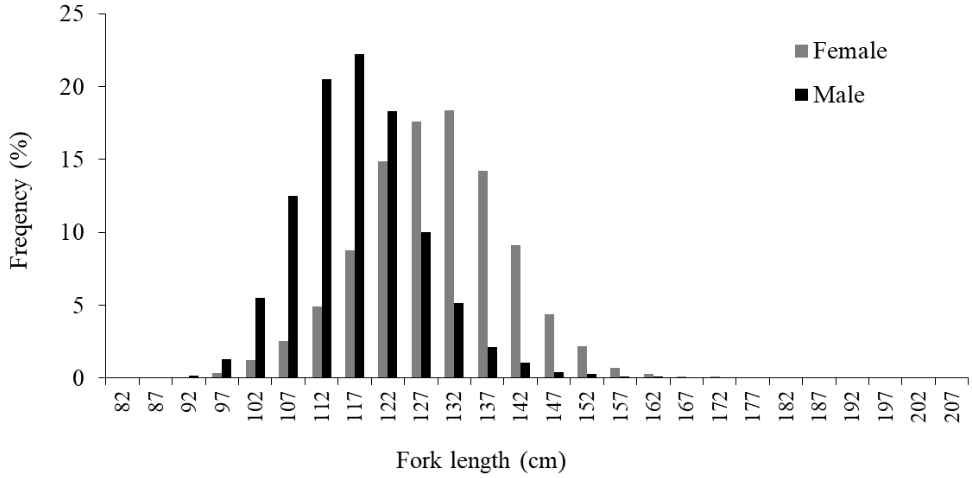

Figure 2: Length frequency distribution of *Acipenser stellatus* in Iranian waters of the Caspian Sea (1990-2011).

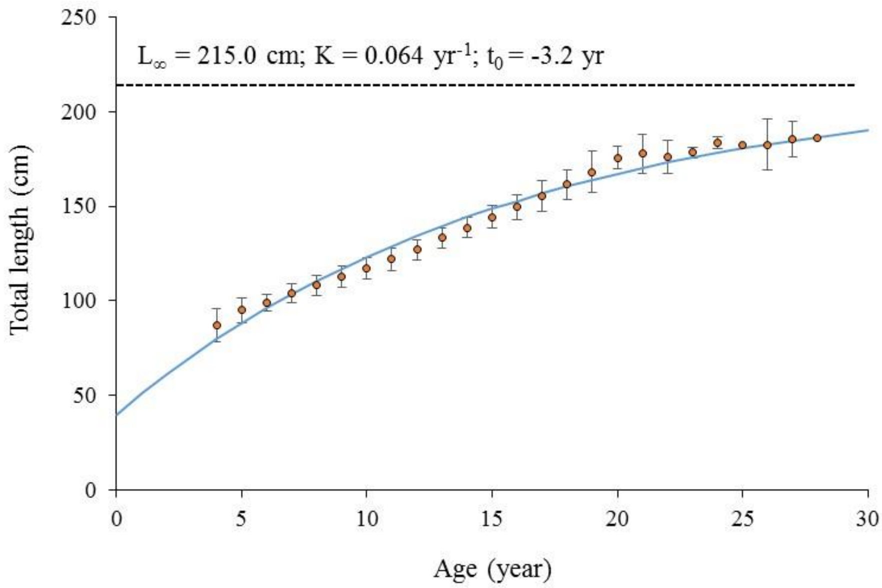

Figure 3: Theoretical growth curve for fork length of *Acipenser stellatus* in Iranian waters of the Caspian Sea (1990-2011).

Maturity

50% of females and males matured at the length of 112 and 110.5 cm, respectively (Fig. 5). Also, mature gonads were present in 8, 72, and 99% for females and 13, 68, and 99% at ages 5, 10, and 15 for males, respectively (Table 1).

Mortality and age at first capture

The annual survival rate (*S*) and total mortality (*Z*) of stellate sturgeon were estimated at 0.52 and 0.65 year^{-1}, respectively. Instantaneous natural mortality (*M*) and age at first capture (t_c) were 0.133 year^{-1} and 10.8 years, respectively (Fig. 6).

