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Describing and forecasting the sardine–anchovy complex in the eastern Mediterranean using Vector AutoRegressions

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ABSTRACT

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A Vector AutoRegressive (VAR) model, including two variables (anchovy and sardine catches) and six lags adequately described and forecasted the anchovy–sardine complex in the eastern Mediterranean (Greece) during 1964–1987. The model explained 93 and 72% of the variability of the anchovy and sardine catches, respectively, and produced accurate and unbiassed fits and forecasts. Annual anchovy and sardine catches were fitted within an absolute percentage error (APE) range of 1.9–26.9% (mean APE=9.5%) and 0.4–13.2% (mean APE=4.6%). Forecasts for 1985–1987 had APE values ranging between 4.9 and 20.9 and 4.7 and 19% for anchovy and sardine, respectively. The model predicted persistence, a 3-year periodicity of catches, and a negative relationship between anchovy and sardine catches, all of which are consistent with micro-economic and biological/oceanographic observations on the fisheries of these species in the Mediterranean.

INTRODUCTION

In view of the considerable interest today in short- and long-term fisheries forecasting, different forecasting techniques have been adapted to fisheries research (Table 1). Recently, Bayesian probability theory has also been used for the development of in-season forecasts of sockeye salmon (Fried and Hilborn, 1988).

In this study, Vector Autoregression (VAR) models, never before applied to fisheries forecasting yet of increasing interest to economic forecasters (Todd, 1984; Schlegel, 1985), are used to describe and forecast, at the operational level (sensu Bocharov (1989): forecasts for up to 1 year ahead), the fishery of the sardine–anchovy complex in Greek waters. The anchovy–sardine complex was selected for this study because (a) VAR models take into account interactions between variables and (b) the replacement of sardine

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TABLE 1

Examples of statistical techniques adapted to fisheries forecasting (letters in parentheses indicate the type of data: a = annual, m = monthly, f = fortnightly; numbers in parentheses indicate the number of data points used in models), cpue = catch per unit of fishing effort, ycs = year class strength

Model variable	Predictors	Source
Multivariate deterministic		
Simple regression		
Pelagic cpue (a, 10)	Rainfall	Pati (1984)
Arctic cisco (a, 19)	Wind	Fechhelm and Fissel (1988)
Dungeness crab catch (a, 26)	Sunspot	Love and Westphal (1981)
Prawn catch (a, 10)	Rainfall	Vance et al. (1985)
Multiple regression		
Capelin recruitment (a, 13)	Sea temperature	
	Wind	Leggett et al. (1984)
Whale number (a, 10)	Different	
	year classes	
	of capelin	Whitehead and Carscadden (1985)
Shad recruitment (a, 13)	Parent stock	
	River flow	
	Rainfall	Crecco et al. (1986)
Coregonid ycs (a, 21)	Wind	
	Sunshine	
	Larvae stocked	
	Coregonid age 1,2	Eckmann et al. (1988)
Categorical regressions		
American shad stock (a, 45)	River flow	
	Water temperature	
	Dissolved oxygen	
	Stock (lagged)	Summers and Rose (1988)
Univariate stochastic		
ARIMA		
Lobster catch (a, 52)	Catch	Boudreault et al. (1977)
Rock lobster cpue (m, 120)	cpue	Saila et al. (1979)
Skipjack tuna catch (m, 180)	Catch	Mendelssohn (1981)
Sardine catch (m, 204)	Catch	Stergiou (1989a)
Anchovy catch (m, 252)	Catch	Stergiou (1990a)
Harmonic regression		
Rock lobster cpue (m, 120)	cpue	Saila et al. (1979)
Decomposition (quadratic trend)		
Aquaculture production (a, 9)	Production	Stergiou and Argyrou (1990)
Multivariate stochastic		
Transfer function models		
Tuna catch (m, 180)	Catch	
	Effort	Mendelssohn (1981)
Total pelagic cpue (f, 360)	cpue	
	Sea temperature	Mendelssohn and Cury (1987)
Herring recruitment	Recruitment	
	Spawn index	
	Ekman transport	
	Sea temperature	Stocker and Noakes (1988)

by anchovy has been observed throughout the Mediterranean Sea (Spain, Adriatic, Greece, Morocco) (Stergiou, 1989a) and elsewhere (Daan, 1980).

