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# A stochastic model to analyse pelagic fishery resource dominance along the Karnataka coast (west coast of India)

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Stochastic models are appropriate for the study of dynamics of fishery and prominent among them are Markov chain models. In this study, the dynamics of the pelagic fishery resource assemblage along the Karnataka coast is analyzed with reference to the change in resource composition and relative dominance using Markov chain. The transition probabilities of the species dominance with respect to four dominant groups namely oil sardine, Indian mackerel, carangids and whitebaits have been estimated. From the higher order transition probabilities it is clear that, if oil sardine is dominant in the fishery now, the probability that it continues to be the dominant group in the next year is 0.4875 and in case of Indian mackerel, the probability that it will dominate in the next year is only 0.3834. It is also observed that in the long run the pelagic fish assemblage is more likely to be dominated by oil sardine than Indian mackerel.

[**Key words** : Stochastic model, Markov chain model, transition probability matrix, fisheries, pelagic fishery, Karnataka]

## Introduction

The marine fisheries along the Karnataka coast are characterized by dominance of pelagic fish assemblage, prominent among them being Indian mackerel (*Rastrelliger kanagurta)* and oil sardine (*Sardinella longiceps*), presently contributing around 30% to the total marine fish landings in coastal Karnataka (central west coast of India) (Fig.1).

During the last four decades there has been structural and qualitative change in the marine fisheries along the Karnataka coast in consonance with the natural scenario. Recently, Mohamed *et al.*[1] analysed the status of marine fisheries in Karnataka, and observed wide fluctuations in the catch of oil sardine and mackerel, and overexploitation in some of the commercially important resources.

The dynamic nature of the pelagic fishery suggests that stochastic models are appropriate for the study of dominance changes over time in these systems. Among this group of models, Markov models are commonly used to model systems, which at a given time can be only in one of a finite number of states. Markov chains are sequence of random variables in which the future variable is determined by the present variable, but is independent of the way in which the present state arose from its predecessors. In addition, there is a probability of transition from one state to another between successive observation times. The objective of Markov analysis is to calculate the probability that a system will be in a particular state at some future time and to determine the long-term behavior of the system.

