A Dynamic Optimization Model for Marine Fisheries Management in Kerala

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Introduction

Kerala state has a coastal length of 590, exclusive economic zone of 0.14 million km^2 and continental shelf area of 39,000 km^2. The state contributed 22.32% of the country's marine fish landings in 2006 (CMFRI, 2007). The marine fishery in the state is characterized by multi-species, multi-fleet and largely open access system. The fishing effort of mechanized vessels was controlled through introduction of fishing ban during the monsoon season from the year 1988 onwards. The monsoon season is considered to be the breeding season of important marine fishery resources of the state. More than 60% of the catch is pelagic resources and the demersal resources contribute the rest. The mechanized trawlers mainly target high valued demersal resources consisting of shrimps, cephalopods and threadfin breams, due to their increased demand in the export market.

Though the marine fish production in the state had registered an impressive growth between 1950 and 1980, it showed a dwindling tendency during 1981-87. The depletion in the stock of several marine fish species, diminishing catch of traditional fishermen and the adverse effect of bottom trawling on the ecosystem called for resource conservation and management measures through legislation. Analysis of the species wise landings for the last four decades showed that many of the marine fish species had depleted with technological change in fish harvesting. (Sathiadhas and Narayanakumar, 2001). The problems of overexploitation were further aggravated by externalities like pollution, shallow water mining and lifting of coastal. The present study with an overall objective of analyzing the bioeconomic conditions of commercially exploited marine fish resources in Kerala state for assessing their sustainability in the context of existing management practices and to suggest appropriate policy strategy for sustainable marine fish production.

Methodology

Time series data on species-wise catch and gear-wise fishing effort for the period from 1985 to 2006 were obtained from publications of Central Marine Fisheries Research Institute (Cochin). The economics of operations of different fishing units were collected from selected landing centres in Kollam, Ernakulam and Kozhikode districts of Kerala for obtaining the cost per hour of fishing for different vessel categories.

Sustainability of marine fish resources

Sustainability of marine fishery resources like pelagics, demersal finfishes, shrimps and cephalopods were analyzed using surplus production model of the exponential form (Fox model). Since there was variation in the fishing power of different categories of vessels and among the same category of vessels due to technological advancements over years, standardization of fishing effort was done by taking the catch per hour of mechanized single day trawlers in 2006 as the standard unit. Since data on resource wise effort was not available, the total vessel effort was apportioned between different resource groups based on the proportion of catch of each resource by the selected vessel category.

A log-linear expression of the logistic model developed by Schaefer was given by Fox (1970) as follows:

$$\ln(CPUE) = \ln(q\ K) - q\ E/\mu \quad \text{...(1)}$$

where CPUE = Catch per unit effort; q = Catchability coefficient; K = Environmental carrying capacity; E = Fishing effort; μ = Intrinsic growth rate of the population

This gives an expression of CPUE as a function of effort

ln(CPUE) = f (effort), which gives

$$\ln(Y/E) = a + bE \quad \text{...(2)}$$

where Y is total annual catch in tonnes, E- annual fishing effort in hours, a and b are constants obtained from the regression.

The effort corresponding to Maximum Sustainable Yield (E_{MSY}) could be obtained from the above equation easily.

$$E_{MSY} = -1/b \quad \text{.............................(3)}$$

The corresponding MSY is obtained by substituting equation (3) into equation (2)

$$MSY = -1/b\ (e^{(a-1)}) \quad \text{.............................(4)}$$

Maximum Economic Yield (MEY) is the yield, which would generate maximum resource rent from the fishery. The resource rent simply refers to the profit earned from the fishery. Maximum Economic Yield is obtained when the marginal cost of fishing effort equals the marginal revenue from the fishery.

Effort at Maximum Economic Yield (E_{MEY}) is worked out using the following equation:

$$E_{MEY} = 1/b\ [-1+(c/(p \exp a))^{-1/2}] \quad \text{..........................(5)}$$

where c is the cost of a unit fishing effort in Rupees per hour, p is the average price per tonne of fish in Rupees and a and b are constants obtained from equation (2)

Maximum Economic Yield (MEY) is obtained from Equation (5) as follows:

$$MEY = E_{MEY} e^{a+bE_{MEY}} \quad \text{.............................(6)}$$

where E_{MEY} is the effort at Maximum Economic Yield and a and b are constant parameters

Standardisation of fishing effort

Effort standardization parameter (S_j) for vessel 'j' is worked out as follows:

$$S_j = \frac{CPH_j}{CPH_m} = \frac{C_j / E_j}{C_m / E_m} \quad \text{.............................(7)}$$

where CPH_j is the catch per hour of vessel 'j' and CPH_m is the catch per hour of vessel 'm' and 'm' is the standard vessel (single day trawler).

