Indian J. Fish., 45(1) : 13-20, Jan.-Mar., 1998

Spectral decomposition of the all India landings of oil sardine, mackerel and Bombay duck

T.V. SATHIANANDAN AND K. ALAGARAJA

Central Marine Fisheries Research Institute, Cochin – 682 014, India

ABSTRACT

All India annual landings of oil sardine, mackerel and Bombay duck from 1950 to 1992 were studied using spectral analysis to bring out the inherent periodicity if any in these time series. The models fitted explained 88.3 % of variations in oil sardine landings, 83.2 % in mackerel and 81.7 % in Bombay duck. The major cyclic components identified are, 21 and 11 year cycles in both oil sardine and mackerel landings, and 21, 11 and 7 year cycles in Bombay duck landings. Projections of landings using the estimated spectral models showed the years of peak landings as 2010-'11 for oil sardine, 2014 for mackerel and 1999 for Bombay duck.

Introduction

Oil sardine, mackerel and Bombay duck are three economically important marine fish species available along the west coast of India. They contribute on an average, about 29 per cent of the all India total landings. Fluctuations in their landings affect the processing industry and hence a critical study on their landings over time is important for planning. Antony Raja (1973) studied oil sardine fishery by relating it to rain fall, atrosia and availability of early juveniles in July-September. Balan (1984) tried to explain the oil sardine fishery as a manifestation of 0-year and 1-year classes. Noble (1980) studiedm the all India mackerel landings of three decades and tried to forecast mackerel landings by observing the ups and downs in the landings and suspected a 10 year cycle in the mackerel fishery. Noble and Sathianandan (1991) used ARIMA models to study the trend in all India mackerel catches. In the present study the all India annual landings of oil sardine, mackerel and Bombay duck are critically examined to study their behaviour and to bring out the inherent periodicity, if any, in the landings through spectral decomposition.

Annual landings of oil sardine, mackerel and Bombay duck during the period 1950–1992 are used in the study. During this period oil sardine landings fluctuated between 7,412 t in 1956 and 3,01,446 t in 1968 and the coefficient of variation during this period is 52 %. Landings were poor (below 80,000 t) during 1950-'56 period and in the years 1959, 1963 and 1986. Years of peak landings were 1957 (1,91,469 t), 1960 (1,89,016 t) 1964 - '68 (about 2.5 lakh t), 1970 (2,26,997 t), 1981 (2,21,024 t) and

1989 (2,78,869 t). During the period 1972 - '80 catch remained almost steady around 1.5 lakh t with little fluctuations.

Landings of mackerel during 1950 - '92 period fluctuated between 16,431 t in 1956 and 2,91,400 t in 1989. Coefficient of variation of mackerel landings was 69 % for the period of study. Poor landings (below 50,000 t) were observed in the period 1954-'56, 1961-'68, 1974-'75 and 1981-'84. Peak landings were observed in the years 1958 (1,23,282 t), 1960 (1,33,655 t), 1971 (2,04,575 t) and 1989 (2,91,400 t).

Bombay duck landings during 1950 - '92 fluctuated between 7,262 t in 1951 and 1,37,790 t in 1981 with a coefficient of variation of 37 %. Landings were poor (below 60,000 t) during 1950-'54 and in 1959 and 1972. During the period 1962-'71 landings of Bombay duck was almost steady near 80,000 t. Peak landings were observed in the years 1956 (1,27,713 t), 1960 (1,08,564 t), 1975 (99,614 t), 1978 (1,25,481 t), 1979 (1, 26,044 t), 1981 (1,37,790 t), 1984 (1,17,742) and 1991 (1,36,442).

Materials and methods

The all India annual landings of oil sardine, mackerel and Bombay duck from 1950 to 1992 estimated by the Fishery Resources Assessment Division of the Central Marine Fisheries Research Institute, Cochin, through a stratified multistage random sampling procedure, were used to study the periodicity through spectral analysis.