The European sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) are the most important pelagic fish, in terms of biomass, in the Mediterranean Sea. These species made up 30% of the mean (1982–1985) total marine catch in Greek waters (Stergiou, 1989b) and accounted for 61% of the total purse-seine catch (Stergiou, 1986a, b). The remaining part of the Greek purse-seine catch was mainly composed of *Trachurus* sp., *Boops boops, Scomber scombrus, Sarda sarda*, swordfish and tuna (Stergiou, 1990b).

Accurate forecasts of the annual sardine and anchovy catches are essential for: (a) pre-seasonal adjustment of fishing quotas; (b) planning of the relative quantity that will be marketed fresh and of that which will be used by the processing industry; (c) organising exports; (d) planning and expansion of the Greek processing industry. Points (b), (c) and (d) may be of primary importance for the Greek economy since market planning and organisation for pelagic fish are practically non-existent. The fish processing industry, which can absorb the surplus yield of pelagic fish, has undergone a recession in the last decade and processed fishing products are competitively inferior to those imported from other EEC countries.

MATERIALS AND METHODS

Sources of data

The data to be analysed are time series of annual catches of sardine and anchovy in Greek waters for 1964–1987 (Table 2), gathered from the Bulletins of the National Statistical Service of Greece (1968–1989).

Development of models

In VAR models, each internal variable is regressed against its own value in each of the *n* preceding periods, against the values in each of the *n* preceding periods of all other variables included in the model, and against a constant term and an external variable (Schlegel, 1985). The equations are estimated individually in order to compute the arithmetic coefficients and the constant. Consequently, the reduced form of the system is calculated and predictions are produced.

In the present study, six VAR models, including two internal variables (anchovy and sardine catches) and lag lengths ranging from one to six, were estimated. The general form of a VAR system including two internal variables, X and Y, n lags and an external variable Z, is as follows (Schlegel, 1985)

$$X_t = c_1 + a_{11}X_{t-1} + a_{21}X_{t-2} + \ldots + a_{n1}X_{t-n} + b_{11}Y_{t-1} + b_{21}Y_{t-2} + \ldots + b_{n1}Y_{t-n} + d_1Z + e_1$$

$Y_t = c_2 + a_{12}X_{t-1} + a_{22}X_{t-2} + \ldots + a_{n2}X_{t-n} + b_{12}Y_{t-1} + b_{22}Y_{t-2} + \ldots + b_{n2}Y_{t-n} + d_2Z + e_2$

where X_{t-n} is the value of X n periods before time t; c is a constant; a, b and d are arithmetic coefficients; e_1 and e_2 are error terms. The arithmetic parameters of the equations were estimated using ordinary least squares. Estimations and forecasts were produced using the RATS Statistical Package (Doan and Litterman, 1984).

Consequently, the most accurate VAR model, in terms of measures of accuracy (described below), was re-estimated using effort (number of boats) as an external variable. In addition, independent regression models were also developed for anchovy/sardine catches and effort (number of boats).

All models were fitted to the 1970–1987 period and 12 measures of accuracy were computed and compared. In addition, a similarity matrix, comparing each model with every other model, was constructed using the Bray–Curtis measure of similarity. The models fitted were compared using complementary cluster (group-average) and non-metric multi-dimensional scaling (sensu Field et al., 1982) performed on the similarity matrix.

