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Research Article

An analysis of the maximum economic yield of Kilka fisheries in the southern Caspian Sea

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Abstract

This study combined socio-economic data with long time series data for Kilka species' annual catch and effort from 2003 to 2017, in the Iranian waters of the Caspian Sea. This analysis was conducted to estimate maximum sustainable yield, maximum economic yield, and their respective effort levels to manage and exploit the Kilka spices in a sustainable manner. According to our estimation, MSY was 22850 t, with a total income of $5587715 at an effort value (fmsy) of 9498 vessel night. The figure for MEY were 21988 t, with a total income of $5376847 with a substantially lower fishing effort value (fmey) of 7653 vessel night. Comparing the landing of Kilka, in 2017 (22602 tonnes) with the results of the surplus production model analysis, it is suggested that in order to conserve stocks of common Kilka, it is necessary to decrease the level of catch and fishing efforts based on the results of the present study.

Keywords: Kilka fishery, MSY, MEY, f_{msy}, f_{mey}, Caspian Sea

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Introduction

In 2018, the global capture fishery production was totaled 96.4 million tonnes with the share of 87.6% (84.4 million tonnes) and 12.4% (12.0 million tonnes) from marine and inland waters respectively. Globally, an estimated 38.98 million people are engaged in the primary sector of fisheries (FAO, 2020). In Iran, the total number of people engaged in the primary sector of fisheries was 140562 (Iran Fisheries Statistical Yearbook, 2021) , However the total people engaged in the primary sector of Kilka fisheries in the Caspian Sea weas estimated to be 480 (Taghavimotlagh *et al*., 2021).

Fisheries management aims to preserve the biological capacity of stocks under fishing and preserve the economic value of the fishery, by setting and implementing regulations that lead to economically viable, biologically and demographically sustainable (Anderson and Seijo, 2010).

With the aim for sustainable fisheries, control of catches and fishing effort of the fishery, it is necessary to have solid scientific research in the field of fishery biology and economics (Defeo and Seijo, 1999 ; Mattos *et al*., 2006; Maynou *et al.*, 2006 ; Anderson and Seijo, 2010; Kar and Chakraborty, 2011; Chakraborty *et al.*, 2011). According to different studies, it is evident that from the last decades the time series catch and effort data, utilized by many scientists, as an important tool to provide management strategies for ensuring the sustainability and economic performance of marine fisheries resources (Hinton, 1998; Maunder and Punt, 2004; Maunder *et al.*, 2006 ; Kar and Chakraborty, 2011). The time series catch and effort data can be analyzed using the surplus production model which is known as the biomass dynamics model (Hilborn and Walters, 1992; Maunder and Punt, 2004). The surplus production models are the simplest method for the management of fishery resources in terms of the biological reference point (MSY) when only the time series catch and effort statistics are available. Similarly, economic variables like revenue and fishing cost can be included in the biological Schaefer model to see the relationship between revenue, fishing cost and fishing effort (King, 2013).

Profit refers to "extra amount", i.e., the profits gained in excess of the level needed to cover all fishing costs and to provide a return to fisheries as well as an incentive to go fishing. In a fishery in which there is no control on fishing effort, "open access fishery", many people are attracted to fishery with high-profit levels, until reach at the economic break-even point, where total costs will equal total catch volume and no excess profits are existing. Thus, at this high level of fishing effort, not only biological sustainability will destroy but profit will have been dissipated (King, 2013).

Many of the world’s fisheries are challenged by overcapacity, overfishing, habitat degradation and low-income returns, the explanation “because too many boats catching few fish” surly fits most aquatic fisheries today (Grafton, 2006) However, modern fisheries bioeconomic handles the complications of overexploitation and overcapacity in marine fisheries that are mainly affected through natural variations, changing coastal ecosystem and nonexistence of a solid governance (Munro, 1992). Thus, bioeconomic analysis of commercial marine fisheries, an activity which is carried out for profit by using the data of prices and cost, to assess, at which extent of efforts the maximum harvest levels will be achieved, without disturbing the stock size under definite conditions (Anderson and Seijo, 2010).