Spectral representation of a time series X(t) can be made by the super position of sine and cosine wave forms (Kendall and Stuart, 1968; Staffer, 1991) as :

$$X(t) = \mu + \sum_{j=i}^{q} [a_j \text{Cos}(2\ \lambda jt) + b_j \text{Sin}(2\ \lambda jt)] \ldots 1$$

where λj are different frequencies measured in cycles per year and X(t), t = 0,1,...., N - 1 represents a time series of size N. The unknown parameters in the above model are μ, q, a_j', s, b_j',s and λj's which are to be estimated. The order q and the frequencies of harmonic components are selected by computing the sine transforms $S(\lambda j)$ and the cosine transforms $C\ (\lambda j)$ for different values of (λj) where:

$$S(\lambda j) = N^{-1/2} \sum_{t=0}^{N-1} X(t)\ \text{Sin}(2\ \lambda jt) \ldots\ldots(2)$$

and

$$C(\lambda j) = N^{-1/2} \sum_{j=0}^{N-1} X(t)\ \text{Cos}(2\ \lambda jt) \ldots\ldots(3)$$

and then the periodogram

$$I(\lambda j) = C^2(\lambda j) + S^2(\lambda j) \qquad \ldots\ldots\ldots (4)$$

Plot of the periodogram against different frequencies will be large for those frequencies if the time series X(t) contains harmonic components near it. Hence in order to select frequencies, which forms part of the spectral decomposition, periodograms are computed for different values of λj's = j/N, for λj that is j cycles in N time points, for j = 1,2,...., N/2, and frequencies which yield maximum values for the periodograms are to be selected and incorporated in the model (1).

After estimating the order q and the frequencies λj's the constant μ, and the coefficients a_j's and b_j's for j = 1,....,q are then estimated by linear least square method by computing the components sin(2 λjt) and cos (2 λjt) for t = 0,1,...., N-1 and j = 1,...., q. The total variation in the time series X(t) is then decomposed into q components each corresponding to sinusoidal wave forms at various frequencies of oscillation.

Results

All India annual landings of oil sardine, mackerel and Bombay duck were converted into units of 1,000 t and used in the analysis.

For oil sardine landings the values of $I(\lambda_j)$ (periodograms) computed for 21 different values of λ_j are given in Table 1 in decreasing order. From the periodogram plot (Fig. 1) it can be seen that maximum values of $I(\lambda j)$ are for the frequencies (λj's) 0.02, 0.04, 0.09, 0.16, 0.27, 0.12, 0.14 and 0.30. Hence these frequencies were selected and the eight harmonic components corresponding to these frequencies were incorporated in the model with $q = 8$. The least square estimates of the sixteen coefficients and the percentage of variation explained by each ha-rmonic component are given in Table 2.

These eight harmonic components were found to explain 88.3 % of the total variation in the all India annual oil sardine landings. The estimate of the constant term μ is 149.322. With the estimated spectrum its decomposition is shown in Fig. 2 and the predicted series ploted along with actual catch in Fig. 3. Harmonic components with frequencies 0.02 (1 cycle in 42 years), 0.05 (2 cycles in 42 years) and 0.09 (4 cycles in 42 years) account for 24.5 %, 24.0 % and 12.7 % respectively of the total variation in oil sardine landings. Other components do not contribute much towards the variations in landings.

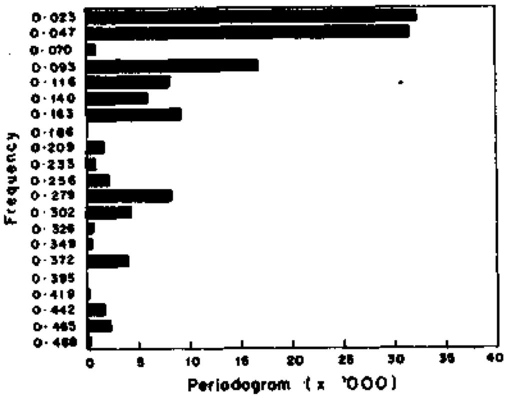

Fig. 1. Periodogram plot for different frequencies (cycles/year) of all India oil sardine landings during 1950-'92.

