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Time series analysis of the Northwest Atlantic mackerel catches

by

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Abstract

Time series analysis and spectral analysis techniques were applied to a long time series of mackerel catch data to evaluate choices of random variables, time lags, and periodic events relevant to modeling.

Introduction

The fishery for mackerel in the Northwest Atlantic was essentially a domestic fishery (USA and Canada) from the early colonial days to the 1960s. In the mid-60s an international fishery developed and catches increased to unprecedented levels. A composite of catch data has been assembled for 1804 to 1975 and methods of time series analysis were applied to study the major features.

A detailed discussion of the history of the fishery has been given by Anderson (1976). The data for the period 1804-1965 is described in Hoy and Clark (1967). The remainder was abstracted from ICNAF Statistical Bulletins (1963-76). The modeling was done on a SIGMA 7 using a package of time series subroutines written by International Mathematical and Statistical Libraries, Inc. (IMSL), Houston, Texas.

Methods

It is reasonable to assume that catch data constitutes a time series, i.e. that it is the resultant of a combination of deterministic and random events occurring in time on a partly deterministic, partly random schedule. It is not a straightforward matter to state the model in terms of the individual factors such as changes in stock density or in fishing effort, or to express those factors as random variables. Time series modeling bypasses many of these problems as the steps can be followed rather mechanically. The results provide insight nonetheless. The techniques used here are based on theory and procedures in Jenkins and Watts (1968), and in Kendall and Stuart (1966). The author presents two parametric models fitting the data from 1804 to 1965. In addition a spectral analysis was done to determine the periods of systematically recurring effects.

Results

The two models are:

(1) $Ct = .2566C_{t-1} + .3621C_{t-2} + .1898C_{t-3} + .07642C_{t-4} - .07721C_{t-5} + .1969C_{t-6} - .2547C_{t-7} + 7610. + A_t + .4583A_{t-1}$

(2) $\text{Ln } Ct = .9236 \text{ Ln } Ct\text{-}1 + .7583 + At - .3829A_{t-1} - .03132A_{t-2} - .08973A_{t-3}$

Ct is catch in year t and A_t is a white noise random variable.

Results are plotted in Figures 2 and 3. A comparison of the autocorrelation functions (2a) and spectra (2b) for C_t showed that the first differences should be used in the derivations, and that seven autoregressive terms should be used. The number of moving average terms was selected by examining estimates of the residual variance for various choices and selecting the parameters corresponding to a relative minimum. The coefficients were then obtained from other IMSL subroutines.

Similar procedures yielded model (2) and Figure 3. The motivation for developing a logarithmic model was not solely to reduce the fluctuations by reducing the scale, but to verify the expectation that ratios of catch in successive years (rather than differences) should prove to be a suitable random variable.

The spectra for both C and ln C display similar properties. The peaks in the curve identify periodic effects of the corresponding frequency, representing major components of variance. Translated into period (the reciprocal of frequency) one can say that time lags of 2 or 3, 5, 8, and 50 years could be important. Since the interval between data points is one year, frequencies higher than 0.5 cannot be detected (but are not relevant here). Low frequencies could be determined more precisely with a longer data series.

Figures 2b and 3b reveal similar periods. Some of these can be traced in the original data (Figure 1), but others are obscured by superposition or by variations in amplitude.

Figures 2a and 3a show that catch in any one year is strongly correlated with catch in preceding years, that the dependence decreases linearly with time lag, and is measurable up to 8 or 10 years although the major contribution is from time lags of 2 or 3 years.

Discussion

Using the model parameters and computer subroutines, one can simulate future values of the catch given that conditions remain basically unchanged. "Conditions" include the underlying probability distributions of the random events implicit in the model, for example, migration patterns, as well as controllable factors such as seasonal distribution of fishing effort. "Unchanged" means changes are admissible if they are similar to changes occurring between 1804 and 1965. These simulations were omitted. Time series theory dictates that the forecast values should follow the previously established pattern and it is obvious from Figure 1 that the recent catches fall outside of standard confidence intervals. It has also been established that the probability associated with these catches is non-zero. Explanations of the reasons for the anomalous catches and arguments as to whether such catch levels are sustainable are not within the scope of time series analysis.

