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Stock assessment and management implications of anchovy kilka (*Clupeonella engrauliformis*) in Iranian waters of the Caspian Sea

Hasan Fazli[a,*], Chang Ik Zhang[b], Douglas Edward Hay[b], Chun-Woo Lee[b]

[a] The Caspian Sea Ecology Research Center, P.O. Box 961, Khazar-abad, Sari, Iran
[b] Pukyong National University, 599-1, Daeyeon 3-Dong, Nam-Gu, Busan 608-737, Republic of Korea

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ABSTRACT

Recent changes in sea level of the Caspian Sea and ecological impacts caused by the invasive ctenophore (*Mnemiopsis leidyi*) have altered the ecosystem. A consequence is the changes in the absolute and relative abundance of the commercially important anchovy kilka (*Clupeonella engrauliformis*) in Iranian waters. To adjust to this change more rigorous management of this fishery is required. This paper examines the maximum sustainable yield (MSY) and fishing intensity at MSY. The paper presents estimates of f_{MSY}, yield-per-recruit and spawning biomass-per-recruit under various harvest strategies of F_{max}, $F_{0.1}$ and $F_{40\%}$. We propose a method for estimating acceptable biological catch (ABC) that accounts for large differences in the quality and quantity of information and available data. The MSY and f_{MSY} were estimated 44,652 mt (metric tons) and 18,609 vessel × nights (a unit of effort). The ABC was estimated at 2190 mt in 2004. In 2005, however, the catch of anchovy kilka was about 4300, over twice the estimated ABC. In 2008 (from January to October) the catch declined to 220 mt. The analyses indicate that overfishing, especially between 2005 and 2008, is the main reason of the collapse of anchovy kilka in the Caspian Sea.
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1. Introduction

The Caspian Sea is a brackish lake with no outlets. It has shores in the five countries: Azerbaijan, Iran, Turkmenistan, Kazakhstan and Russia. The surface area is about 436,000 km^2, and the volume is about 77,000 km^3 (Aladin and Plotnikov, 2004). The maximum depth is 1025 m, with an average of 184 m. The surface area of the Caspian Sea can be divided into three, approximately equal parts: north, middle and south. The volume of each part is very different, making up 1%, 35% and 64% of the total, respectively. The average salinity of the Caspian is 12.85 ppt (parts per thousand). The lowest salinities occur in the northern areas (about 5–10 ppt). Salinities in the middle and southern area are higher: about 12.7 and 13 ppt, respectively (Aladin and Plotnikov, 2004).

The most abundant fishes in the Caspian Sea are three small species of clupeids known as "kilka": common kilka (*Clupeonella cultriventris caspia* Svetovidov, 1941), anchovy kilka (*C. engrauliformis* Bordin, 1904), and bigeye kilka (*C. grimmi* Kessler, 1877). In the Iranian coastal areas of the Caspian Sea, kilka were important sources of income and protein. All the three kilka species are caught by commercial fisheries that use liftnets or fish pumps with underwater electric lights (Nikonorov, 1964). Annual catch of kilka increased to maximal levels of about 423,000 mt (metric tons) in 1970 (Ivanov, 2000) when kilka accounted for about 70% of total fish catch in the Caspian Sea (Sedov et al., 1997). Kilka fishing in Iran started with six ships in the port of Anzali in 1970. Until 1976, annual kilka catch were less than 4000 mt (Razavi, 1993).

Anchovy kilka comprised about 80–90% of the total kilka catch (Sedov and Rychagova, 1983; Fazli and Besharat, 1998). Anchovy kilka concentrate in the central and southern Caspian Sea in the areas with depths greater than 30 m (Prikhod'ko, 1981).

During the past 30 yr the environment of the Caspian Sea has 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. The greatest abundance of the species was recorded during the period of minimum sea level, 1960–1980 but the stocks decreased over the last decades of the sea level rise (http://www.caspianenvironment.org). In particular, the invasive jellyfish (Ctenophora, *Mnemiopsis leidyi*), first observed in November 1999 (Ivanov et al., 2000) has subsequently affected the distribution and abundance of zooplankton species and their predators, especially the three kilka species (Kideys and Moghim, 2003).

