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Benefits of stock enhancement: The case of the Iranian kutum fishery

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Benefits of stock enhancement: The case of the Iranian kutum fishery

by

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Abstract

Harvesting of the fish resources as an economic activity, which is strictly tied to biological matters, needs to be modeled proficiently through bioeconomic analysis. In this study, a bioeconomic age-structured model is used to analyse the profitability of *Kutum* fishing in Iranian coastal waters of the Caspian Sea. Dwindling population of this species has been revived through an enhancement programme, since 1982 in southern Caspian areas by Iranian Fisheries Organization (IFO). Biological age-structured models in this paper were used to estimate the catch amount under two different hypotheses of Beverton-Holt and Ricker about stock-recruitment relationship. Considering the effects of the enhancement programme on recruitment and catch and also on the fishing activity costs, the net present value of the profits from fishing activity is calculated economically. The results showed a significant positive effect of the programme on profitability. Finally, the effect of fishing mortality adjustment, as a management tool, on profitability is also evaluated and it is shown that the reduction in fishing mortality causes a consequent increase on the NPV of profits from fishing activity. According to the results, one can consider the enhancement programme as a valuable addition to good management for the purpose of increasing economic performance when combined with appropriate management adjustments; in our case: reduction of the fishing mortality.

Key Words: Bioeconomic Modelling, Age-Structured Models, Enhancement Programme, Fishing Mortality, NPV, Kutum, Caspian Sea.

SNF-prosjekt 5187 AGAMEM

1. Introduction

The objective of this paper is to analyse the profitability of *Kutum* fishing in the Iranian coast of the Caspian Sea. *Kutum* is a fish of the family *Cyprinidae* and endemic to the Caspian Sea, north of Iran. The Iranian *Kutum* population has been dwindling for four decades, from 1940s to the 1980s, due to overfishing and loss of natural spawning grounds. In the early 1980s, these stocks have improved through an enhancement programme by releasing fingerlings. Despite the costly nature of this programme, it has played a significant role in reviving the stock and increasing the yield (Salehi, 2011). A cost benefit analysis of the enhancement programme for the *Kutum* fishery for different fishing mortality levels, based on an age-structured bioeconomic model, will be undertaken.

Age-structured models can be used to separate and analyze a fishery into distinct age or size classes of cohorts (Bjørndal and Munro, 2012). This allows for greater understanding of the fishery, as harvesting often takes place on a small number of cohorts, and sizeable differences in the relative strengths of cohorts are important determinants that affect the total catch (Grafton *et al.*, 2004). Bioeconomic age-structured models are used to develop estimates of optimal yield or harvest-per recruit relationships that depend on, among other things, fishing mortality, natural mortality and the age or size at which fish from a given cohort or age class become vulnerable to fishing. These models have recently been developed for general cases that represent not only uniformly distributed fish stocks, but also any degree of schooling and unevenly distributed fish (Steinshamn, 2011).

Tahvonen (2009) derived both analytical and numerical results on optimal harvesting in a dynamic setting under various simplifying assumptions with age-structured models. Tahvonen (2010) investigated the background and development of discrete time age-structured optimization models in fisheries economics. Skonhoft *et al.* (2012) studied an age-structured model of a fishery and described the optimal harvesting policy when the fleet can choose different fishing gear with perfect and imperfect fishing selectivity.

The age-structured bioeconomic model in this paper is a fairly standard Beverton-Holt model that is used to evaluate the enhancement programme for Iranian Kutum. This model will be used to maximise the Net Present Value (NPV) of benefits from *Kutum* fishing in the presence of stock enhancement programme and thus to determine optimal policies. For that, we use the estimated yield and recruitment data to calculate the NPV under different levels of fishing mortality, applying two forms of stock-recruitment (S-R) relationships due to Beverton-Holt (1957) and Ricker (1954). Data and information were collected from the annual reports of *Kutum* stock assessment, operated by the Iranian Fisheries Research Organization (IFRO).

The paper is organized as follows: In section 2, a summary of the status of *Kutum* stock in the Caspian Sea, with regard to its declining stock in the past and recent improvements through the enhancement programme, is discussed. Section 3 gives an overview of bioeconomic age-structured models, as a basis for yield and recruitment calculation, which will be used to calculate the profitability of fishing activities. In section 4, the bioeconomics of the *Kutum* fishing is analysed. This includes considering the effects of the enhancement programme as well as varying fishing mortality to find the optimal level. Policy implications are presented in the final section. The results from statistical testing are given in the appendix.

2. An overview of the Iranian *Kutum* fishery

The Caspian Sea is quite remarkable as an immense ecosystem in ecological, biological and economic terms. It is a brackish lake with no outlets, lying to the east of the Caucasus Mountains and to the west of the vast steppe of Central Asia. It has shores in the five countries: Russia, Azerbaijan, Iran, Turkmenistan and Kazakhstan. One of the main features of this sea is its unique and valuable aquatic community that includes sturgeons and several bony fish species. In recent years, on the Iranian coast of the Caspian Sea, fishing cooperatives have exploited various types of bony fish, of which *Kutum* fish (*Rutilus frisii Kutum*) is the most popular and commercially important (Valipour and Khanipour, 2009).

Kutum is a fish from brackish water habitats of the Caspian Sea and from its freshwater tributaries. The main distribution of *Kutum* belongs to the southern part of the sea. The highest density of *Kutum* fish was traditionally distributed between the Kura River in Azerbaijan and Sefidrood River in Iran (Razavi Sayyad, 1995). Nevertheless, during the last three decades, after massive releasing of fingerlings along the Iranian coast of the Caspian

Sea, its distribution has changed and its density on the Iranian southeastern coast of the sea has increased (Abdolhay et al., 2011).