TABLE 2

Annual catches (in tons) of anchovy and sardine and number of purse-seiners (B) in Greek waters, 1964–1987

Year	B	Anchovy	Sardine
1964	363	5 449	12 984
1965	373	4 260	10 611
1966	389	5 147	11 437
1967	394	7 272	8 987
1968	398	6 353	9 120
1969	366	7 035	10 615
1970	354	6 373	8 823
1971	343	8 043	9 132
1972	332	8 495	11 743
1973	360	8 062	13 241
1974	380	6 173	10 906
1975	401	5 675	12 488
1976	441	9 281	12 674
1977	435	7 326	12 148
1978	447	8 358	11 888
1979	446	9 865	12 715
1980	456	11 223	12 062
1981	481	9 992	12 453
1982	487	14 206	12 378
1983	497	11 916	10 279
1984	499	16 529	10 356
1985	489	17 544	11 495
1986	495	18 339	10 366
1987	502	24 735	9 685

As good fitting does not necessarily imply good forecasting, the ability of the best fitted model to produce forecasts was tested by fitting this model to three different periods: 1970–1984, 1970–1985 and 1970–1986. The parameter values estimated each time were used to develop three sets of one-step-ahead forecasts (1985–1987, 1986–1987 and 1987, respectively). Forecasts were then compared with actual catches in 1985–1987.

Measures of accuracy

There are many measures of accuracy that one may use to compare different models (for a general discussion see Makridakis et al., 1983). Comparisons of different models on a single measure are of limited value (Makridakis et al., 1983). Hence, the following general categories of statistical measures were used: (1) standard statistical measures (mean error, ME; mean square error, MSE; standard deviation of errors, SDE); (2) relative statistical measures (absolute percentage error, APE; and its minimum, maximum and range, mean absolute percentage error, MAPE; mean absolute error, MAE) (for computations see Makridakis et al., 1983); (3) other statistical measures (bias, B; Durbin–Watson statistic, DW; coefficient of determination, r^2) described below.

Theil's (1966) bias component B = [(average of forecasts) – (average of actual values) $]^2$/MSE is a measure of the over- or underestimation of actual values. Low values of B indicate small bias. The Durbin and Watson (1951) statistic (DW) is used to indicate whether there is any pattern left in the errors or not. The value of the DW statistic ranges between 0 and 4. When errors are essentially white noise, it attains a value of ~ 2. Values >2 and <2 indicate negative and positive autocorrelation of the residuals, respectively. However, tables are referred to (Durbin and Watson, 1951) for significance tests since the value of DW indicating no residual autocorrelation depends on the number of data points and predictors. Lastly, the coefficient of determination $r^2 = 1-$ (variance of residuals)/(variance of variable) ranges between 0 and 1 (Saila et al., 1979).

RESULTS

Model fitting

Six different VAR models were estimated: VAR_1 (one lag) to VAR_6 (six lags). In addition, the following quadratic regression models (QR) were found to describe the relationship between the annual sardine (X) and anchovy (Y) catches and the number of boats (B) for 1970–1987 (Fig. 1; all coefficients were statistically different from 0 ($P<0.05$))

Anchovy: $Y = 159481.41 - 788.12(B) + 1.01(B^2)$ ($F = 25.9, P < 0.001$)

