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Stock Management Implication of Caspian kutum (*Rutilus frisii kutum* Kamensky, 1901) in Iranian Waters of the Caspian Sea

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ABSTRACT Recently the previous Caspian ecosystem is in a catastrophic condition which caused changes in the absolute and relative abundance of the commercially important Caspian kutum (*Rutilus frisii kutum*) in Iranian waters. The paper presents estimates of yield-per-recruit and spawning biomass-per-recruit under various harvest strategies of F_{max}, $F_{0.1}$, $F_{30\%}$. It proposes a method for estimating acceptable biological catch (ABC) that accounts for large differences in the quality and quantity of information and available data. The current average Y/R (with F=0.61/y, and t_c=3.2 y) was 218.3 g per recruit, which indicates that the fishery is operating below the maximum Y/R at 236.9 g when t_c = 3.5 y. The Y/R was the highest at F_{max} and $F_{0.1}$, when t_c = 4 y (244.8 g and 214.2 g), respectively. The $F_{30\%}$ value was 0.85/y at t_c of 4 y with the SB/R of 338.3 g. The $F_{current}$ (0.61/y at current t_c is 3.2 y) is higher than the corresponding reference points, $F_{0.1}$ (0.47/y) and $F_{30\%}$ (0.46/y). The ABC of kutum was estimated at 7,850 mt in 2009-2010.

Key words: *Acceptable biological catch, Reference point, Rutilus frisii kutum, Spawning biomass per recruit, Yield per recruit*

1 INTRODUCTION

The Caspian kutum (*Rutilus frisii kutum* Kamensky, 1901) is a migratory anadermous fish (Berg, 1964). In Iranian waters of the Caspian Sea, spawning migratory of kutum occurs in the rivers and Anzali lagoon from March to May (Adeli Mosabbab and Piri, 2005; Afraei Bandpei *et al*., 2009), depending on water temperature, Sea processes and ecological conditions (Valipour and Khanipour, 2006).

Caspian kutum is also a principal species in Iranian commercial catches. According to Valipour and Khanipour (2006), Caspian Kutum has mostly been recorded in the southern waters than the North and Volga River. Total annual catch of Caspian kutum during 1950-1980 ranged from 100-2100 mt. A decrease in the Sea water levels from the 1950s has caused a drastic decline in the stocks of Caspian kutum (Valipour and Khanipour, 2006). Due to the sharp decrease in stock of Caspian kutum, artificial propagation for enhancing and restocking has been started by

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Iranian Fisheries Organization (IFO) since 1981. The fingerlings releasing increased from 2 million in 1981 to more than 140 million in 2008 (Yousefian and Mosavi, 2008). Subsequently, the catch of kutum increased more than 10000 mt during 2000s, and reached to highest level in 2007-2008 (17,200 mt).

During the past 30 years the environmental condition of the Caspian Sea has been changed significantly in response to impacts of various factors, such as fluctuations in sea level, pollution (Ivanov, 2000; Salmanov, 1999), and introductions of exotic species. In particular, the invasive jellyfish (Ctenophora, *Mnemiopsis leidyi*), that appeared in 1999 (Ivanov *et al*., 2000), affected all components of the ecosystem (Roohi *et al*., 2010), and specially had negative affects on two pelagic species (anchovy, *Clupeonella engrauliformis* and bigeye kilka, *C. grimmi* (Fazli *et al*, 2007 and 2009), and positive affects on golden grey mullet and Caspian kutum stocks (Fazli *et al*., 2008 and 2011).

f_{MSY}, yield-per-recruit and spawning biomass-per-recruit for four different harvest strategies or fishing mortality rates: F_{max}, $F_{0.1}$, $F_{35\%}$, $F_{40\%}$ were considered (Mace, 1994; Kirchner, 2001). F_{max} is fishing mortality rate at which yield-per-recruit is maximal, $F_{0.1}$ is the rate at which the slope of the yield-per-recruit curve (as a function of fishing mortality) is 10% of its value near the origin), $F_{35\%}$ and $F_{40\%}$ is the fishing mortality for 35 and 40% of spawning biomass-per-recruit when fishing mortality is zero, respectively (Mace, 1994; Kirchner, 2001). The paper presents estimates of yield-per-recruit and spawning biomass-per-recruit under various harvest strategies of F_{max}, $F_{0.1}$, $F_{30\%}$. It proposes a method for estimating acceptable biological catch (ABC) that accounts for large differences in the quality and quantity of information and available data. Finally, a method for estimating ABC is proposed for dealing with the differences in the quantity of information and available fishery data.