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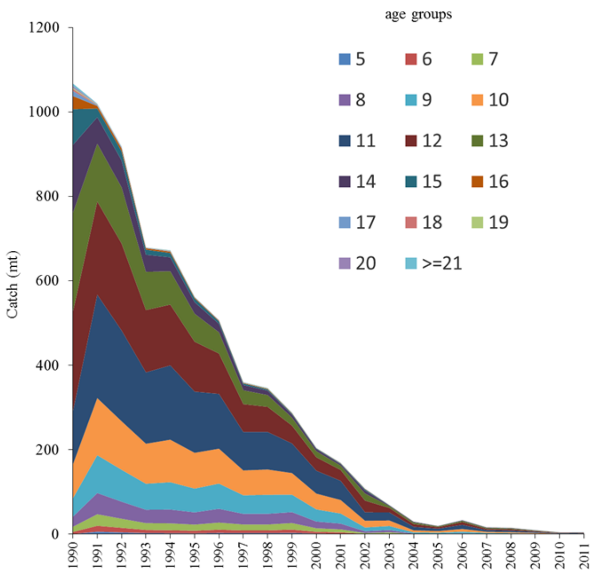

Figure 4: Catch at age of *Acipenser stellatus* in Iranian waters of the Caspian Sea (1990-2011).

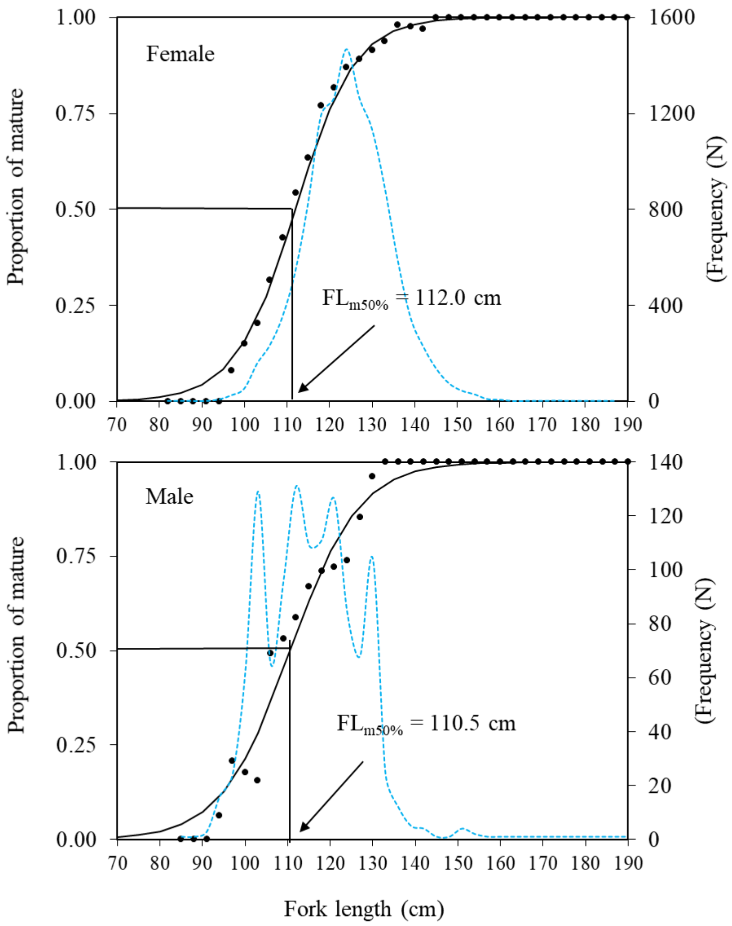

Figure 5: Female and male maturity ogive by the length of *Acipenser stellatus* in Iranian waters of the Caspian Sea (1990-2011).

Table 1: Average of fork length, weight, and maturity at age of *Acipenser stellatus* in Iranian waters of the Caspian Sea (1990-2011).