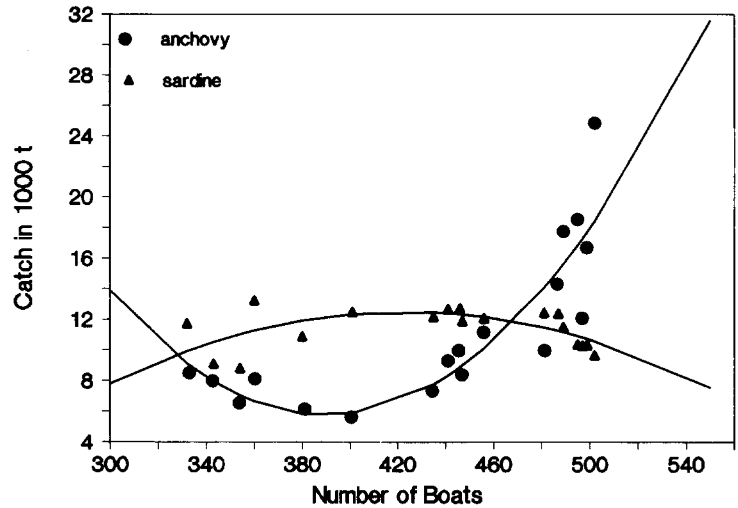


Fig. 1. Quadratic regressions between anchovy and sardine catches and fishing effort (number of boats) in Greek waters 1970–1987.

Sardine: $X = -42522.28 + 259.92(B) - 0.31(B^2)$ $(F = 4.0, P < 0.05)$

All measures examined (Table 3, Fig. 2) indicate that models VAR_3–VAR_6 and QR are, by far, superior when compared with VAR_1 and VAR_2. Although VAR_3–VAR_6 have almost similar SDE, MSE, r^2 and bias, and no autocorrelated residuals (with the exception of VAR_3) (Table 3), VAR_6 is characterised by the lowest MAPE, APE range and number of data points fitted with APE > 10%. The incorporation of effort (number of boats) as an external variable in VAR_6 (Model VAR_{6b}) did not improve fitting (Table 3, Fig. 2). QR has the lowest ME (for anchovy) and bias (anchovy and sardine). However, ME is not a very indicative measure since positive and negative errors may cancel one another (Makridakis et al., 1983). Low bias also does not imply good fitting unless other error measures indicate that this is so. All remaining errors (r^2, MAPE, APE range, min., max., MSE, SDE, MAE) indicate that QR is inferior to VAR_3 to VAR_6. In addition, QR is characterised by highly significant residual autocorrelation.

The values of VAR_6 model coefficients are shown in Table 4. Actual catches for 1970–1987 and fitted values for those years are plotted in Fig. 3. The integrated periodograms of the residuals for both anchovy and sardine (not shown here) indicated that residuals approximated white noise. VAR_6 explained 93% of the variability of anchovy catches and 72% of the variability of sardine catches, and produced unbiased fits (Table 3). Fitted values were close to the observed values: APE ranged from 1.9 to 26.9% (MAPE = 9.5%) and 0.4 to 13.2% (MAPE = 4.6%) for anchovy and sardine, respectively, and 66 and 83% of the 1970–1987 anchovy and sardine catches, respectively, were

TABLE 3

Forecasting accuracy measures for the VAR and QR models estimated. Fitting period 1970–1987

Measure	VAR_1	VAR_2	VAR_3	VAR_4	VAR_5	VAR_6	VAR_{6b}	QR
Anchovy								
ME	−14147.8	−6589.7	−131.3	−483.1	−388.8	−266.5	−13782.3	24.5
SDE	12381.8	6544.4	1283.9	1376.0	1221.5	1311.4	19365.0	2367.1
MSE[a]	364816.2	86252.8	1665.7	2126.8	1643.3	1790.9	564955.4	5603.6
MAE	14147.8	6658.0	1152.8	1222.9	1009.0	1038.7	13884.7	1602.1
MAPE	107.3	50.5	12.2	13.3	10.7	9.5	87.5	13.0
APE min.	8.8	3.2	2.2	0.4	0.0	1.9	0.9	0.8
APE max.	214.0	111.1	36.8	42.2	44.4	26.9	290.1	44.9
APE range	205.2	107.9	34.6	41.8	44.4	25.0	289.2	44.1
APE> 10	17.0	15.0	12.0	11.0	7.0	6.0	15.0	7.0
BIAS	0.55	0.50	0.01	0.11	0.09	0.04	0.34	0.00
r^2	0.00	0.00	0.93	0.92	0.94	0.93	0.00	0.78
DW	0.0[b]	0.1[b]	2.6[b]	2.3	2.5	2.6	0.1[b]	1.2[b]
Sardine								
ME	1875.5	840.2	18.5	11.9	−38.6	−76.2	−2803.7	−42.6
SDE	2197.9	1448.1	924.6	859.3	716.6	683.7	4122.3	1037.1
MSE[a]	8347.9	2803.0	855.3	738.5	514.9	473.3	24853.6	1077.3
MAE	2467.4	1462.8	760.5	725.5	543.9	515.9	2850.0	824.5
MAPE	22.4	13.4	7.0	6.6	4.9	4.6	27.0	7.6
APE min.	1.7	0.7	0.1	0.3	0.0	0.4	0.3	0.9
APE max.	55.3	27.5	22.6	17.3	13.0	13.2	157.8	24.9
APE range	53.6	26.8	22.5	17.0	13.0	12.8	157.8	24.0
APE> 10	15.0	9.0	4.0	4.0	3.0	3.0	7.0	4.0
BIAS	0.42	0.25	0.00	0.00	0.00	0.01	0.32	0.00
r^2	0.00	0.00	0.48	0.55	0.69	0.72	0.00	0.35
DW	0.2[b]	0.5[b]	1.4	1.5	1.5	1.1	0.1[b]	1.4[b]

