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Original Article

Stock enhancement and density-dependence of Caspian kutum (*Rutilus kutum* Kamensky, 1901) in Iranian waters of the Caspian Sea

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Abstract: The Caspian kutum (*Rutilus kutum* Kamensky, 1901) is an important economic species in the southern, uniquely Iranian waters of the Caspian Sea. The present study aimed to assess the desirable levels of the Caspian kutum for stock enhancement with two scenarios using fingerlings released (FR) and recruitments (R) density-dependence and macrobenthic production (P). Based on the results, in the years 1989-2018, the FR increased from 72 million in 1989 to 400 million in 2009 and then declined to 176 million in 2018. In contrast, the R with a lag of 2 years declined from 44.53 million in 1991 to 25.77 million in 1998, increased to 65.07 million in 2005, and then collapsed to 25.01 million in 2018. Based on FR-R relationships of Ricker and segment regression models, the lowest level of FR, which resulted in the highest R (39 million), was about 200 and 150 million fingerlings, respectively. Based on the P/Biomass ratio of macrobenthic species, the annual production was 241.6 thousand mt. It concluded that the desired number of the Caspian kutum fingerling concerning stock enhancement could be lower than 150 million to prevent overcompensation in the Iranian waters of the Caspian Sea.

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Introduction

The carrying capacity (CC) is a useful method to consider sustainable development in water resources management. The CC is the result of all the environmental components of the ecosystem, density-dependent (DD) factors, and sets the long-term maximum level of population density. According to Einum and Nislow (2005), if the population size of an area approaches the CC, emigration, and mortality will increase. After adjusting to a specific condition, mortality is influenced mainly by density-dependent factors (Milner et al., 2003; Su et al., 2004). Stock enhancement is releasing of the cultured juveniles to increase the natural stock of juveniles and optimize harvest. Stock enhancement of Caspian kutum, *Rutilus kutum*, in Iranian waters of the Caspian Sea (IWCS) is conducting on a massive scale since 1989 (Abdolhay et al., 2011; Fazli et al., 2012).

The Caspian kutum is a bottom feeder and migratory anadromous species. This fish contains >70% of the annual Iranian bony fish catches in the Caspian Sea (Yousefian and Mosavi, 2008; Fazli et al., 2013). It has mostly recorded in the southern waters of this sea, especially Iranian waters (Valipour and Khanipour, 2006). With regards to the recent collapse of two species of kilka and sturgeon stocks (Khodorevskaya and Krasikov, 1999; Pourang et al., 2016; Tavakoli et al., 2019) in the Caspian Sea, catch of Caspian kutum (as an endemic species) is also declined in Iran in recent years.

From the 1950s to the 1980s, the annual catch of Caspian kutum ranged 100-2100 mt. In this period, the seawater levels declined, which caused a drastic decline in the stock of Caspian kutum (Valipour and Khanipour, 2006). Since 1981, after a decrease in the stock of Caspian kutum, the Iranian Fisheries Organization (IFO) has been started artificial propagation for the restocking of this species in the IWCS. The fingerlings releasing increased from 2 million in 1981 (Yousefian and Mosavi, 2008) to more

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than 100 million in 1993 (Abdolhay et al., 2011). Afterward, the catch of Iran reached >10000 mt and reached to the highest level in 2007-2008 (17,200 mt) (Fazli et al., 2012). IFO has successfully done the restocking of Caspian kutum in the IWCS, and Abdolhay et al. (2011) concluded that due to the restocking program, the landings from capture fisheries as well as the number of fishers have increased. In contrast, Fazli et al. (2012) reported that there is a significantly negative correlation between fingerlings released and condition factor. They concluded that more research needs to determine the desired level of artificial propagation. Also, perceiving how the density-dependence of Caspian kutum has impacted by anthropogenic activities (e.g., fishing and stock enhancement) is required for reasonable stock management. Therefore, the main objective of the present study was to assess the desirable levels of the Caspian kutum in the stock enhancement with two scenarios using (1) fingerlings released (FR) and recruitments (R) density-dependence and (2) macrobenthic production (P) in the IWCS.

