Indian J. Fish., 56(3) : 163-168, 2009

ICAR

Managing marine fishery in Kerala through simulation using surplus production model, genetic algorithm and spectral methods

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ABSTRACT

Outboard ring seines and mechanized trawl nets form the two major fisheries in Kerala accounting for about 72% of the total catch in the state. A genetic algorithm was developed for simulation of trawl net and ring seine fishery using surplus production model and spectral methods. Simulations were carried out for six different levels of exploitations and the average biomass and average yield were calculated and compared with the maximum sustainable yield (MSY). The simulation results based on ring seine fishery revealed that the optimum level of exploitation is at 86.3% of the current level of exploitation to keep the annual average yields during 2005-2014 just below MSY, for both oil sardine and mackerel. Simulations based on trawl net fishery suggested maintaining the exploitation level at 87.9% of the current level to retain the average annual yields of penaeid prawns, cephalopods and threadfin breams below the MSY level during 2005-2013.

Keywords : Fisheries management, Genetic algorithm, Simulation, Spectral methods, Surplus poduction model

Introduction

One of the objectives of fisheries management is to maximize long-term benefit from marine fishery resources. Control mechanisms usually adopted to achieve this objective are fishing capacity restrictions by limiting the number of vessels, restrictions on gear based on type, size as well as mesh size, and also through restrictions on fishing area. Prior knowledge about the effect of implementation of these management options on the fishery resources is very much essential to implement the correct management strategy. A quantitative assessment of the effect of different management options on the fishery resources is possible through simulation modeling of the system. Systems analysis and simulation techniques have been incorporated into fishery management programmes as means of assisting resource managers in evaluating potential course of action to meet certain goals. Simulation models use the most recent information available about the fishery and attempt to estimate resulting future changes associated with the implementation of different management options. A simulation study conducted to examine the effects of restrictions imposed on the total hours of operation of two major gears on the fishery in the maritime state of Kerala, India is reported.

Genetic algorithm (GA) is a searching algorithm, based on the principle of evolution. It considers many points at each step in the searching process so that it does not converge to a local optimal solution. A solution in GA is an individual belonging to a population, possessing a character sequence or binary sequence defined as its chromosome (genotype). A fitness function is defined to evaluate the individuals and the one with highest fitness score is the best solution. Evolution takes place over generations through processes such as selection, crossover and mutation.

Simulation models were used by many research workers to examine the effect of management options on fisheries. Grant *et al.* (1981) gave a generalized bio-economic simulation model for annual-crop fisheries and demonstrated its use in marine fisheries management. George and Grant (1983) described a stochastic simulation model for the dynamics of brown shrimp (*Penaeus aztecus*) in Galveston Bay, Texas and used this model to evaluate the effects of management alternatives and changing environmental conditions. Carothers and Grant (1987) through a general stochastic simulation model explored the relationship between recruitment seasonality and ordination of alternative management policies. 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.

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 and 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:

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

and the biomass is calculated as:

$$B_{t+1} = \begin{cases} \dfrac{\alpha_t \exp(\alpha_t)\, B_t}{\alpha_t + \beta(\exp(\alpha_t)-1)\, B_t} & when \quad \alpha_t \neq 0 \\ & \qquad for \quad t = 1,\cdots,T \\ \dfrac{B_t}{1+\beta\, B_t} & when \quad \alpha_t = 0 \end{cases} \quad (2)$$

where, $\beta = \frac{r}{K}$, $\alpha_t = r - F_t$ and

Here, is the fishing mortality rate, f_t fishing effort, K carrying capacity, r intrinsic rate of increase of the stock, B_t biomass at time t (year) and q the catchability coefficient. Based on this model yield is calculated as:

$$Y_t = \begin{cases} \dfrac{F_t}{\beta} \ln\left[1 - \dfrac{\beta\,(1-\exp(\alpha_t))\, B_t}{\alpha_t}\right] & when \quad \alpha_t \neq 0 \\ & \qquad for \quad t = 1,\cdots,T \\ \dfrac{F_t}{\beta} \ln[1+\beta\, B_t] & when \quad \alpha_t = 0 \end{cases} \quad (3)$$

Parameters of this model are the initial biomass B_0, carrying capacity K, intrinsic growth rate r and catchability coefficient q. The estimates of 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:

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

A genetic algorithm was developed for estimation of these parameters using time series data on catch and effort of mechanized trawl net and outboard ring seine in Kerala during 1985-2004 obtained from the Central Marine Fisheries Research Institute, Cochin. Management options can be introduced only on the effort series on hours of operation of the gears. Hence, simulation of effort series for future years is necessary. For simulating effort series, spectral time series models are adopted by estimating model parameters and residual variance using time series data on effort of these gears. The spectral model expression is:

$$y_t = a_0 + \sum_{i=1}^{k}\left[a_i Sin(2\pi\lambda_i t) + b_i Cos(2\pi\lambda_i t)\right] + \varepsilon_t \quad (5)$$

The error term ε_t was assumed to be from a normal distribution with zero mean and constant variance for simulation purpose. For each future year, 1000 simulations of effort were made using the fitted spectral model and drawing the error term from its fitted probability distribution and for each simulated effort biomass, fishing mortality and yield were calculated using the estimated production model and averages of these quantities recorded. For each of the future years from 2005 to 2014, such simulations were carried out. Restrictions on hours of operations were introduced by multiplying the simulated effort by a suitable factor before calculation of biomass, fishing mortality and yield.

Each parameter of the Schaefer's model was represented by a binary coded string of length 32 to form a chromosome of length 128. Parameter values were converted into binary after transformation to integers using the formula :

$$x = z_{\min} + (z_{\max} - z_{\min})\,\frac{z}{(2^{32}-1)} \quad (6)$$

where z is the value of the parameter and $z_{\max}$, $z_{\min}$ are prefixed minimum and maximum values. A fraction 0.20 (selection fraction) of the individuals in the population with higher fitness, were selected for inclusion in the new generation. The remaining individuals are offsprings generated from parents selected at random with probability proportional to fitness. The crossover probability was fixed as 0.60 and the methods adopted at random were single point crossover, two point crossover and uniform crossover. The mutation probability was fixed as 0.05 and the locus for mutation was chosen at random with equal probability. The fitness function used was the reciprocal of the residual sum of squares.

The population size was fixed as 30 and the initial population was generated by creating chromosomes randomly. Initial estimates of B_0, K, r and q were obtained by following the procedure given by Wang (2002) and an individual corresponding to these estimates was created and included in the initial population. The process of evolution takes place by generating new individuals for the next generation from the existing generation through the application of selection, crossover and mutation. New generations were formed one after another and individuals were evaluated using the fitness function. This is continued till convergence when all the individuals in the population become genetically identical or improvement is below the pre-assigned precision level.

For implementation of the genetic algorithm, spectral model estimation and simulation of effort, biomass, fishing mortality and yield, computer software were developed in C++.

Results and discussion

Kerala contributes about 25% to the total marine fish production in India. Mechanized trawl net and outboard ring seine are the two major gears operated in the state. During the period 2000-2004, the average contribution by these gears were 35.7% (trawl net) and 36.1% (ring seine) of the total catch of the state. The composition of species caught by these gears is given in Table 1 along with their percentage contribution. Oil sardine, *Sardinella longiceps* and the Indian mackerel, *Rastrelliger kanagurta* form more than 84% of the ring seine catch whereas penaeid prawns, cephalopods, threadfin breams and soles form around 50% of the trawl net catches.

Table1. Percentage composition of trawl net and ring seine catches in Kerala during 2000-2004

Mechanized trawl net	
Penaeid prawns	17.9
Cephalopods	13.5
Threadfin breams	11.0
Soles	7.5
Lizard fishes	5.5
Ribbon fishes	5.4
Non-penaeid prawns	4.9
Stolephorus	4.5
Others	29.8
Outboard ring seine	
Oil sardine	77.1
Indian mackerel	7.1
Scads	2.3
Stolephorus	3.8
Other sardines	2.4
Penaeid prawns	2.4
Others	5.0

Initial estimates of parameters of the surplus production model obtained for trawl net and ring seine fishery through the method of Wang (2002) and final estimates made through GA are given in Table 2. Estimates of parameters of spectral models used for the effort series of the two gears are given in Table 3. During 2000-2004, on an average, oil sardine formed 77.1% of the catches in outboard ring seines (Table 1), which accounted for 82.6% of the total oil sardine catch of Kerala. Using the surplus production model for ring seine fishery and based on the above facts, the estimate of MSY for oil sardine in Kerala was obtained as 2,11,306 t. The average catch of oil sardine during 2000-2004 was 2,21,459 t which is above the MSY level. The estimate of average biomass at MSY level was 1,79,931 t and the fishing mortality corresponding to MSY was 1.096. Indian mackerel formed 7.1% of the outboard ring seine catches and on an average it, accounted for 61.2% of the mackerel catch in Kerala during 2000-2004. The estimate of MSY for mackerel in Kerala was arrived at 26,246 t which is below the average catch of 33,419 t of mackerel during 2000-2004. The average biomass estimated for mackerel for the MSY level was 22,349 t.