In recent years *Kutum* make up more than 60% of the total catch of bony fish on the Iranian coast of the Caspian Sea. As shown in fig. 1, before the 1980s, the highest recorded catch was 5,854 tonnes in 1939. Later on, the stock declined and the catch reached its lowest point of approximately 350 tonnes in the early 1980s (Valipour and Khanipour, 2009; PDD, 2011). This reduction was caused by over-fishing, decreasing water level in the Caspian Sea, agricultural, municipal and industrial emissions, over-exploitation of sands and sediments from coastal rivers and the Anzali Bay, and construction of bridges and dams that modify or block the natural spawning grounds (Ralonde and Walczak, 1971; Razavi Sayad et al., 1972; Coad, 1980).

The Iranian Fisheries Organization (IFO) started to revive the declining stock of *Kutum* by releasing fingerlings in the rivers in 1982. In the last three decades, a total of 4.62 billion fingerlings were released into the rivers and Anzali Bay, which had a significant positive effect in reviving reserves and increasing total yield (Abdolmalaki and Ghaninezhad, 2007). At present, artificial breeding and restocking programmes represent the main method for maintaining and enhancing the *Kutum* population.

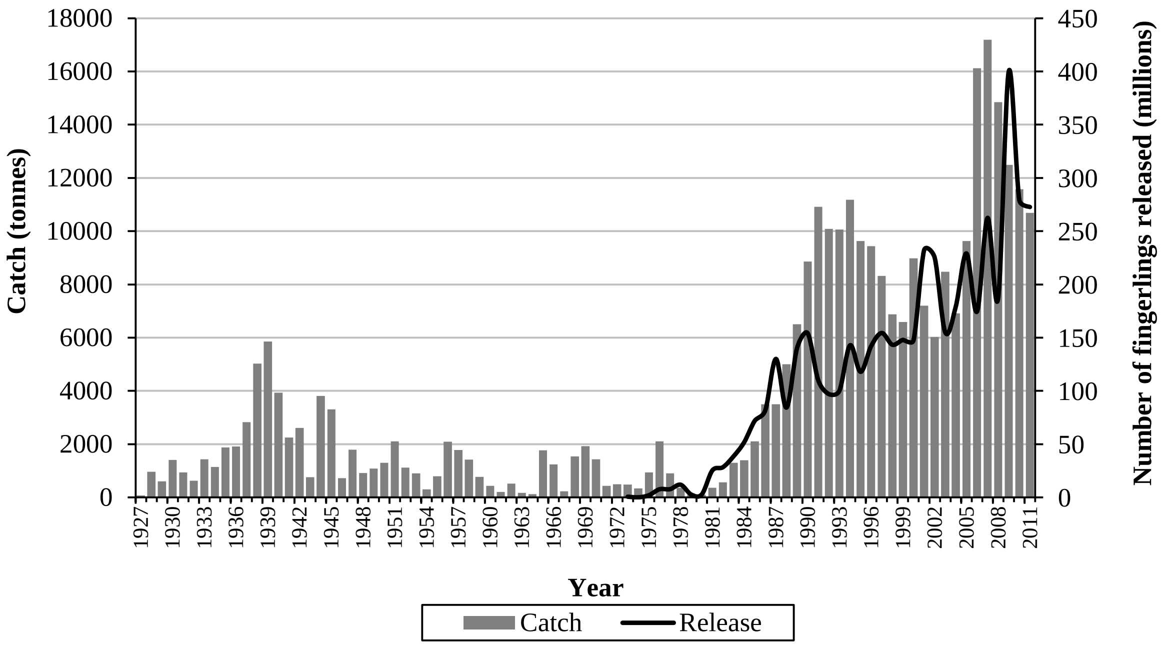

Figure 1: Catch and released fingerlings of Kutum in the Iranian coast of the Caspian Sea

3. Bioeconomic modelling

An age-structured bioeconomic model is used to determine the optimum policy of maximizing fishing profits. For that, the dynamics of the *Kutum* population is analyzed by determining the weight at each age class (W_i), each cohort's population (N_i) and each year's recruitment to the stock (R_t). This will allow us to determine the total yield for each year of the study period (Y_t).

The age-structured estimation of total yield will then be used to calculate the total revenue from harvesting which is a part of estimating the net present value of fishing activities. The second part of the profit function is the total cost, which includes the costs of harvesting and the costs of releasing fingerlings. Finally, the effects of implementing the enhancement programme and fishing mortality adjustment on profitability of fishing activities will be investigated.

The analysis is based on economic data, such as prices and costs, which are collected through IFRO and price indices, which are obtained from the annual economic report and balance sheet from the Central Bank of Iran (Anonymous, 2013). The biological data, including the von Bertalanffy equation parameters and the weight, length, percentage share in population and mortality rates for each age group, are collected from the annual reports of *Kutum* stock assessment, performed every year by IFRO, at the Iranian coast of the Caspian Sea.

3-1. Modeling Population Dynamics

A key component in determining the yield or harvest per age class or cohort is the relationship between weight and age of fish. Due to limited availability of data, this is commonly approached through a weight-length relationship (WLR):

$$W = aL^b \tag{1}$$

where W is total body weight (gr), L is the fork length (cm), constant a is related to the condition of fish and constant b is designated as an allometric constant.

Kutum is typically a medium sized fish, reaching 45-55 cm in length, rarely up to 70 cm, and weighing up to 4.00 kg, rarely 5.00 kg (Freyhof and Kottelat, 2008). Parameters of the weight-length relationship (eq. 1) were estimated for 10 year-classes, from 1989 until 2007. Performing a panel unit root test on weight and length data series, confirms stationary for both of them (appendix, table A1). The estimation results are presented in table 1.

