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Long term projection of the marine fish landings along southwest coast of India using Markov chain model

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Abstract

The variable nature of biological systems suggests that stochastic models are appropriate for the study of the dynamic changes in space or time. Among this group of models, Markov chain model is popular and widely used. A four state Markov chain model is applied to study the changes in the landings along southwest coast of India. Time series data on marine fish landings along southwest coast of India during 1961 to 2003 are examined by Markov chain model after deriving transition probability matrices. Using these matrices, the estimated steady state value of exploited marine fish landings along southwest coast of India is 6,56,709 tonnes. The projection indicates that there will be decline in the landings in the long run, if the present mode of exploitation is continued.

Keywords : Markov chain, transition probability, stochastic models

Introduction

The precautionary approach has become a basic necessity in fish stock assessment. This concept implies that uncertainties have to be taken into account in the assessment of the fishery. Fisheries are managed in an arena of uncertainty that includes an incomplete understanding of their dynamics, interactions among species, effects of both environmental factors and human interferences on fish populations. In such situations the future behaviour cannot be predetermined with certainty and hence deterministic forecasting models are not applicable. Successful fishery management should incorporate and deal with uncertainties and errors. Stochastic models can offer better forecasts by allowing for random elements in the model.

The quantification of the uncertainties has emphasized the need for developing stochastic assessment approaches (Lewy and Nielson, 2003). Numerous stochastic assessment methods including frequentist, state space, time series, Bootstrap models and Bayesian methods have been suggested (Fournier and Archibald, 1982 ; Methot, 1990; Gudmundsson, 1994; Kinas, 1996). Saila and Erzini (1987) presented a review of the methods and the models used in the fisheries context to study fish assemblages with special reference to Markov process application. Formacion and Saila (1994) studied the dynamics of pelagic fish stocks in the purse seine fishery in Phillippines based on simple Markov chain model. Srinath (1996) used Markov chain model to study the changing pattern of the composition of the pelagic fish assemblage in Kerala. In this paper, an attempt is made to project the marine fish landings along southwest coast of India using Markov chain model.

Material and methods

In order to make use of Markov chain model, time ordered observations on the landings data are necessary. The marine fish landings from 1961-2003 in southwest coast of India estimated through stratified multistage random sampling design developed by the Central Marine Fisheries Research Institute, Cochin form the database for this study. Time series data on marine fish landings are examined by Markov chain model after deriving transition probability matrices. Then, matrices are projected to provide some insight about changes in the landings.

Markov chain model

A stochastic process is a family of random variables that describes the evolution through time of some processes. A Markov chain is a stochastic process, in which the transition probabilities of moving from one state to another are dependent only upon the starting state of any transition rather than upon how the state was reached. In other words, the model computation is based on a memory less assumption that the future of the process is determined by its present, and not by the past. Markov chains are useful and important stochastic processes and application of this is endless, and they have well-developed theory (Morgan, 2000).

The Markov chain is described by its transition probability $P_{ij}(n,n+1)$, the conditional probability that the system in state 'j' at time 'n+1' given that it was in state 'i' at time 'n'. The transition probabilities are most conveniently handled in matrix form $P=\lfloor P_{ij} \rfloor$ called transition probability matrix. The elements in transition probability matrix will be non-negative and the elements in each row sum to unity. The transition probability can be represented by the n x n matrix ***P*** given by

$$P=\left(P_{ij}\right)=\begin{bmatrix} P_{11}P_{12}----P_{1n} \\ P_{21}P_{22}----P_{2n} \\ ---------- \\ P_{n1}P_{n2}----P_{nn} \end{bmatrix}$$

The notation $P_j^{(n)}$ denotes the probability that the chain is in state 'j' at step n. Then it can easily be proved that $P_j^{(n)}=\sum_{j=1}^{m} P_{ij}P_j^{(n-1)}$ which in matrix notation can be written as $P^{(n)}=P^{(0)}P^n$ where $P^{(0)}$ is the unconditional probability vector at time '0'. As the Markov chain advances in time, $P_j^{(n)}$ becomes less and less dependent as $P^{(0)}$. That is to say that the probability of being in state 'j' after a large number of steps becomes independent of the initial state of the chain. When this occurs, the chain is said to have reached a steady state.