Materials and Methods

Study area and input data: The Caspian Sea, with an area of about 436×10^3 km^2, can be divided into three parts, including the northern, middle, and southern. This study focuses on the deeper southern part i.e. Iranian waters (Fig. 1). Two different scenarios are applied, the "Recruitment/Fingerlings" and the "macrobenthic production" scenarios. For scenario (1) two datasets used: R numbers and FR over the period of 1989-2018. The data series achieved from the final reports of the Iranian Fisheries Science Research Institute (IFSRI). The R numbers calculated by dividing the biomass at age 2 (the youngest fish in the catch; Table 1) by the average weight of the age (estimated from growth parameters and length-weight relationship equations).

One of the primary goals of the Iranian Fisheries Organization (IFO) is to produce fingerling and releasing them in the rivers of the Caspian Sea (Abdolhay et al., 2011). The data on released fingerlings used as input data (Table 1; http://www.shilat.com). Nowadays, due to degradation of the spawning ground, most of the stocks of Caspian kutum (more than 90%) have been recovered by artificial propagation. Therefore, in the present study, the FR set as Spawning Stock Biomass (SSB) in the relationship between R and SSB. The data on released fingerlings used as input data (Table 1; http://www.shilat.com).

Table 1. The number of Caspian kutum fingerlings released and recruit numbers in Iranian waters of the Caspian Sea during the years 1989-2018.

Year	Fingerlings 10^6	Biomass (mt) at age 2 year	Recruit num-bers (10^6) at age = 2
1989	72.0	-	-
1990	84.3	-	-
1991	109.8	5526.6	44.53
1992	96.6	5315.3	42.83
1993	100.0	4400.7	35.46
1994	142.7	4193.1	33.78
1995	125.1	4075.6	32.84
1996	142.1	3905.0	31.46
1997	154.4	3698.0	29.80
1998	143.3	3197.9	25.77
1999	147.8	3461.6	27.89
2000	147.4	4508.0	36.32
2001	233.0	5610.1	45.20
2002	225.2	5915.5	47.66
2003	155.5	7311.0	58.91
2004	179.4	7769.4	62.60
2005	229.1	8076.4	65.07
2006	174.5	7080.7	57.05
2007	262.5	6797.5	54.77
2008	187.1	6447.6	51.95
2009	400.5	6261.0	50.45
2010	279.5	6167.2	49.69
2011	272.7	5269.6	42.46
2012	249.6	4145.1	33.40
2013	200.9	3819.3	30.77
2014	176.3	3893.6	31.37
2015	185.6	3980.7	32.07
2016	192.6	3590.1	28.93
2017	-	3323.9	26.78
2018	-	3104.5	25.01

The FR-R models: The FR-R relationships of Caspian kutum were estimated from time series of fingerlings released and recruitment. Among several functions to fit FR-R, three models are used in this study as follows: (1) Ricker FR-R model fit:

$$\frac{R}{FR} = a\exp(-bFR)$$

Table 2. The annual mean wet weight of different macrobenthic groups in of Iranian coastal waters of the Caspian Sea during 2008-2010.

Area	Surface km^2	Mean wet weight (g/m^2)		
		Bivalvia	Polychaeta	Total Macrobenthos
Astara	3705.5	40.22	3.40	52.56
Anzali	682.9	15.28	1.52	22.43
Sefidrood	814.7	13.48	1.49	17.65
Tonekabon	1269.7	11.00	1.83	17.35
Nohahar	1023.9	13.75	2.50	17.64
Babolsar	1400.2	37.07	1.17	42.97
Amirabad	1691.8	45.96	2.86	53.32
Torkman	3876.5	26.88	3.37	59.41