Routine annual quantitative assessments are necessary for effective utilization and management of the stock. Despite the economic and ecological importance of anchovy kilka as a major commercial and forage species, scientific information related to population dynamics and stock assessment is inadequate. Previous analyses

* Corresponding author. Tel.: +98 151 346 2512; fax: +98 151 346 2495.
E-mail addresses: hn_fazli@yahoo.com, fazlihasan@gmail.com (H. Fazli).

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Table 1
Parameter estimates used in yield-per-recruit and spawning biomass-per-recruit for anchovy kilka *Clupeonella engrauliformis*, in Iranian waters of the Caspian Sea taken from Fazli (2007).

Parameter	t_c	t_r	t_0	K	W_∞	M	F_c
	2.49 yr	0.18 yr^{-1}	−1.340 yr^{-1}	0.238 yr^{-1}	20.6 g	0.473 yr^{-1}	1.28 yr^{-1}

(Vinogradov et al., 1989; Harbison, 2001) indicated that of the invasion of *Mnemiopsis* in the Black Sea in the 1980s radically affected the whole ecosystem. This species negatively impacted the anchovy (*Engraulis encrasicolus*), the most dominant fish of the Black Sea, by competing for the edible zooplankton and by consuming anchovy eggs and larvae (Kideys, 1994).

In this paper, the maximum sustainable yield (MSY) and fishing intensity at MSY (f_{MSY}) were examined, and then the f_{MSY}, yield-per-recruit and spawning biomass-per-recruit for three different harvest strategies or fishing mortality rates: F_{max}, $F_{0.1}$ and $F_{40\%}$ were considered. F_{max} is the 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, $F_{40\%}$ is the fishing mortality for 40% of spawning biomass-per-recruit when fishing mortality is zero. A method for estimating ABC, using different categories of information is proposed that considers the large variation in the quality and quantity of information and available fishery data. Finally, it recommends a specific ABC and presents an explanation for the decreasing of the catch of anchovy kilka during 2005–2008.

2. Materials and methods

Sampling areas of anchovy kilka were located in the fishing regions in the Iranian Provinces of Mazandaran (with two sampling locations: Amir-abad and Babolsar harbors) and Guilan. Biological parameters from the previous study (Fazli, 2007) were used as input parameters in this analysis (Table 1 and Fig. 1).

Samples were caught from depths ranging from 30 to 100 m by conical liftnets equipped with underwater electric lights. The mesh size between two knots of the net is 7–8 mm. Sizes and shapes of the conical liftnets are nearly the same among all fishing vessels, so for the purposes of our analysis, we assumed that all ships were equipped with the same basic net. The fishing vessels are small (<100 tons) and fishing operations are conducted at night. Total kilka catch by each vessel was recorded by fishers and was collected by the Iranian Fisheries Organization in two different administration regions (Mazandaran and Guilan branches) from 1991 to 2004. A density index, CPUE (catch by a vessel per night) was calculated as an estimate of the relative abundance of anchovy kilka.

Production models of Schaefer (1954) and Fox (1970), which assume logistic and Gompertz population growth, respectively,

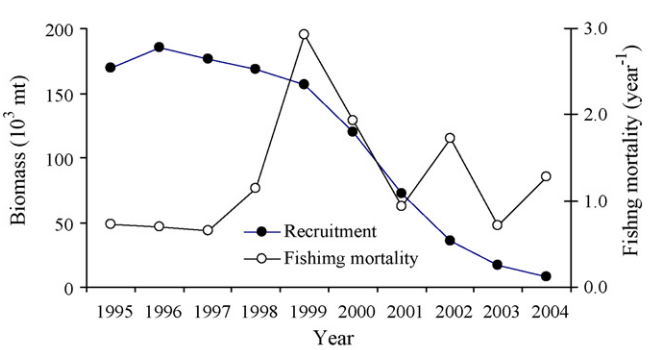

Fig. 1. Annual changes in total biomass and instantaneous coefficient of fishing mortality of anchovy kilka in Iranian waters of the Caspian Sea between 1995 and 2004 (from Fazli, 2007).

were used to determine MSY and the fishing intensity at MSY, f_{MSY}. The equation of the Schaefer model for variance proportional to f_t^2 is a simple linear regression equation:

$$\frac{Y_t^*}{f_t} = U_\infty - \frac{U_\infty q}{r} f_t + \varepsilon_t \tag{1}$$

where Y_t^* is the equilibrium yield in year t, U_∞ is an asymptotic CPUE, q is a catchability coefficient, r is the intrinsic natural growth rate, f_t is the fishing effort in year t and ε_t is the random error in year t. The Fox model equation, assuming a multiplicative error structure with variance proportional to f_t^2 becomes

$$\ln\frac{Y_t^*}{f_t} = \ln U_\infty - \frac{q}{r} f_t + \varepsilon_t \tag{2}$$

which is also in the form of a simple linear regression equation. The annual index of total fishing effort was calculated by dividing total catch by CPUE.