In the present study, a four state Markov chain model is used. The four states of the model are identified based on the quartiles of the time series distribution of the exploited marine fish landings of southwest coast of India. The four states of the model are given by $<Q_1$, Q_1-Q_2, Q_2-Q_3 and $> Q_3$ where Q_1, Q_2 and Q_3 are the quartiles. Let n_{ij} denotes frequency by which the system moves from state i to state j, i = 1, 2, 3, 4; j = 1, 2, 3, 4. The estimates of the transition probabilities are given by $P_{ij} = n_{ij}/n_1$, where $n_1 = \sum_j n_{ij}$. To check the appropriateness of a Markov chain model, it is required to test the independence of the four states. This is done using chi-square test statistic as follows. $H_0 : P_{ij} = \Pi_j$, j = 1, 2, 3, 4 where Π_j is the unconditional probability of being in state j.

$$\text{The test statistic } \chi^2 = \sum_i \sum_j \frac{\{n_{ij} - n_i n_j / n\}^2}{n_i n_j / n}$$

follows chi square distribution with $(n_i-1)(n_j-1)$ degrees of freedom. To make a decision about H_0, calculated value of chi square is compared with the table value at the required level of significance. If the calculated value is greater than table value, H_0 is rejected, which means that the states are not independent. This implies that the data satisfies the basic criterion of a Markov chain model. The transition probability matrix is given by $P = [P_{ij}]_{4\times4}$

It is known that after a sufficiently long period of time, the system settles down to a condition of statistical equilibrium at which state, probabilities become independent of the initial condition. The steady state probabilities are obtained by powering the transition matrix *P*. The system would reach equilibrium after n steps if $P^n = P^{n+1}$ and the steady state probabilities are given by the elements of P^n. The steady state probabilities are used to forecast the landings. This is done as follows.

$$\text{Forecast} = \hat{\Pi}_1 Q_1^* + \hat{\Pi}_2 Q_2^* + \hat{\Pi}_3 Q_3^* + \hat{\Pi}_4 Q_4^*$$

where $\hat{\Pi}_j$ is the steady state probability of state j, j = 1, 2, 3, 4 and Q_1^*, Q_2^*, Q_3^* and Q_4^* are the mid values of the range which are represented by the four states of the Markov chain model.

A brief review of the fishery

The southwest coast region comprising the states Kerala, Karnataka and Goa, had been the most productive and the largest contributor to the country's total marine fish landings upto 1994. The region contributed 9.03 lakh tonnes which amounted to one third of the total marine fish landings in India during 2003. With a coastline of about 1000 km and encompassing an area of 23,000 sq km, the sea is rich in a diverse group of marine living resources. The region pioneered many technological innovations in fishing equipment and methods during the last five decades such as increase use of synthetic gear materials, introduction of mechanized craft, extension of fishing grounds, introduction of purse seine, ring seine and initiation of motorisation of country craft and increase in fishing hours by resorting to voyage fishing. The striking feature of the marine fisheries of the region was the predominance of the pelagic resources. However, their contribution to the total marine fish production had fallen from about 80% during 60's and 70's to just about 50% in late nineties, mostly due to the increased representation of the demersal fishery resources. The relative contribution of the southwest region to the country's total production had dwindled from about 42% in the 1965 to 29% during 2003 with increase in production in the other regions (Fig.1). However, after registering peak landings of about 1.02 million tones in the year 1989, there had been a gradual decline (Srinath, 2003).

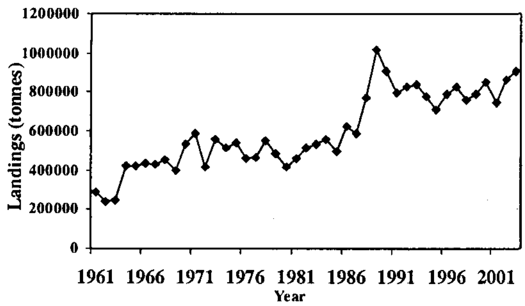

Fig.1. *Marine fish landings in southwest coast of India during 1961 to 2003*

Results and discussion

A four state Markov chain model is used to represent the time series on marine fish landings in the southwest coast of India. Quartiles of the series were located at Q_1 = 456654, Q_2 = 553310, Q_3 = 785794. According to the states, the frequencies were calculated. Values of n_{ij}, the frequency by which the system moves from state 'i' to state 'j' were found out and are given in Table 1.