Since the effort towards the selected category of resource groups were not available separately, the total effort of each vessel category was apportioned based on the average proportion of landings of each resource group by the vessel category. It was assumed that the species-wise distribution of effort of a given vessel is proportional to the species distribution of catch.

The proportion of effort towards the resource group 'i' by vessel 'j' is given by

$$E_{ij} = d_{ij} \times E_j \qquad ....(8)$$

where E_j is the nominal effort of vessel 'j' and d_{ij} is the proportion of catch of resource 'i' by vessel 'j'.

Standardized effort for vessel 'j' towards resource 'i' = $S_j \times E_{ij}$ ....(9)

Total standardized effort (TE) for a year = $\sum_{j=1}^{n} S_j E_{ij}$ ....(10)

where 'n' is the number of vessel types. This procedure results in the total annual standardized fishing effort in terms of single day trawler hours.

Dynamic fishery optimization model

A fishery optimization model incorporating the dynamics of fish stocks was developed to obtain the optimal combinations of fleet effort levels and landings for a ten year period from 2006. The dynamic nature of fishery was captured through an inter temporal stock growth equation. The optimal model maximised fishery net returns subject to the constraints of fleet effort levels and natural growth of stock over a ten year period from 2006. General Algebraic Modeling Systems (GAMS) software was used for simulating optimal scenarios. Validation of the model was done by projecting the baseline scenario in 2006 and comparing it with the observed catch and effort levels in 2006. The nonlinear programming model was solved using minos 5 solver. The alternative scenarios were:

i. 20% reduction in the catch rate of all mechanised and motorised units

ii. 30% reduction in the catch rate of all mechanised and motorised units

iii. 20% reduction in the effort of all mechanised units and 20% reduction in the catch rate of all mechanised and motorised vessels and

iv. 20% reduction in the effort of all mechanised units and 30% reduction in the catch rate of all mechanised and motorised vessels.

The catch rate reduction could be implemented at the field level through strict adherence of regulations on the mesh size of fishing gears. The catch rate reduction was incorporated in the model through reduction in the effort standardisation parameter of all mechanised and motorised units by the required percentage for each alternative scenario.

The model required three types of data: (a) economic data consisting of market prices and fishing costs; (b) technological data including effort standardization parameters, catchability coefficient and annual available fishing capacity and (c) biological data that include initial period stock estimates and growth parameter (Bhat and Bhatta, 2001).

$$\text{Max } Z = \sum_{t}(\sum_{i} P_i Q_{it} - \sum_{v} C_v E_{vt}) \quad \text{.................................(11)}$$

where Z is the value of objective function, E_{vt} is the level of effort spent by vessel type v in year t, C_v is the average cost of fishing by vessel type v (Rs/ actual fishing hour), Q_{it} is the quantity of resource 'i' caught in year 't', P_{it} is weighted price (Rs/tonne) of resource i. The objective function is the sum total of annual revenues generated from the fishery minus the annual costs of harvesting during the entire period of 't' years. The resources (i) consisted of pelagics, demersal fin fishes, shrimps and cephalopods in the model. The six vessel categories (v) included in the model were single day trawlers, multiday trawlers, mechanised seiners, mechanised gillnetters, motorised crafts and non-motorised units.

Weighted price $(P_{it}) = \Sigma P_i \, Q_i / \Sigma Q_i$

where P_i and Q_i are the price per tonne and quantity in tonnes of the resource i

The objective function was maximized subject to the constraints of available fleet capacity, level of effort required for keeping the minimum level of employment in fishing and fishing related operations, standardized effort exercised by all vessel types directed toward a species, standard non-linear catch- effort- stock relationship associated with resource group 'i' and time period 't' and the constraint which balances the fish stock in the next period to the current period stock plus current period net recruitment less current period catch.