2 MATERIALS AND METHODS

There are about 131 fishing cooperatives in Iranian part of Caspian Sea in which use beach seines, along the coastal zone in three seashore regions (Golestan, Mazandaran and Guilan). Biological parameters from the previous study (Fazli *et al*., 2011; Table 1) and catch-at-age data during 1991-2010 were used as input data for the analysis. The biomass-based cohort analysis was used to estimate biomass and instantaneous fishing mortality (Zhang and Sullivan, 1988).

Table 1 Parameter estimates used in yield-per-recruit and spawning biomass-per-recruit for Caspian kutum, in Iranian waters of the Caspian Sea taken from Fazli *et al*., 2011.

Variable	t_c (y)	t_r (y)	t_0 (y)	K (y^{-1})	W_∞ (y)	M (y)
quantity	3.2	1.3	-0.13	0.22	3250	0.39

The Eq. (1) was used to determine the optimal fishing mortality and the optimal age at first capture (Beverton and Holt, 1956):

$$\frac{Y}{R} = Fe^{-M(t_C - t_r)]} W_\infty \sum_{n=0}^{3} \frac{U_n . e^{[-nK(t_C - t_0)]}}{F + M + nK} (1 - e^{[-(F+M+nK)(t_L - t_C)]})$$

(1)

where, asymptotic weight (W_∞) of 3250 g, growth coefficient (K) of 0.22 y^{-1} and age at zero length (t_0) of −0.13 are parameters of von Bertalanffy growth function; R is the number of fish at time t_r of 1.3 y, the age at recruitment, which was the youngest age in the catch; Y is the yield; M is the instantaneous coefficient of natural mortality of 0.39 y^{-1} (Fazli *et al*., 2011); t_L is regarded as the maximum age in the catch of 10 y (Vossoughi and Mostajeer, 1994); and U_n is a

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summation parameter equal to +1, −3, +3, and −1 for n=0, 1, 2 and 3, respectively (Beverton & Holt, 1956).

An estimate of $F_{0.1}$, which represents the fishing mortality corresponding to 10% of the slope at the origin when no fishing occurs, was calculated based on the following differential equation of Beverton and Holt's (1956) Y/R model (Eq. 2).

$$\frac{d(Y/R)}{dF} = e^{-M(t_c - t_r)]} W_\infty \sum_{n=0}^{3} \{ \frac{(M+nK).U_n e^{[-nK(t_c - t_0)]}}{(F+M+nK)^2} + \frac{e^{[-(F+M+nK)(t_L - t_c)]}}{(F+M+nK)^2} [(t_L - t_c)F^2 + (M+nK)(t_L - t_c)F - (M+nK)] \} \quad (2)$$

when F=0, the spawning biomass-per-recruit (SB/R) will be shown as Eq. (3).

$$\frac{SB}{R}\Big|_{F=0} = \sum_{t=t_r}^{t_\lambda} m_t e^{-M(t_c - t_r)} e^{-M(t-t_c)} W_\infty (1 - e^{-K(t-t_0)})^3 \quad (3)$$

where SB is spawning biomass and m_t is the age-specific proportion of mature females relative to all females in the cohort. In this study m_t is represented by a logistic equation fitted to maturity data collected from Caspian kutum caught in the waters around Iran. The proportions of mature female of Caspian kutum are 0.08, 0.70, 0.90 and 0.10 for ages 3, 4, 5 and 6, respectively (Afraei *et al*., 2009). Age 7 and later was the age of full maturity. The Eq. (3) was used to estimate the instantaneous coefficient of fishing mortality which would maintain the spawning biomass at a level equivalent to 30% ($F_{30\%}$) at a given age of recruitment in an un-fished population.