Table 1: Estimated parameters of weight-length relationship ($W = aL^b$) for *Kutum* in Iranian coast of the Caspian Sea, using unbalanced panel with 155 observations (1989-2007)

Model	Parameters	Coefficient	t-statistic	Probability	D.W.	R^2
$W = aL^b$	a	0.020	4.832	0.000	**1.26**	**0.973**
	b	2.904	55.394	0.000		

The coefficients are statistically significant and the fit is very good ($R^2 = 0.973$). Due to the low value of the calculated Durbin-Watson statistic, the possibility of serial correlation was tested and the results rejects the presence of serial correlation in residuals (appendix, table A3). Estimated parameter b, the exponent of the arithmetic form of the weight–length relationship, is 2.904; confirming the suggestion of Carlander (1969) that the exponent should normally fall between 2.5 and 3.5. The estimated value of b is often around three (Mir, *et al.*, 2012; Ahmed *et al.*, 2011; Bhattacharya and Banik, 2012; Tavares-Dias *et al.*, 2011). Using a simple t-statistic test ($t = -1.83$), it is found that in this study, there is no significant difference between the allometric parameter and three at the 90% significance level.

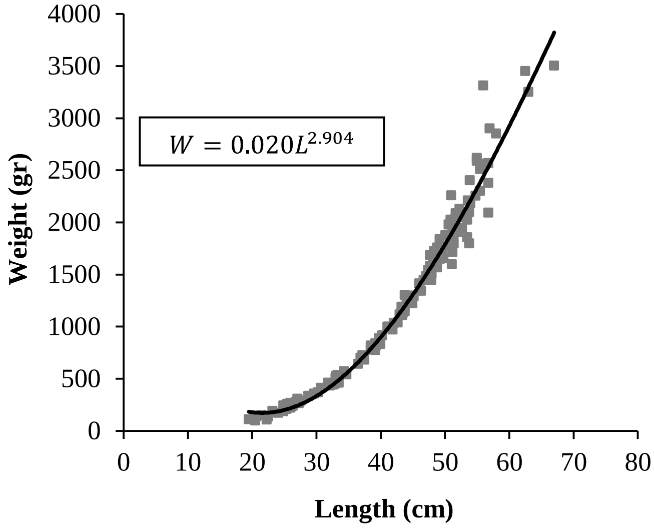

Figure 2: Weight-length Relationship for *Kutum* in Iranian coast of the Caspian Sea (1989-2007); the dots denote the data points

The commonly used von Bertalanffy growth equation in terms of weight, which is designated as the Richards (1959) equation, is given by:

$$W_i = W_\infty \left(1 - e^{-k(i-i_0)}\right)^b \tag{2}$$

where W_i is the weight of a fish at age i, W_∞ is the asymptotic body weight of the fish, k is called the Brody growth coefficient and determines the rate at which fish increases weight and i_0 is the hypothetical age at which the fish has zero weight. These parameters are collected from the cohort analysis reports of IFRO for *Kutum* in the study period and the parameters' values are W_∞=3675.09 gr, k=0.20 year^{-1} and i_0=-1.20 year on average for the study period. Parameter b is the allometric constant of the weight-length relationship function (eq. 1). The graph of the von Bertalanffy growth equation, is shown in fig. 3. It is seen that weight asymptotically approaches 3.675 kg.

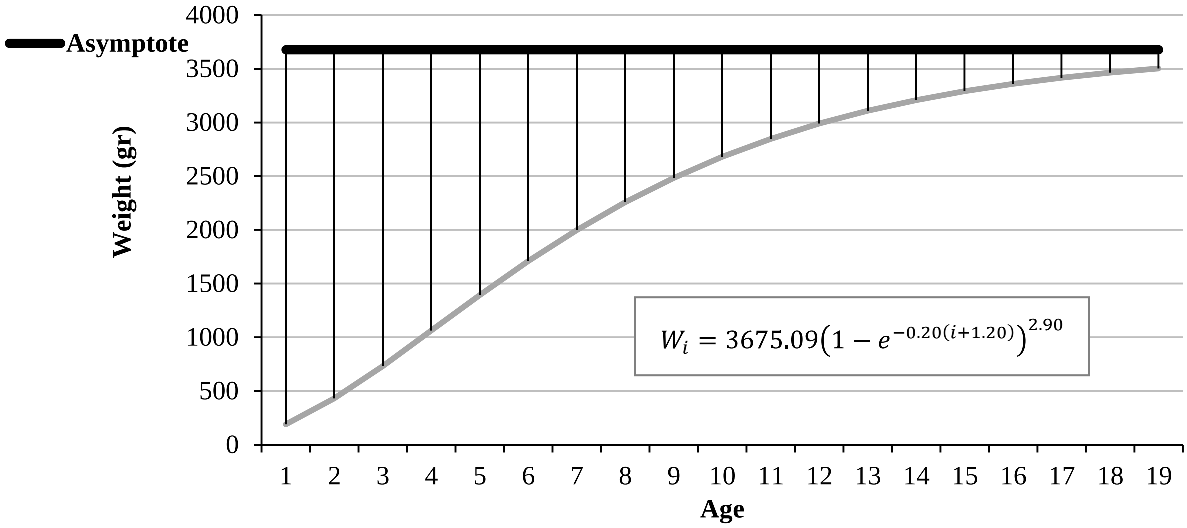

Figure 3: von Bertalanffy equation in terms of weight for Iranian *Kutum* (1989-2007)

After estimating the weight at age for each cohort, we calculated the catch per age class along with the recruitment to the stock. The first term was estimated through age-structured models and the second from stock-recruitment relationship:

According to the age-structured theoretical basis, the catch from each cohort in numbers ($C_{i,t}$) can be obtained as:

$$C_{i,t} = \frac{F_{i,t}}{F_{i,t} + M_i} N_{i,t}\left(1 - e^{-\left(F_{i,t}+M_i\right)}\right) \tag{3}$$

where $N_{i,t}$ is the number of fish of age-group i at time t and the parameters F and M denote instantaneous fishing and natural mortality and determine how quickly the stock is depleted (Hannesson, 1993). $(F_{i,t} + M_i)$ denotes the total mortality so that $(\frac{F_{i,t}}{F_{i,t}+M_i})$ is the fraction of total mortality due to harvesting (Bjørndal and Munro, 2012).