Age	N	Fork length (cm)		Weight (Kg)		Maturity (%)	
		Mean	SD	Mean	SD	Female	Male
4	3	91.0	8.5	3.83	1.44	-	-
5	52	101.0	6.6	4.45	0.80	8	13
6	891	102.1	4.6	5.02	0.94	14	19
7	2297	105.5	5.1	5.43	1.05	28	35
8	4322	109.5	5.5	6.09	1.22	41	47
9	7383	113.3	5.7	6.84	1.34	56	58
10	11999	117.7	5.7	7.88	1.55	72	68
11	15082	123.2	5.8	9.22	1.67	85	79
12	22471	128.3	5.6	10.56	1.71	92	86
13	15846	134.7	5.5	12.19	1.81	98	93
14	8116	140.3	5.4	13.75	2.03	99	97
15	3198	145.8	5.9	15.40	2.31	99	99
16	926	150.5	6.7	17.37	3.12	100	100
17	243	156.3	8.0	19.60	4.29		
18	67	161.4	7.6	22.63	4.81		
19	28	167.9	10.8	25.09	6.58		
20	25	176.7	6.0	31.55	5.70		
21	6	177.8	10.3	31.37	6.25		
22	7	175.0	8.9	34.86	5.95		
23	4	178.3	2.6	26.43	2.34		
24	3	183.7	3.2	40.50	1.73		
25	1	182.0	-	41.00	-		
26	4	184.8	13.3	31.25	7.89		
27	4	188.0	9.6	36.88	10.62		
28	1	186.0	-	35.80	-		
29	1	181.0	-	37.00	-		
Total	**92980**	**126.3**	**11.9**	**10.15**	**3.22**		

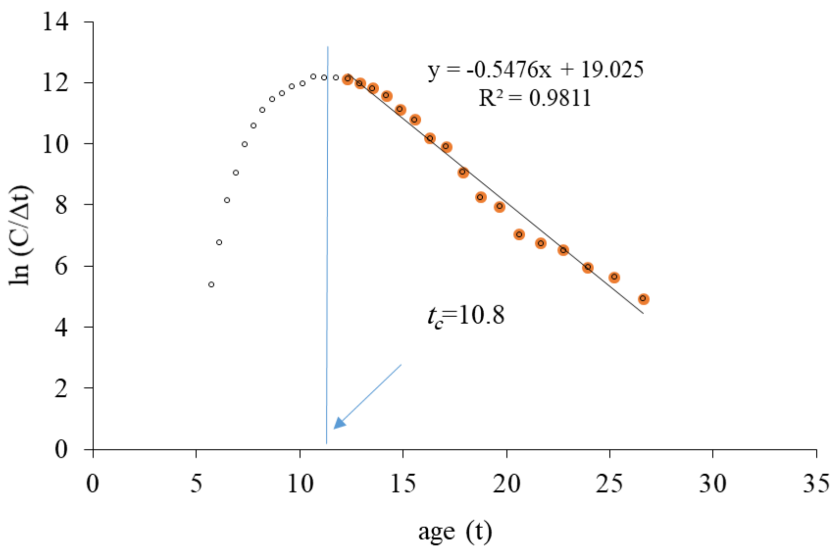

Figure 6: Estimation of the selection ogive of *Acipenser stellatus* from length converted catch curve analysis in Iranian waters of the Caspian Sea (1990-2011).

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Stock assessment

Biomass stellate sturgeon showed a decreasing trend, it collapsed from 4983.5 mt in 1990 to 278.9 mt in 2002-03 (Fig. 7). Finally, in 2011 the biomass was the lowest level and accounted 10.6 mt. The average biomass of age 10 was comprised of the highest proportion of total biomass at 14.9% (189.2 mt), followed by the ages of 9 and 11 (14.6% and 13.4%, respectively). Annual F fluctuated between 0.23^{-1} and 1.14 $year^{-1}$, with a high C.V. of 0.36. During this period the exploitation rate of stellate sturgeon fluctuated between 0.64 and 0.90 (Fig. 8).