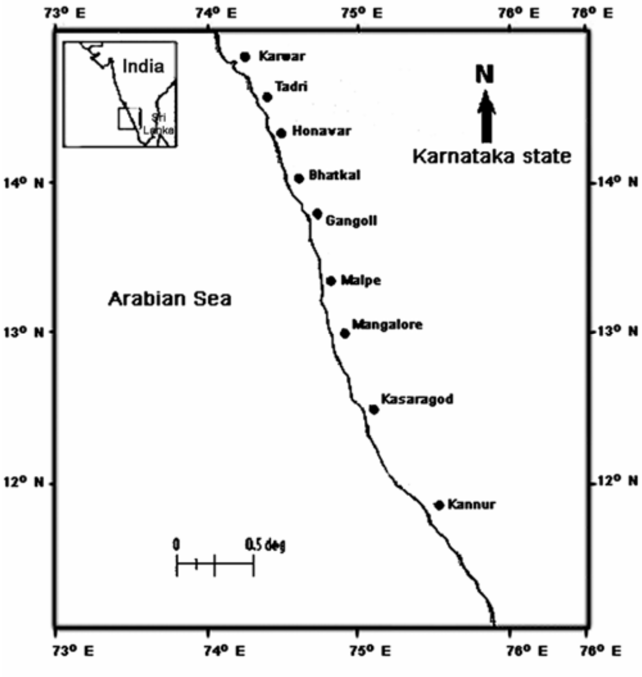

Fig. 1—Location map of Karnataka

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Perhaps the earliest application of Markov process for multispecies fishery is by Riffenburgh[2]. Later Swartzman & Getz[3] used a markov submodel for recruitment, while Rothschild & Mullen[4] considered the stock recruitment relationships in the context of a first order Markov process. Saila & Erzini[5] presented a review of the methods and models used in the fisheries context to study fish assemblage changes, with special reference to Markov process applications. Formacion & Saila[6] studied the dynamics of the dominance order of pelagic fish stocks in the purse seine fishery in Phillippines based on a simple Markov Chain Model. Srinath[7] modelled the changing pattern of the composition of pelagic fish assemblage in Kerala in the context of introduction of ring seine gear using Markov process. Routledge & Irvine[8] used a Markovian approach to demonstrate chance fluctuations and the survival of small salmon stocks and found that stocks with modest growth potential at low abundance can be driven quite rapidly to extinction. Vivekanadan *et al.*[9] employed Markov chain model to assess the changes in species composition of threadfin breams over 15 years. Karnataka with a coastline of 300 km and a shelf of 25,000 km$^2$ is historically known as the “mackerel coast”. Earlier to the eighties, the pelagic stocks were exploited mainly by employing traditional gears such as boatseine, shore seine and small gillnets. Motorisation of the indigenous fishing crafts and introduction of purse seines during eighties resulted in heavy exploitation of the pelagic fish stocks. Over the years the landings of pelagic fish resources exhibited wide fluctuations and also perceptible change in the resource dominance. These transitions in resource dominance and dynamics of the pelagic fishery resource assemblage along Karnataka coast (Fig. 1) is analysed using Markov Chain models.

## Materials and Methods

The most important information about a fishery is the total catch, by species, over time. Examining time series of catches allows for first-order assessment of the fisheries over time, and of the status of the species and populations upon which the fisheries depend[10,11] . In the present study the quarter-wise estimates of pelagic fish landings in Karnataka (Fig.1), for the period 1961-2003 made from the stratified multistage random sampling design (developed by the Central Marine Fisheries Research Institute) were used. The four dominant pelagic species/groups considered were oil sardine (A), Indian mackerel (B), carangids (C) and whitebaits (D). The carangids are extensively exploited by gears like trawl, gillnets, hooks and line, purse seine etc. and comprised mainly of horse mackerel (*Megalaspis cordyla*), Scads (*Decapterus* sp.) and Leather-Jackets (*Scomberoides* sp.). The whitebaits comprised of a group of small pelagic fishes belonging to the genus *Stolephorus* and *Encrasicholina* which are mainly exploited by purse seine and trawl. The Markov chain model was employed to assess the resource dominance pattern for the period 1961-2003.

### *The model*

Markov chain is a discrete-time stochastic process with the Markov property in which the previous states are irrelevant for predicting the subsequent states, given knowledge of the current state. The basis of the simple Markov model applied to fish dynamics is that at a particular period, the fishery can be classified into discrete number of states, and that the probability of change from one state to another over a particular time interval depends on the present state. The changes of state are called transitions. The controlling factor in a Markov chain is the transition probability; which is the probability for the system to go to a new state, given the current state of the system. Markov chains are useful and important stochastic processes and application of this is endless, and have well-developed theory[12].

Let $p_{ij}$ be the transition probability assuming that the fishery is at state ‘$j$’, given that the fishery was in state ‘$i$’ during the immediately preceding period. The state ‘$i$’ at time ‘$t$’ of a fishery denotes that group ‘$i$’ is the dominant group in the fishery and let there be ‘$s$’ states that dominate the fishery at one time or other during the various periods under study. The matrix of one-step transitions for all the states of the fishery is given as

$$P = \begin{bmatrix} p_{11} & p_{12} \cdots\cdots\cdots p_{1s} \\ p_{21} & p_{22} \cdots\cdots\cdots p_{2s} \\ . & \\ . & \\ p_{s1} & p_{s2} \cdots\cdots\cdots p_{ss} \end{bmatrix}$$

where $p_{ii}$ is the probability that the species remains dominant in the fishery in two consecutive periods and $p_{ij}$ denote the probability that the dominance changes from ‘$i$’ to ‘$j$’ in one period.

The maximum likelihood estimator of the transition probability, $p_{ij}$ , is given by

$$p_{ii} = \frac{n_{ij}}{n_i} \qquad \ldots(1)$$

where $n_{ij}$ is the number of observed direct transitions from state '*i*' to state '*j*' in one step and $n_i$ is the total number of observations in state '*i*'. The process of dynamic change in the fishery with respect to most abundant species in the fishery can be studied over long periods of change through higher order transition probabilities $p_{jk}^{(n)}$. These higher order transition probabilities may be obtained from the one step transition probability as

$$p_{jk}^{(n+1)} = \sum_{l} p_{jl}^{(n)} p_{lk}^{(1)} \qquad \ldots(2)$$

which gives the probability that the system is in state '*j*', given the system has reached state '*l*' in *n* steps and to state '*k*' in the next step.