The following equation was used to determine the optimal fishing mortality and the optimal age at first capture:

$$\frac{Y}{R} = Fe^{-M(t_c-t_r)} W_\infty \sum_{n=0}^{3} \frac{U_n e^{-nK(t_c-t_0)}}{F+M+nK}\left(1-e^{-(F+M+nK)(t_L-t_c)}\right) \tag{3}$$

where asymptotic weight (W_∞) of 20.6 g, growth coefficient (K) of 0.238 yr^{-1} and age at zero length (t_0) of −1.340 are parameters of von Bertalanffy growth function; R is the number of fish at time t_r of 0.18 yr, 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 0.473 yr^{-1} (Fazli, 2007); t_L is the maximum age (8 yr) of kilka in the catch (Poorgholam et al., 1996; Fazli and Besharat, 1998); and U_n is a summation parameter equal to +1, −3, +3 and −1 for n = 0, 1, 2 and 3, respectively (Beverton and 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 the Beverton and Holt (1956) Y/R model:

$$\begin{aligned}\frac{d(Y/R)}{dF} &= e^{-M(t_c-t_r)} W_\infty \sum_{n=0}^{3} \frac{(M+nK)U_n e^{-nK(t_c-t_0)}}{(F+M+nK)^2} \\ &\quad + \frac{e^{-(F+M+nK)(t_L-t_c)}}{(F+M+nK)^2}[(t_L-t_c)F^2 + (M+nK)(t_L-t_c) \\ &\quad F-(M+nK)]\end{aligned} \tag{4}$$

When F = 0, the spawning biomass-per-recruit (SB/R) is:

$$\frac{SB}{R}\Big|_{F=0} = \sum_{t=t_r}^{t_\lambda} m_t e^{-M(t_c-t_r)} e^{-M(t-t_c)} W_\infty (1-e^{-K(t-t_0)})^3 \tag{5}$$

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 anchovy caught in the waters around Iran. The proportions of mature female of anchovy kilka are 0.04, 0.52, 0.80 and 1.00 for ages 1, 2, 3 and 4, respectively (Fazli, 2007). Age 4 was the age of full maturity. The SB/R equation (5) was used to estimate the instantaneous coefficient of fishing mortality which would maintain the spawning biomass at a level equivalent to 40% ($F_{40\%}$) at a given age of recruitment in an un-fished population.

When $F = F_1$ the (SB/R) is:

$$\frac{\mathrm{SB}}{R}|_{F=F_1} = \sum_{t=t_r}^{t_\lambda} m_t e^{-M(t_c-t_r)} e^{-(M+F)(t-t_c)} W_\infty (1-e^{-K(t-t_0)})^3 \quad (6)$$

The estimation of acceptable biological catches (ABCs) of pelagic 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 we adapted 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). For tiers 1–3, once the reference fishing mortality (F_{ABC}) was determined, the following equation was used to determine ABC:

$$\mathrm{ABC} = \mathrm{ABC}_r + \sum_{i=r+1}^{t_\mathrm{L}} \frac{B_i F_{\mathrm{ABC}}}{M+F_{\mathrm{ABC}}}(1-e^{-(M+F_{\mathrm{ABC}})}) \quad (7)$$

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 following equation:

$$\mathrm{ABC}_r = \frac{RF_{\mathrm{ABC}}}{M+F_{\mathrm{ABC}}}(1-e^{-(M+F_{\mathrm{ABC}})}) \quad (8)$$

where R is the estimate of biomass at age 3, which was estimated from Fazli (2007).

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).

Table 2
Methods used to determine the acceptable biological catch (ABC) for anchovy kilka in the Iranian fisheries management system (from Zhang and Lee, 2001).