Total yield (Y_t), measured in weight in period t, is found by multiplying the catch from each cohort by the average weight for that cohort ($W_{i,t}$) and summing over all age-classes:

$$Y_t = \sum_i C_{i,t} \cdot W_{i,t} = \sum_i \frac{F_{i,t}}{F_{i,t} + M_i}\left(1 - e^{-\left(F_{i,t}+M_i\right)}\right) N_{i,t} \cdot W_{i,t} \tag{4}$$

In order to have a complete age-structured model, we also specify the initial population. The initial population ($N_{i,1}$) in each age group i, used in this analysis, is calculated through:

$$N_{i,t} = \frac{Y_1 \cdot Q_{i,1}}{F_1 \cdot W_{i,1}} \tag{5}$$

where Y_1 is the initial yield reported by beach seine cooperatives; F_1 is the fishing mortality rate for the first year; $Q_{i,1}$ is the percentage share of age group i's population in the stock and $W_{i,1}$ is the average weight at same age group. The index 1 in subscripts indicates the first year of analysis. These data are collected from sampling operations analysis, performed every year by IFRO, at Iranian coast of the Caspian Sea.

The stock-recruitment relation, known as the S-R relationship, relates recruitment to the stock in a given year, usually in numbers, to the size of the spawning stock in an earlier year. Two functional forms for the S-R relationship are applied in this paper. The first one is the Ricker recruitment function (Ricker, 1954):

$$R_{t+1} = \gamma S_t e^{-\lambda S_t} \tag{6}$$

where R_{t+1} denotes recruitment to the year-class $t+1$ and S_t denotes the spawning stock in the fishery in the year t. An alternative functional form introduced by Beverton and Holt (1957) is:

$$R_{t+1} = \frac{\sigma S_t}{1 + \omega S_t} \quad (7)$$

γ, λ, σ and ω are parameters in both models.

The S-R relationship in this study is estimated as follows: Considering that *Kutum* maturity occurs at age two or three for males, and three or four for females (Valipour and Khanipour, 2009), in this study three-year-old fish and older are considered as spawning stock. The recruitment is considered to occur at age one according to Fazli *et al.* (2013). A schematic view of the observed data is shown in figure 4.

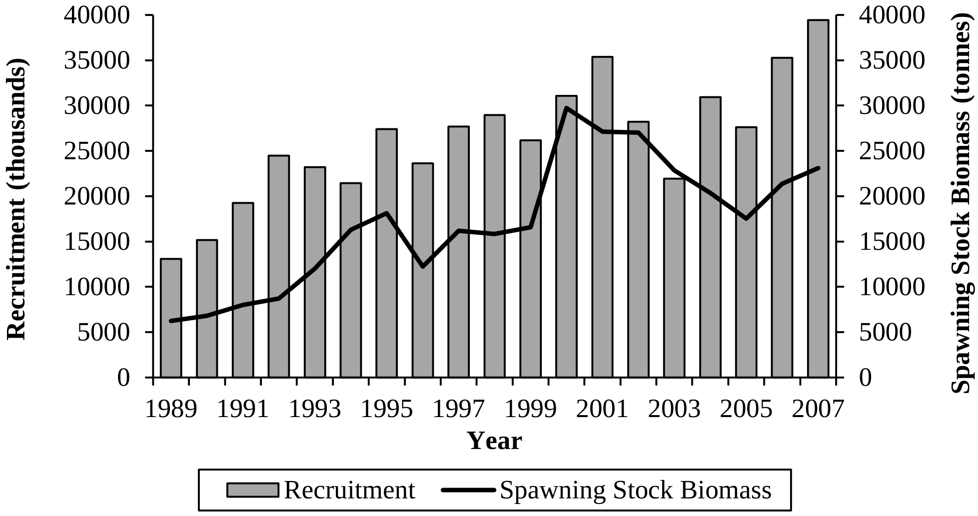

Figure 4: Time series of spawning stock and recruitment for *Kutum* in Iranian coast of the Caspian Sea

Performing the Ng-Perron unit root test, it follows that both of the data sets of spawning stock and recruitment are stationary (appendix, table A2). The estimated relationship between spawning stock and recruitment is displayed in table 2.

Table 2: Estimated parameters of spawning stock and recruitment relationship for Kutum in Iranian coast of the Caspian Sea

Model	equation	Parameters	Coefficient	t-statistic	Probability	D.W.	R^2
Ricker	$R_{t+1} = \gamma S_t e^{-\lambda S_t}$	γ	3679.659	8.316	0.000	**1.43**	**0.484**
		λ	0.000044	7.181	0.000		
Beverton-Holt	$R_{t+1} = \frac{\sigma S_t}{1 + \omega S_t}$	σ	6096.537	2.959	0.009	**1.30**	**0.459**
		ω	0.000157	2.156	0.046		

The parameters of both models are statistically significant. Due to the low D.W. level, the possibility of serial correlation was tested through the Breusch-Godfrey LM test, for both of the equations. The results reject the presence of serial correlation in both models residuals (appendix, table A3). A schematic view of the observed data and estimation results are shown in figure 5:

