A Seasonal Autoregressive Model of the Anchovy Engraulis encrasicolus Fishery in the Eastern Mediterranean

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Accurate forecasting is a difficult issue mainly because forecasters are confronted by all sorts of uncertainty (in resource production, budgets, political decisions, etc.) (Hilborn 1987). Although not widely employed, Autoregressive Integrated Moving Average (ARIMA) stochastic models (Box and Jenkins 1976) have been successful in describing and forecasting the fishery dynamics of a wide variety of species (lobster: Boudreau et al. 1977, Salla et al. 1979; tuna: Mendelssohn 1981; pilchard: Stergiou 1989a). Although multivariate, deterministic models (e.g., regression models: Ryan 1986, Koslow et al. 1987) are more common in fishery forecasting, these deterministic models often suffer from (1) artificial correlations introduced to the data, (2) residual autocorrelation, (3) high residual variance, and (4) colinearity between the independent variables that may bias the fit (Stergiou 1989b, In press).

In this note, a seasonal autoregressive model is presented that produces forecasts of the monthly purse-seine catches of anchovy Engraulis encrasicolus in Greek waters. The anchovy is one of the most important pelagic fish, in terms of biomass, in the Mediterranean Sea. Mean annual anchovy catch in Greek waters during 1982–85 amounted to 12,820 t, representing 17% of the total marine catch (Stergiou 1989b). Of the anchovy catch in Greek waters, 96% is attributed to the purse-seine fishery, accounting for 26% of the total purse-seine catch (Stergiou 1989b). Monthly catches of anchovy for January 1964–December 1986 (Fig. 1) (National Statistical Service of Greece 1968–88) show a marked seasonal pattern (Figs. 1, 2) and an increasing trend in the variability of monthly catches for the years following 1980. The latter may indicate that anchovy has suffered recruitment overfishing in recent years (since the late 1970s, purse-seine fishing in Greek waters is anchovy-oriented rather than pilchard-oriented due to the higher price of anchovy [Stergiou 1986a, b, 1989a, 1990]).

The ARIMA processes (Box and Jenkins 1976, Makridakis et al. 1983) apply to stationary series (time series with no systematic change in mean and variance and free of periodic variations). First- or second-order differencing (nonseasonal and/or seasonal) handles problems of nonstationarity in the mean, and logarithmic (or power) transformation of the raw data handles nonstationary variance. The general form of the ARIMA models,

\[ \text{Figure 1} \]

\[ \text{Figure 2} \]
Seasonal subseries plot of monthly catches of anchovy in Greek waters, 1964–86. Horizontal lines represent the average catch of each month. Vertical lines are plotted from the average catch to the actual catch of each year of the 1964–86 period.
ARIMA \((p, d, q)(P, D, Q)S\), can be described by the following equation:

\[
(1-n_1B^p)(1-N_1B^P)
\]
\[
(1-B^d)(1-B^D)X_t = (1-u_1B^q)(1-U_1B^Q)e_t
\]

where \(X_t\) = the value at time \(t\), \(B^p\) is a backward shift operator that is used as \(B^pX_t = X_{t-p}\), \(n_1, N_1, u_1, U_1\), and \(U_1\) = arithmetic coefficients, \(e_t\) = error term at time \(t\), \(p\) = order of autoregressive term (AR term), \(d\) = degree of differencing involved to achieve stationarity (I term), \(q\) = order of moving average term (MA term), and \(S\) = seasonality (number of periods per season); \(P, D, Q\) = seasonal terms (corresponding to \(p, q, d\) respectively).

Based on the examination of autocorrelation and partial autocorrelation functions (not shown here) of the original logarithmically transformed series, the following model was fitted to the logarithms of the raw data, ARIMA \((1, 1, 0)(1, 1, 0)_{12}\) (Table 1), or, after substituting the autoregressive coefficients and expanding the backward shift operator \((X_t = \text{logarithm of raw data})\),

\[
X_t = 0.792X_{t-1} - 0.208X_{t-2} + 0.684X_{t-12}
\]
\[-0.862X_{t-13} + 0.138X_{t-14} + 0.336X_{t-24}
\]
\[-0.266X_{t-25} - 0.07X_{t-26} + e_t.
\]

The unit of time (\(t\)) is one month. The model was estimated using the approximate maximum-likelihood algorithm of McLeod and Sales (1983). Parameters were estimated using backcasting with length of 13.

The examination of the cumulative periodogram of the residuals (not shown here) (Box and Jenkins 1976) indicated that residuals approximated random noise. Actual catches for January 1985–December 1986, not used in the development of the model, and forecasts for those years are plotted in Figure 3. The coefficient of determination (Table 1) was found to be \(r^2 = 0.94\) for January 1985–December 1986 (for the untransformed series).

Mean absolute percentage error (MAPE) (Table 1) for January 1985–December 1986 was 20.4%. Except for March and October 1985 and February, October and November 1986, when the absolute percentage error (APE) was higher than 26% (Table 1), monthly catches were predicted reasonably accurately within an APE range of 2–26% (MAPE of the remaining 19 forecasts was 11%) (Table 1).