[a]Divided by 1000.
[b]Statistically significant residual autocorrelation.

fitted with an APE< 10% (Table 3). The amplitude and duration of the between-year fluctuations of both sardine and anchovy catches are adequately described by the model (Fig. 3a).

The fitted (VAR_6) anchovy/sardine ratio also paralleled the actual ratio in 1970–1987 reasonably well (not shown here). The amplitude and duration of the between-year fluctuations are very well described ($r^2=0.91$, APE ranged between 0.6 and 34.5%, MAPE = 9.8%, only five data points had APE> 10%). The total anchovy–sardine catch (Fig. 3b) fitted by VAR_6 also parallels well the actual total catch ($r^2=0.9$, APE ranged between 0.1 and 17.4%, MAPE = 4.8%, only two data points had APE> 10%).

One important aspect of VAR models (and of multiple regression models in general) that has to be considered is collinearity (Schlegel, 1985; Stergiou, 1989c) between the lagged terms in the right side of the equations. From a strictly statistical viewpoint, when intercorrelations are present between the right side variables standard errors of partial regression coefficients are large

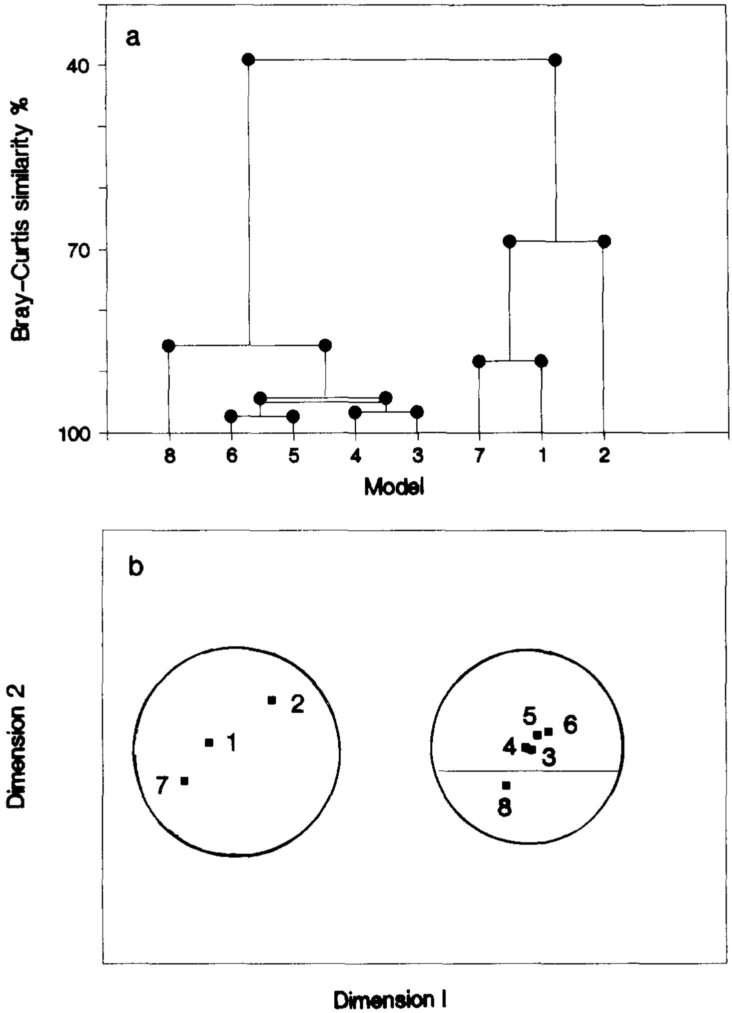


Fig. 2. (a) Dendrogram for group-average clustering of Bray–Curtis similarities (y-axis) between the eight models estimated (x-axis). (b) Non-metric multi-dimensional scaling ordination, based on Bray–Curtis similarities between models estimated; the low stress = 0.006 implies adequate representation in two dimensions. For both plots, models are grouped by similarity in all measures (square root of measure) estimated, except ME and DW (see Table 3). 