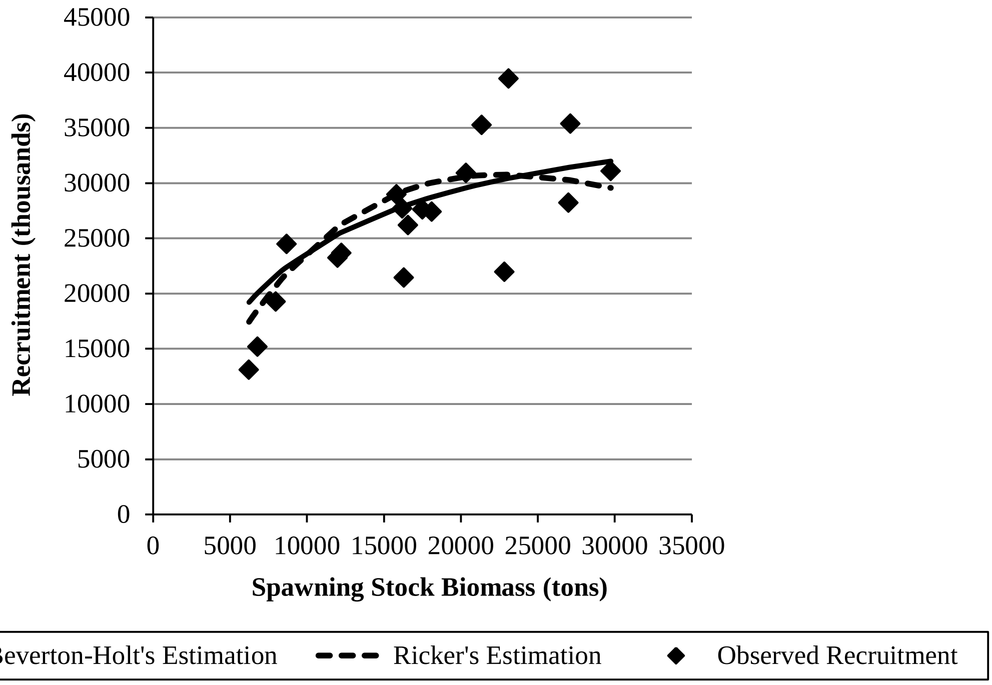

Figure 5: Observed and estimated values for recruitment through Beverton-Holt and Ricker S-R models for *Kutum* in Iranian coast of the Caspian Sea (1989-2007)

As seen in figure 5, the Ricker and B-H give very much the same results for a wide range of biomass values and with the exception of a few outliers, they fit well with the data as well. According to the results, the asymptotic value of recruitment numbers for the B-H model is calculated to 38841 thousands, whereas the maximum recruitment numbers for the Ricker model is calculated 30765 thousands, which corresponds to a maximum spawning-stock value of 22727 tonnes.

3-2. The Economic Model

Calculated total yield (Y_t) through the age-structured model, can be used to construct the economic part of the bioeconomic model. The economic submodel in this study is determined from data on wholesale prices of *Kutum* fish and calculating the annual costs.

The net present value of profits (B) from Kutum fishing is calculated due to the availability of data for the 13 years from 1993 to 2006:

$$B_t = TR_t - TC_t = P_t \cdot Y_t - TC_t \tag{8}$$

$$NPV = \sum_{t=0}^{T} B_t \cdot \left(\prod_{i=0}^{t} \left(\frac{1}{1+r_i} \right) \right) \tag{9}$$

where TR_t is the total revenue from harvesting, which obtained through multiplying the wholesale price of *Kutum* fish (P_t) by the biomass yield (Y_t) for the year *t*; TC_t is the total cost of fishing activities, including harvesting and enhancement costs, in year *t* and r_i is the annual real interest rate for the year i, which ranges from 0 to t. The graph of fishing activity costs and prices is displayed in figure 6:

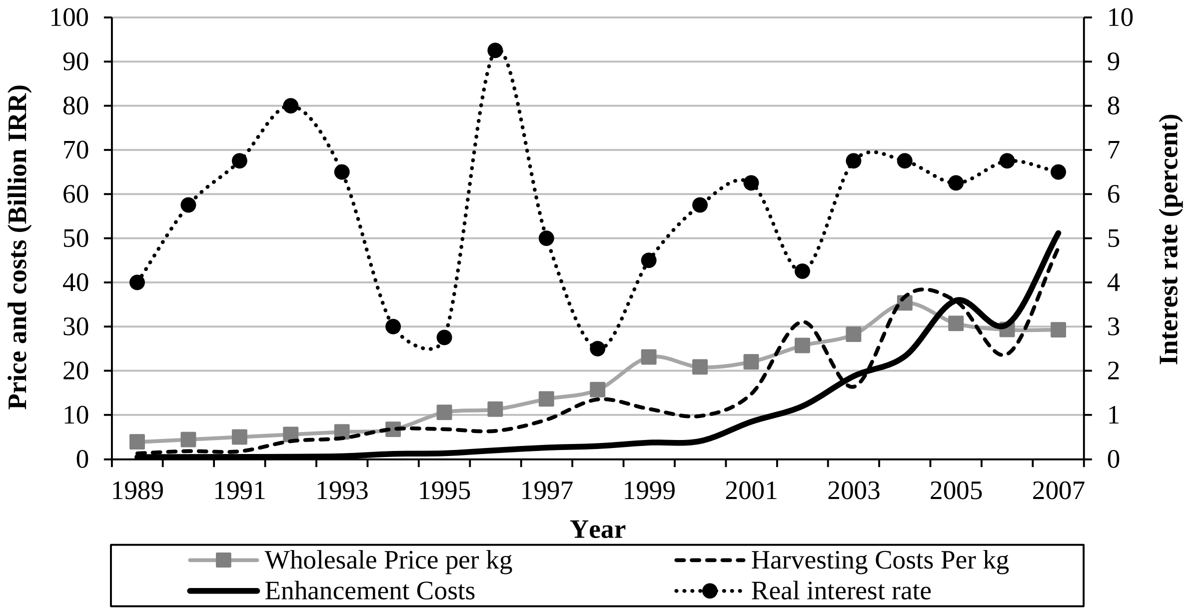

Figure 6: Price and costs regarding *Kutum* production in the Iranian coast of the Caspian Sea along with the real rate of interest (1989-2007)

4. Results

The fishing mortality rate that maximizes the net present value of profits from *Kutum* fishing is determined for two cases, with and without taking into consideration releasing of fingerlings. We assume that total recruitment consists of two independent parts that are added together, namely endogenous recruitment that depends on the stock, and recruitment from the enhancement programme. Endogenous recruitment can be calculated through the stock-recruitment relationship models (eqs. 6 and 7), whereas enhanced recruitment depends on the number of released fingerlings and their survival rate (Ye and Valbo-Jørgensen, 2012). There is obviously a cost associated with enhanced recruitment. Cost components for the enhancement programme include cost of labour, feed and fertilizer, chemical and drugs, harvesting and post harvest, water and energy, maintenance, depreciation and miscellaneous. On the other hand, fishing operating costs contain cost of labour, fuel and energy, fishing gear, maintenance, fishing taxes, insurance, productive and non-productive depreciation, administrative procedure costs, discounts and brokerage (Salehi, 2011). It is necessary to point out that, all the values in this study are modified by relevant price indices so as to account for inflation. In addition, the interest rate used in this study is obtained from the results of estimating the real equilibrium interest rate for Iran (Shahmoradi et al., 2010).