In the Caspian Sea, the composition of Kilka species is included: *Clupeonella engrauliformis* (Anchovy Kilka), *Clupeonella caspia* (Common Kilka), *Clupeonella grimmi* (Big eye Kilka). Until 1990, more than 90% of the catches of Kilka were comprised of Anchovy species, but as the total catches declined the share of the Anchovy species in the catch gradually started to decrease to zero (Fazli *et al*., 2020). Since 2003, the Kilka catch composition has totally changed from Anchovy species (*C. engrauliformis*) to the Common Kilka species (*C. caspia*). The composition of the big eye species has been very low from the beginning, mostly because this species area distributed at greater depths, (more than 80 meters), and therefore the catch quantity of this species has always been near zero (Fazli *et al*., 2020).

The aim of the present study is to use a long series of Kilka annual catch and effort data in the Caspian Sea (Iranian waters), to estimate MSY, MEY and other economic indicators which could help to manage and exploit Kilka spices in a sustainable manner. The Gordon-Schaefer (Gordon, 1953, 1954) model will be employed for the estimation of biological harvest levels of Kilka fishing as well as economical parameters and their respective effort levels and also economic revenues. Finally, this study will suggest the appropriate policies recommendations based on MSY and MEY calculation results for improving the commercial catch status of Kilka fishing with the enhancement of revenue function.

Materials and methods

The data for this study comes from two sources, a socio-economic study was recently completed (Taghavimotlagh *et al.*, 2021; Taghavimotlagh *et al*., 2018) which was used for the economic data while time-series catch and effort statistics, 2003-2017, of Kilka fishing in the southern Caspian Sea were acquired from the Department of Fisheries Statistics (Iran Fisheries Statistical Yearbook, 2018) (Table 1).

Catch and effort data

Time series catch and effort statistics, 2003-2017, of Kilka fishing in the southern Caspian Sea were acquired from the department of fisheries statistics (Table 2), (Iran Fisheries Statistical yearbook, 2018) to depict the economic model of Kilka fishing, estimation of MSY, MEY and determination of optimum fishing effort (f_{msy}).

Model description

By employing the economic data (costs and revenue), bioeconomic analyses of commercial marine fisheries can be conducted, to evaluate the optimum fishing effort for maximizing the amount of fish harvest without harming long term sustainability of fish stock (Anderson and Seijo, 2010). Fisheries can be controlled by using a surplus production model, if time-series catch and data are available (Omori *et al.*, 2016). Determination of the optimum levels of fishing effort which guarantee the long-term productivity of the fish stock is the main goal of the use of the surplus production model (Cochrane, 2002).

Table 1: Total number of Kilka vessels operating in the Caspian Sea , number of fleet segments and number of sampling vessels (Taghavimotlagh *et al.*, 2021).

Province	LOA (M)	Total number of vessels	Number Of Samples	Non Response	Activity Rate (%)
Mazandaran	12-18	44	**22**	2	100
Guilan	12-18	20	**10**	0	100
	18-24	10	**5**	0	100
Total		74	**37**	2	100

Table 2: Time-series catch and effort data of Kilka fishery in the Caspian Sea 2003-2017.

Year	Catch (tonnes)	Effort (Vessel Night)	CPUE (kg/ (Vessel Night))
2003	15497	13405	1156
2004	19610	12992	1509
2005	22626	13676	1654
2006	22303	12816	1740
2007	15411	9309	1655
2008	16743	7364	2274
2009	25483	7295	3493
2010	27110	7853	3452
2011	20717	7473	2772
2012	24086	8767	2747
2013	23222	8438	2752
2014	22873	7216	3170
2015	21553	8205	2627
2016	22428	8065	2781
2017	22602	9307	2428

The main goal of the commercial fishery is to maximize profit. Although, reduction of the costs is a common objective of many fisheries, but there are few fisheries which considered only for their economic value (King, 2013). As proposed by Gordon (1954), surplus production curves can be converted into revenue curves, and the maximum economic yield, MEY, estimated as the greatest difference between this curve and the fishing cost line.