1 = VAR_1; 2 = VAR_2; 3 = VAR_3; 4 = VAR_4; 5 = VAR_5; 6 = VAR_6; 7 = VAR_{6b}; 8 = QR.

(Zar, 1984). As a consequence, partial regression coefficients are not found to be statistically significant, even when the independent and dependent variables are related in the population (Stergiou, 1989c). In addition, collinearity may lead to increased round-off error in the computation of regression statistics (Zar, 1984). Although various methods for coping with collinearity are available (ridge regression: Dixon, 1983; selective drop of variables: Intrilligator, 1978; Freund and Minton, 1979; factor analysis: Stergiou, 1989c), the

TABLE 4

Coefficients (C) of the terms of the VAR_6 model fitted to the Greek catches of anchovy and sardine in 1970–1987. Sardine catch $= X_t$, anchovy catch $= Y_t$

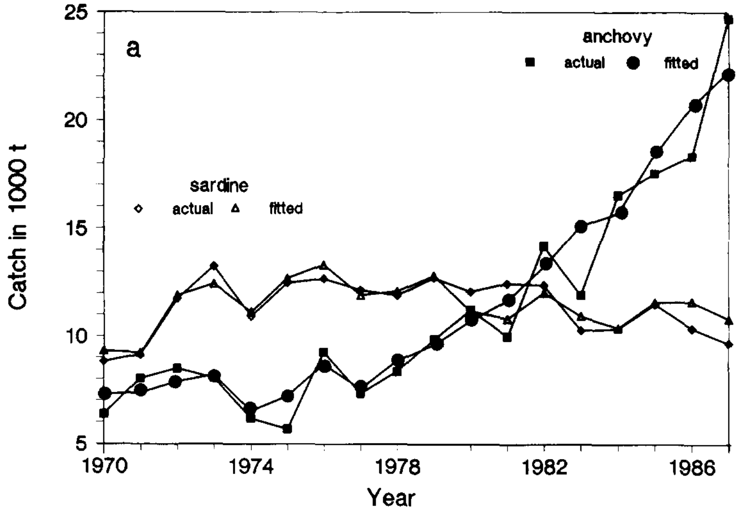
Anchovy[1]		Sardine[1]	
−456.261[2]		17199.95[2]	
Term	C	Term	C
Anchovy catch			
Y_{t-1}	−0.249	Y_{t-1}	0.544
Y_{t-2}	0.811	Y_{t-2}	0.391
Y_{t-3}	0.955	Y_{t-3}	−0.451
Y_{t-4}	−0.064	Y_{t-4}	−0.761
Y_{t-5}	0.133	Y_{t-5}	−0.229
Y_{t-6}	−0.065	Y_{t-6}	0.151
Sardine catch			
X_{t-1}	−0.546	X_{t-1}	−0.115
X_{t-2}	−0.908	X_{t-2}	0.161
X_{t-3}	0.531	X_{t-3}	0.896
X_{t-4}	0.531	X_{t-4}	0.160
X_{t-5}	0.873	X_{t-5}	−0.773
X_{t-6}	−0.655	X_{t-6}	−0.674