The limiting probability gives the unconditional probabilities of the states of the fishery at every step.

$$\pi_k = \lim_{n \to \infty} p_{ij}^{n} \qquad \ldots(3)$$

These limiting probabilities are used to find out whether the fishery will ever reach a stable state or equilibrium if the conditions affecting the fishery remain the same over time. The transition probabilities and the limiting probabilities are found using the Macro tool in Microsoft Excel.

## Results and Discussion

Over the years the estimated marine fish landings in Karnataka showed a general increasing trend with small fluctuations during last 10 years (Fig. 2). The landings increased from 18,000 tonnes in 1961 to 184,000 tonnes during 2003. This increase was mainly due to the introduction of more efficient gears, increase in effort and extension of fishing area. The average landings of pelagic fish resources during the 1960's were around 55,000 tonnes, which formed about 80% of the total marine fish landings in Karnataka (Fig. 2). Even though during the 1980's the total fish landings were about 177,916 tonnes with a peak of 251,012 in 1989, the percentage contribution of pelagic fish landings dropped to 65%. During 1996-2003, the contribution from pelagic fish resources varied between 93,000 tonnes and 107,000 tonnes with an average of 100,000 tonnes.

The pelagic fisheries resources of Karnataka are largely of multispecies multisector fisheries; prominent among them are oil sardine, Indian mackerel, carangids and whitebaits. The average landings of oil sardine during the two decadal periods of 1961-1970 and 1971-1980 were more or less steady with 31,000 tonnes and increased to 39,000 tonnes during the 1981-1990 (Fig. 3A). During the sixties, oil sardine accounted for more than 50% of the pelagic fish landings in Karnataka. The average landings of oil sardine during the 90's has fallen down to 12,000 tonnes and drastically reduced in 1994 to around 1,600 tonnes. During 2001-2003, the landings of oil sardine show an upward trend with an average landing of about 43,000 tonnes, contributing 43% of the total pelagic fish landings in Karnataka (Fig. 3A).

The landings of Indian mackerel (Fig.3A) exhibited an increasing trend with an average of about 15,000 tonnes during 1961-70 and 31,000 tonnes in 1971-80

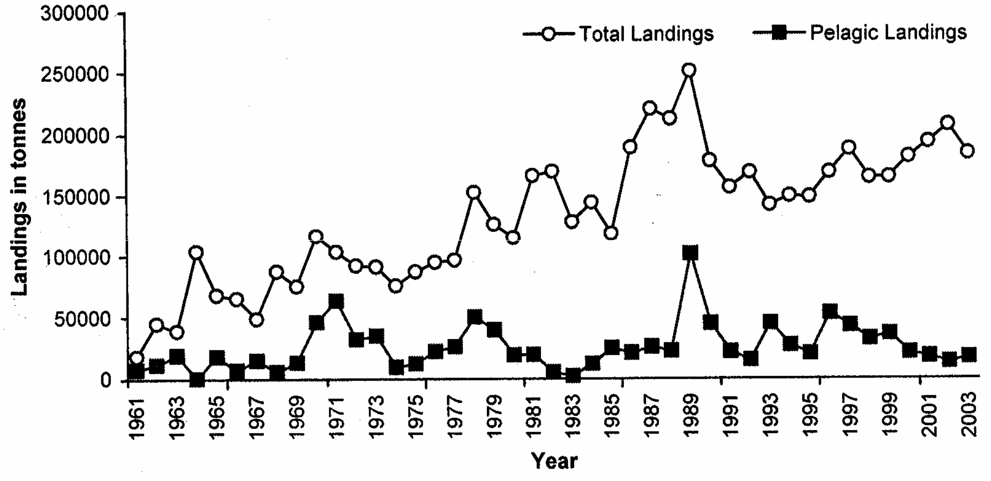

Fig. 2—Estimated landings of total and pelagic fishery resources in Karnataka during 1961-2003