For the first case, which shows the actual status of *Kutum* fishing that has already taken place; we consider the enhancement programme, conducted every year by the IFO. For this purpose, the costs relating to the enhancement programme are subtracted from total revenue along with harvesting costs in order to find the annual net revenue. In the study period, the average fishing mortality was 0.498 and the net present value of profits from *Kutum* fishing, for the actual case by considering the enhancement programme, was calculated 1,169 and 1,055 bn IRR[1], using Ricker and Beverton-Holt functions respectively. Application of Ricker's recruitment function shows that if the average fishing mortality decreases to 0.284, the NPV of profits from fishing would be maximized to 1,772 bn IRR. Considering Beverton-Holt equation, if the average fishing mortality rate in this situation decreases to 0.247, NPV would be maximized to 1,689 bn IRR (table 3).

[1] Iranian Rial; officially equivalent with 0.00025 of one U.S. Dollar in average and fluctuated between 0.00010 to 0.016 of one U.S. Dollar for the study period.

Table 3: Effects of fishing mortality on the net present value of *Kutum* fishing profits in Iranian coast of the Caspian Sea, considering the enhancement programme

Fishing mortality Rate (F)	**NPV** (Million IRR)	
	applying the Ricker recruitment model	**applying the B-H recruitment model**
0.498	1,168,725	1,054,995
0.400	1,571,229	1,409,733
0.300	1,767,696	1,648,016
0.284	**1,771,996**	**-**
0.247	**-**	**1,688,848**

For the counterfactual case without releasing fingerlings, we have to exclude the impact of this programme on recruitment by subtracting enhanced recruitment from total recruitment. This leads to a reduction in catch and a subsequent decrease in total income of fishing. It is worth noticing that without an enhancement programme, production costs only include the harvesting costs, whereas with an enhancement programme we must also include the costs of the programme. The discounted cost of releasing fingerlings in the period 1993-2006 is 118 bn IRR and the discounted income loss due to eliminating enhanced recruitment is 2,016 and 1,432 bn IRR applying Ricker and Beverton-Holt formulations respectively. Without such a programme, net present value of *Kutum* fishing profits was calculated -729 and -259 bn IRR, using Ricker and Beverton-Holt functions respectively, with the same high fishing mortality as above, namely 0.498 (table 4). However, it is natural to expect that the fishing effort and fishing mortality should be lower.

Next, we calculate the optimal fishing mortality without an enhancement programme. In the absence of an enhancement programme, application of Ricker's recruitment function shows that if the average fishing mortality decreases to 0.133, the NPV of profits from fishing would be maximized to 432 bn IRR. Considering Beverton-Holt equation, if the average fishing mortality rate in this situation decreases to 0.166, NPV would be maximized to 661 bn IRR (table 4).

Table 4: Effects of fishing mortality on the net present value of *Kutum* fishing profits in Iranian coast of the Caspian Sea, without taking into consideration releasing fingerlings

Fishing mortality Rate (F)	**NPV** (Million IRR) **applying the Ricker recruitment model**	**NPV** (Million IRR) **applying the B-H recruitment model**
0.498	-729,468	-258,979
0.400	-338,775	118,515
0.300	55,818	445,683
0.200	356,752	445,683
0.166	**-**	**661,420**
0.133	**431,620**	

Using Ricker's recruitment model, reducing the fishing mortality rate to 0.284 and 0.133 maximizes the net present value of profits, respectively for the cases with and without enhancement programme. The optimal policy increases profits 603 bn IRR with and almost 1,161 bn IRR without such a programme. Applying the Beverton-Holt stock-recruitment relationship implies reduction of fishing mortality to 0.247 with stock enhancement and 0.166 without stock enhancement in order to maximize discounted profits. An optimal policy yields 634 bn IRR higher profits with an enhancement programme whereas it yields 920 bn IRR higher profits without the programme (tables 3 and 4).

The results in both cases are shown in figures 7 and 8. It is seen in figure 7 that at each level of fishing mortality, the NPV level is higher considering fingerlings released compared with the counterfactual case of not releasing fingerlings, indicating that the introduction of an enhancement programme has proved to be very profitable in both recruitment models for all fishing mortality rates under consideration.