Tier 1. Information available: Reliable estimates of B, B_{MSY}, F_{MSY} and $F_{40\%}$
(1a) Stock status: $B/B_{\mathrm{MSY}} > 1$
$F_{\mathrm{ABC}} = F_{\mathrm{MSY}}$
(1b) Stock status: $\alpha < B/B_{\mathrm{MSY}} \le 1$
$F_{\mathrm{ABC}} = F_{\mathrm{MSY}} \times (B/B_{\mathrm{MSY}} - \alpha)/(1-\alpha)$
(1c) Stock status: $B/B_{\mathrm{MSY}} \le \alpha$: $F_{\mathrm{ABC}} = 0$

Tier 2. Information available: Reliable estimates of B, $B_{X\%}$ and $F_{X\%}$
(2a) Stock status: $B/B_{40\%} > 1$
$F_{\mathrm{ABC}} = F_{40\%}$
(2b) Stock status: $\alpha < B/B_{40\%} \le 1$
$F_{\mathrm{ABC}} = F_{40\%} \times (B/B_{40\%} - \alpha)/(1-\alpha)$
(2c) Stock status: $B/B_{40\%} \le \alpha$: $F_{\mathrm{ABC}} = 0$

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

Tier 4. Information available: Times series catch and effort data
(4a) Stock status: $\mathrm{CPUE}/\mathrm{CPUE}_{\mathrm{MSY}} > 1$
ABC = MSY
(4b) Stock status: $\alpha < \mathrm{CPUE}/\mathrm{CPUE}_{\mathrm{MSY}} \le 1$
$\mathrm{ABC} = \mathrm{MSY} \times (\mathrm{CPUE}/\mathrm{CPUE}_{\mathrm{MSY}} - \alpha)/(1-\alpha)$
(4c) Stock status: $\mathrm{CPUE}/\mathrm{CPUE}_{\mathrm{MSY}} \le \alpha$: ABC = 0

Tier 5. Information available: Reliable catch history
$\mathrm{ABC} = P \times Y_{\mathrm{AM}}$ (arithmetic mean catch over an appropriate time period), $0.5 \le P \le 1.0$

(i) Equation used to determine ABC in tiers 1–3:
$$\mathrm{ABC} = \mathrm{ABC}_r + \sum_{i=r+1}^{t_\mathrm{L}} \frac{B_i F_{\mathrm{ABC}}}{M+F_{\mathrm{ABC}}}(1-e^{-(M+F_{\mathrm{ABC}})})$$
$$\mathrm{ABC}_r = \frac{RF_{\mathrm{ABC}}}{M+F_{\mathrm{ABC}}}(1-e^{-(M+F_{\mathrm{ABC}})})$$
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.

3. Results

The annual catches of anchovy kilka increased from 12,390 mt (metric tons) in 1991 to 67,450 mt in 1999, but dropped to about 5100 mt in 2004 (Fig. 2). The fishing effort in Iranian coastal areas increased from 2240 VN (number of vessels × number of nights) in 1991 to 28,736 VN in 2001 and declined to 12,992 VN in 2004 (Fig. 2). During the years 1991–1999 the CPUE ranged between 2.92 and 5.53 mt per VN, then it declined sharply to less than 0.40 mt per VN in 2004.

Fishing effort and CPUE data for anchovy kilka during 1991–2004 were fitted and compared between the Schaefer and Fox production models. The coefficient of determination (R^2) and probability (P) were 0.646 ($P = 0.013$) and $R^2 = 0.431$ ($P = 0.124$) for the Schaefer and Fox models, respectively. The Schaefer model provided a better fit to the data. Based on the Schaefer model, MSY was about 44,652 mt, and F_{MSY} was 18,609 VN (Fig. 3).

Fig. 4 shows the yield isopleths of anchovy kilka that were constructed to examine the response of Y/R estimates with respect to the age at first capture and fishing mortality. In 2004, the average Y/R (with $F = 1.27\ \mathrm{yr}^{-1}$, and $t_c = 2.49$ yr) was 1.38 g per recruit, which indicates that the fishery was operating below the maximum Y/R at 1.47 g when $t_c = 2.2$ yr. Fixing t_c at the current level, maximum Y/R was 1.46 g when F increased to $2.0\ \mathrm{yr}^{-1}$, but this F is out of range of the maximum Y/R line. Fixing F at the current level, maximum Y/R was 1.321 g when t_c decreased to 1.6 yr which increased Y/R by 5.8% (0.05 g).

