

Asian Fisheries Society, Selangor, Malaysia

Simulation Model for Evaluating the Response of Management Options on the Demersal Resources of Tamil Nadu Coast

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Abstract

The response of different management options on demersal fish catch in Tamil Nadu was examined using simulation model and time series data on catch and effort of demersal resources in Tamil Nadu during 1989-2005. For the simulation study surplus, production model and spectral models were used to simulate effort, yield and biomass. Genetic algorithm was used to estimate parameters of surplus production model. Effort, biomass and yield were simulated for the period 2006 to 2015 under different levels of effort such as reducing by 25%, 50%, and 75% of present level increasing by 25%, 50%, 75% and 100% of present level and also for the present level. The simulation results revealed that when the level of exploitation is kept at 25%, 50%, 75%, and 100% of the present level, the yield falls below the maximum sustainable yield (MSY) level and the biomass is kept above its MSY level. When the exploitation level is increased by 25% of the present level of exploitation, the yield falls below the MSY level in the years up to 2013 and the biomass remains above that at MSY level. But at this level of exploitation, the yield falls above the MSY level and the biomass falls below its MSY level for the years 2014 and 2015. The optimum exploitation level was worked out as 91.25% of the present level of exploitation.

Introduction

Systems analysis and simulation techniques have been applied in marine fisheries management as a tool to assist resource managers for evaluating proposed management actions. Using information available about the fishery and related aspects, simulation models attempt to estimate resulting future changes due to implementation of different management options. Prior knowledge about the effect of implementation of these management options on the fishery resources is very much essential to implement the correct management measure. A quantitative assessment of the effect of different management options on the fishery resources is possible through simulation modeling of the system. Here, a simulation study was conducted to examine the effects of restrictions imposed on fishing effort on the demersal fishery resources of Tamil Nadu, India.

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With regard to marine fish production, the state of Tamil Nadu stands fourth among the maritime states, after Kerala, Gujarat, and Maharashtra. During the period 2001-2005, the estimate of average annual landings in the state is 3,55,451 t (tonnes), which accounts for 14.45% of the total production in the country. The average demersal landing during 2001-2005 is 1,08,561 t, which is about 30.91% of the marine fish landings in the state. Important demersal resources, based on landings in the state, are silverbellies (30.88%), perches (29.49%), elasmobranchs (14.14%), croakers (7.64%), goatfishes (5.54%), lizardfishes (4.06%), catfishes (2.68%), and pomfrets (2.48%). Important gears that caught demersal resources are mechanized trawl-net, mechanized hooks and lines, multiday trawl-net, outboard hooks and lines, and outboard gill-nets. On an average during 2001-2005, about 61.07% of the demersal landings were by mechanized trawl-nets, 14.74% by outboard gill-nets, 6.8% by outboard hooks and lines, and 5.93% by multiday trawl-nets.

Application of simulation model into fisheries research was considered by many authors. [Grant et al. \(1981\)](#) gave a generalized bio-economic simulation model for annual-crop fisheries and demonstrated its use in marine fisheries management. [George & Grant \(1983\)](#) described a stochastic simulation model for the dynamics of brown shrimp (*Penaeus aztecus*) in Galveston Bay, Texas. [Parker \(1986\)](#) used data from the Celtic sea and formulated a dynamic simulation model to describe the accumulation of chlorophyll within the thermocline. [Carothers & Grant \(1987\)](#) explored the relationship between recruitment seasonality and ordination of alternative management policies through a general stochastic simulation model.

[Ackley \(1995\)](#) developed a simulation model of the Bering Sea fishery as a quantitative means for estimating the impacts of management actions on catch and bycatch. [Christensen \(1998\)](#) constructed two mass-balance trophic models to describe the Gulf of Thailand ecosystem and validated the dynamic simulation model, *Ecosim*, to predict ecosystem level changes following changes in fishing pressure. [Senina et al. \(1999\)](#) developed a stochastic simulation model for the community of competing anchovy *Engraulis encrasicolus* and sprat *Clupeonella delicatula* in the Azov Sea in Russia and investigated their extinction risk on the basis of time series of population abundance and environmental factors that influence reproduction.