Both Schaefer (1954) and Fox (1970) models (1970) were examined to see the correlation coefficient (R) of the regression curves, as there were no significant differences between the correlation coefficients (R= 0.85 for Schaefer, R= 0.87 for Fox model) therefore in this paper a Schaefer type production technology, where the yield

(Y) is proportional to fishing effort (E) and stock biomass (B) through a catchability coefficient q, was assumed to analyze the commercial Kilka fishing in the southern Caspian Sea:

$Y = qEB$ (1)

Under equilibrium condition, the Schaefer model suggests that the equilibrium yield can be related to fishing effort through a symmetrical parabola curve.

Assuming the following equation for the population growth dynamics (Graham, 1935):

$\frac{dB}{dt} = rB\left(1 - \frac{B}{K}\right)$ (2)

Where r and K represent the intrinsic rate of population growth and the carrying capacity of the environment respectively, eq. 1 and eq. 2, allow the equilibrium biomass and yield to be expressed as follows (Seijo *et al*., 1998):

$B_{eq} = \left(1 - \frac{qE}{r}\right)K$ (3)

$Y_{eq} = qE\left(1 - \frac{qE}{r}\right)K$ (4)

Given $a = qK$ and $b = q^2K/r$, eq. 4 can be rewritten as follows:

$Y = aE - bE^2$ (5)

Which represents the classical parabolic curve relating yield to fishing effort in the Schaefer equilibrium model.

Based on Schaefer’s model, Gordon (1954) introduced an economic model where profits (π) are estimated by assuming constant price per unit of yield (p) and constant cost per unit of fishing effort (c),

$\pi = pY - cE$ (6)

Where pY represents the equilibrium revenues, assuming that landings are approximately equal to yields, and cE the total cost of fishing.

MSY and MEY under the Gordon-Schaefer model are estimated as follows:

$E_{MSY} = \frac{a}{2b};\ Y_{MSY} = \frac{a^2}{4b}$ (7)

$E_{MEY} = \frac{pa-c}{2pb};\ Y_{MEY} = aE_{MEY} - bE_{MEY}^2$ (8)

Analysis of variance (ANOVA) was used to test statistical significance regression.

The catch-effort model described above was estimated for the Kilka fishery in the southern Caspian Sea by using annual catch and effort data in the period 2003-2017, where fishing effort is intended in terms of fishing nights. Parameters a and b were estimated by rewriting eq. 5 in terms of catch–effort ratio and using fishing effort as regression:

$\frac{Y}{E} = a - bE$ (9)

Parameters p and c were estimated on 2017 data as the average price of Kilka and the average cost per day, respectively.

Results

Table 2, demonstrated time series catch and effort data of Kilka fishery in the south Caspian Sea (Iranian waters) from 2003- 2017. The results of regression analysis presented such as *a* and *b* which are estimated through the regression of the CPUE on the corresponding fishing effort calculated as 4811.71 and -0.2533 respectively and presented in Table 3. The regression analysis reveals R^2=0.72 which means the linear regression model explains the 72.0% variation in CPUE data. Total costs and revenue for the whole fleet and average costs and revenue for each vessel were calculated and demonstrated in Table 4.

Table 3: Regression analysis of CPUE against fishing effort of Kilka fishery in the southern Caspian Sea

Regression statistics	
Multiple R	0.85
R Square	0.72
Adjusted R Square	0.70
Standard Error	398.47
Observations	15

ANOVA	df	SS	MS	F	Significance F
Regression	1	5314161.82	5314161.82	33.47	6.32863E-05
Residual	13	2064151.57	158780.90		
Total	14	7378313.39			

	Coefficients	Standard Error	t Stat	*p*-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4811.71	427.62	11.25	4.50328E-08	3887.89	5735.53	3887.89	5735.53
Effort (Vessel night)	-0.25	0.04	-5.79	6.32863E-05	-0.35	-0.21	-0.35	-0.21

Table 4: Costs and revenue analysis of Kilka fishery in the southern Caspian Sea (Taghavimotlagh *et al*., 2021).