The summary of simulation results for the two gears for the period 2005-2014 at different levels of exploitation are given in Table 4. Plot of simulated biomass and yield for the ring seine fishery in Kerala for different levels of exploitation are given in Fig. 1 and 2. Fig. 3 and 4 show the plot of simulated biomass and yield for trawl net fishery in

Table 2. Initial estimates obtained through Wang's method and final estimates arrived through genetic algorithm for the parameters of Schaefer's surplus production model for trawl net and ring seine fishery in Kerala.

Parameter	Description	Trawl net	Ring seine
	Initial estimates		
B_0	Initial Biomass (tonnes)	93609	23425
K	Carrying Capacity (tonnes)	183859	34530
r	Intrinsic rate of increase	1.056670	2.34874
q	Catchability coefficient	0.00000019	0.00000139
	Final estimates		
B_0	Initial Biomass (tonnes)	5082574	261540
K	Carrying Capacity (tonnes)	713760	385534
r	Intrinsic rate of increase	1.061829	2.348739
q	Catchability coefficient	0.00000014	0.00000139

Table 3. Estimates of parameters of spectral model for the effort series of trawl net and ring seine fishery in Kerala.

		Ring seine			Trawl net	
a_o		524517			2305683	
No (i)		a_1	b_1		a_1	b_1
1	0.0625	84946.3	-23694.3	0.0500	-451959.0	-1659547.3
2	0.1250	68896.8	-42437.5	0.3000	-316354.0	294236.2
3	0.3125	15482.2	-59594.2	0.3500	-191536.3	-380294.7
4	0.4375	20780.5	-49093.3	0.1500	-297713.0	194914.4
5	0.2500	19986.8	18889.5	0.4000	206163.2	258847.9
6	0.3750	24837.3	-1185.6	0.2500	289525.8	-94181.2

Table 4. Fishing mortality, average biomass and average yield (tonnes) for different levels of exploitation for ring seine and trawl net fishery in Kerala.

Management strategy	Year	Ring Seine			Trawl net		
		Fishing mortality	Average biomass	Average yield	Fishing mortality	Average biomass	Average yield
Retain at current exploitation level	2005	0.9473	306838	251974	0.0604	583134	36747
	2006	0.7917	245348	197312	0.0832	637168	53150
	2007	0.9007	253402	220513	0.0968	650012	62406
	2008	0.9259	241270	219108	0.1314	649242	83693
	2009	0.8922	235435	210647	0.3625	634649	209500
	2010	0.7013	238290	177179	0.3773	539653	194079
	2011	0.5806	263594	160008	0.4155	497107	198659
	2012	0.8739	285364	229186	0.4192	465231	190790
	2013	0.6682	250866	175014	0.4460	448885	195618
	2014	0.7283	270882	194518	0.6733	432174	262075
Reduce to 75% of presentlevel	2005	0.7081	306838	202568	0.0470	583134	28805
	2006	0.5967	275942	167765	0.0615	642687	39934
	2007	0.6665	285520	186509	0.0720	661217	47411
	2008	0.6897	277864	189173	0.1002	663869	65603
	2009	0.6667	273386	182662	0.2748	652997	167290
	2010	0.5216	275628	149887	0.2827	579112	158334
	2011	0.4345	295746	132291	0.3118	547804	166305
	2012	0.6602	311382	192873	0.3152	523890	162761
	2013	0.5018	282943	146884	0.3323	512096	167802
	2014	0.5479	299808	162464	0.5036	500617	233986
Increase to 125% of presentlevel	2005	1.1827	306838	292658	0.0797	583134	48035
	2006	0.9963	217133	217172	0.1049	629277	65912
	2007	1.1168	220840	236152	0.1203	637919	75850
	2008	1.1489	207426	231992	0.1606	634919	99559
	2009	1.1132	200075	222791	0.4566	617379	249889
	2010	0.8742	202104	190659	0.4789	500003	223991
	2011	0.7247	231632	178498	0.5186	445813	219677
	2012	1.0921	258937	254053	0.5231	408071	206966
	2013	0.8275	219059	191602	0.5552	387679	208551
	2014	0.9072	242378	216062	0.8358	367505	268279
Optimal level (86.25% for Ring seine and 87.9% for Trawlnet)	2005	0.8148	306838	225734	0.0545	583134	33217
	2006	0.6859	262051	182827	0.0796	639614	51034
	2007	0.7739	270864	204127	0.0861	652471	55835
	2008	0.7955	261016	204559	0.1159	654646	74578
	2009	0.7738	256271	198407	0.3195	643093	189257
	2010	0.6053	258116	164135	0.3324	558608	178094
	2011	0.4970	280855	144947	0.3698	521109	186065
	2012	0.7586	300117	211369	0.3703	491646	178756
	2013	0.5776	268193	160908	0.3933	477932	184445
	2014	0.6289	286675	178157	0.5890	463596	249985