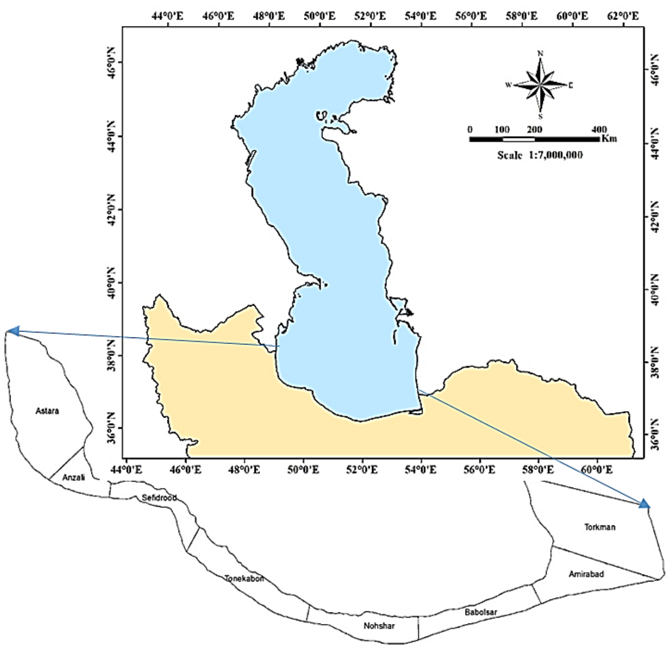

Figure 1. Map of macrobenthic sampling stations in the Iranian waters of the Caspian Sea.

(2) Beverton-Holt FR-R model fit:

$$\frac{R}{FR} = \frac{a}{1 + bFR}$$

(3) Segmented regression FR-R model fit:

$$R = if\ FR \leq b\ then\ a \times FR\ else\ a \times b$$

Where a is the intercept and b is the negative initial slope. All models with assuming lognormal error structures carried out using the Fisheries Library in R (FLR) framework (Kell et al., 2007). The relationship with the best overall fit based on the Akaike Information Criterion selected the best fitting. In this study, the recruits are the fish of age two years; hence, the lag between FR and recruits is two years. The starting years for FL is 1989, whereas for recruits it is 1991.

Caspian Kutum is a bento-pelagic species and carnivorous. This fish feeds on a variety of prey items, however, bivalves and cirripeds as the main prey groups consisting of 80% of the diet (Bandpei et al., 2009). Therefore, for scenario 2, the archival data were used on macrobenthic biomass collected in the years 2008-2010 (Soleimani Roudi, 2013; Hashemian Kafshgari et al., 2015) to estimate productivity. The data were collected seasonally using Veen Grab Sampler (0.1 m^2) at eight transects (Astara, Anzali, Sefidrood, Tonekabon, Noshahr, Babolsar, Amirabad and Torkman) with five stations at each transect located depths 5, 10, 20, 50 and 100 m (Fig. 1). A rapid method suggested by Nilsen et al. (2006) and Gray and Elliott (2009) used to estimate annual production. The production/Biomass, P/B ratio set to 0.75, 0.35, and 0.35 for Polychaeta, Mollusca, and total macrobenthic, respectively. To estimate the biomass of Caspian kutum based on macrobenthic annual production, the biomass transfer efficiency between macrobenthic and Caspian kutum set between 10 and 20%.

Results

For scenario one, under recruitment (R) and fingerlings released (FR), the FR was 72 million in 1989, and the R with a lag of 2 years (1991) was 44.53 million. The FR had two trends, first, increased from 72 million (in 1989) to the highest level (400 million) in 2009, then declined to 176 million in 2018. In contrast, R had different trends. During the years 1991-2018, it was declined to 25.77 million in 1998 and then increased to the highest level i.e. 65.07 million in 2005. In 2011, it was 42.46 million, and then it declined to the lowest level (25.01 million) in

Table 3. The estimates of Fingerlings Released-Recruitment, FR-R relationships using Ricker, Beverton-Holt and segmented regression models for *Rutilus kutum* in Iranian water of the Caspian Sea. Models performance ranked by ascending order of AIC.

Model		Log-likelihood	AIC
Ricker	$R = 5.1\times10^{-4} \times FR \times \exp(-4.8\times10^{-9} \times FR)$	23.508	-43.015
Beverton-Holt	$R = 46198 \times FR/(31651333 + FR)$	23.102	-42.204
Segment	$R =$ if $FR\leq150\times10^6$ then $2.6\times10^{-4} \times FR$ else $2.6\times10^{-4} \times150\times10^6$	23.066	-42.132