When F= F_1 the SB/R will be shown as Eq. (4).

$$\frac{SB}{R}\Big|_{F=F_1} = \sum_{t=t_r}^{t_\lambda} m_t e^{-M(t_c - t_r)} e^{-(M+F)(t-t_c)} W_\infty (1 - e^{-K(t-t_0)})^3 \quad (4)$$

The estimation of acceptable biological catches (ABCs) of bony fish stocks in the Iranian fisheries management system must take into account the quantity and quality of data available and the exploitation history of the fishery. In this study, a five-tier-classification system (Table 2), which was modified from the six-tier system used under the US Fisheries Management Plan for the North Pacific groundfish fisheries (Anon., 1998), was used. For tiers 1-3, once the reference fishing mortality (F_{ABC}) was determined, the Eq. (5) was used to determine ABC:

$$ABC = ABC_r + \sum_{i=r+1}^{t_L} \frac{B_i F_{ABC}}{M + F_{ABC}} (1 - e^{-(M+F_{ABC})}) \quad (5)$$

where F_{ABC} is the instantaneous coefficient of fishing mortality for ABC determined by the available data and the stock status, r is a recruit age, and t_L is a maximum fishing age. ABC_r was calculated as Eq. (6).

$$ABC_r = \frac{RF_{ABC}}{M + F_{ABC}} (1 - e^{-(M+F_{ABC})}) \quad (6)$$

where R is the estimate of biomass at age 3, which was estimated from Fazli *et al*. (2011). ABCs for tiers 4 and 5 are based on maximum sustainable yield (*MSY*) and the arithmetic mean catch over an appropriate period (Y_{AM}), respectively (Table 2).

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Table 2 Methods constructed to determine the acceptable biological catch (ABC) for Caspian kutum in the Iranian fisheries management system. (From Zhang and Lee, 2001).

Tier 1. Information available: Reliable estimates of B, B_{MSY}, F_{MSY} and $F_{30\%}$

1a) Stock status: $B/B_{MSY}>1$

$F_{ABC}=F_{MSY}$

1b) Stock status: $\alpha<B/B_{MSY}\leq 1$

$F_{ABC}=F_{MSY}\times(B/B_{MSY}-\alpha)/(1-\alpha)$

1c) Stock status: $B/B_{MSY}\leq \alpha$: $F_{ABC}=0$

Tier 2. Information available: Reliable estimates of B, $B_{X\%}$ and $F_{X\%}$

2a) Stock status: $B/B_{30\%}>1$

$F_{ABC}=F_{30\%}$

2b) Stock status: $\alpha<B/B_{30\%}\leq 1$

$F_{ABC}=F_{30\%}\times(B/B_{30\%}-\alpha)/(1-\alpha)$

2c) Stock status: $B/B_{30\%}\leq \alpha$: $F_{ABC}=0$

Tier 3. Information available: Reliable estimates of B and $F_{0.1}$

$F_{ABC}=F_{0.1}$

Tier 4. Information available: Times series catch and effort data

4a) Stock status: $CPUE/CPUE_{MSY}>1$

ABC=MSY

4b) Stock status: $\alpha<CPUE/CPUE_{MSY}\leq 1$

$ABC=MSY\times(CPUE/CPUE_{MSY}-\alpha)/(1-\alpha)$

4c) Stock status: $CPUE/CPUE_{MSY}\leq \alpha$: ABC=0

Tier 5. Information available: Reliable catch history

$ABC=P\times Y_{AM}$ (arithmetic mean catch over an appropriate time period), $0.5\leq P\leq 1.0$

i) Equation used to determine ABC in tiers 1-3:

$$ABC = ABC_r + \sum_{i=r+1}^{t_L} \frac{B_i F_{ABC}}{M + F_{ABC}}(1 - e^{-(M+F_{ABC})})$$

$$ABC_r = \frac{RF_{ABC}}{M + F_{ABC}}(1 - e^{-(M+F_{ABC})})$$

where B_i: biomass at age i, M: instantaneous coefficient of actual mortality, F_{ABC}: instantaneous coefficient of fishing mortality for ABC determined by the data available and the stock status, r: recruit age, t_L: maximum fishing age.

ii) For tiers 1, 2 and 4, α is set at a default value of 0.05.