[Beare et al. \(2000\)](#) examined the potential of real-time performance indicators in the Australian northern prawn fishery using a stochastic optimal control model of the fishery. [Chen et al. \(2000\)](#) developed a fuzzy logic model with genetic algorithm for analyzing stock-recruitment relationships of southeast Alaska pink salmon (*Oncorhynchus gorbuscha*) and West Coast Island Pacific herring (*Clupea pallasii*) stocks. [Azadivar et al. \(2002\)](#) used simulation-based optimization to determine an area management policy with optimal fishing rate for the sea scallop resources of Georges Bank in Northwest Atlantic Ocean. [Mishra et al. \(2002\)](#) developed a bio-energetic

dynamic simulation model for the growth of penaeid shrimps based on an existing model on tilapia growth, and it was consisting of submodels for molting, feed consumption, digestion and biosynthesis, energy metabolism, oxidation, and growth. [Prager \(2002\)](#) made a comparison of results from logistic and generalized surplus production models by the simulation of stock of swordfish *Xiphias gladius* in the North Atlantic Ocean. [Schnute & Haigh \(2003\)](#) used a simulation model based on compound binomial-gamma distribution to assist the planning and design of ground fish trawl survey.

Materials and Methods

The basic surplus production model ([Schaefer 1954](#)) is used for calculation of biomass, fishing mortality, and yield in the simulation. The model is given by

$$\frac{dB_t}{dt} = rB_t \left(1 - \frac{B_t}{K}\right) - F_t B_t$$

where B_t is the biomass at time t (year), r is the intrinsic rate of increase of the stock, K is the carrying capacity, and F_t is the fishing mortality rate. The recursive expressions for calculating biomass and yield given by [Prager \(1994\)](#), based on the model parameters initial biomass B_0 , carrying capacity K , intrinsic growth rate r , and catchability coefficient q using time series data on catch and effort, were followed in this study. The maximum sustainable yield (MSY), biomass at MSY, fishing mortality that generates MSY, and the fishing effort corresponding to MSY were estimated ([Prager 1994](#)) as given below.

$$MSY = \frac{Kr}{4}; \quad B_{MSY} = \frac{K}{2}; \quad F_{MSY} = \frac{r}{2}; \quad f_{MSY} = \frac{r}{2q}$$

A genetic algorithm developed was used for estimation of the parameters of the surplus production model using time series data on catch and effort of demersal resources of Tamil Nadu during 1989-2005 obtained from the database of the Central Marine Fisheries Research Institute, Cochin. Effort series for demersal catch were computed using the effort of mechanized trawl net, mechanized hooks and lines, multiday trawl net, outboard hooks and lines, and outboard gillnets, which mainly catch demersal resources. Management options can be introduced only on the effort series on hours of operation of the gears. For simulating effort series for future years, spectral time series models were adopted by estimating model parameters and residual variance using time series data on effort of these gears. The spectral model used has the expression

$$y_t = a_0 + \sum_{i=1}^k [a_i \sin(2\pi\lambda_i t) + b_i \cos(2\pi\lambda_i t)] + \varepsilon_t$$

The error term ε_t was assumed to be from a normal distribution with zero mean and constant variance for simulation purpose. For implementation of the genetic algorithm, spectral model estimation and simulation of effort, biomass, fishing mortality, and yield computer software were developed in-house in C++. For the prediction of

future biomass and yield, the effort scenario was simulated first, which was then used for the yield forecast. The simulation of effort was carried out as follows. From the spectral model that was exclusively fitted on the effort time series, the mean effort for a future year was computed with the parameters. Then, the distributional aspect of effort sequence was assumed to be normal with standard error estimated from the effort series. With each of the predicted mean effort, 1000 numbers of simulated normal values with appropriate error were added to get the sequence of 1000 effort values for each year of forecast. For each value of the simulated effort, biomass, fishing mortality, and yield were calculated using the estimated surplus production model, and averages of these quantities were recorded. Such simulations were carried out for each of the future years from 2006 to 2015. Restrictions on hours of operations were introduced by multiplying the simulated effort by a suitable factor before calculation of biomass, fishing mortality, and yield.

Results and Discussion

Estimates of parameters of surplus production model obtained through the genetic algorithm using time series data on catch and effort for demersal resources of Tamil Nadu and the estimates of spectral model parameters used for modeling effort series are given in Table 1.