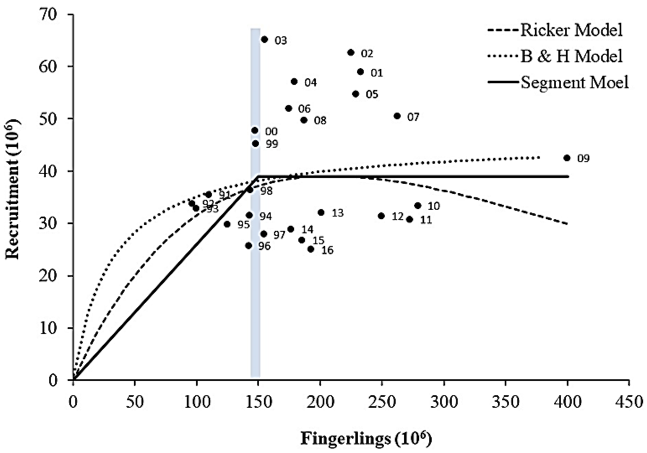

Figure 2. Fingerlings Released–recruitment (FR–R) relationships for *Rutilus kutum* in the Caspian Sea. Ricker fit (dash line), Beverton–Holt fit (dotted line) and Segment fit (Solid line).

2018 (Fig. 2). Three different FR-R relationships, Ricker, Beverton–Holt, and segment regression models, were very similar (Fig. 2). This study showed that the lowest level of FR, which resulted in the highest R (about 39 million), was about 200 and 150 million fingerlings for Ricker and segment regression models, respectively. However, the Ricker model resulted in giving the overall best fit for fingerlings and R of Caspian kutum, based on the AIC (Table 3).

For scenario two, under the macrobenthic P/B ratio of Polychaeta, Mollusca, and other microbenthic species, the annual production in eight strata was estimated (Fig. 3). The results showed that the minimum of production occurred in the Anzali strata, and the maximum one in Torkman and Astara strata in east and west regions, respectively. In general, the annual production of Polychaeta, Mollusca, other groups, and total macrobenthos was 29.5, 151.3, 60.8, and 241.6 thousand mt, respectively. If the biomass transfer efficiency is 10-20 and 80% of the Caspian kutum diet belonged to macrobenthic, the annual biomass of Caspian kutum could be about 20-40 thousand mt. Based on Table 1, the average R/total biomass ratio of Caspian kutum is 12.1%, and the R estimated numbers ranged between 20 and 38 million.

Discussions

This study indicated that during the last three decades, over restocking of Caspian kutum have been occurred in the IWCS. Several marine fish populations have strong density-dependent (Myers and Cadigan, 1993; Andersen et al., 2017; Mirzaei et al., 2019). Density-dependent regulation is related to the size of the habitat. In small habitats (e.g., lakes), the regulation happens late in life, when exploiting the juveniles fish maximizes yield. In contrast, in marine habitats, the regulation is occurred early in life, when the yield maximized by the exploitation of matures (Andersen et al., 2017). Overcompensation is a competition between juveniles and adults when juveniles are the superior competitors (De Roos et al., 2008), usually occurred is small habitat, results in stunted growth (Andersen et al., 2017). Therefore, Caspian kutum exists mostly in the IWCS (Haghi Vayghan et al., 2013, 2015; Valipour and Khanipour, 2006) has a small habitat with late in life regulation.

Persson et al. (2007) reported that the presence of predators (e.g., sturgeon fishes, Caspian seal (*Phoca capsica*), pike-perch (*Sander lucioperca*) in the case of the Caspian Sea) can decrease the population from the density-dependent competition and remove the stunting. However, several works (Raisa Khodorevskaya et al., 2014; Pourang et al., 2016; Cites, 2017; Fazli et al., 2017; Tavakoli et al., 2019) indicated that during the last decades the top predator's stocks collapsed in the Caspian Sea. Therefore, at least during the two last decades, the predators could not affect the density of Caspian kutum in the Caspian Sea.

