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: Boudreault et al. 1977, Saila 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).

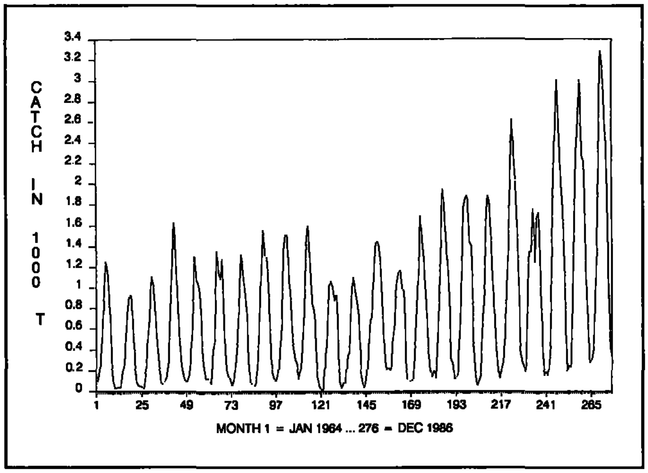

Figure 1
Monthly catches of anchovy in Greek waters, January 1964–December 1986.

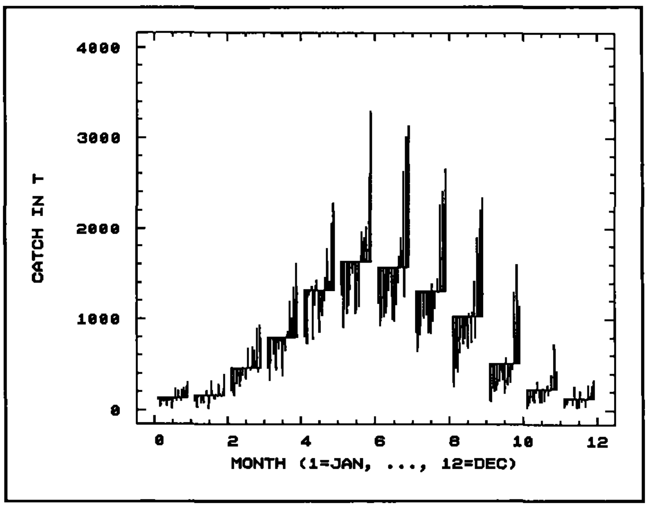

Figure 2
Seasonal subseries plot of monthly catches of anchovy in Greek waters, 1964–86. Horizontal lines represent the average catch of each month. Vertical lines are plotted from the average catch to the actual catch of each year of the 1964–86 period.

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 Mediteranean 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 1986a, b). 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 1986b, 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,

Manuscript accepted 28 December 1989.
Fishery Bulletin, U.S. 88:411–414.

$$\text{ARIMA } (p,d,q)(P,D,Q)^S,$$

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, 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,

$$\text{ARIMA } (1,1,0)(1,1,0)^{12} \text{ (Table 1)},$$

or, after substituting the autoregressive coefficients and expanding the backward shift operator (X_t = 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

Parameter estimates of the anchovy fishery model. MAPE = mean absolute percentage error, APE = absolute percentage error, r^2 = coefficient of determination.

APE = $\dfrac{\text{Absolute (actual catch at time } t \text{ − forecast at time } t\text{) } 100}{\text{Actual catch at time } t}$

MAPE = mean of APE, and

r^2 = 1 − (variance of residuals)/(variance of variable)

Parameter	Estimate	SE	Significance
n_1	−0.208	0.067	$p<0.01$
N_1	−0.336	0.059	$p<0.001$
r^2 for 1985–86		0.94	
Residual mean		0.007	
MAPE 1985		13.3	
MAPE 1986		27.4	
MAPE 1985–86		20.4	
APE>26%			
March 1985		31.5	
October 1985		33.5	
February 1986		47.7	
October 1986		65.9	
November 1986		95.6	
MAPE excluding APE>26		11	