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3 RESULTS

The annual catches of Caspian kutum decreased from about 11,000 mt in 1991-1992 to 6,580 mt in 1999-2000 which was recorded a minimum, but increased to highest level (17,200 mt) in 2007-2008, and finally declined to 12,400 mt in 2009-2010 at the Iranian parts of the Caspian (Figure 1).

Biomass estimation of kutum of biomass-based cohort analysis (Figure 2) were decreased from 31,800 mt in 1991-1992 to 25,200 mt in 1999-2000, and then increased to 56,600 mt in 2008-2009 which was recorded a maximum. It was estimated 55,700 mt in 2009-2010. During this period, the average biomass of 3-year fish represented the highest proportion of total biomass at 29.2% (10,700 mt), followed by the 4-year biomass (26.0%) and 2-year biomass (17.8%). Annual changes in the instantaneous coefficient of fishing mortality varied between 0.40/y to 1.49/y, with a high C.V. of 43.3% during 1991-2010 (Figure 2).

Figure 3 showed the yield isopleths of Caspian kutum that were constructed to examine the response of Y/R estimates with respect to the age at first capture and fishing mortality. The current average Y/R (with F=0.61/y, and t_c=3.2 y) was 218.3 g per recruit, which indicates that the fishery is operating below the maximum Y/R at 236.9 g when t_c = 3.5 y. Fixing t_c at the current level, maximum Y/R was 230.5 g when F increased to 2.0/y which resulted increase of 12.2 g in Y/R, but this F is out of range of the maximum Y/R line. Fixing F at the current level, maximum Y/R was 218.3 g when t_c was 3.2 y (current t_c).

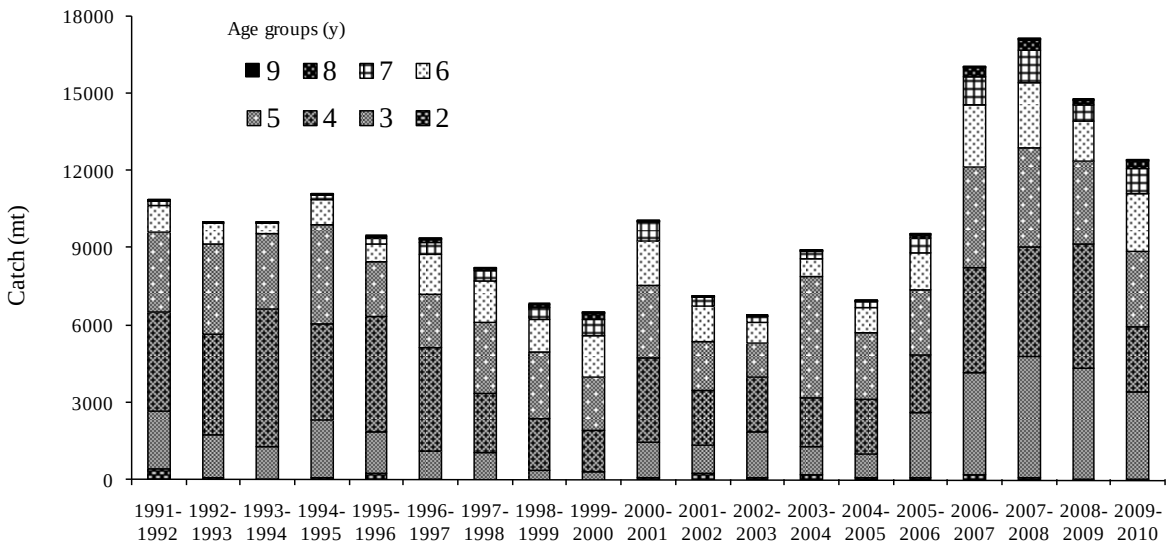

Figure 1 Catch-at-age of Caspian kutum in Iranian commercial catches during 1991-2010.