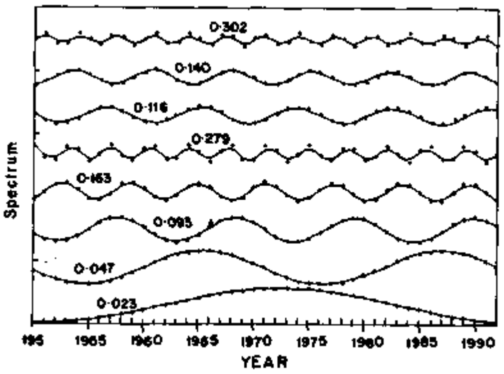

Fig. 2. Decomposition of the spectrum into harmonic components of different frequencies (cycles/year) for oil sardine landings.

TABLE 1. *Periodogrames computed for different frequencies for all India oil sardine landings*

J	λ_j	$I(\lambda_j)$	j	λ_j	$I(\lambda_j)$
1	0.02326	32287	12	0.44186	1727
2	0.04651	31552	13	0.20930	1669
3	0.09302	16709	14	0.06977	960
4	0.16279	9177	15	0.23256	860
5	0.27907	8146	16	0.32558	620
6	0.11628	8053	17	0.34884	526
7	0.13953	5930	18	0.48837	253
8	0.30233	4334	19	0.41860	210
9	0.37209	3992	20	0.18605	136
10	0.46512	2292	21	0.39535	31
11	0.25581	2116	–	–	–

Periodograms computed with the all India mackerel landings for different frequencies are given in Table 3 in decreasing order of magnitude. Higher

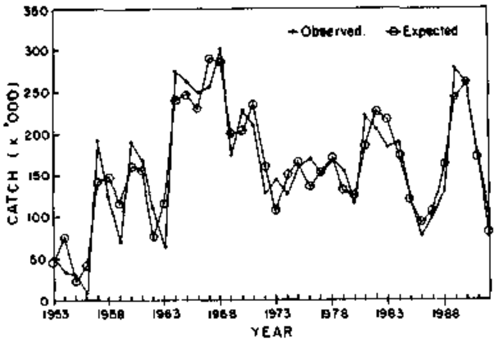

Fig. 3. Plot of observed and expected landings (in units of 1,000 t) of oil sardine in India during 1953-'92.

TABLE 2. *Least square estimates of coefficients of harmonic components included in the spectral model of all India oil sardine landings and percentage of variation explained by each component*

j	λ_j	a_j	b_j	% Var.
1	0.02	-53.91491	-9.83139	24.5
2	0.05	-10.98876	-53.04980	24.0
3	0.09	-10.14574	-38.09678	12.7
4	0.16	-26.61336	12.05680	7.0
5	0.28	26.38469	-7.84748	6.2
6	0.12	3.70434	-27.11768	6.1
7	0.14	-23.44358	-1.43330	4.5
8	0.30	-1.79533	19.99864	3.3

TABLE. 3. *Periodogrames computed for different frequencies for all India mackerel landings.*

J	λ_j	$I(\lambda_j)$	J	λ_j	$I(\lambda_j)$
1	0.04651	11763	12	0.30233	876
2	0.09302	10502	13	0.23256	875
3	0.06977	10299	14	0.25581	767
4	0.16279	8335	15	0.41860	714
5	0.02326	3807	16	0.13953	623
6	0.11628	3109	17	0.39535	416
7	0.34884	2238	18	0.48837	335
8	0.37209	2145	19	0.18605	243
9	0.44186	1899	20	0.32558	170
10	0.27907	1866	21	0.46512	70
11	0.20930	1653	-	-	-

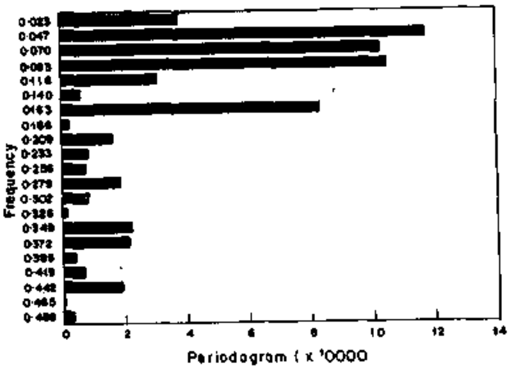

Fig. 4. Periodogram plot for different frequencies (cycles/year) of all India mackerel landings during 1950-'92.

values of I (λj) as seen from Fig. 4 are for frequencies 0.05, 0.09, 0.07, 0.16, 0.02, 0.12, 0.35 and 0.37 in decreasing order and these frequencies when selected and incorporated in the model explained 83.2 % of the total variation in mackerel landings. Hence the estimate of q is eight and the above frequencies are the estimates of corresponding λj's.