Revenue-Total ($)

Variable	Mazandaran 12-18	Guilan 12-18	Guilan 18-24	Total
Value of landings	3964378	1079857	408004	5452238

Revenue- Average per vessel ($)

Variable	Mazandaran 12-18	Guilan 12-18	Guilan 18-24	Total
Value of landings	90099	53993	40800	73679

Costs-Total ($)

Variable	Mazandaran 12-18	Guilan 12-18	Guilan 18-24	Total
Energy costs	277365	73752	39300	390417
Maintenance costs	326622	117439	92330	536391
Operational costs	315034	53236	24994	393264
Commercial costs	37599	6380	3032	47011
Fixed costs	221591	170888	23283	415762
Crew share (salary)	1848115	395099	148653	2391868
Total operating costs	3026327	816794	331591	4174713

Costs- Average per vessel ($)

Variable	Mazandaran 12-18	Guilan 12-18	Guilan 18-24	Total
Energy costs	6304	3688	3930	5276
Maintenance costs	7423	5872	9233	7249
Operational costs	7160	2662	2499	5314
Commercial costs	855	319	303	635
Fixed costs	5036	8544	2328	5618
Crew share (salary)	42003	19755	14865	32323
Total operating costs	68780	40840	33159	56415

Some of the Kilka fishery socio-economic indicators, extracted from the analysis of variables are presented in Table 5. Interpreting the results into indicators for the present position of Kilka fishery in the Caspian Sea shown that in average this fishery, create at least 480 direct different job opportunity in harvest part. The result of costs and revenue analysis implies the profitability of this fishery.

Table 5: Some of the Kilka fishery socio-economic indicators in 2017, in the southern Caspian Sea (Taghavimotlagh *et al*., 2021).

Total Revenue in Kilka fishery ($)	Average Revenue per vessel ($)	Total costs in Kilka fishery ($)	Average costs Per vessel ($)	Total different employments in Kilka fishery	Average different employment /vessel
5452238	73679	4174713	56415	480	6.5

Biological and economical reference points such as harvest levels of Maximum sustainable yield (MSY) and Maximum economic yield (MEY), with their corresponding effort levels (E_{MSY} and E_{MEY}), were calculated for the present study as shown in Table 6.

Figure 1, illustrated the fishing revenue curve, fishing costs line and fishing profit curve for Kilka fishery in the south Caspian Sea. Also, the economic break-even point, where the two lines (revenue and costs) are crossed, is demonstrated.

Table 6: Harvest levels of maximum sustainable yield (MSY) and maximum economic yield (MEY) with their corresponding effort levels (E_{MSY} and E_{MEY}) for the Kilka fishery in the southern Caspian Sea

Kilka Fishery Reference Points	Values
MSY	22850 tonnes Catch Per Year
E_{msy} (MSY Corresponding Effort Level)	9498 Vessel night
R_{msy} (Revenue, At MSY Point)	$ 5587718
MEY	21988 t Catch Per Year
E_{MEY} (MEY Corresponding Effort Level)	7653 Vessel night
R_{mey} (Revenue At MEY Point)	$ 5376847

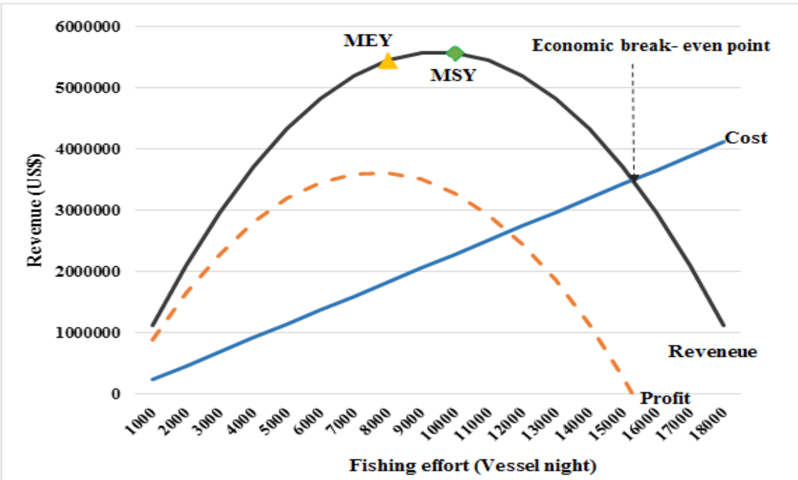

Figure 1: A fishing revenue curve, a fishing cost line and a fishing profit line for Kilka fishery in the southern Caspian Sea

The results showed that at the economic break-even point, the average annual catch of each vessel is about 205 tonnes. According to data analysis, the mean range of landing volume for three segments of Kilka vessels in the southern Caspian Sea are 163 (18-24 Guilan), 216 (12-18 Guilan), and 322 (12-18 Mazandaran) tonnes with an average of 266 tonnes per year . The gain of profit at MEY point was calculated to be more than $362015, while this figure for MSY, was less than $347490. At open access fisheries system, the total revenue is equal to total costs, which means zero profit.