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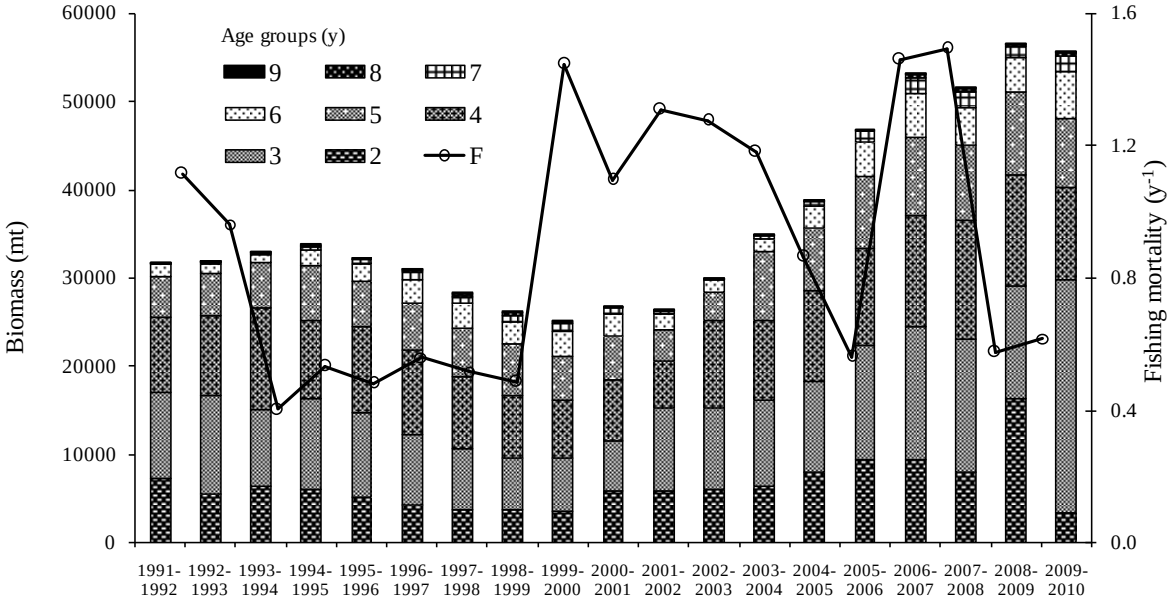

Figure 2 Biomass at age and fishing mortality of Caspian kutum in Iranian waters of the Caspian Sea during 1991-2010.

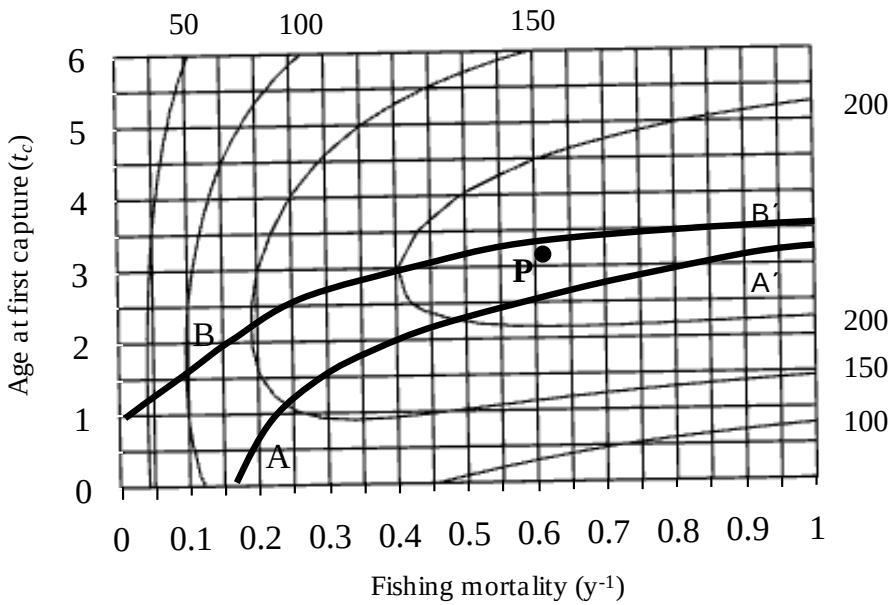

Figure 3 Response surface of yield-per-recruit of Caspian kutum with respect to fishing mortality and age at first capture. *P* indicates the current state of fishing mortality (*F*) and age at first capture (t_c) in 2010. *AA′* represent the maximum-yield-per-recruit line at a given t_c and *BB′* indicates the maximum-yield-per-recruit line at a given *F*.