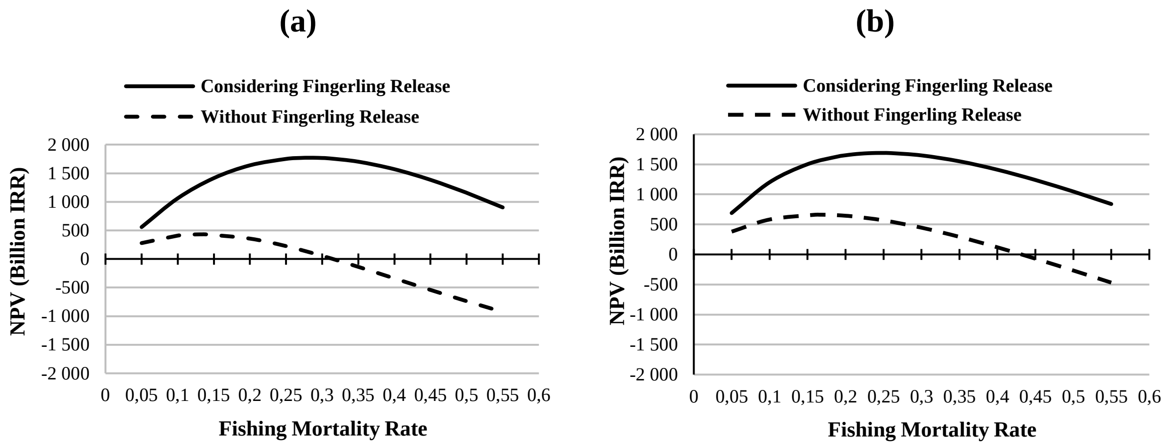

Figure 7: Effects of the enhancement programme and fishing mortality on NPV of Kutum fishing profits in Iranian coasts of the Caspian Sea, 1993-2006: (a) applying Ricker and (b) applying Beverton-Holt Models of spawning-stock and recruitment relationship

In figure 8, the comparison between two forms of S-R relationship shows that, considering the enhancement programme (fig. 8-a) applying Ricker's recruitment model for higher fishing mortality levels makes higher profit than the Beverton-Holt model; while applying Ricker's recruitment model in the case without taking into consideration of enhancement programme (fig. 8-b), implies lower profit than the Beverton-Holt formulation:

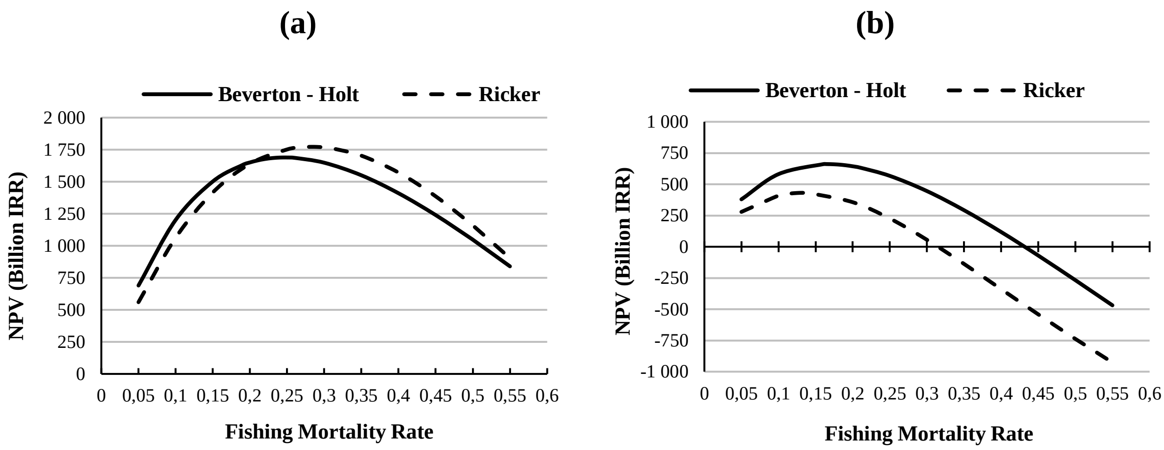

Figure 8: Comparison between Beverton-Holt and Ricker recruitment functions in calculating the NPV of Kutum fishing profits in Iranian coasts of the Caspian Sea, 1993-2006: (a) Considering fingerlings releasing (b) Without fingerlings releasing

In addition, the benefits of the programme are higher if the fishing mortality is at its optimal level as opposed to its average level of the study period. Using Ricker, the enhancement programme increases profits by 1,898 (=1,169-(-729)) bn IRR with "business as usual" whereas it increases profits by 2,501 (=1,772-(-729)) bn IRR if fishing mortality is optimized, which is 32 percent more in relative terms. With Beverton-Holt, the benefits of the programme is 1,314 (=1,055-(-259)) bn IRR higher profits with the present fishing mortality and 1,948 (=1,689-(-259)) bn IRR higher profits with optimal fishing mortality. That is 48 percent more in relative terms (tables 3 and 4).

Altogether, this leads to the conclusion that the combination of keeping the stock enhancement programme in place and reducing fishing mortality approximately to half its average level of the study period is by far the best policy.

5. Policy implications

The purpose of this article has been to analyse the economic performance of a stock enhancement programme, and its implications for optimal management, using the Iranian *Kutum* fishery as case.

First, the structure of *Kutum* fishing on the Iranian coast of the Caspian Sea is analysed and the weight-length relationship estimated.

Then the optimal policy and its economic performance are found and compared in the two cases, with and without an enhancement programme. This is then compared with the actual policy (actual fishing mortality) for the two above cases. Although the numbers are different with respect to the net present value depending on which stock-recruitment relationship we use, the policy implications are more or less the same, given the inherent uncertainties in the model. In the present situation of considering enhancement programme, the advice is to reduce fishing mortality by about 50 percent. If we isolate the effect of the fingerling release programme, it is seen that reducing fishing mortality by about 70 percent increases net present value by 1,161 bn IRR with the Ricker recruitment model and 920 bn IRR with the Beverton-Holt model.

Further it is worth noticing that the benefits of reducing fishing mortality is relatively higher when the enhancement programme is in place, and similarly, the benefits of the enhancement programme is relatively higher when the fishing mortality is close to its optimal level.

The main conclusion based on this study is clearly to continue the enhancement programme for Iranian *Kutum* but reduce fishing mortality to approximately one half.

Stock enhancement has been performed for a range of species various places around the world dating back to the 19th century. The first marine stock enhancement programmes in the United States started in the late 19th century in Massachusetts and Maine. For over 60 years, many millions of young cod, haddock, pollock and flounder were released annually in an effort to enhance wild populations. These programmes were stopped due to lack of measurable effect (Lorenzen *et al.*, 2010).