The time series approach is also useful for future modeling or management studies since it indicates particular time lags that should be investigated, and also the correlations between catch in one year and conditions in previous years. Detailed modeling can then follow when appropriate data becomes available.

Literature cited

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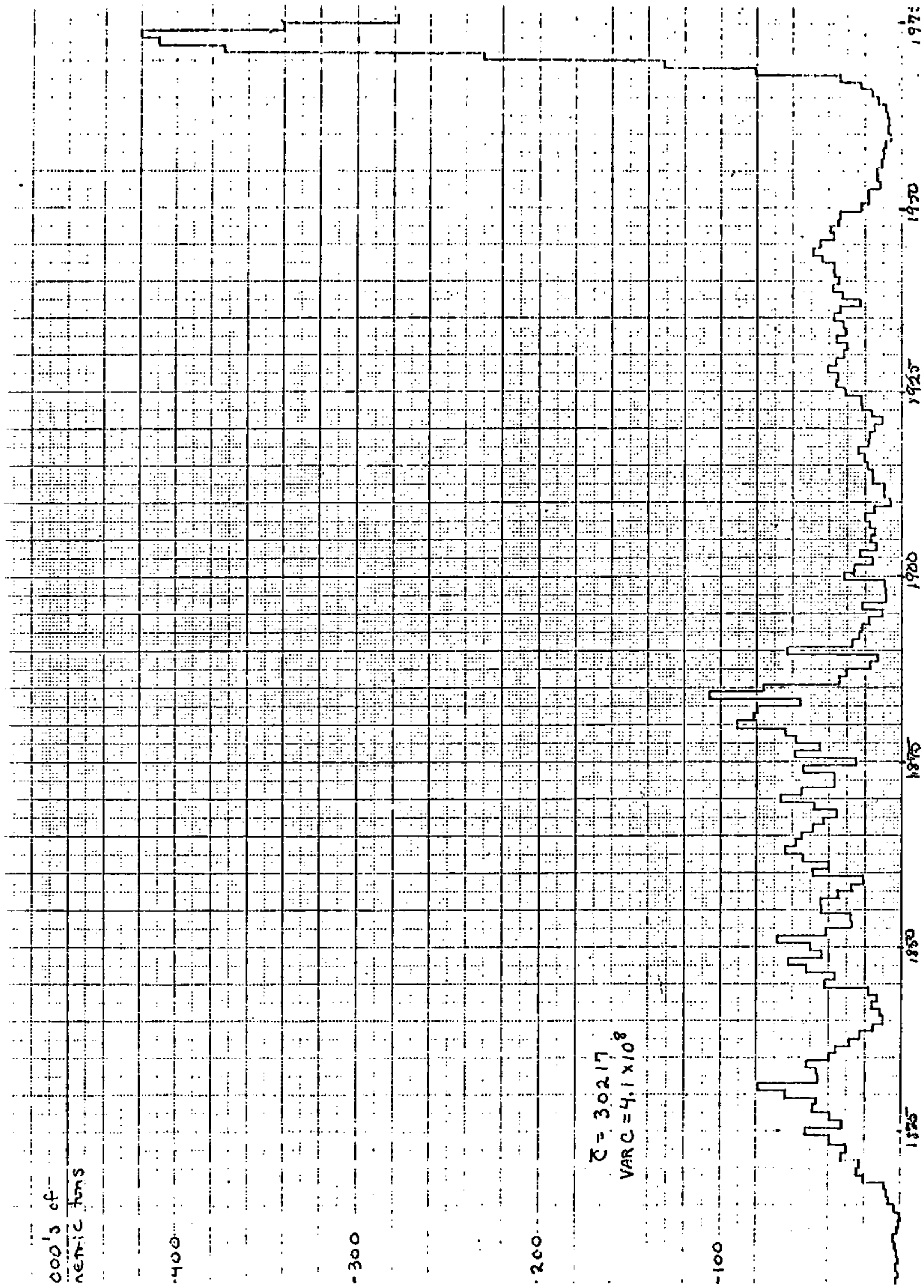

Figure 1. Mackerel catch in the Northwest Atlantic.