[1]Dependent variable
[2]Constant.

assumption that regressors are independent is arbitrary (Fewster, 1987). This assumption serves the limitations inherent in the use of the standard distributions for significance tests and "...by relaxing the statistical bounds and including variables which interact with each other one may develop a model more like the real system examined..." (Fewster, 1987). Yet, predictability and fitting increase along with the expansion of the model (Goodall, 1972; Fewster, 1987). The VAR_6 model estimated in this study was characterised by significant correlations between lagged catches (not shown here). However, regression is used here merely as a curve-fitting method sensu Goodall (1972) and Fewster (1987).

Forecasting

The predictors of anchovy and sardine catches which have been obtained in VAR_6 allow one to forecast 1 year in advance. Forecasts for 1985–1987 (produced as described earlier) are of acceptable accuracy (Table 5). All APE are within the APE ranges of VAR_6 fitted to the 1970–1987 period (Table 3). The APE in forecasting the 1987 anchovy catch (20.9%, Table 5) is relatively high when compared with the MAPE for 1970–1987 (9.5%, Table 3). This is quite reasonable since the anchovy catch increased from 18 339 t in 1986 to



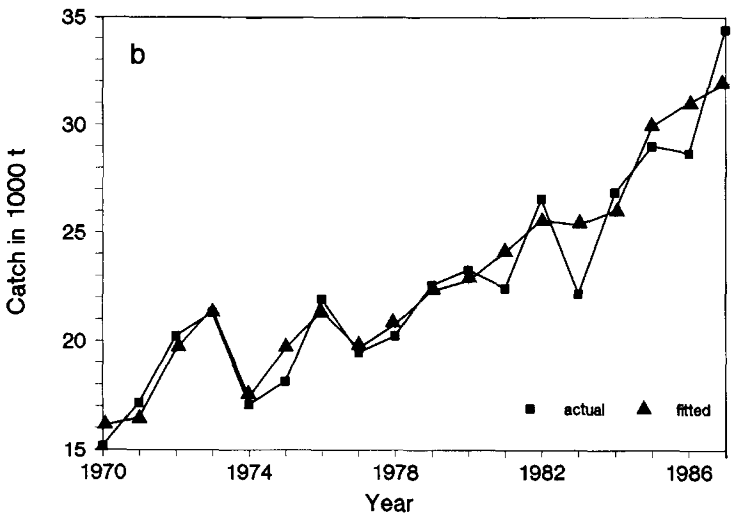


Fig. 3. (a) Observed and fitted (VAR_6) anchovy and sardine catches in Greek waters, 1970–1987; (b) observed and fitted (VAR_6) annual anchovy+sardine catch in Greek waters, 1970–1987.

24 735 t in 1987, representing a rate of increase of 34.9% which is considerably higher than the mean (1964–1986) annual absolute rate of increase, 19.7%. In general, all models estimated produced more accurate fits and forecasts for sardine than for anchovy (Tables 3 and 5). This may indicate that the accuracy of the model is higher when catches do not fluctuate considerably from year to year.