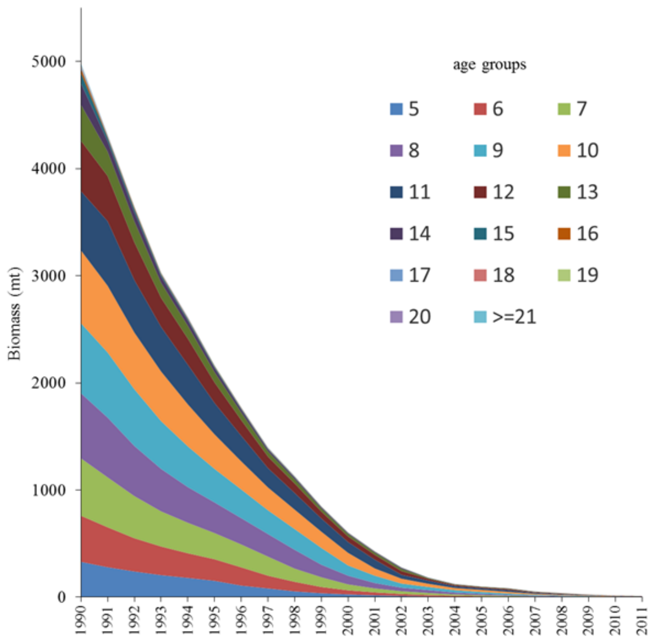

Figure 7: Biomass at age of *Acipenser stellatus* in Iranian waters of the Caspian Sea during 1990–2011.

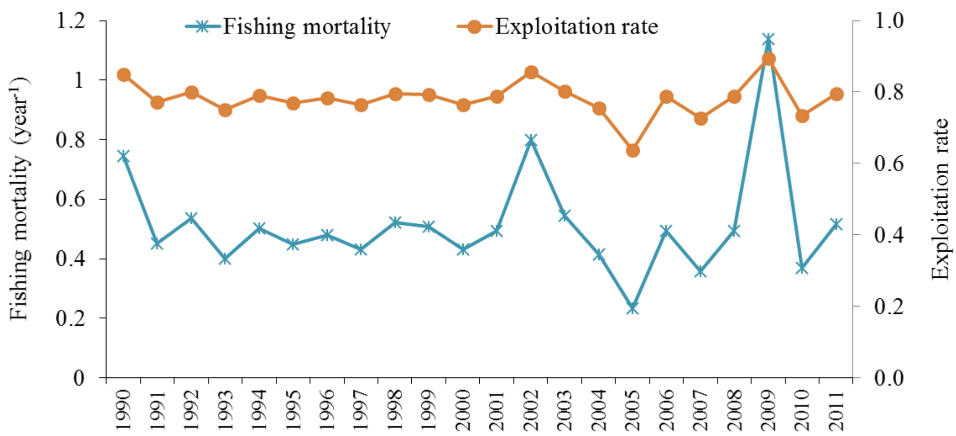

Figure 8: Estimated instantaneous fishing mortality and exploitation rate of *Acipenser stellatus* in Iranian waters of the Caspian Sea during 1990-2011.

Stock status

In the catch composition, the juveniles of the stellate sturgeon represented about 11% of the catch. Also, L_{opt} range comprised 74% of the samples, and mega-spawners were 10% (Fig. 9).

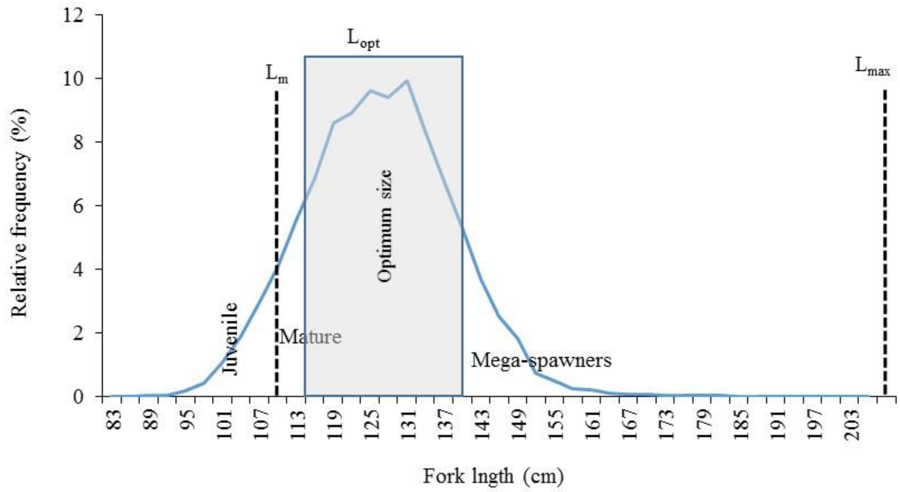

Figure 9: Length–frequency of *Acipenser stellatus* in landings between 1990 and 2011 in Iranian waters of the Caspian Sea. L_m indicates length at first maturity, L_{opt} indicates the length range where optimum yield could be obtained, and L_{max} is the maximum recorded size.