Table 1. *Frequencies classified according to four states*

i/j	1	2	3	4	n_i
1	8	2	1	0	11
2	1	7	3	0	11
3	1	2	3	4	10
4	0	0	3	7	10
n_j	10	11	10	11	42

The dependence of the four states is tested using a chi-square statistic. The calculated value of χ^2 is found to be 39.358 and is significant at 1% level. Hence it is concluded that the identified states are not independent and thus the system satisfies the basic criterion of a Markov chain model. The estimated transition probability matrix of first order is as follows.

$$\begin{bmatrix} 0.727 & 0.182 & 0.091 & 0 \\ 0.091 & 0.636 & 0.273 & 0 \\ 0.100 & 0.200 & 0.300 & 0.400 \\ 0 & 0 & 0.300 & 0.700 \end{bmatrix}$$

The second and higher order transition probabilities are estimated through applying the stated property of Markov chain, namely $P^{(n)} = P^n$, n = 2,3,..... It is seen that the transition probabilities reach an equilibrium state after 20 steps. The twentieth order transition probabilities are given by

$$P^{(20)} = \begin{bmatrix} 0.170 & 0.227 & 0.258 & 0.344 \\ 0.170 & 0.227 & 0.258 & 0.344 \\ 0.170 & 0.227 & 0.258 & 0.344 \\ 0.170 & 0.227 & 0.258 & 0.344 \end{bmatrix}$$

From this, the steady state probabilities are $\pi_1 = 0.170$, $\pi_2 = 0.227$, $\pi_3 = 0.258$ and $\pi_4 = 0.344$. The equilibrium matrix indicates the average proportion of time spent in each state in the long term. The concept of equilibrium is considered to be statistical in nature for the assemblage for the species groups. The stochastic concept of equilibrium explicitly requires movement into and out of each state. The interpretation of the properties of the transition probability matrix involves projecting successive changes in the fishery as a guide to management. By projection, here it means determining what would happen to the fishery, if the present conditions were to be maintained over a protracted period.

From this analysis, the steady state value of exploited marine fish landings along southwest coast of India is 6,56,709 tonnes. The projection indicates that there will be decline in the landings in the long run, if the present mode of exploitation is continued. This can also be taken as the average long-term yield. In addition to markov chain model, projections were made based on annual average growth rate for the period 1993-2003. The annual average growth rate is 0.01%. The projections of the landings based on annual average growth rate, half of the annual average growth rate and negative growth rate as of now were made (Fig.2).

The Projected landings for the year 2025 based on the assumption that there will be negative growth rate as of now is 6,60,392 tonnes and this figure is consistent with the markov chain model prediction (Table 2).

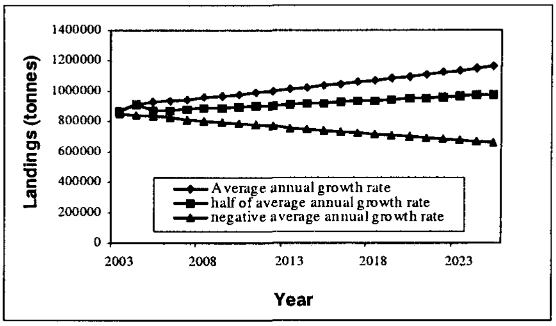

Fig. 2. *Projected landings based on different growth rates*

Srinath (2003), after an appraisal of marine fish landings during the different decadal periods since 1961, indicated the growth rates as 9.4, 3.2, 10.7 and 0.7 %. The growth during the latest phase is indicative of the true state of the fishery. All these results clearly indicate that with the existing technology, there could not be any significant augmentation in the total landings from the presently exploited

Table 2. *Projected landings in tonnes for the year 2010, 2020 and 2025 based on different growth rates*

Growth rate/year	2010	2020	2025
Annual average growth rate	944391	902266	785586
Half of the annual average growth rate	1058860	955539	699733
Negative growth rate	1121196	983345	660392

grounds off this region. Thus, Markov chain model has got potential for drawing some useful management related conclusions.

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