Discussion

In many fisheries, management objectives are based on a recommended Total Allowable Catch (TAC), which can be framed as biological reference points, such as MSY, or economic reference points, such as MEY. The present study attempt to estimate MSY and MEY for Kilka fishery in the southern Caspian Sea (Iranian waters) using catch series and effort data. According to our estimation, MSY was at 22850 tonnes, with total revenue of $5,587,718 at an effort value of 9498 vessel fishing night, while these figures for MEY, was 21988 tonnes, with total revenue of $ 5,376,847 at substantially lower fishing effort value of 7653 vessel fishing night.

The bioeconomic analyses indicate excessive fishing efforts. The results showed that some improvements in the Kilka fishery (in the southern Caspian Sea) could be acknowledged, in order to maximize economic benefits, if the E_{MEY} optimal management option is applied. It was also shown that the MEY option not only increases the revenue but also reduces the total cost, consequently increasing the net benefits of the fishery. Therefore, the results suggest that in order to reach the optimum sustainable yield and maximize economic yield, fishing effort needs to be reduced from 9498 vessel night fishing to 7653 vessel night fishing.

Historically, the main objective of fisheries management has been the conservation of fish stocks. In modern fisheries management this limited aim has been extended to address additional economic, social and environmental objectives such as fishers' welfare, economic efficiency, the allocation of resources, and environmental protection (King, 2013). The broad objectives of fisheries management may, therefore, include the conservation of fisheries resources and their environment, the maximization of profit from the fishery, and payment fees to the community from profit made by the exploitation of a public resource.

The output of data analysis to quantitative socio-economic indicators implies the profitability of Kilka fishery in the southourn of the Caspian Sea, however, the capital costs which is influenced by the rate of inflation (Opportunity costs and depreciation costs) did not include in the calculation of costs and revenue analysis.

The employment opportunity indicators show that at the present situation, Kilka fishery, created about 480 direct different job opportunity in harvesting section in coastal area of Iran in the south Caspian Sea, if we assume that each direct job created three indirect jobs (Iran Fisheries Organization Five-Year Development Plan, for 2005-2009), the number of direct and indirect jobs created by Kilka fishery in this area, are more than 1400 jobs.

The results of the present study suggest that, in order to enhance economic efficiency and total revenue from Kilka fishery and ensuring that stock would not be decreased below some minimum level, there is need to reduce the fishing effort. The surplus production models are responsible for estimation of stock size and catch rates mainly based on biological reference points such as MSY, which are among of the most significant strategies for fisheries management. Similarly, the estimation of fishing effort levels to attain MSY (E_{MSY}) is also plays a crucial role to achieve these objectives (Hoggarth *et al.,* 2006). However, MSY should not be considered as a constant, extraction of a constant yield every year, but relatively encourage the theoretical policy requirement to overcome the overfishing state (Beddington and Shepard, 1993). If the total catch is going beyond the MSY levels, not only the fishery is not in the sustainable state but also the profit from the fishery is decreased until meets the point where the costs and revenue are equal (economic break-even point). The advantage of maintaining a fishery at the level of MEY from a biological perspective is that fishing effort is generally lower than that required to maximize yield in weight. Because of this, fishing to secure MEY reduces the probability of recruitment overfishing, which happened to Anchovy Kilka in the Caspian Sea in 2000. Therefore, maintaining Kilka fishery in the south Caspian Sea, at MEY, can result in excess profits by fishers and reduce the risk of stocks collapsing, as happened for Anchovy Kilka, in 2003. As it is clear from the fishing revenue curve (Fig. 1) for Kilka fishery, when the level of fishing exceeds MEY point, the amount of economic rent gradually decreased until reached break-even point, where the revenue and costs of fishing are equal and there is no profit gain.