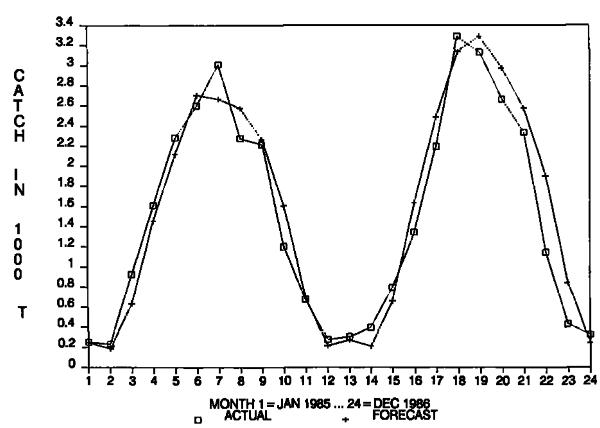

Figure 3

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 oceanographic conditions. Catches exhibit a marked seasonal 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 Caragitsou 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 preseasonal 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 equillibrium, 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

Boudreault, F.R., J.N. DuPont, and C. Sylvain
1977 Modeles lineaires de prediction des debarquement de homard aux Iles-de-la-Madeleine (Golfe du Saint-Laurent). J. Fish. Res. Board Can. 34:379–383 [in French, Engl. abstr.].

Box, G.E.P., and G.M. Jenkins
1976 Time series analysis, forecasting and control. Holden-Day, San Francisco, 575 p.

Dement'Eva, T.F.
1987 A method for correlation of environmental factors and year-class strength of fishes. J. Icthyol. 27:55–59.

Hilborn, R.
1987 Living with uncertainty in resource management. N. Am. J. Fish. Manage. 7:1–5.

Koslow, A.J., K.R. Thompson, and W. Silvert
1987 Recruitment to Northwest Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) stocks: Influence of stock size and climate. Can. J. Fish. Aquat. Sci. 44:26–39.

Makridakis, S., S. Wheelwright, and V. McGee
1983 Forecasting: Methods and applications. John Wiley, NY, 926 p.

McLeod, A.I., and P.R.H. Sales
1983 An algorithm for approximate likelihood calculation of ARMA and seasonal ARMA models. Algorithm AS 191. Appl. Stat. 1983:211–223.

Mendelssohn, R.
1981 Using Box-Jenkins models to forecast fishery dynamics: Identification, estimation and checking. Fish. Bull., U.S. 78: 887–896.

National Statistical Service of Greece
1968–88 Results of the sea fishery survey by motor vessels. Section G, 20 issues (for the years 1964–86), Athens, Greece.

Petrova-Karadjova, V.J., and E.M. Apostolov
1988 Influence of solar activity upon the diatoms of Black Sea plankton. Rapp. Comm. Int. Mer Medit. 31, p. 224.

Polli, S.
1955 I cicli climatici di 5.6 e 8.0 anni e la loro realta' fisca. Riv. Meteor. Aeronautica 2, 12 p.

Pucher-Petkovic, T., M. Zore-Armanda, and I. Kacic
1971 Primary and secondary production of the Middle Adriatic in relation to climatic factors. Thalassia Jugosl. 7:301–311.

Regner, D.
1985 Seasonal and multiannual dynamics of copepods in the middle Adriatic Sea. Acta Adriat. 26:11–99.

Regner, S.
1982 Investigations of qualitative and quantitative composition of the larval fish stages in the plankton at the high sea of the middle Adriatic. Stud. Mar. Fauna 11/12:45–60.
1985 Ecology of planktonic stages of anchovy, *Engraulis encrasicolus* (Linnaus, 1758), in the central Adriatic. Acta Adriat. 26:5–113.

Regner, S., and J. Gacic
1974 The fluctuation of sardine catch along the eastern Adriatic coast and solar activity. Acta Adriat. 15, 15 p.
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 of fisheries data. J. Cons. Cons. Int. Explor. Mer 39:44–52.
Schlegel, G.
1985 Vector autoregressive forecasts of recession and recovery: Is less more? Econ. Rev. IIQ/1985:2–12.
Stergiou, K.I.
1986a On the anchovy and pilchard fishery in Greek waters, 1964–1982. Rapp. Comm. Int. Mer Medit. 30, p. 241.
1986b On the assessment of the pelagic fishery resources in Greek waters. Rapp. Comm. Int. Mer Medit. 30, p. 241.
1989a Modeling and forecasting the fishery of pilchard, *Sardina pilchardus* in Greek waters using ARIMA time series models. J. Cons. Cons. Int. Explor. Mer 46:16–23.
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 Soc. Ichthyol., June 1988 [in Greek, Engl. abstr.].
Tsimenidis, N., and H. Caragitsou
1984 The state of the sardine and anchovy resources in Greek Seas. Proc. 1st Hellenic Symp. Ocean. Fish., p. 578–589. Natl. Cent. Mar. Res., Athens [in Greek].