Kerala under different levels of exploitation. The average annual yield of ring seines during the five-year period 2000-2004 was 2,16,614 t and the average of the yield during 2005-2014 obtained through simulation retaining the present level of exploitation is 2,03,546 t. This accounts for a reduction in average yield to the tune of about 6% compared to the average yield during 2000-2004. The average of simulated yield of oil sardine for 2005-2014 at the present level of exploitation is 1,89,993 t and the corresponding average biomass is 2,41,875 t. The average simulated yield is below the MSY and it accounted for about 14.2% reduction in average catch of oil sardine compared to that during 2000-2004. The average biomass of oil sardine obtained for 2005-2014 by simulation at current level of exploitation was 2,41,875 t and the estimated average biomass for 2000-2004 was 2,62,078 t. The reduction in biomass of oil sardine is then 7.7% during 2005-2014 compared to that during 2000-2004.The simulated average yield for mackerel for the period 2005-2014 is 23,599 t and it is also below the MSY for mackerel.

When the fishery was simulated with effort maintained at 75% of the present level of exploitation, the average

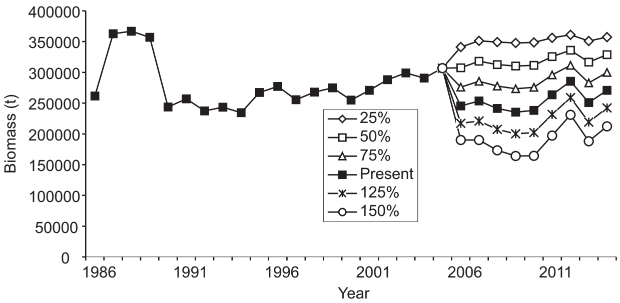

Fig. 1. Simulated biomass (tonnes) for ring seine fishery in Kerala for the period up to 2014 at six different levels of exploitation namely, reduced to 25% of present level, reduced to 50% of present level, reduced to 75% of present level, present level continued as such, increased by 25% of present level and increased by 50% of present level.

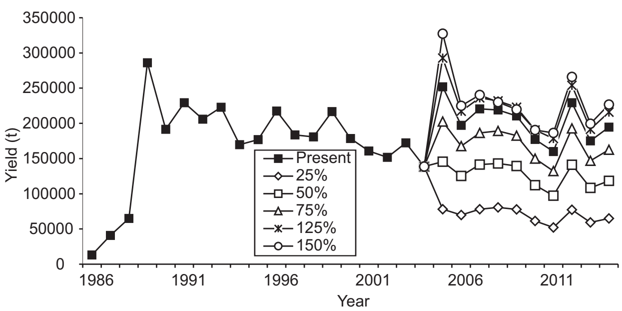

Fig. 2. Simulated yield (tonnes) for ring seine fishery in Kerala for the period up to 2014 at six different levels of exploitation namely, reduced to 25% of present level, reduced to 50% of present level, reduced to 75% of present level, present level continued as such, increased by 25% of present level and increased by 50% of present level.