The generation length of the stellate sturgeon was estimated at 16 years. During the years 1990-2011, the proportional rate of population mature biomass of stellate sturgeon showed an exponential reduction which the next few years, the population will be close to zero (Fig. 10). Under ICUN criterion A, the reduction rate was more than 99% which showed Critically Endangered for this species.

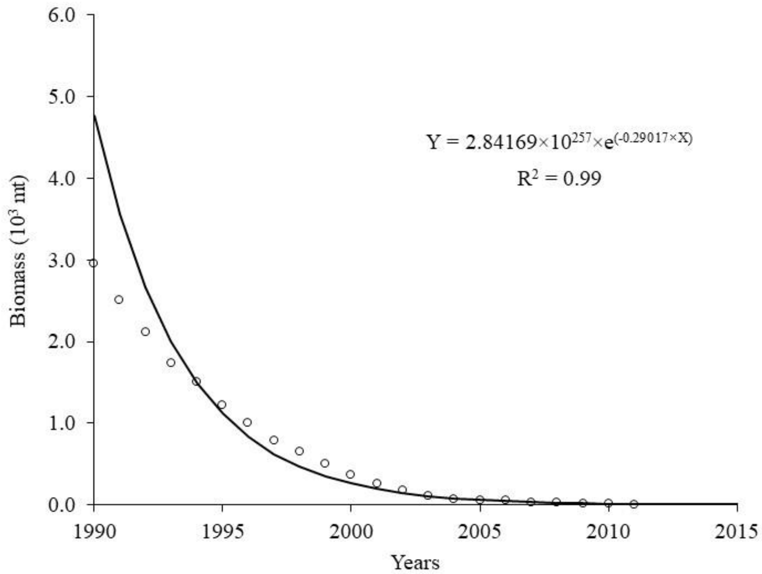

Figure 10: The population mature biomass and exponential reduction of *Acipenser stellatus* in Iranian waters of the Caspian Sea, during 1990-2011.

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Discussion

This study presents some information on the life history and stock of stellate sturgeon in the Caspian Sea. Stellate sturgeon is a slow-growing and its recorded age in a study in 1976-1978 were 35 years (Pirogovskii and Fadeeva, 1982). Makarova and Alekperov (1988), Bakhshalizadeh *et al*. (2012), Levin (1997) found a similar age structure as well. The long-term age composition of the catches data (1990-2011, Fig. 2), revealed 26 age groups varied between 4 and 29 and the majority of the catch (67.4-90.1%, averaged 80.0%) belonged to 9-13 year old.

The results showed that the estimated value of L_∞ (215.0 cm) was higher than the observed $L_{\max}$ (206.0 cm), an agreement with $L_{\max} \approx 0.95L_\infty$ (Mathews and Samuel, 1990). Similar results for growth parameters have been reported by Coad (2017) from the Southern Caspian Sea, while Bakhshalizadeh *et al*. (2012), Froese and Pauly (2017) reported a lower and different L_∞ and K, in the Caspian Sea, Sea of Azov and Danube, respectively (Table 2). The growth performance index (φ') was higher than with previous estimations in the Danube and Caspian Sea (Table 2), indicates the linear growth of the fish is quicker in the Caspian area. Also, Stellate sturgeon has several local populations in the Caspian Sea (Norouzi and Pourkazemi, 2016). Holmgren and Appelberg (2001) reported that the growth characteristics of the local populations in the same species change due to habitat variations, water quality, and nutrients.

Lengths at first maturity were 112 and 110.5 cm for females and males, respectively. The youngest males and females reach maturity at 5 years, in accordance with Volga spawners (Vecsei *et al*., 2007) and contrast with Kura River (Coad, 2017) reported 7-8 years.

Table 2: Comparison of growth parameters of *Acipenser stellatus* between previous and present study.