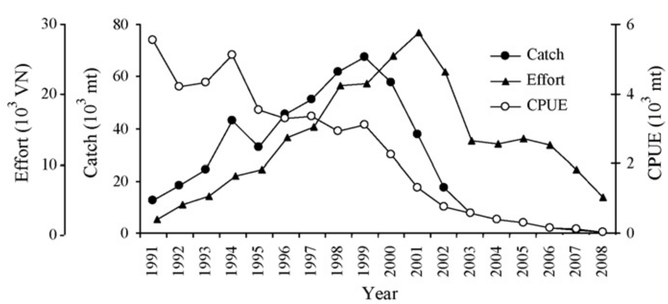

Fig. 2. Annual changes in catch, effort and CPUE of anchovy kilka in Iranian waters between 1991 and 2008.

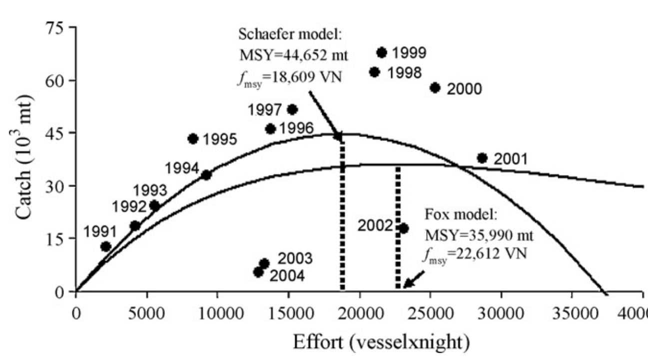

Fig. 3. Equilibrium yield curves for anchovy kilka using the Schaefer (1954) and Fox (1970) models.

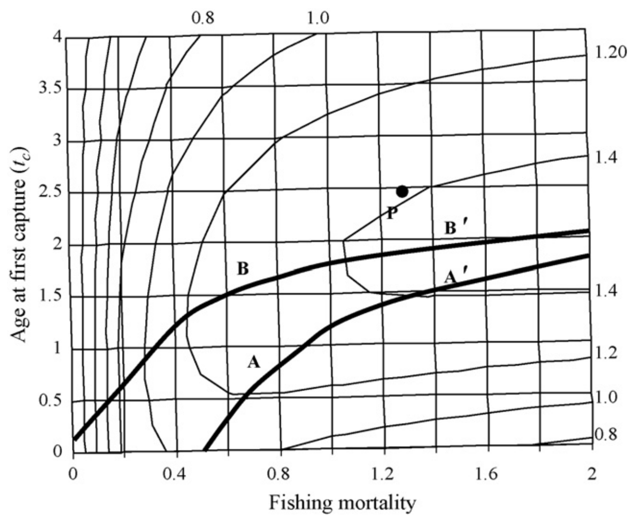

Fig. 4. Response surface of yield-per-recruit of anchovy kilka with respect to fishing mortality and age at first capture. *P* indicates the state of fishing mortality (F) and age at first capture (t_c) in 2004. *AA′* represents the maximum yield-per-recruit line at a given t_c and *BB′* indicates the maximum yield-per-recruit line at a given *F*.

Table 3
Yield and spawning biomass-per-recruit of anchovy kilka in Iranian waters under different harvest strategies corresponding to F_{max}, $F_{0.1}$ and $F_{40\%}$.

Age at first capture	F_{max}	$F_{0.1}$	$F_{40\%}$	Y/R (g)		SB/R (g)
				F_{max}	$F_{0.1}$	$F_{40\%}$
1	1.00	0.45	0.31	1.32	1.20	2.35
2	>2	0.61	0.523	1.47	1.27	
2.49	>2	0.69	0.67	1.46	1.23	
3	>2	0.79	1.350	1.44	1.19	

Table 3 shows the F_{max} and $F_{0.1}$ values from ages 1 to 4 of anchovy kilka estimated from the Beverton and Holt (1956) model. The Y/R was the highest at F_{max} and $F_{0.1}$, was the highest when $t_c = 2$ yr (1.47 and 1.27 g, respectively). F_{max} and $F_{0.1}$ increased until age 4. The Y/R for each F value increased with t_c when $t_c < 2$ yr, and gradually declined when $t_c > 2$ yr. The $F_{40\%}$ value was 0.527 yr^{-1} at t_c of 2 yr with the spawning with the SB/R of 2.35 g (Table 3).