Results and Discussion

Sustainability analysis of pelagics, demersal finfishes, shrimps and cephalopods

The Fox model regression showed that for demersal finfishes, the MSY of 1,33,342 t was attained at 9,91,484 fishing hours. The results when compared with the observed catch- effort levels showed that the effort towards demersal resources in most of the years had far exceeded the MSY and MEY levels and the catch had exceeded the Maximum Economic Yield levels in the years 1990, 1992, 1993, 1994 and 1996. The Maximum Sustainable Yield was achieved at 59,176 t in the case of shrimps whereas the maximum economic yield was achieved at 57,922 t. The catch had exceeded the MEY levels in 1998 and thereafter with reduction in effort, the catch had declined. In the case of cephalopods, even though the Maximum Sustainable Yield (34,678 t) and the Maximum Economic Yield (33,944 t) were below the catch level of 31,302 t in 2006, both the MSY and MEY effort levels were almost half of that of the effort in 2006 showing an uneconomic level of harvest (Table1).

Dynamic fishery optimization and management model

Validation of the model was done by projecting the catch and stock levels using the observed effort levels during 2006. The results showed the predicted catch levels were near to the observed catch levels in 2006. Hence the model was used for projecting the optimal catch–effort levels.

The optimal model was projected with a minimum constraint of at least 50% of effort levels of 2006 in the case of all mechanised and motorised units and a maximum constraint of 25% increase in the effort levels of 2006 for all fishing units. A minimum constraint of at least the current level of effort was given in the case of non-motorised units. The minimum constraint was decided in order that no fishing method will be completely eliminated from the system. The maximum constraint was decided with the assumption of a maximum of 25% increase in effort in terms of fishing hours through reinvestment of profit earned in the same fishing units or through entry of new vessels.

Table 2 shows that the stock levels of demersal finfishes and shrimps were increasing with the optimal catch-effort levels whereas the stocks of pelagic and cephalopod resources were decreasing towards the year 2015. In the optimal harvesting scenario, the effort of mechanised seiners was found to increase by 20% from the base year effort which might be making the harvest of some of the pelagic resources unsustainable. The

Table 1: Fox model results - sustainability of pelagic and demersal resources

Parameters	Pelagic finfishes	Demersal finfishes	Shrimps	Cephalopods
Intercept	5.2274**	5.9014**	5.7139**	5.4702**
Slope	-1.7808E-07**	-1.0085E-06**	-1.8840E-06**	-2.5196E-06**
E_{MSY}(hours)	56,15,384	9,91,484	5,30,778	3,96,876
MSY(tonnes)	3,84,891	1,33,342	59,176	34,678
E_{MEY} (hours)	26,97,210	7,57,846	4,28,388	3,20,370
MEY (tonnes)	3,10,860	1,29,004	57,922	33,944
Open access effort (hours)	73,50,564	28,66,238	17,46,843	13,06,725
R^2	0.92	0.91	0.78	0.89

** Significant at 1% level

motorised sector which is contributing 70% of the landings of pelagics will be suffering much with the reduction in the stocks of pelagic resources. The mechanised trawl sector which is contributing 15% of the catch of pelagics and 90% of the catch of cephalopod resources will also be suffering with the resource stock depletion.

Management options

A 50% reduction in the effort levels of mechanised trawlers, gillnetters and motorised units is difficult under the present socio-political situation of marine fisheries. Hence alternate policy scenarios were analysed in tune with the existing fishery regulatory mechanism. The marine fishery regulation at present in Kerala follows a closed season of 45 days for all mechanised vessels during the monsoon season. Mesh size regulation was also suggested as a measure for minimising the capture of juveniles but it is not followed strictly. Various studies in the past and field level observation at different harbours showed that the loss due to bycatch and juvenile fishing was more than 30% (Sathiadhas and Narayanakumar, 2001). Hence different alternative management scenarios were simulated with reductions in the fishing effort of mechanised categories alone and reductions in the catch rate of all mechanised and motorised fishing units.

Effect of policy options on resource stock dynamics

In the scenario of continuing the base year effort levels and in the policy scenario of 20% reduction in the catch rate of all mechanised and motorised units, the stocks of all major resources were found to decline drastically in 2015. By following a policy option of 30% reduction in the

Table 2: Optimal model solution of resource stocks (in tonnes)

Years	Pelagics	Demersal fin fishes	Shrimps	Cephalopods
2006	22,69,200	1,12,380	1,32,430	36,817
2007	22,25,800	1,21,520	1,41,050	36,764
2008	21,89,600	1,30,570	1,49,300	36,717
2009	21,59,300	1,39,430	1,57,110	36,674
2010	21,33,700	1,47,980	1,64,390	36,636
2011	21,12,100	1,56,110	1,71,110	36,601
2012	20,93,700	1,63,750	1,77,230	36,571
2013	20,78,000	1,70,830	1,82,750	36,543
2014	20,64,600	1,77,330	1,87,670	36,518
2015	20,35,800	1,58,910	1,80,560	34,936

catch rate, the stocks of all resources with the exception of shrimps were found to decline. Also the fishery net returns became negative in this alternate scenario. A 30% catch rate reduction of all mechanised and motorised units without effort reduction made those fishing units unprofitable.