Table 1. Estimates of parameters of surplus production model and spectral model

Parameter	Estimate	No	Frequency	Periodogram	Sine term	Cos term
B_0	197369.24	1	0.0588	141493	-16603.51	-1191.87
K	474003.06	2	0.1176	53593	4792.94	4096.61
r	1.268522	3	0.2353	43819	138.69	-5153.34
q	0.000004028	4	0.4706	33695	2143.46	-3334.68
		5	0.3529	29502	3375.61	807.13
		6	0.1765	29134	-3427.17	-48.35

The estimate of MSY for demersal resources in Tamil Nadu calculated using the estimates of surplus production model parameters is 1,50,320 t (tonnes), estimate of biomass corresponding to the MSY level is 2,37,001 t, estimate of fishing mortality rate at MSY level is 0.6343, and estimate of effort corresponding to MSY level is 1,57,463 hours of operation. Plot of the biomass and yield calculated using the estimated surplus production model along with the observed catch is given in Figure 1.

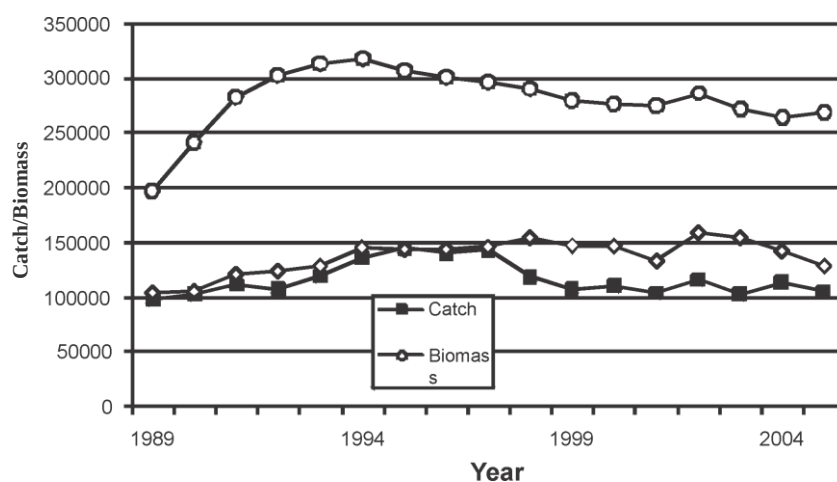


Figure 1. Plot of observed catch along with yield and biomass computed using the estimated surplus production model for the demersal resources of Tamil Nadu

The observed effort series and the corresponding fitted series based on spectral model are shown in Figure 2.

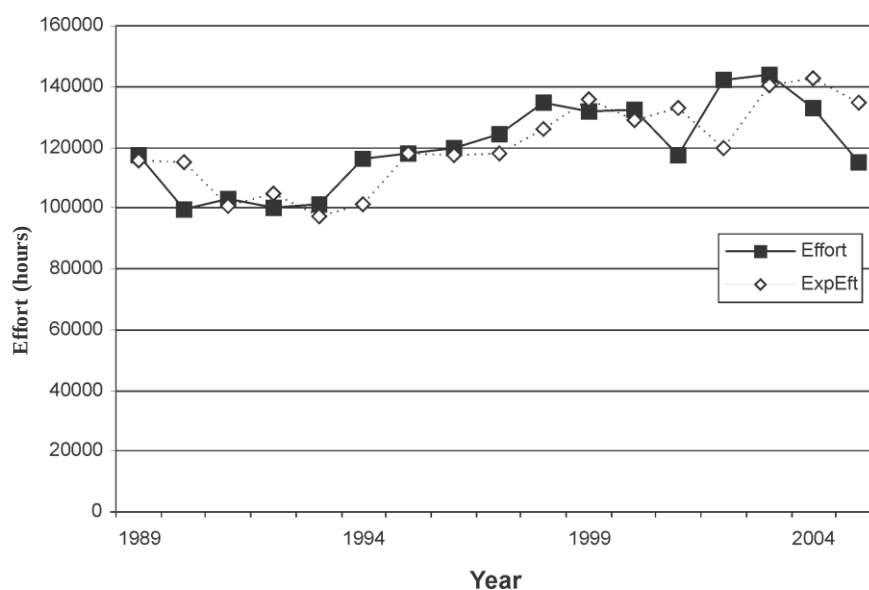


Figure 2. Plot of observed effort and effort computed using the fitted spectral model

Estimates of fishing mortality rate, biomass and expected yield based on the fitted model are given in Table 2. During the period 1996-2005, the observed demersal catch is below the MSY level for all the years. The average annual demersal catch during this period is 1,16,433 t, which is far below the MSY.