and contributed 39% of the total pelagic fish landings during 1971-1980 and 21% in the consecutive decadal period. During 1991-2000, the landings of Indian mackerel fluctuated between 15,000 to 53,000 tonnes with an average of 32,000 tonnes and drastic reduction in landings was observed during 2001-2003 with an average landing of 16,000 tonnes. A conspicuous increase in the landings of carangids (Fig. 3B) was observed from 1984 onwards, the contribution of which was negligible prior to that. The carangid fishery during the decade 1991-2000 with an average annual estimate of about 18,000 tonnes, formed 20% of the pelagic fishery of Karnataka. Currently, the landings of carangids show a declining trend with average landings of 11,000 tonnes during 2001-2003, contributing only 11% to the total pelagic fish landings (Fig. 3B). Similar trends were also observed in case of whitebaits, whose landings increased tremendously from 1980-1995 recorded a maximum of 18,000 tonnes during 1988 with an average annual landings of 10,000 tonnes. The average annual landings of whitebaits reduced significantly to 3,700 tonnes during 2001-2003 (Fig. 3B).

Quarter wise landings of the pelagic fishery resources showed that the four resources oil sardine, Indian mackerel, carangids and whitebaits were dominant at one time or other (Table 1). Considerable differences are observed in the dominance pattern over the years. Transitions are then recognized as occurring when dominance at a time period (quarter) changes from one species to another. The transition probabilities of the dominant species were estimated using the maximum likelihood estimator given in Eq. (1) and are given in Table 2. The four step transition probabilities are computed using Eq. (2) and are given in Table 3. From Table 2, the probability that oil sardine is dominating the fishery in a quarter, given that the same was dominating in the fishery in the previous quarter period ($p_{00}$) is 0.6786. From the higher order transition probabilities (Table 3) it is clear that, if oil sardine is dominant in the fishery now, the probability that it continues to be the dominant group in the next year ($p_{00}^{(4)}$) is 0.4875. In

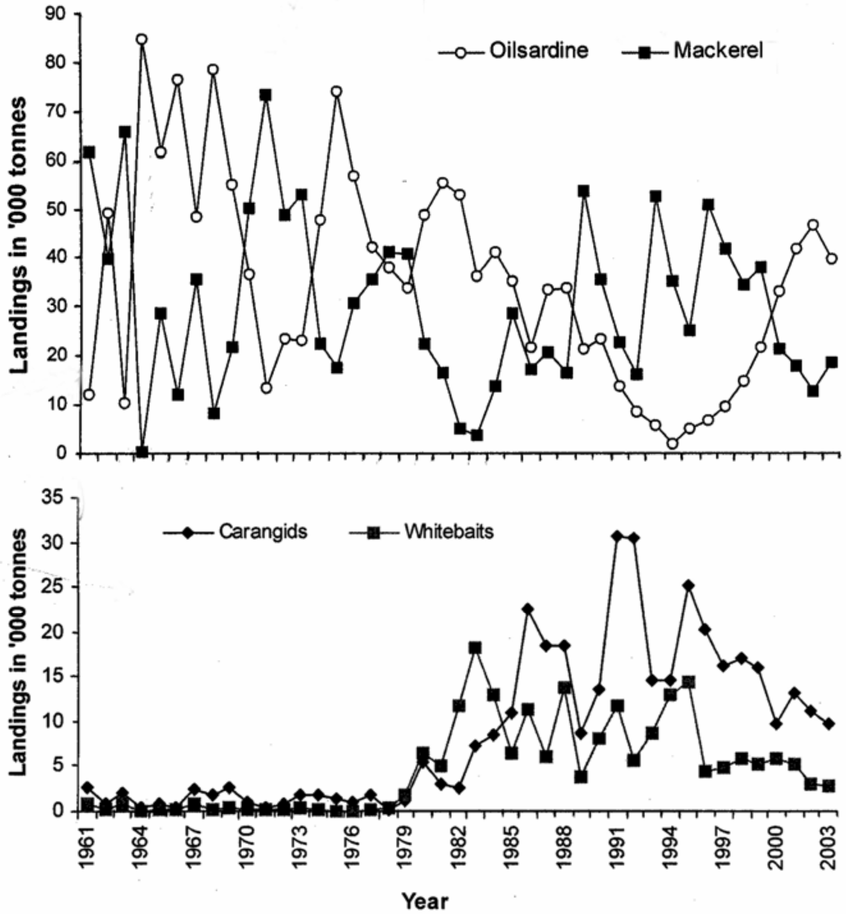

Fig. 3—Estimated landings of (A) Oilsardine and Mackerel, and (B) Carangids and Whitebaits in Karnataka