Figure 2, illustrates that the increasing trend began in 1990, reached its maximum in 1999 and then the decreasing trend of the catches began. Some scientist believes (Parafkandeh Haghighi and Kaymaram, 2012) that the decline was the result of the invasion and bloom of jellycomb (*Mnemiopsis leidyi)* in the Caspian Sea, while other scientists believe (Karimzadeh *et al.,* 2010) that the decline was the result of both the jellycomb invasion and overfishing as a consequence of high and unregulated fishing effort. According to Fazli *et al.* (2020), the sharp decrease in both anchovy and bigeye stocks in the Caspian Sea are due to competition of *M. leidyi* with these two species.

Kilka catches started to decline in 2000, and almost stabilized in 2006 when nearly more than 50% of the catch composition belonged to Common Kilka. The graph also explains the stable status of Kilka fishing from 2006. After sharp decline in Kilka catches in the southern Caspian, fisheries authority and fishers together fixed the number of

Kilka fleets to 74, and regulate fishing time, therefore, the level of fishing effort rarely passed beyond MSY level.

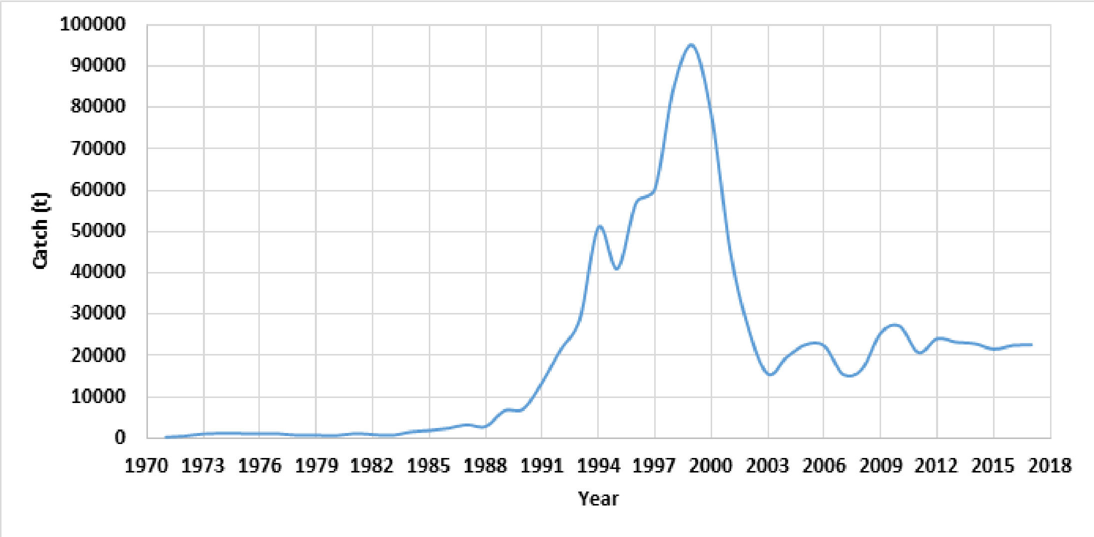

Figure 2: Kilka landings in tonnes from 1971-2018 fishery in the southern Caspian Sea

Comparing the landings of Kilka (22602 tonnes in 2017) with the results of the surplus production model analysis in the present study, it is suggested that in order to conserve stocks of common Kilka, which is dominated the composition of the catch, secure sustainable exploitation and maximizing the profit from Kilka fishery, it is necessary to decrease the level of catch and fishing effort as outlined in Table 6. Fazli e*t al*. (2017) estimated MSY and f_{MSY} for common Kilka, as 22670 tonnes and 8690 vessel night fishing and they used Schaefer model analysis but had a different result from that of the present study, which might be related to the number of series of catch and fishing effort used by two studies.

In conclusion, to secure Kilka fisheries in the south Caspian Sea, sustainable with maximizing profitability, it is suggested to set and regulate fishing harvest and fishing effort at a lower level as outlined by the present study (MEY, at 21988 tonnes with the fishing effort of 7653 vessel× night).

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