Table 2. Estimates of fishing mortality, biomass and yield calculated based on the fitted surplus production model

Year	F (t)	Biomass	Yield
1989	0.473234	197369	104625
1990	0.399908	241940	105903
1991	0.414505	283894	122132
1992	0.402365	303107	124592
1993	0.407327	314682	129121
1994	0.467437	318752	146056
1995	0.474535	307751	144375
1996	0.482095	301587	144229
1997	0.500229	297330	147151
1998	0.54349	291747	155137
1999	0.531442	280622	148316
2000	0.533488	277885	147742
2001	0.473576	276195	133727
2002	0.57314	287251	159957
2003	0.580032	272828	155651
2004	0.534568	264854	143015
2005	0.464775	269660	129503

Simulation of the demersal fishery for Tamil Nadu was carried out by generating effort series using the estimated spectral model with a normal error term having zero mean and constant variance for different levels of effort such as 25%, 50%, 75%, 100%, 125%, 150%, 175%, and 200% of the current level of exploitation. One thousand such simulations were made, and for each simulation mortality, biomass and yield series were generated for the period from 2006 to 2015, and the averages of the results of simulation are given in the Table 3 for different levels of exploitation.

Table 3. Fishing mortality, biomass, and yield simulated for different levels of exploitation for the demersal resources of Tamil Nadu

Year	25%			50%		
	Mortality	Biomass	Yield	Mortality	Biomass	Yield
2006	0.1159	285781	38593	0.2317	285781	73688
2007	0.1016	371239	40196	0.2031	344048	73760

2008	0.1051	413569	44362	0.2102	377674	80781
2009	0.0981	427884	42339	0.1964	389098	77275
2010	0.1018	434374	44273	0.2035	396596	80816
2011	0.1187	435474	51396	0.2375	397485	93285
2012	0.1180	431483	50833	0.2362	389532	91658
2013	0.1186	430410	51014	0.2370	387087	91570
2014	0.1269	429913	54367	0.2537	386040	97283
2015	0.1370	427652	58320	0.2740	381652	103555

75%				100%		
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Year	Mortality	Biomass	Yield	Mortality	Biomass	Yield
2006	0.3469	285781	105430	0.4633	285781	134510
2007	0.3045	318418	101202	0.4063	293948	122982
2008	0.3153	343045	109590	0.4212	309636	131340
2009	0.2949	351005	104837	0.3934	313588	125046
2010	0.3046	358863	109436	0.4068	321286	130782
2011	0.3553	359684	125458	0.4750	321686	148879
2012	0.3543	348409	122584	0.4719	307401	143597
2013	0.3549	344311	121834	0.4745	301972	142475
2014	0.3807	342547	128981	0.5079	299064	149543
2015	0.4105	336112	135812	0.5480	290967	155829

125%				150%		
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Year	Mortality	Biomass	Yield	Mortality	Biomass	Yield
2006	0.5787	285781	160554	0.6950	285781	184192
2007	0.5077	271105	139567	0.6087	249494	151339
2008	0.5252	277971	145925	0.6322	248077	155058
2009	0.4909	277862	138228	0.5891	243114	144869
2010	0.5089	284586	144681	0.6099	248306	151036
2011	0.5933	284193	162999	0.7125	247244	168734
2012	0.5898	267600	155467	0.7077	228717	158443
2013	0.5919	260518	152901	0.7118	220087	154535
2014	0.6344	256684	159380	0.7603	214778	158799
2015	0.6854	247033	164023	0.8223	204133	160935

Plots of observed catch, estimated average biomass, and average yield for different exploitation levels are shown in Figures 3 and 4.