Table 1—Dominance of major species/species groups in the pelagic fishery resource landings of Karnataka during 1961-2003

| Quarter | I | II | III | IV | Quarter | I | II | III | IV |
|---|---|---|---|---|---|---|---|---|---|
| 1961 | C | A | A | B | 1983 | A | A | A | D |
| 1962 | A | A | A | B | 1984 | A | A | A | A |
| 1963 | B | B | B | B | 1985 | D | A | B | A |
| 1964 | A | C | A | A | 1986 | A | A | B | C |
| 1965 | B | A | B | A | 1987 | C | A | A | A |
| 1966 | A | A | A | A | 1988 | A | D | B | A |
| 1967 | A | A | D | B | 1989 | A | B | B | B |
| 1968 | A | C | A | A | 1990 | A | A | B | B |
| 1969 | A | A | A | A | 1991 | A | D | C | C |
| 1970 | A | A | B | B | 1992 | A | D | B | B |
| 1971 | B | B | B | B | 1993 | D | C | B | B |
| 1972 | B | B | B | A | 1994 | D | C | B | B |
| 1973 | A | B | B | B | 1995 | C | C | B | C |
| 1974 | A | B | B | A | 1996 | B | B | B | B |
| 1975 | A | A | B | A | 1997 | C | C | B | A |
| 1976 | A | B | B | B | 1998 | C | C | B | A |
| 1977 | A | B | B | A | 1999 | B | C | B | A |
| 1978 | A | A | B | B | 2000 | B | A | B | A |
| 1979 | B | B | B | B | 2001 | A | A | A | A |
| 1980 | A | A | A | A | 2002 | A | A | A | A |
| 1981 | A | A | B | A | 2003 | A | A | A | A |
| 1982 | A | A | A | A | | | | | |

| | | | |
|---|---|---|---|
| Quarter I - | January-March | A - | Oil sardine |
| Quarter II - | April-June | B - | Indian mackerel |
| Quarter III - | July-September | C - | Carangids |
| Quarter IV - | October-December | D - | Whitebaits |

case of Indian mackerel, $p_{22}$, which gives the probability of dominance in two successive quarters is 0.5606, and if Indian mackerel is dominant in the fishery now, the probability that it will dominate in the next year is only 0.3834.

The higher step transition probabilities can be generated to predict the fishery at various time periods. The limiting probabilities of the various states are estimated using Eq. (3) and are given in Table 4. Though there is an increased probability (0.6786) for oil sardine dominating in the fishery, the limiting probability of oil sardine dominating in the pelagic fishery of Karnataka is 0.4773 and for Indian mackerel it is only 0.375. From the limiting probabilities, we can see that the probability of carangids and whitebaits dominating the pelagic fishery were only 0.05 and 0.01 respectively. The analysis indicates that in the long run the pelagic fish assemblage of Karnataka coast is more likely to be dominated by oil sardine rather than Indian mackerel.

The Markov chain model is a probabilistic model to produce estimates of unobservable, yet meaningful

Table 2—Transition probability matrix

| | Oil sardine | Indian mackerel | Carangids | Whitebaits |
|---|---|---|---|---|
| Oil sardine | 0.6786 | 0.22619 | 0.0238 | 0.0714 |
| Indian mackerel | 0.2879 | 0.5606 | 0.1212 | 0.0303 |
| Carangids | 0.3333 | 0.3889 | 0.2778 | 0 |
| Whitebaits | 0.250 | 0.375 | 0.375 | 0 |

Table 3—Four step transition probabilities

| | Oil Sardine | Indian mackerel | Carangids | Whitebaits |
|---|---|---|---|---|
| Oil sardine | 0.4875 | 0.3667 | 0.0991 | 0.0467 |
| Indian mackerel | 0.4671 | 0.3834 | 0.1053 | 0.0442 |
| Carangids | 0.4712 | 0.3798 | 0.1043 | 0.0447 |
| Whitebaits | 0.4677 | 0.3825 | 0.1056 | 0.0442 |