### Table 1

<table>
<thead>
<tr>
<th>Parameter estimates of the anchovy fishery model. MAPE = mean absolute percentage error. APE = absolute percentage error, (r^2) = coefficient of determination.</th>
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<tbody>
<tr>
<td>Parameter</td>
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</tr>
<tr>
<td>(n_1)</td>
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<tr>
<td>(N_1)</td>
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<td>(r^2) for 1985–86</td>
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<td>Residual mean</td>
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<td>MAPE 1985</td>
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<td>MAPE 1986</td>
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<td>MAPE 1985–86</td>
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<td>APE &gt; 26%</td>
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<td>March 1985</td>
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<td>October 1985</td>
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<td>February 1986</td>
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<td>October 1986</td>
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<td>November 1986</td>
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<td>MAPE excluding APE &gt; 26</td>
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**Figure 3**

Comparison between actual monthly catches (□) of anchovy in Greek waters during January 1985–December 1986 and the forecasts (+) estimated from the model.

The error in predicting the February–March and October–November catches may be attributed to the highly variable timing of the initiation of the inshore (prespawning migration, which occurs sometime in March) and the offshore migrations (in fall) both of which are expected to be affected greatly by ocean-
Engraulis (Linnaeus, 1758), in the central Adriatic. Acta morkua) and 10%, respectively). Fishing activity in Greek waters does not operate in the pattern (Figs. 1, 2) which is likely related to these seasonal offshore and inshore migrations. Purse-seine fishing activity in Greek waters does not operate in the open sea but is mainly restricted to coastal areas where schools of anchovy migrate on a seasonal basis. The anchovy starts its inshore migration in early spring, but the peak occurs in coastal waters in May–August and schools disperse again during late summer–fall (Fig. 2; Tsimenidis and Caragtsiu 1984).

In Greek waters trawling and coastal seining are prohibited from the 1st of June to the 30th of September. As a result, the landings of demersal species (e.g., Merluccius merluccius, Micromesistius poutassou, Lophius sp., Mullus sp., Pagellus sp.) are low. This combined with the increased demand for fish in summer, drives up fish prices in Greece. In this context, accurate forecasts of the catches of anchovy (and of pelagic fish in general) during June–September are essential for market and industrial planning. APE in June–September was <11.2% in 1985 (mean 7.7%) and <10.6% in 1986 (mean 7.8%).

Strict monitoring and accurate forecasts are essential for pelagic fisheries that are heavily dependent on a single year-class, inasmuch as they are prone to collapse when conditions for recruitment in a particular year are not favorable and fishing is intense (as for anchovy in Greek waters). In this context, accurate forecasts of the annual anchovy catch together with information related to optimal management of anchovy estimated by deterministic fishery-management models, can be used by resource managers for the pre-seasonal adjustment of anchovy fishing mortality. The model produced reasonable forecasts of the annual 1985 and 1986 catches. Total observed annual catches in 1985 and 1986 were 17 544 t and 18 339 t, respectively, while the model predicted 17 369 t and 20 210 t (APE 1% and 10%, respectively). It must be pointed out, however, that although the model will most likely produce accurate forecasts if the anchovy stock is under equilibrium, it may fail to produce reliable forecasts for years characterized by weak year-classes of anchovy. (In fact there may be a lag of some months between the occurrence of a turning point and its recognition by the model; for a general discussion on turning points and out-of-sample forecasting, see Schlegel 1985.)

The model presented here has also an interesting biological interpretation. The seasonal-difference term of the model indicates the seasonal migratory nature of anchovy in Greek waters. Moreover, climate-plankton-anchovy interactions in the Eastern Mediterranean have been found to involve time lags of 2 to 3 years (Pucher-Petkovic et al. 1971). Yet, a 2–3 year cycle has been identified in the variability of different biotic (zooplankton, phytoplankton, fish) and abiotic (air and sea temperature, salinity and air pressure) components of the Eastern Mediterranean/Black Sea ecosystem (Polli 1955; Regner and Gacic 1974; S. Regner 1982, 1985; D. Regner 1985; Dement’eva 1987; Petrova-Karadjova and Apostolov 1988). The autoregressive terms ($X_{t-24}$, $X_{t-25}$, $X_{t-26}$) of the model seem to be consistent with these biological/oceanographical observations.

Citations


Regner, S., and J. Gacic
1974  The fluctuation of sardine catch along the eastern Adriatic

Ryan, P.M.
1986  Prediction of angler success in an Atlantic salmon,
Salmon salar, fishery two fishing seasons in advance. Can.
J. Fish. Aquat. Sci. 43;2531–2534.

Saila, S.B., M. Wigbout, and R.J. Lermit
1979  Comparison of some time series models for the analysis

Schlegel, G.

Stergiou, K.I.
1986a  On the anchovy and pilchard fishery in Greek waters,
1986b  On the assessment of the pelagic fishery resources in
1989a  Modeling and forecasting the fishery of pilchard, Sardina pilchardus in Greek waters using ARIMA time series
1989b  Multivariate analysis and trends in Greek fishery.
Fishbyte 7(2):4–7. ICLARM, Manila.
1990. On the Greek fishery production. Greek Fishing News
103:31–38 [in Greek].
In press  On different statistical methods for the analysis of
fishery time series. Proc. 4th Conf., Hellenic Ichthyol.,
June 1988 [in Greek, Engl. abstr.].

Tsimenidis, N., and H. Caragitisou
1984  The state of the sardine and anchovy resources in Greek