Least square estimates of the eight pairs of cosine and sine coefficients are tabulated in Table 4 along with the

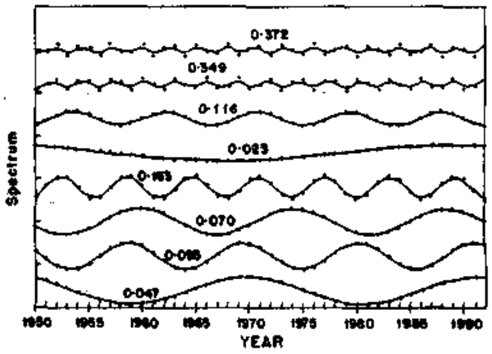

Fig. 5. Decomposition of the spectrum into harmonic components of different frequencies (cycles/year) for mackerel landings.

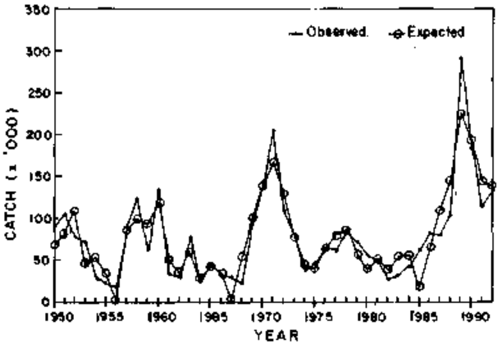

Fig. 6. Plot of observed and expected landings (in units of 1,000 t) of mackerel in India during 1950-'92.

TABLE 4. *Least square estimates of coefficients of harmonic components included in the spectral model of all India mackerel landings and percentage of variation explained by each component*

J	λ_j	a_j	b_j	% Var.
1	0.05	29.16329	-15.61277	18.8
2	0.09	11.49141	-29.06680	16.7
3	0.07	-11.66679	-28.66973	16.4
4	0.16	-21.50087	17.69350	13.3
5	0.02	16.02234	-9.87046	6.1
6	0.12	-14.31236	8.35353	5.0
7	0.35	-12.19922	-7.70492	3.6
8	0.37	-6.80308	-12.38066	3.4

TABLE 5. *Periodogrames computed for different frequencies for all India Bombay duck landings.*

J	λ_j	$I(\lambda_j)$	J	l_j	$I(\lambda_j)$
1	0.09302	3826	12	0.23256	480
2	0.13953	3794	13	0.25581	444
3	0.04651	3505	14	0.46512	395
4	0.11628	1931	15	0.18605	242
5	0.02326	1801	16	0.39535	151
6	0.16279	1143	17	0.30233	150
7	0.27907	965	18	0.48837	113
8	0.20930	704	19	0.44186	90
9	0.37209	665	20	0.32558	37
10	0.06977	649	21	0.41860	16
11	0.34884	513	-	-	-

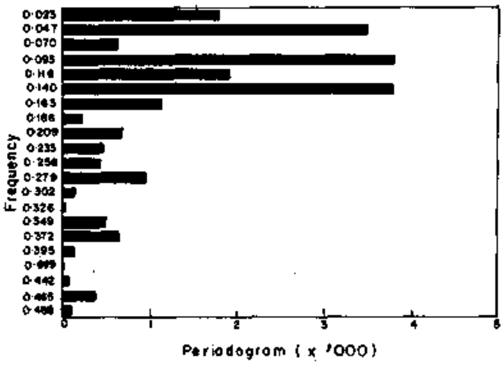

Fig. 7. Periodogram plot for different frequencies (cycles/year) of all India Bombay, duck landings during 1950-'92.

percentage of variation explained by each harmonic component. The estimate of the constant term in the model is 78.072. With the estimated model the decomposition of the spectrum is shown in Fig. 5 and predicted and actual landings are plotted in Fig. 6. From Table 4 it can be seen that the first four harmonic components explain 65.2 % of the total variability in mackerel landings. The component with frequency 0.05 (2 cycles in 42 years) contributes to 18.8 % of the variability and those with