According to Fazli et al. (2012), during 1991-2011, the average condition factor of both sexes of Caspian kutum had a decreasing trend, and they concluded that

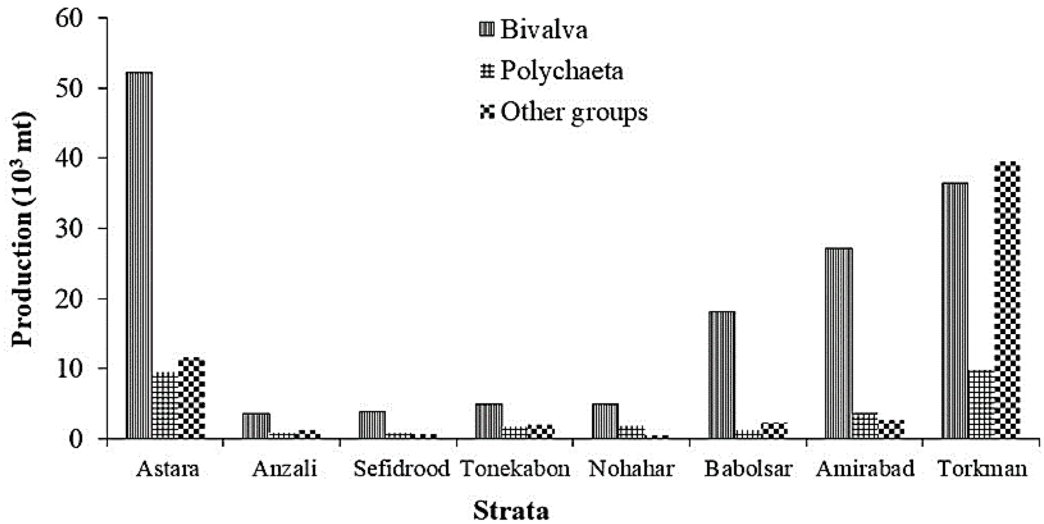

Figure 3. Annual macrobenthic production in different strata in the Iranian waters of the Caspian Sea.

condition factor is adversely influenced by the number of fingerlings released (Fazli et al., 2012) which confirm the results of the present study.

The average depth of the northern part is about 3.5 m, comprised of fresh-water benthic species. The average depth of the middle and southern parts is 190 and 300 m, respectively, and occupied by brackish-water benthic species (Khodorevskaya et al., 2009; Karpinsky, 2010). The most concentration of benthos biomass (more than 95%) was reported at depths <100 m. The highest biomasses are observed at the eastern and western coast of the middle Caspian Sea (more than 1.0 kg/m^2). In contrast, the lowest biomass (less than 30 g/m^2) remarked in the Southern Caspian Sea (Khodorevskaya et al., 2009) at depths <100 m, whereas the most stocks of Caspian kutum settle here. Furthermore, since the 1990s, the new invader (*Mnemiopsis leydei*) affected all components of the Caspian Sea (Pourang et al., 2016) and its environment shifted to new conditions (Kashkooli et al., 2017). During this period, the most important anthropogenic pressures are such as invasive species and pollution, which have affected in abundance and then extinction of some benthic species (Lattuada et al., 2019).

The primary benthos consumers are sturgeon fishes and cyprinids in the Caspian Sea. The fry of all sturgeons feed on crustaceans and worms and adult sturgeon of Russian sturgeon, *Acipenser gueldenstaedtii*, and Persian sturgeon, *A. persicus* prefer to feed on mollusks. It revealed that during very long periods at depths of 100 m, the benthos biomass and species diversity are sharply decreased due to the influence of severe grazing pressure by sturgeons (Karpinsky, 2010). However, during a few decades, the sturgeon stocks collapsed to the lowest level and even extinction (Cites, 2017). On the other hand, the catch of other benthos feeders such as common carp (*Cyprinus carpio*) and roach (*Rutilus lacustris*) had a decreasing trend. The portion of these species from the total catch of bony fishes declined from 17.5% in 1997 to 3.5% in 2013 in the IWCS. These decreases could be the influence of severe grazing pressure by the over fingerlings released of Caspian kutum during the last years.

In conclusion, due to changing the ecosystem of the Caspian Sea, anthropogenic pressures, and extinction of benthic species, to protect this unique habitat, it actively encourages to decline the fingerlings released of Caspian kutum. Based on two scenarios in the present study, FR-R relationship, and macrobenthic production, the desirable number of the Caspian kutum fingerling concerning stock enhancement is lower than 150 million.

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