By following the 3rd policy option of 20% reduction in the effort of all mechanised vessels and a 20% reduction in the catch rate of all mechanised and motorised units, the stock of shrimps alone was found to improve. By the adoption of fourth policy option of 20% reduction in the effort of all mechanised vessels and a 30% reduction in the catch rate of all mechanised and motorised units, all resources stocks were found sustainable by the year 2015 (Table 3).

Table 3: Comparison of stocks of resources under baseline effort and alternative management scenarios in 2015 (in tonnes)

Resources	Initial Stock	Baseline effort	Scenario I	Scenario II	Scenario III	Scenario IV
	2006	2015	2015	2015	2015	2015
Pelagic finfishes	22,69,222	15,63,100	19,30,400	22,29,700	20,68,300	23,62,200
Demersal finfishes	1,12,381	13,335	47,773	1,03,620	97,000	1,93,960
Shrimps	1,32,430	84,522	1,21,220	1,54,940	1,49,720	1,90,000
Cephalopods	36,817	1,512	6,928	17,325	15,958	38,044

Comparison of costs and returns in baseline, optimal and alternate management scenarios

The net returns realised from the fishery over the ten year period was higher in the optimal scenario than continuing the base year effort levels. Even though the gross returns realised from the fishery was almost same in all the scenarios, the cost involved in fishing was almost half in the optimal scenario as compared to the all other scenarios through reduction and redistribution of fishing effort (Table 4).

Table 4: Comparison of returns and costs in baseline and optimal scenarios (in million rupees)

Particulars	Baseline scenario	Optimal scenario
Net returns	2,079	25,760
Gross returns	1,27,200	1,36,800
Total cost	1,22,100	73,480

Comparison of returns realised from the fishery over the ten year period by following the different management options showed that by following a policy option of 20% reduction in the catch rate of all mechanised and motorised units, the net returns realized was only 264 million rupees and a 30% reduction in the catch rate resulted in negative net returns. With a 20% reduction in catch rate and effort the net returns realised was 5,336 million rupees. With 30% reduction in catch rate and 20% reduction in effort, the net returns was 4,269 million rupees (Table 5).

Table 5: Comparison of returns and costs in alternative management scenarios (in million rupees)

Particulars	Policy scenario I	Policy scenario II	Policy scenario III	Policy scenario IV
Net returns	264	-2,126	5,336	4,269
Gross returns	1,22,700	1,16,900	1,21,500	1,13,800
Total cost	1,22,100	1,22,100	1,08,300	1,03,300

Conclusion

The results of the study showed the marine fish catch and effort levels are both biologically and economically unsustainable and the current effort levels will deplete the fish stocks considerably in the future and hence there is an urgent need to restrict the current effort levels. The policy scenario of 30% reduction in the catch rate of all mechanised and motorised units and 20% reduction in the effort of all mechanised units will conserve resource stock for the future as well as generate comparatively higher net returns from the fishery. Reduction in the fishing effort of all mechanized units by 20% either through reduction in the number of fishing units or reduction in fishing hours through seasonal closure may be recommended. Even with the optimal catch effort levels, the stocks of pelagic and cephalopod resources were unsustainable. Hence the catch rates of motorised units which contribute 70% of the landings of pelagic resources also need to be reduced. Preventing the use of destructive fishing gears and by strict monitoring of mesh size of all fishing units need to be implemented for reducing the losses due to bycatch and juvenile fishing. The optimal harvesting simulation showed that the gross returns realised from the fishery will be almost the same even with 50% effort levels of all mechanised and motorised fishing units. This showed the uneconomic levels of operations of these fishing units and hence redistribution of fishing effort in profitable methods like mechanised seiners may be recommended.

As most of the workers in the mechanised units are traditional fishermen, compulsory reduction in their effort levels will affect the livelihood security of these fishermen. Reduction in employment need to be compensated by creating alternate opportunities in fishing related activities. Generation of employment in value addition and processing of fish and creation of opportunities in recreational fisheries may be suggested. In addition to restriction of effort and catch rates, measures to improve the resource stock through community based fishery management practices like creation of marine parks and marine protected areas, promotion and expansion of mariculture/aquaculture activities, and initiation of sea ranching and open sea farming may also be recommended.

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