It must be pointed out that both model fitting and forecasting may fail after

TABLE 5

Actual catches and out-of-sample 1985–1987 forecasts (= 1985–1987 catches were not included in the development of the models) produced by three VAR_6 models. APE is also shown; catches are in tons

VAR_6	Fitting period	Forecasts
1	1970–1984	1985–1987
2	1970–1985	1986–1987
3	1970–1986	1987

Actual catches 1985–1987						
	1985		1986		1987	
	Anchovy	Sardine	Anchovy	Sardine	Anchovy	Sardine
	17544	11495	18339	10366	24735	9685
Model	Forecasted catches 1985–1987					
1	19739	10066	21906	9612	26175	9299
2			19241	8979	20635	7842
3					19565	9182
Model	APE of forecasts 1985–1987					
1	12.5	12.4	19.5	7.3	5.8	4.7
2			4.9	13.4	16.6	19.0
3					20.9	5.2

a certain period of time, even if the parameters of the model are readjusted each year, and different variables (external and/or lagged) may have to be taken into account from time to time (e.g. Dement'Eva, 1987).

Interpretation of the model

The VAR_6 model may also have interesting explanations. Fishing effort affects the level of sardine and anchovy catches (Fig. 1). The decrease in the catches of sardine along with an increase in fishing effort (Fig. 1) may imply that sardine is overfished. However, this is probably not true. Since the late 1970s, purse-seine fishing in Greece has been anchovy oriented rather than sardine oriented due to the higher price of the former. As a result, sardine catches may have been stabilised, in contrast to the increased fishing effort, thus giving the impression of overfishing. However, fishing effort is only one factor affecting catches. Year-to-year changes in oceanographic and biological conditions (Zupanovic, 1968, 1985; Pucher-Petkovic et al., 1971; Regner and Gacic, 1977; Porumb and Marinescu, 1979; Belveze and Erzini, 1983; Dement'Eva, 1987; Dickson et al., 1988) and micro-economic factors (because of their low commercial price and demand: Tsimenidis and Caragitsou, 1984; Stergiou, 1986a 1989a) also affect catches.

In VAR$_6$, the response variables are anchovy and sardine catches at time t, and the predictors are anchovy and sardine catches at time $t-1$ to $t-6$. The model predicts persistence of both sardine and anchovy catches (successive positive or negative lagged terms) (Table 4). In other words, once anchovy and/or sardine catches are high they tend to remain high for two to three successive years. Persistence may indicate that environmental conditions favouring the formation of good year classes (and/or large schools) and/or the micro-economic factors affecting the fisheries of these species tend to persist.

The model also points to a negative relationship (negative coefficients) between sardine and anchovy catches (anchovy: at lags $t-1$, $t-2$ and $t-6$, highest negative coefficient at lag $t-2$; sardine: at lags $t-3$ to $t-5$, highest negative coefficient at lag $t-4$) (Table 4). A 2–3-year lag in the replacement of sardine catches by anchovy catches has also been observed in Spain (Larraneta, 1982). This is consistent with the fact that small pelagic fish are characterised by widespread shifts in dominance. Daan (1980), in a review of the replacement of depleted stocks by other species, reached the conclusion that this phenomenon is most evident for the sardine–anchovy complex. In general, the replacement of sardine by anchovy has been observed throughout the Mediterranean Sea (Spain, Adriatic, Greece, Morocco) (Stergiou, 1989a).

Finally, the fact that the coefficients of the anchovy terms (Y_{t-1},..., Y_{t-6}) in the anchovy equation, and of the sardine terms (X_{t-1},..., X_{t-6}) in the sardine equation, attain their highest value at lag $t-3$ (Table 4) may indicate a 3-year periodicity in the catches. Cycles with periods of 2–3 years are suggested for anchovy (Dement'Eva, 1987; Stergiou, 1990a), sardine (Zupanovic, 1968; Regner and Gacic, 1977; Stergiou, 1988) and other biological (zooplankton, phytoplankton, fish eggs and larvae, fish) and environmental variables (air temperature and pressure, nutrients, sea temperature and salinity) in different areas of the eastern Mediterranean and the Black Seas (see references in Stergiou, 1990a).

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