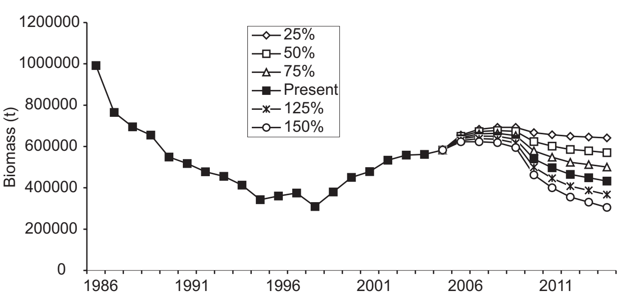

Fig. 3. Simulated biomass (tonnes) for trawl net fishery in Kerala for the period up to 2014 at six different levels of exploitation namely, reduced to 25% of present level, reduced to 50% of present level, reduced to 75% of present level, present level continued as such, increased by 25% of present level and increased by 50 % of present level.

annual ring seine yield obtained for the period 2005-2014 was 1,71,308 t, which amounts to a reduction of about 20.9% compared to the average annual yield during 2000-2004. The simulated average annual yield for the period

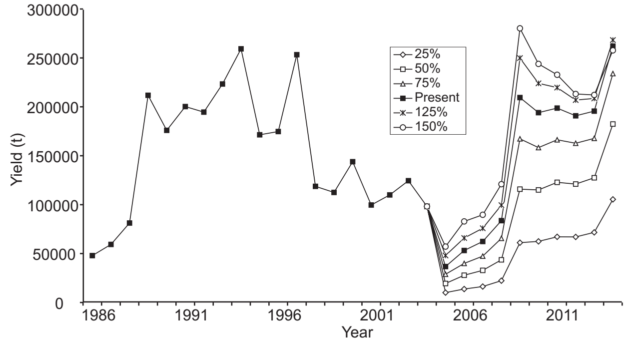

Fig. 4. Simulated yield (tonnes) for trawl net fishery in Kerala for the period up to 2014 at six different levels of exploitation namely, reduced to 25% of present level, reduced to 50% of present level, reduced to 75% of present level, present level continued as such, increased by 25% of present level and increased by 50% of present level.

2005-2014 for oil sardine was 1,59,901 t and that for mackerel was 19,861 t. In all the years, the average annual yield was found to fall below the MSY levels for both oil sardine and mackerel. The simulated average biomass for the period 2005-2014 for oil sardine is 2,69,296 t and that for mackerel is 33,449 t. For both oil sardine and mackerel, the simulated average biomass is higher than the biomass at their MSY levels. Also, biomass estimates for each individual years were found to fall above the MSY level biomass.

The average of simulated yield for outboard ring seine during 2005-2014 , when the effort level was increased to 125% of the present level of exploitation is 2,23,164 t. The simulated average yield for oil sardine for the period 2005-2014 at this level of exploitation is 2,08,304 t and that for mackerel is 25,873 t and both these values fall below corresponding MSY values. But the simulated average annual yields in the years 2005, 2007, 2008 and 2012 were found to be higher than the MSY for both oil sardine and mackerel. The average of biomass obtained through simulation for 2005-2014 for oil sardine is 2,15,285 t and for mackerel, it is 26,740 t. These are above the respective biomass MSY levels for oil sardine and mackerel. Individual year's estimates of biomass for these two species were also found to be higher than the respective MSY level biomass.

These results suggest that there is a need to reduce the effort below the present level of exploitation but above 75% of the present level. Hence an effort was made to find the level of exploitation, which will keep the estimated annual average yields in all the years just below the MSY level for both oil sardine and mackerel. For this the simulation experiments were repeated for finer divisions of effort level between 75% and 100% of the present level of exploitation. This resulted in obtaining the optimum level of exploitation as 86.25% of the present level to keep the annual average yields in all the years during 2005-2014 just below the MSY for both oil sardine and mackerel. At this level of effort, the average annual yield for the period for ring seine is 1,87,517 t and the average annual yields for oil sardine and mackerel were 1,75,031 t and 21,740 t respectively. The average biomass for the period for oil sardine is 2,56,782 t and that for mackerel is 31,894 t. The maximum yield is 2,10,703 t for oil sardine and 26,171 t for mackerel in 2005 and the minimum yield is 1,35,296 t for oil sardine and 16,805 t for mackerel in 2011.