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Table 3 showed the F_{max} and $F_{0.1}$ values from age 2 to 6 of Caspian kutum. The Y/R was the highest at F_{max} and $F_{0.1}$, when t_c = 4 y (244.8 g and 214.2 g) respectively. The Y/R for each F value increased with t_c when t_c <4 y, and gradually declined when t_c >4 y. The $F_{30\%}$ value was 0.85/y at t_c of 4 y with the SB/R of 338.3 g, (Table 3).

Information considered for tier 1 includes the historic estimates of biomass, M, B_{MSY}, F_{MSY} and $B_{30\%}$ for Caspian kutum. The information of B_{MSY} and F_{MSY} were not available.

Reliable current biomass, M, $B_{30\%}$ and $F_{30\%}$ for Caspian kutum were available to be use for tier 2 in this study (Table 4). Biomass data estimated for Caspian kutum were available for age classes taken the fishery (age 2-10 fish) from 1991-2010. The current estimated biomass at the 2009-2010 was estimated to be 55,700 mt. The biological reference point, $F_{30\%}$, was estimated to be 0.46/y, and $B_{30\%}$ was estimated for current biomass as the 2009-2010 was 72,519 mt which the ratio of $B/B_{30\%}$ was 0.77, tier 2b was used to determine F_{ABC}, 0.36/y. The biomass at recruited age (age 3) in 2009-2010 was fixed at the recruitment (R) of 26,400 mt. Thus, ABC for Caspian kutum with recruited age 3 was estimated to be 7,850 mt (Table 4).

In tier 3, the F_{ABC} value was derived from the estimated $F_{0.1}$, 0.47/y. Thus, ABC for Caspian kutum was estimated to be 9,870 mt (Table 4).

Information available in tier 4 is the time-series catch and effort data for Caspian kutum. The information of maximum sustainable yield (MSY) and f_{MSY} were not available.

The only information available in tier 5 is the annual catch which based on: i) a period that is, at least, longer than the time from the age at first capture to oldest age in catch, ii) a period of little variation in catch data, iii) a period of little variation in fishing effort data, and iv) a period of little variation in fisheries management, such as a quota. The ABC in tier 5 could not be estimated due to lack of acceptable data.

Table 3 Yield and spawning biomass per recruit of Caspian kutum in Iranian waters under different harvest strategies corresponding to F_{max}, $F_{0.1}$ and $F_{30\%}$.

Age at first capture	F_{max}	$F_{0.1}$	$F_{30\%}$	Y/R (g)		SB/R (g)
				F_{max}	$F_{0.1}$	$F_{30\%}$
2	0.65	0.35	0.28	196.3	187.0	
3	1.40	0.46	0.43	228.9	210.3	
3.2	1.50	0.47	0.47	233.9	210.6	338.3
4	>2	0.60	0.85	244.8	214.2	
5	>2	0.75	>2	240.1	200.3	
6	>2	1.03	>2	213.3	179.4	