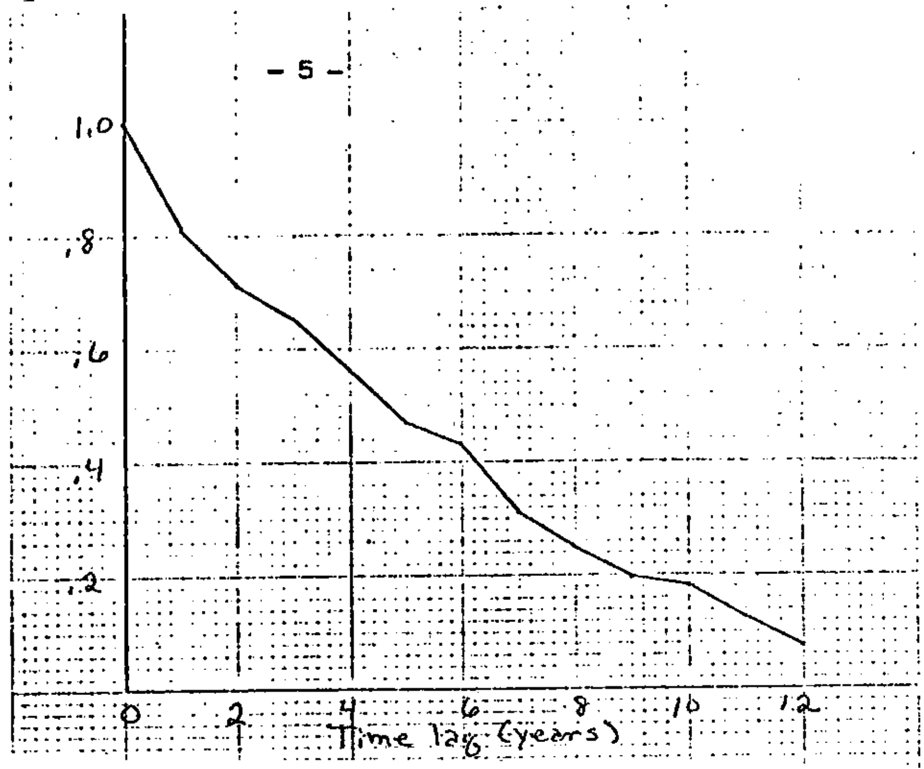

Figure 2a. Autocorrelation function for catch.