The estimates of biological reference points ($F_{0.1}$ and $F_{40\%}$) and current F in 2004, fixing t_c at current level for anchovy kilka are summarized in Fig. 5. The corresponding estimate for $F_{current}$ is 1.28 yr^{-1}, which is higher than the corresponding reference points, $F_{0.1}$ (0.69 yr^{-1}) and $F_{40\%}$ (0.67 yr^{-1}).

Information considered for tier 1 includes the historic estimates of biomass, M, B_{MSY}, F_{MSY} and $B_{40\%}$ for anchovy kilka. The information of B_{MSY} and F_{MSY} was not available, because the fit of the

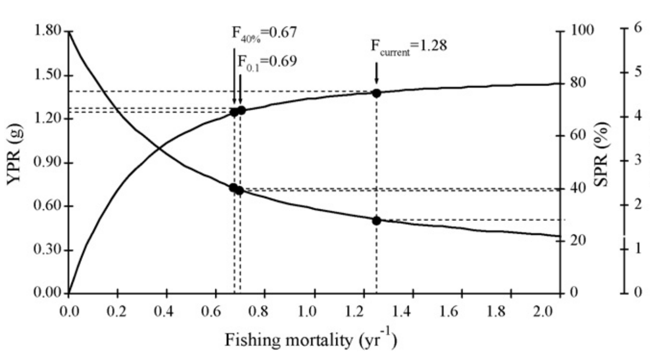

Fig. 5. Estimates of biological reference points ($F_{0.1}$ and $F_{40\%}$) and F (x-axes) for anchovy kilka where t_c is fixed at 2.49 yr. The corresponding levels of spawning biomass and Y/R (yield-per-recruit) in 2004 are shown on the y-axes.

Table 4
ABC (acceptable biological catch) estimates for anchovy kilka 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 $t_c = 2.49$: $B/B_{40\%} = 8320/11{,}800 < 1$ Stock status: 2b $F_{ABC} = F_{40\%} \times (B/B_{40\%} - \alpha)/(1 - \alpha) = 0.46$	2190
Tier 3	With current $t_c = 2.49$; $F_{ABC} = F_{0.1} = 0.69$ yr^{-1}	2970
Tier 4	CPUE/CPUE$_{MSY}$ = 0.397/2.400 = 0.165 < 1 Stock status: 4b	5419
Tier 5	Y_{AM}	Not available

biomass-based approach to the production model (Zhang, 1991), using biomass and fishing mortality, was not statistically significant, so these values could not be estimated.

However, reliable information on current biomass in 2004, M, $B_{40\%}$ and $F_{40\%}$ was available to consider for tier 2 in this study (Table 4). Biomass data were available for each age class (ages 1–7 fish) taken in the fishery from 1995 to 2004. The biomass in 2004 was estimated to be 8320 mt and the biological reference points, $F_{40\%}$ and $B_{40\%}$, were estimated to be 0.67 yr^{-1} and 11,800 mt, respectively. Since the ratio $B/B_{40\%}$ of was 0.71, tier 2a was used to determine F_{ABC}, 0.46 yr^{-1}. The biomass at recruited age (age 3) in 2004 was fixed at the recruitment (R) of 2680 mt. Therefore the ABC for anchovy kilka, recruited at age 3, was estimated to be 2190 mt (Table 4).

To calculate ABC in tier 3, estimated reliable biomass in 2004, M and $F_{0.1}$ for anchovy kilka is required. The F_{ABC} value was derived from the estimated $F_{0.1}$, 0.69 yr^{-1}. Thus, ABC for anchovy was estimated to be 2980 mt (Table 4).

Information available in tier 4 is the time-series catch and effort data for anchovy kilka. The maximum sustainable yield (MSY) for anchovy kilka was 44,652 mt and CPUE at MSY 2.400 mt/V^{-1} N^{-1} from the Schaefer model (Fig. 3). Since the stock falls into category 4b and the ratio of CPUE/CPUE$_{MSY}$ was 0.165, the ABC was 5419 mt (Table 4).