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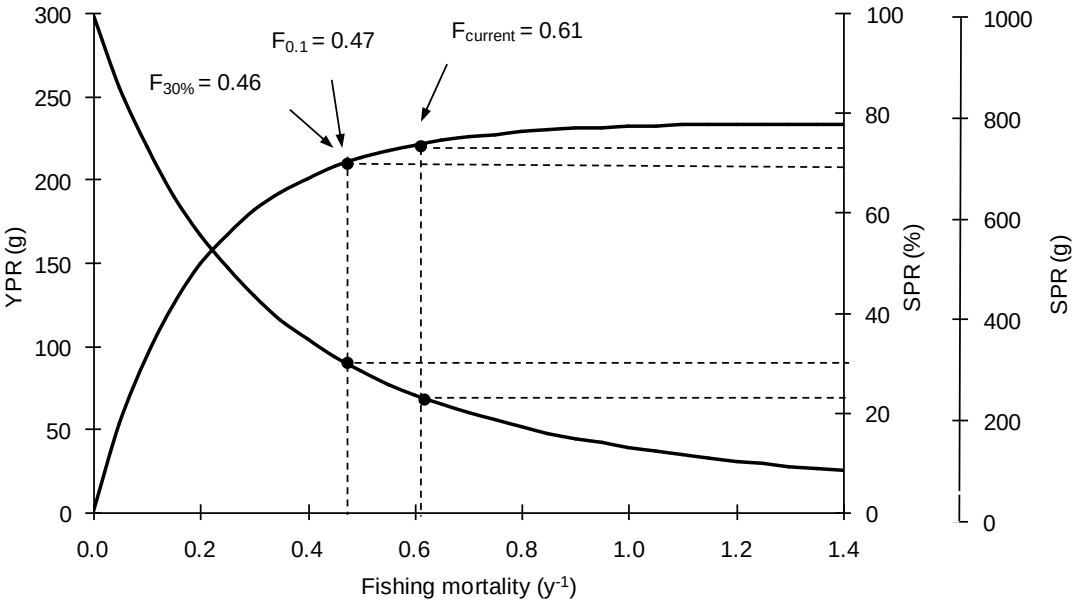

Figure 4 Estimates of biological reference points ($F_{0.1}$and $F_{30\%}$) and F (x-axes) for Caspian kutum where t_c is fixed at 3.2 y. The corresponding level of spawning biomass and Y/R (yield-per- recruit) in 2010 are shown on the y-axes.

Table 4 ABC estimates for Caspian kutum by the Iranian TAC fisheries management system.

	Stock status	ABC (mt)
Tier 1	B_{MSY}, F_{MSY} = not available	Not available
Tier 2	with current t_c = 3.2: $B/B_{30\%}$= 55,700/72,519<1	
	Stock status: 2b	
	$F_{ABC}=F_{30\%}\times(B/B_{30\%}-\alpha)/(1-\alpha)$ = 0.36/y	7,850
Tier 3	with current t_c= 3.2; $F_{ABC}=F_{0.1}$ = 0.47/y	9,870
Tier 4	CPUE/$CPUE_{MSY}$= Not available	Not available
Tier 5	Y_{AM}	Not available

4 DISCUSSION

The annually average biomass of the Caspian kutum was 46,000 mt during 2002-2010, it is 1.5 times more than the average biomass during 1991-2002, and it was remained fairly stable during the years of 2006-2010 (Figure 2). Also the maximum catch of kutum (17,200 mt) was recorded in the years 2007-2008 which it declined to 12,400 mt in 2009-2010 (Figure 1). Similar results reported for golden grey mullet in the Caspian Sea. According to Fazli *et al*., 2008 and 2010, the biomass of golden grey mullet remained fairly stable during the years of 1991-1995 (13,527-13,960 mt). In the years 2002-2003, biomass increased reaching the highest level (about 26,307 mt). Also the catches of golden grey mullet increased to highest level in 2002-2003

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(about 6,200 mt), but in the years 2007-2008 the biomass decreased to lowest level (about 11,000 mt), and the catch declined to 2600 mt.

Environmental factors can affect any stage of the life history to some degree. There is evidence that differences in recruitment are determined by the degree to which eggs and larvae are affected by environmental factors such as temperature, salinity, and food availability (Hermann, 1967; Tang, 1985; Ellersen *et al*., 1989). In the Caspian Sea, the major factors affecting the population of kutum, mullet and kilka are sea water level, temperature, stock enhancement, new invader and food availability (Fazli *et al*., 2008, 2009 and 2011). Although, according to Fazli *et al*., 2011, during the years 1991-2010 the exploitation ratio of Caspian kutum was high and they concluded that enhancement program supported the high exploitation ratios of kutum in the years 1991-2010, but they suggested application of a precautionary management approach of kutum stocks in the Caspian Sea.

The Y/R at the 2009-2010 estimation was about 218.3 g with an F of 0.61 y and the age at first capture (t_c) is 3.2 y. The Y/R was highest at 236.9 g with a t_c of 3.5 y (Figure 3). Therefore, the current age at first capture in 2009-2010 was lower than the t_c for the equilibrium maximum yield.