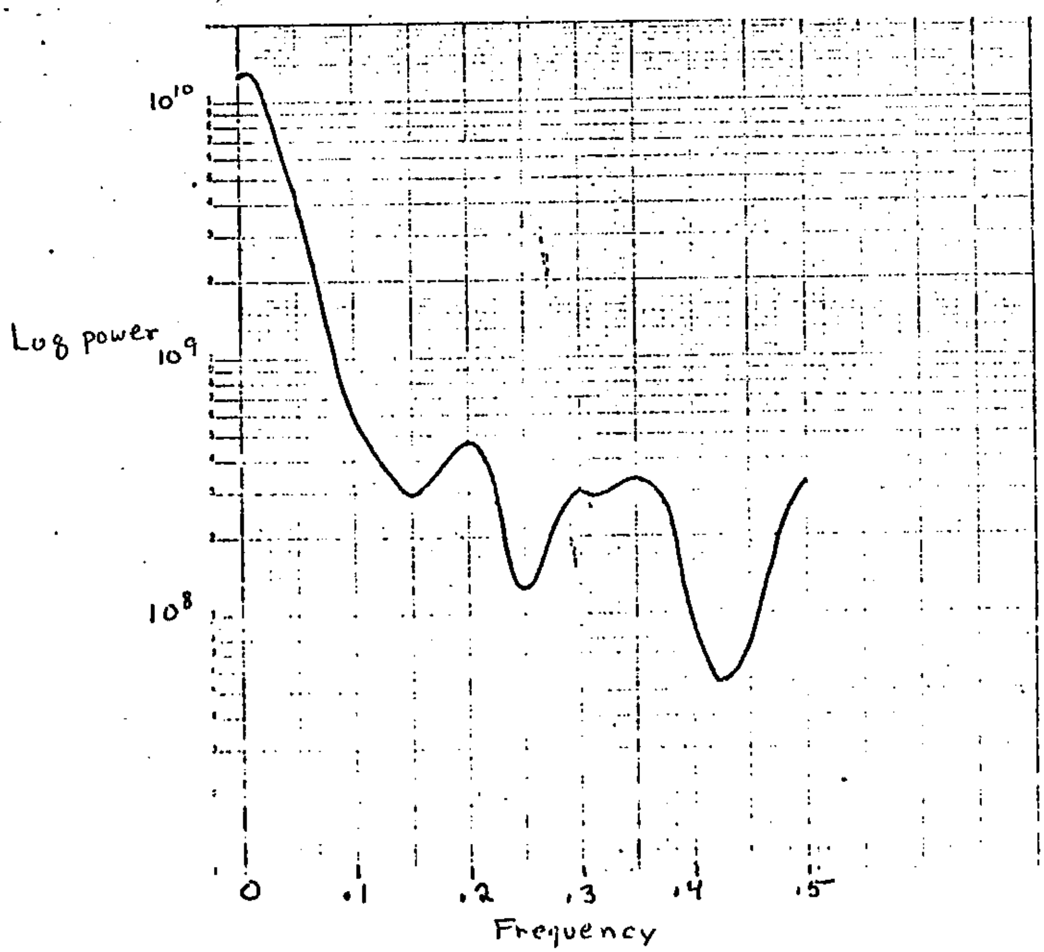

Figure 2b. Power spectrum for catch.