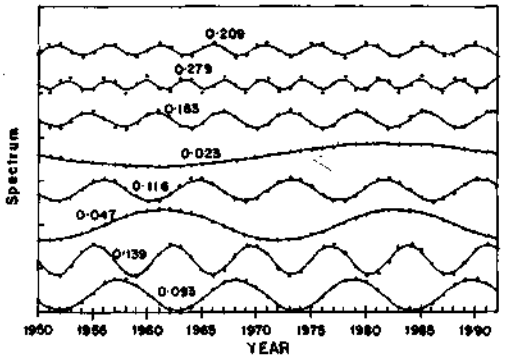

Fig. 8. Decomposition of the spectrum into harmonic components of different frequencies (cycles/year) for Bombay duck landings.

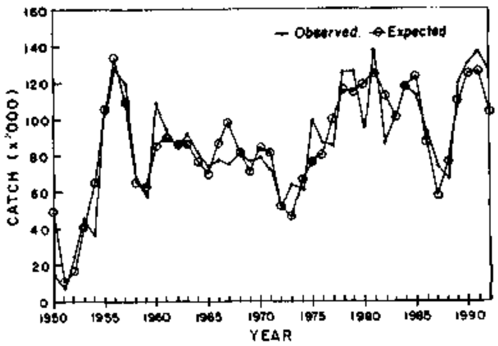

Fig. 9. Plot of observed and expected landings (in units of 1,000 t) of Bombay duck in India during 1953-'92.

frequencies 0.09 (4 cycles in 42 years), 0.07 (3 cycles in 43 years) and 0.16 (7 cycles in 42 years) contribute 16.7, 16.4 and 13.3 % respectively towards the variations in mackerel landings.

TABLE 6. *Least square estimates of coefficients of harmonic components included in the spectral model of all India Bombay duck landings and percentage of variation explained by each component*

j	I_j	a_j	b_j	% Var.
1	0.09	-7.06242	-17.49339	17.7
2	0.14	-2.56853	-18.60971	17.6
3	0.05	-17.80687	-2.99156	16.2
4	0.12	-4.23267	-12.71530	8.9
5	0.02	-0.62515	-12.92867	8.3
6	0.16	0.08312	-10.31165	5.3
7	0.28	0.02433	-9.47309	4.5
8	0.21	-4.15297	6.94467	3.3

Periodograms computed for the all India Bombay duck landings are given in Table 5 in descending order and the periodogram plot is shown in Fig. 7. The first eight high values of $I(\lambda_j)$ are for the frequencies 0.09, 0.14, 0.05, 0.12, 0.02, 0.16, 0.28 and 0.21. The eight harmonic components corresponding to these frequencies explained 81.7 % of the variations in Bombay duck landings. Least square estimates of the coefficients with the estimate of q as eight and the above computations of λ_j 's are given in Table 6 along with the percentage of variation explained by each calculated harmonic component. Estimate of the constant term is 85.961. Decomposition of the spectrum with the computed harmonic components is given in Fig. 8 and the catch predicted with the estimated model is ploted in Fig. 9 along with the actual catch. Among the computed harmonic components, 17.7 % of the variation in landings was due to that with frequency 0.09 (4 cycles in 42 years), 17.6 % with frequency 0.14 (6 cycles in 42 years) and 16.2 % with frequency 0.05 (2 cycles in 42 years). These three componets accounted for 51.5 % of the variations in Bombay duck landings.

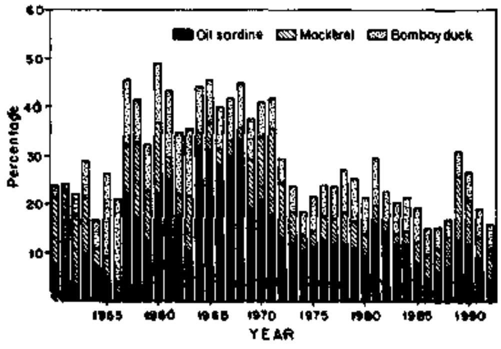

Fig. 10. Percentage contribution of oil sardine, mackerel and Bombay duck towards all India total marine fish landings.