Penaeid prawns, cephalopods and threadfin breams are the three important groups caught by mechanized trawlers in Kerala. During the period 2000-2004, these three groups, on an average, accounted for 42.4% of the trawl net catches and 75.54% of the penaeid prawns, 89.18% of the cephalopods and 99.07% of the threadfin breams caught in Kerala are by mechanized trawl nets. Using the estimated surplus production model for mechanized trawlers, the MSY for these groups arrived at are 44,902 t for penaeid prawns, 28,685 t for cephalopods and 21,040 t for threadfin breams. The estimates of biomass at the MSY level for these groups are 84,566 t for penaeid prawns, 54,024 t for cephalopods and 39,625 t for threadfin breams. The average annual yield for these groups in Kerala during 2000-2004 are 43,596 t for penaeid prawns, 31,719 t for cephalopods and 34,555 t for threadfin beams. The average yield is below the MSY for penaeid prawns and it is above the MSY level for the other two groups. The expected average annual yield for mechanized trawl nets obtained through simulation for the period 2005-2014 under the current level of effort is 1,48,672 t. The simulated average yield for 2005-2014 for the three groups under current level of effort are 35,229 t for penaeid prawns, 22,506 t for cephalopods and 16,507 t for threadfin breams and these estimates fall below their respective MSY. But the simulated average annual yields are above the MSY for the years from 2009 to 2014 for all the three groups. Similar results hold when the yields were simulated for efforts at 125% and 150% of the current level. When the effort was reduced to 75% of the present level the expected average annual yields obtained fall above MSY only for the year 2014. Further simulation experiments carried out considering effort levels between 75% and 100% of the present level resulted in finding 87.9% of the current level of effort as the level that will retain average annual yields below the MSY levels of the three groups for all the simulated years except for 2014. The reduction in the level of effort necessary to retain average annual yields below MSY levels of the three groups for all the years including 2014 was found to be at 52.75% of the present level.

The observed catch and effort during 2005-2007 were compared with that made through simulation using data from 1985-2004. In the case of mechanized trawlers, the observed effort was 2.6 to 2.9 times higher compared to the effort during 2002-2004. The forecasts calculated based on simulated yields at present level, taking into account the said increase in effort level, showed 40% less for 2005, 20% less for 2006 and excess by 14% for 2007compared to the actual observed catches. In the case of ring seine, the effort levels for 2005, 2006 and 2007 were 72%, 62% and 81% respectively of the effort level during 2002-2004. The forecasts made based on these levels of effort and simulated yields revealed that the forecast was excess by 12% in 2005, less by 11% and 13% in 2006 and 2007 respectively compared to the actual observed catches.

Acknowledgments

The authors wish to thank Prof. (Dr.) Mohan Joseph Modayil, former Director, Central Marine Fisheries Research Institute, Cochin for extending necessary facilities for conducting the study.

References

Ackley, D. 1995. Bering sea fishery simulation model. *Alaska Fish. Res. Bull*., 2(1): 83-86.

Carothers, P. E. and Grant, W. E. 1987. Fishery management implications of recruitments seasonality: simulation of the Texas fishery for the brown shrimp, *Penaeus aztecus*. *Ecol. Model*., 36: 239-268.

George, L. C. and Grant, W. E. 1983. A stochastic simulation model of brown shrimp (*Penaeus aztecus* Ives) growth, movement, and survival in Galveston Bay, Texas. *Ecol. Model*., 19: 41 70.

Grant, W. E., Isakson, K. G. and Griffin, W. L. 1981. A general bioeconomic simulation model for annual-crop marine fisheries. *Ecol. Model*., 3(3): 195–219.

Prager, M. H. 1994. A suite of extensions to a non-equilibrium surplus-production model. *Fish. Bull.,* 92(2): 374-389.

Prager, M. H. 2002. Comparison of logistic and generalized surplus-production models applied to swordfish *Xiphias gladius* in the north Atlantic Ocean. *Fish. Res.,* 58: 41-57.

Schnute, J. T. and Haigh, R. 2003. A simulation model for designing groundfish trawl surveys. *Can. J. Fish. Aquat. Sci*., 60: 640-656.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. *Bull. Inter-Am. Trop. Tuna Comm.,* 1(2): 27-56.

Wang, C. H. 2002. Estimating the population parameters *r, q,* and *K* based on surplus production model. *15th meeting of the Standing Committee on Tuna and Billfish,* July 22-27, 2002, Honolulu, Hawaii., SCTB-15 working paper, ALB-7,19pp. URL: *http://www.spc.org.nc/OceanFish/Html/SCTB/SCTB17/MGW-2.pdf.*

Date of Receipt : 05/02/08
Date of Acceptance : 25/04/09