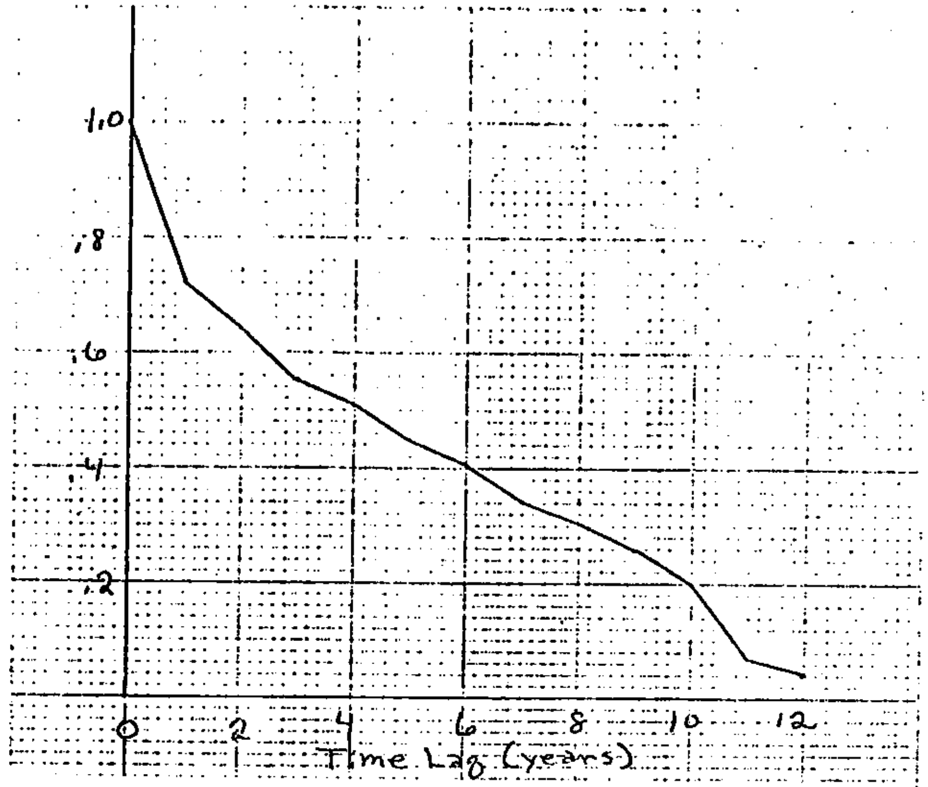

Figure 3a. Autocorrelation function for Ln catch.

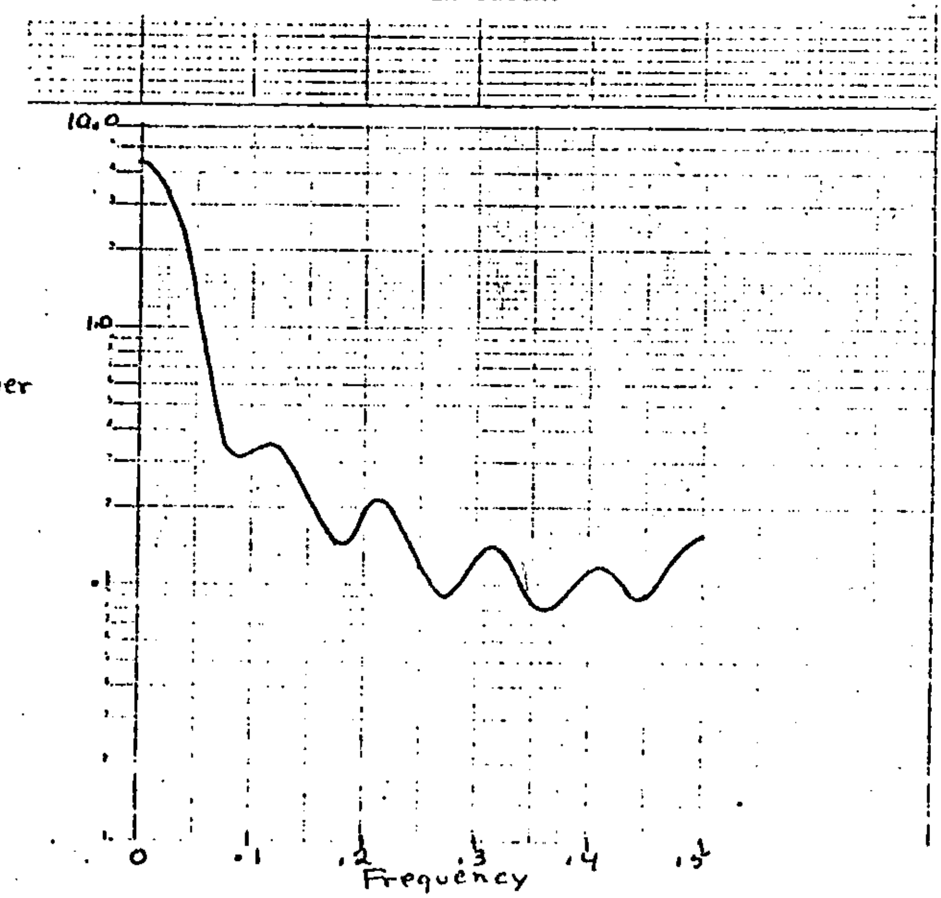

Figure 3b. Power spectrum for Ln catch.