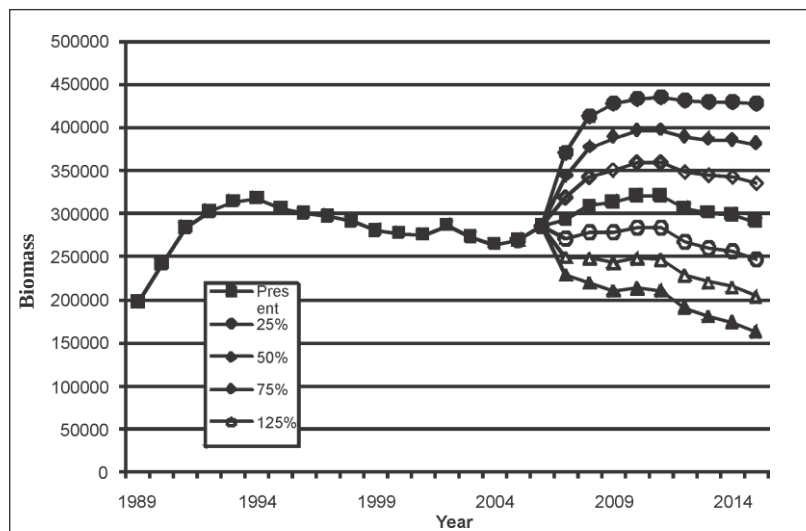


Figure 3. Simulated biomass for demersal fishery in Tamil Nadu for the period up to 2015 for different exploitation levels (as percentages of present level)

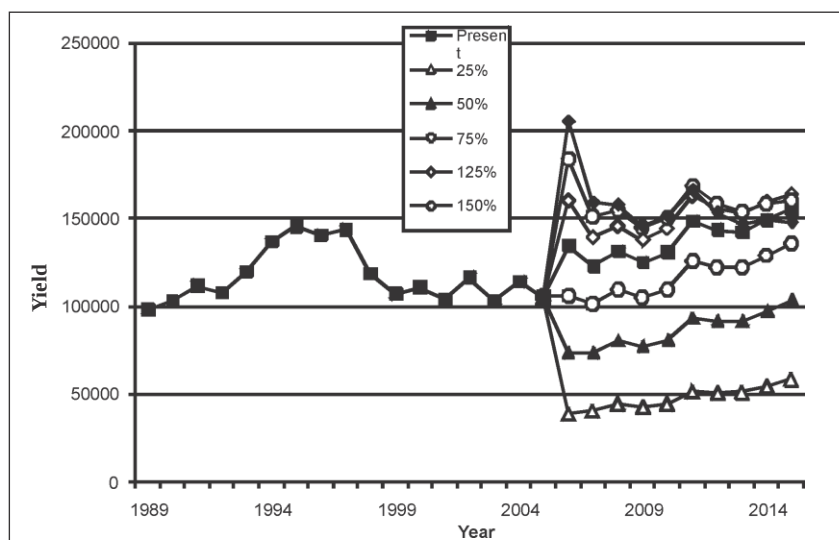


Figure 4. Simulated yield for demersal fishery in Tamil Nadu for the period up to 2015 for different exploitation levels (as percentages of present level)

When the fishery was simulated for the period 2006-2015 maintaining the present level of exploitation, the average annual yield obtained for the period was 1,38,498 t which is below the MSY and the average biomass obtained for the period was 3,04,533 t. The yield obtained in individual years is below the MSY except for the year 2015 in

which the expected annual yield is 1,55,829 t. The expected minimum yield was 1,22,982 t for the year 2007. In the case when the exploitation level was reduced to 75% of the present level, the expected yield in all the years from 2006 to 2015 was found to fall below MSY with 1,16,516 t, as the average annual yield for the period and the average annual biomass for the period was 3,38,818 t. The maximum yield expected was 1,35,812 t for the year 2015, and the minimum expected was 1,01,202 t in 2007. Simulation results were also obtained by keeping the exploitation level at 125% and 150% of the present level. The simulated average yield during 2006-2015 for 125% level was 1,52,373 t and for 150% level was 1,58,794 t both falling above MSY level. The maximum expected yield for these two exploitation levels was 1,64,023 t in 2015 and 1,84,192 t in 2006, respectively. In these cases, the expected average annual yields were above MSY in most of the years. The annual average biomass during the period 2006-2015 in the two cases was 2,71,333 and 2,38,973 t, respectively.

From the above results, it was observed that the optimum level of exploitation is between 75% of the present level and the present level of exploitation (100%). To work out the optimum level of exploitation that will retain all the years expected yield below the MSY level, further simulations were carried out for finer divisions of levels of exploitations, and it was found that at 91.25% of the present level of exploitation, the expected yields for all the years from 2006 to 2015 are below MSY.

Acknowledgment

The authors wish to express their gratitude to Prof. (Dr.) Mohan Joseph Modayil, Director, Central Marine Fisheries Research Institute, Cochin, for providing facilities necessary for the conduct of the simulation study.

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