Discussion

The contribution of oil sardine, mackerel and Bombay duck towards the total marine fish production in the country ranged between 49 and 34 % with an average of 29 % during 1950-'92. Oil sardine contributed between 1% (in 1956) and 33% (in 1968), mackerel between 2% (in 1982) and 20 % (in 1951) and Bombay duck between 1% (in 1951) and 18 % (in 1956) in the total landings. From the plot of percentage contributions of these species (Fig. 10), it can be seen that during the period 1957-'71 the per cent share reached the maximum ranging between 30 and 50 % of the total landings. Thereafter it reduced and in the last two decades it varied between 15 and 30 %. More than 80 % of the landings of oil sardine and mackerel are from the southwest coast region comprising Kerala, Karnataka and Goa. In the case of Bombay duck, more than 90 % of the catches are from the states of Maharashtra and Gujarat.

From the spectral decomposition of oil sardine landings, (Fig. 2) it can be seen that the component contributing maximum towards the variance has frequency 0.02 which corresponds to a 42 year cycle. But a time series of 43 data points is not adequate to bring out such a big cycle and we cannot ascertain whether this cycle actually is of a period 42 or more. The component with frequency 0.046 which corresponds to a cycle of 21 years, also contributes equally towards the variance and can be considered as the important cyclic behaviour of oil sardine landings. The next important component corresponds to a 11 year cycle and its contribution towards the variance is just half that of the 21 year cycle. Since the harmonic components in the model are orthogonal their effects will be independent. The effect of the identified harmonic components at any point of time is estimated as a modulation of the components which are the sum of their independent effects. Using the model computed with eight harmonic components, the expected landings were calculated and then projected for future years upto 2020. From the projections it is found that the next highest landings can be expected in the years 2010 - '11 and is comparable with those of the years 1967-'68 and 1989-'90.

In the case of mackerel, the components contributing the maximum towards the variance in their order of importance are those with frequencies 0.047, 0.093, 0.070 and 0.163. They correspond to cyclic components of 21, 11, 14 and 6 years respectively and these four components explain 65 % of the variations in mackerel landings. The projections of landings upto the year 2020 using the model estimated with eight harmonic components showed that the year of next peak landings is in the year 2014 and is comparable with the landings of 1971. It is noticed that both in the case of oil sardine and mackerel the first two important cyclic components are those with 21 years and 11 years in the same order of importance eventhough there is difference in their levels of contribution towards the variation in landings.

The harmonic components which contribute the maximum towards the variation in Bombay duck landings in the order of importance are those with cycles 11, 7 and 21 years. These three components with almost equal weightage explained 52 % of the variation and the contribution by other components are small. Projections of landings using the estimated model revealed that the next peak landings of Bombay duck can be expected in year 1999.

Quantitative prediction of all India landings of these species attempted with the estimated spectral models was found to go beyond the acceptable range in a few years in the case of oil sardine. Hence, spectral models are found not suitable as a forecasting model for these species. But it is observed as an efficient tool for understanding the behaviour of the series and then to predict years of peak landings.

Acknowledgment

The authors are grateful to Dr. P.S.B.R. James, the Director, Central Marine Fisheries Research Institute, for encouragement in the preparation of this paper.

References

Antony Raja, B.T. 1973. Forecasting the oil sardine fishery *Indian J. Fish.*, **20** (2): 599-609.

Balan, V. 1984. The Indian oil sardine fishery : A review. *Mar. Fish. Infor. Serv., T & E Ser.*, No. 60, p. 1-10.

Kendall, M.G. and A. Stuart 1968. *The Advanced Theory of Statistics. Vol. 3. Design and Analaysis, and Time Series.* Charles Griffin & Co. Ltd., London, 557 pp.

Noble, A. 1980. Is there a ten year cycle in the maekerel fishery ? *Seafood Export Journal,* **12**(4) : 9-13.

Noble, A. and T.V. Sathianandan 1991. Trend analysis in all India mackerel catches using ARIMA models. *Indian J. Fish.*, **38**(2) : 119-122.

Stoffer, D.S. 1991. Walsh-Fourier analysis and its statistical applications. *J. Am. Stat. Ass.*, **86**(414) : 461-479.