Study area	L_∞ (cm)	K (yr^{-1})	t_0 (yr)	φ'	Author (s)
Danube	Female: 192.0 TL* 164.8 FL	0.054	-10.0	3.17	Froese and Pauly, 2017
Danube	Male: 194.0 TL* 166.5 FL	0.051	-10.0	3.15	Froese and Pauly, 2017
Romania	201 TL* 172.5 FL	0.060	-	3.25	Froese and Pauly, 2017
Caspian Sea	Female: 153.7 FL	0.08	-3.8	3.28	Bakhshalizadeh *et al*., 2012
Caspian Sea	Male: 131.0 FL	0.15	-0.5	3.41	Bakhshalizadeh *et al*., 2012
Caspian Sea	219 FL	0.06	-	3.46	Coad, 2017
Caspian Sea	215.0 FL	0.064	-3.2	3.47	Present study

*TL converted to FL by using TL=1.165×FL (Froese & Pauly, 2017)

The result showed that the catch of stellate sturgeon collapsed from 1067.0 mt in 1990 to about 4.0 mt in 2011. This catch could be a combination of natural breeding and artificial reproduction by the Iranian Fisheries Organisation, annually released into the sea with the aim of strengthening its stocks. For the whole Caspian basin, the total catch of stellate sturgeon collapsed from 13,700 mt in 1977 to 305 mt in 2003 and declined to 240 mt in 2008 (Pikitch *et al*., 2005; Qiwei, 2010). According to Khodorevskaya *et al*. (2009), the annual numbers of spawners entering the lower Volga declined from 230000 in the years 1986-90 to 50000 in 1998-2002, represented a decline of 78%, and Qiwei (2010) expected that the decline has been continued at a similar rate to the present time and future.

In the present study, the biomass of stellate sturgeon estimated by using official fishing statistics data, without taking into account the poaching and illegal fishing, which resulted in an underestimation of the absolute biomass. The estimated biomass had a decreasing trend which collapsed to about 10.6 mt in 2011. A similar reduction in CPUE (as the relative abundance) was reported by Moghim *et al*. (2006). They reported that the CPUE of stellate sturgeon decreased from 3.75 specimens per trawl in 2001 and 0.18 specimens in 2004 to close to less than 0.10 specimens per trawl in 2010 in the Southern Caspian Sea.

During the twenty two years, the *E* was>0.5 which is higher than the maximum harvest level (0.5), suggested by Gulland (1983). Therefore, one of the main reasons for the reduction of stellate sturgeon is overfishing.

During the past decades, the Caspian Sea environment has been changed significantly, and the new invasive species (Ctenophora, *Mnemiopsis leidyi*) caused the biomass diminution of zooplankton (Pourang *et al*., 2016), the main food of kilka species. Therefore, the stocks of anchovy kilka collapsed to the lowest level (Fazli *et al*., 2020). This species is the main food item for sturgeons (Prikhod'ko, 1979). Also, the habitat of sturgeons restricted due to the deterioration of their spawning grounds (Kiabi *et al*., 1999). Therefore, other reasons for the reduction of sturgeons' stocks could be the decrement of food resources and the destruction of spawning grounds.

The length distribution of stellate sturgeon was assessed by three simple indicators. Based on indicator I, 100% of the fish caught should be from mature fish (Froese, 2004). Based on this study, 89% of catch were mature individuals, which means only 11% of the catch was juveniles (immature fish). Also, the mature and optimum fish length comprised 74%. Finally, 10% of the fish captured comprise mega-spawners (Indicator III). Froese (2004) reported that in the regions where there is no upper size limit for captures, in the case of stellate sturgeon in the Caspian Sea, mega-spawners lower than 30–40% display a healthy population.

According to Kiabi *et al*. (1999), under IUCN Red List Categories based

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on data collected in the southern Caspian Sea, three species of sturgeons (Persian, Russian and stellate sturgeons) are Vulnerable (*VU*) category due to overfishing, deterioration of their spawning grounds, and restricted habitat. In this study, we found that the stellate sturgeon is critically endangered. Also, Khodorevskay *et al*. (2014) supposed that due to the anthropogenic factors all species of sturgeon populations will be closed to extinction.

Based on generation length (16 years), if all bordering countries would decide to have rational management with control of the threatening factors and increasing the level of artificial propagation for restocking and stock enhancement, at least two decades need to recover the stocks of stellate sturgeon in the Caspian Sea.

Acknowledgments

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