Systematic large-scale programmes for the release of fingerlings for stock replenishment and augmentation were not common until the 1970s. A modern pioneer country has been Japan. The Japanese programmes include around 80 species of marine fish, molluscs and crustaceans, of which the most important ones are scallops, prawns, sea bream and flounders (Masuda and Tsukamoto, 1998).

Another pioneer has been Iran, which shares the fisheries resources of the Caspian Sea with four other states: Azerbaijan, Kazakhstan, Russia and Turkmenistan. Fisheries scientists in Iran release around 12 million juveniles of sturgeon species, which support the valuable caviar industry. In addition, state hatcheries release juvenile Bream, Kutum, Pike-Perch, and Caspian Trout, all of which support fisheries harvested by licensed coastal cooperatives (Bartley and Leber, 2004).

Many different purposes and objectives for such programmes have been mentioned: stock conservation, stock augmentation, recreation and improving economic performance to mention a few. In this article, however, we concentrate mainly on the latter.

Although there has been written many studies about the biological and ecological aspects of stock enhancement and ocean ranching (Blankenship and Leber, 1995), relatively few studies have been made about the economic performance of such programmes. The most noticeable one is perhaps Hilborn (1998). He reviewed nine marine enhancement programmes and found that only one, the Japanese chum salmon programme, appeared to be a clear success. Other programmes, for example pink salmon in Alaska, chinook and coho salmon in the U.S. and Canada, lobster in the U.K. and France, cod in Norway, and Kemp's ridley sea turtle were clear failures. Other again lacked data or the conclusion was ambiguous. Hermann (1993) performed another considerable analysis about sea ranching of salmon in Alaska, which indicated that expanding the enhancement programme for sockeye salmon and contracting for pink salmon have positive effects on future revenues generated to fishers.

However, the future may not be entirely bleak. Lorenzen et al. (2013) state that "*The science base of marine restocking, stock enhancement, and sea ranching continues to advance rapidly and has now reached a point where it is becoming possible to assess the likely contribution of such approaches to fisheries management goals prior to major investments being undertaken and to design enhancement programmes effectively and responsibly where good potential is judged to exist*"

Another important conclusion when it comes to policy implications is that stock enhancement is not, and never will be, a substitute for management. It may, however, be a valuable addition to good management for the purpose of increasing economic performance when combined with appropriate management adjustments; in our case: reduction of the fishing mortality rate and consequently also reduction in fishing effort. The lack of profitability of various stock enhancement programmes, as shown by Hilborn (1998), may therefore not necessarily be due to the design of the programme as such but due to lack of appropriate adjustment of fishing effort and fishing mortality. This is a novel discovery that has not been paid attention in the economic literature earlier as far as we know.

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Appendix: Results of hypothesis testing

Table A1: Results of panel unit root test* for weight and length data series

Series name	Method	Statistic	Probability
Weight	Levin, Lin and Chu	-2.602	0.005
	Im, Pesaran and Shin	-3.071	0.001
	ADF-Fisher	39.865	0.002
	PP-Fisher	44.870	0.000
Length	Levin, Lin and Chu	-2.924	0.002
	Im, Pesaran and Shin	-2.201	0.014
	ADF-Fisher	31.691	0.024
	PP-Fisher	58.611	0.000

* the summary panel unit root test, using individual effects as regressors, and automatic lag difference term and Schwars Information Criterion (SIC) maximum based on observations, Bartlett kernel method and automatic bandwidth selection with Newey-West.

Table A2: Unit root test results* for the spawning stock and recruitment data series

	Series name		MZ_{α}	MZ_{t}	MSB	MP_{T}
Ng-Perron test statistic	**Spawning stock**		**-11.066**	**-2.301**	**0.209**	**10.781**
	Recruitment		**-7.096**	**-1.836**	**0.259**	**12.886**
Asymptotic critical values		1%	-23.800	-3.420	0.143	4.030
		5%	-17.300	-2.910	0.168	5.480
		10%	-14.200	-2.620	0.185	6.670

* Ng-Perron unit root test at level, including the constant and linear trend in the test regression, applying AR GLS-detrended spectral estimation method and employing automatic selection of lag length with Schwars Information Criterion (SIC) and a maximum lag length of 3.

Table A3: Breusch-Godfrey serial correlation LM test results* for the WLR and S-R relationship

Model	equation	Statistic	Statistical Value	Probability
Weight-Length Relationship	$W = aL^b$	F-statistic	0.898	0.444
		Obs*R-squared	2.039	0.383
Beverton-Holt	$R_{t+1} = \frac{\sigma S_t}{1 + \omega S_t}$	F-statistic	0.758	0.487
		Obs*R-squared	1.758	0.415
Ricker	$R_{t+1} = \gamma S_t e^{-\lambda S_t}$	F-Statistic	0.935	0.416
		Obs*R-squared	2.120	0.347

* up to order 2 of serial correlation

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Harvesting of the fish resources as an economic activity, which is strictly tied to biological matters, needs to be modeled proficiently through bioeconomic analysis. In this study, a bioeconomic age-structured model is used to analyse the profitability of *Kutum* fishing in Iranian coastal waters of the Caspian Sea. Dwindling population of this species has been revived through an enhancement programme, since 1982 in southern Caspian areas by Iranian Fisheries Organization (IFO). Biological age-structured models in this paper were used to estimate the catch amount under two different hypotheses of Beverton-Holt and Ricker about stock-recruitment relationship. Considering the effects of the enhancement programme on recruitment and catch and also on the fishing activity costs, the net present value of the profits from fishing activity is calculated economically. The results showed a significant positive effect of the programme on profitability. Finally, the effect of fishing mortality adjustment, as a management tool, on profitability is also evaluated and it is shown that the reduction in fishing mortality causes a consequent increase on the NPV of profits from fishing activity. According to the results, one can consider the enhancement programme as a valuable addition to good management for the purpose of increasing economic performance when combined with appropriate management adjustments; in our case: reduction of the fishing mortality.

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