The only information available in tier 5 is the annual catch. Selection of the most appropriate time periods to determine the arithmetic mean catch (Y_{AM}) is 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. Because acceptable data were not available, the ABC in tier 5 could not be estimated.

4. Discussion

To establish the ecological sustainability in fish harvests, the estimated MSY and the corresponding effort level were compared with actual catch and effort figures. Obviously a fishery is not sustainable if total catch exceeds the MSY level. In this study the MSY, estimated from a Schaefer model, was about 44,652 mt, and the fishing intensity needed to achieve this MSY was 18,609 VN. This indicates that anchovy kilka stocks were in a situation of biological overfishing since 1997 (Fig. 2). The catch and stock of anchovy kilka (Figs. 1 and 2) occurred when maximum fishing mortality (Fig. 1) simultaneous with first record of jellyfish in the Caspian Sea in 1999 reported.

The Y/R at the 2004 estimate is about 1.38 g with an F of 1.28 yr and the age at first capture (t_c) is 2.49 yr. The Y/R is highest at 1.47 g with a t_c of 2.2 yr (Fig. 4). Therefore, the age at first capture in 2004 is much higher than the t_c for the equilibrium maximum yield.

Reference points such as F_{max}, $F_{0.1}$, $F_{30\%}$ and $F_{40\%}$ have often used to develop fishery management strategies. Several authors have advocated designating $F_{0.1}$ or $F_{35\%}$ or $F_{40\%}$ as 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; Quinn et al., 1990; Hildén, 1993; Leaman, 1993; Rivard and Maguire, 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 2.49 yr suggests that the current fishing mortality rates (in 2004) on anchovy kilka in the Iranian waters of the Caspian Sea are higher than the target reference point $F_{0.1}$ and $F_{40\%}$ as well (Fig. 5).

Considering the current stock status of anchovy kilka (in 2004), acceptable biological catches are estimated in Table 4. In 2004, the ABC of anchovy kilka stock in tier 3 and tier 4 estimated according to available catch and effort information, is 35.6% and 147.4% more than in tier 2, respectively (Table 4). The ABC with a lower and more accurate value based on more information, should be selected for the implementation of a precautionary management approach. Therefore, the ABC under the tier 2 was estimated at 2190 mt, should be selected.

The results show that the ABC of tier 4 in 2004 is about 8 times lower than MSY. Karpyuk et al. (2004) reported that the biomass of anchovy kilka declined from 944,000 mt in 1998 to 122,000 mt in 2003. According to several recent reports the invasive ctenophore (*Mnemiopsis*) caused the collapse in the stock of anchovy kilka in the Caspian Sea (Karpyuk et al., 2004; Kideys et al., 2001a, 2001b; Kideys and Moghim, 2003; Kideys et al., 2005). The explanation for the collapse is a competitive interaction: *Mnemiopsis* is a voracious predator on zooplankton that is the food for the zooplanktivorous kilka species (*Clupeonella* spp.).

Daskalov and Mamedov (2007) reported that the most obvious factors that may have influenced anchovy kilka dynamics negatively are excessive fishing, climate change, seismic activity, and invasion by the exotic *Mnemiopsis*. They concluded that the increased commercial catch of anchovy kilka after 2000 followed the drop in SSB in 1999 and led to a very high fishing mortality in 2000. Further, the stock has been additionally subject to mass mortality following the seismic events in 2001 (Sedov et al., 2002). As cited in Daskalov and Mamedov (2007), earthquake data reveal that, in the first quarter of 2001, the local Absheron seismic plate was active, and water and gas systems in the soil were unstable and indicative of hydro-volcanic events or significant gas blow-outs containing poisonous substances, which most probably contributed to the mass kill (Katunin et al., 2002).

In 2005, the catch of anchovy kilka was about 4300, more than 2 times greater than the ABC was estimated for Iranian waters. In the years 2006–2008 (till October) the catch declined to 1900, 1200 and 220 mt, respectively.

As above mentioned, overfishing simultaneous with several factors, such as sea level changes, invasive species and pollution affected kilka stocks during last decades. Because of these factors, the natural mortality is not constant. We concluded that to management of kilka stocks all factors affected on kilka stocks should take into account and a coordinated international effort is needed to provide immediate implementation of management in the Caspian Sea.

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