Reference points such as F_{max}, $F_{0.1}$, $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ have often used to develop fishery management strategies. Several authors have advocated designating $F_{0.1}$ or $F_{35\%}$ or $F_{40\%}$ at target reference points and $F_{30\%}$ as a threshold reference point in order to obtain near optimal yields while guarding against stock collapse (Gulland and Boerema, 1973; Deriso, 1987; Hildén, 1993; Leaman, 1993; Thompson, 1993; Mace, 1994; Chen 1997; Griffiths, 1997; Kirchner, 2001; Zhang and Lee, 2001). The result of the base Y/R and SB/R analyses in this study with t_c of 3.2 y suggests that the current fishing mortality rates on Caspian kutum in the Iranian waters of the Caspian Sea are higher than the target reference point $F_{0.1}$ and $F_{30\%}$ as well (Figure 4).

Considering the current stock status of kutum in 2009-2010, acceptable biological catches are estimated in Table 4. The ABC of Caspian kutum stock in tier 3 estimated according to available information, is 25.7 per cent more than in tier 2 (Table 4). The ABC with a lower and more accurate value based on more information, should be selected for implementation of a precautionary management approach. Therefore, the ABC under the tier 2 was estimated at 7,850 mt, should be selected.

5 CONCLUSIONS

In a precautionary approach the ABC of kutum was estimated at 7,850 mt. During last decades, there were high variations in the stock of Caspian kutum in the Caspian Sea. Caspian kutum is vulnerable to environmental factors, and these factors should consider in the stock assessment and management of the fish. Therefore, further research is needed to complete the study of stock assessment and management of kutum in the Caspian Sea.

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مدیریت ذخایر ماهی سفید (*Rutilus frisii kutum* Kamensky, 1901) در آب‌های ایرانی دریای خزر

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چکیده تغییرات اخیر در اکوسیستم دریای خزر شرایط بغرنجی را ایجاد نموده که سبب تغییر در فراوانی مطلق و نسبی گونه مهم تجاری ماهی سفید *(Rutilus frisii kutum)* در آب‌های ایران شده است. در این مقاله برآوردی از مقدار تولید به‌ازاء رکروئیت (Y/R) و زیتوده مولدین به ازاء رکروئیت (SB/R) تحت استراتژهای مختلف برداشت شامل F_{max}، $F_{0.1}$ و $F_{30\%}$ ارائه می‌شود. هم‌چنین با در نظر گرفتن اطلاعات کمی و کیفی مختلف موجود، روشی برای برآورد صید بیولوژیک قابل قبول (ABC) پیشنهاد شده است. در حال حاضر متوسط Y/R (با F=0.61/y و t_c=3.2y) برابر ۲۱۸/۳ گرم به‌ازاء رکروئیت است که نشان می‌دهد بهره‌برداری پائین‌تر از حداکثر Y/R در ۲۳۶/۹ گرم وقتی که t_c= 3.5 y می‌باشد، قرار دارد. بیش‌ترین مقدار Y/R به‌ترتیب در نقاط F_{max}و $F_{0.1}$ وقتی که t_c = 4 y مشاهده شد (۲۴۴/۸ و ۲۱۴/۲ گرم). با t_c = 4 y مقدار $F_{30\%}$ برابر ۰/۸۵ و SB/R برابر ۳۳۸/۳ گرم محاسبه شد. مقدار مرگ و میر صیادی فعلی (یعنی $F_{current}$= 0.61/y وt_c=3.2y) بیش‌تر از نقاط مرجع $F_{0.1}$ (۰/۴۷ در سال) و $F_{30\%}$ (۰/۴۶ در سال) می‌باشد. در سال ۸۹-۱۳۸۸ مقدار ABC ماهی سفید ۷۸۵۰ تن برآورد شد.

کلمات کلیدی: *Rutilus frisii kutum*، تولید بازاء رکروئیت، زیتوده مولدین به‌ازاء رکروئیت، صید بیولوژیک قابل قبول، نقطه مرجع

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