Table 4—Limiting probabilities of major species

| Oil sardine | Indian mackerel | Carangids | Whitebaits |
|---|---|---|---|
| 0.4773 | 0.3750 | 0.1023 | 0.0455 |

parameters. Formacion & Saila[6] used Markov Chain model to evaluate the changes in the dominance order of pelagic fish assemblages exploited by purse seine in the Philippines, in which the dominance order was classified using six assemblage groups at various sampling intervals. Limiting probabilities for the various groups suggested ultimate replacement of the larger pelagic species with the family Clupeidae. Only very few attempts have been made to study the resource status using markov chain models in Indian waters. Srinath[7] investigated the change in the dominance of the major pelagic fish assemblage along the Kerala coast in the context of introduction of ring seine and found that in the pre-ring seine phase oil sardine has the maximum likelihood of dominating the pelagic fish assemblage. However, in the post ring-seine phase its likelihood of being the most dominant group has considerably decreased. With the introduction of mass harvesting gears like purseines and ringseines along with the motorization of the traditional fishing crafts, resulted in significant increase in the landings of pelagic fish resources along the Karnataka coast. The results of the present study indicated that oil sardine has the maximum probability of dominating along this coast, considering landings from all major gears.

Markov models make good descriptors of what has happened over the period of data collection, but they will not be good predictors of what might happen in the future if the conditions change. The method described here is useful at estimating the transition probability matrix that yields information about the dominance pattern, which would be difficult to observe directly. The transition probabilities give fishery managers and biologists an index of how long a species/species group will dominate in the fishery. But these are merely records of what change has happened with no reference to any mechanisms of change or reasons why the change has occurred. This model provides an initial framework for describing and analysing what has happened in the fishery and for comparing changes that are taking place in two different time periods.

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## References

1 Mohamed,K.S., Muthiah,C., Zacharia, P.U., Sukumaran, K.K, Rohit, P. & Krishnakumar, P.K, Marine fisheries of Karnataka state, India, *Naga*, 21 (1998) 10-15.

2 Riffenburgh,R.H, A stochastic model of interpopulation dynamics in marine ecology, *J. Fish. Res. Board Can.*, 26(1969) 2843-2880.

3 Swartzman, G. & Getz, W.M, A probability transition matrix model for yield estimation in fisheries with highly variable recruitment, *Can. J. Fish. Aquat. Sci.,* 38 (1981) 847-855.

4 Rothschild, B,J. & Mullen, A.J. The information-content of stock-and-recruitment data and its nonparametric classification, *J. Cons.Int. Explor.Mer,* 42 (1985) 116-124.

5 Saila, S.B. & Erzini, K, Empirical approach to multispecies stock assessment, *Trans. Am. Fish. Soc.,* 116 (1987) 601-611.

6 Formacion, S.P. & Saila S.B., Markov chain properties related to temporal dominance changes in Philippine pelagic fishery, *Fish. Res*., 19(1994) 257-268.

7 Srinath, M, Markov chain application to the dynamics of the pelagic fishery along the Kerala coast, India, *Indian J. Fish.*, 43 (1996) 115-120.

8 Routledge, R.D. & Irvine, J.R, Chance fluctuations and the survival of small salmon stocks, *Can. J. Fish. Aquat. Sci.*, 56 (1999) 1512-1519.

9 Vivekanandan, E., Venugopalan, R. & Ramadoss, P, Assessment of changes in the threadfin bream species composition, *Indian. J. Fish*. 49 (2002) 241-245.

10 Caddy, J. & Gulland, J.A, Historical patterns of fish stocks, *Mar. Policy*, 7(1983) 267-278.

11 Grainger, R.J.R. & Garcia, S.M, Chronicles of marine fishery landings (1950-1994): Trend analysis and fisheries potential, *FAO Fish.Tech.pap.,* 359 (1996) 51 pp.

12 Morgan, B.J.T, *Applied stochastic modelling,* (Hodder & Stoughton, London) 2000, pp 297.