INTERACTIONS BETWEEN FISHING EFFORT AND CATCH PER UNIT EFFORT IN THE SAN PEDRO FISHERY: A STATISTICAL NOTE

G. MICHAEL PHILLIPS
Department of Finance and Business Economics
Graduate School of Business
University of Southern California
Los Angeles, California 90089

ABSTRACT

Time series methods are applied to daily data of trips and average catch per trip (effort and CPUE) for anchovy and mackerel fishing in the San Pedro, California, purse seine fishery. The study shows that high fishing effort leads to a slight increase in CPUE, whereas high CPUE attracts additional fishing effort. The data show little evidence of local stock depletion in the short run. An additional result is that forecast models of anchovy or mackerel CPUE should not be cast in a single equation framework; rather, a four-equation system simultaneously forecasting CPUE and effort for each species is the appropriate specification.

RESUMEN

Los métodos períodicos se aplican a los datos diarios de viajes y el promedio de captura por viaje (esfuerzo y captura por unidad de esfuerzo: CPUE) para las pesquerías de anchoa y jurel utilizando red de cerco, en la región de San Pedro, California. El estudio demuestra que un esfuerzo de pesca elevado incrementa ligeramente el CPUE, mientras que la elevación de la captura por unidad de esfuerzo, implica esfuerzo de pesca adicional. Los datos no señalan que exista a corto plazo, una reducción de las reservas pesqueras. Los modelos para predecir las capturas de anchoa y jurel por unidad de esfuerzo, no debían de encajarse en la rigidez de una ecuación, mas bien la apropiada especifidad requeriría de un sistema simultáneo de cuatro ecuaciones para predecir captura por unidad de esfuerzo (CPUE) y el esfuerzo, para cada una de las especies.

INTRODUCTION

The question "how does today's fishing effort in-influence tomorrow's catch?" may receive very different answers depending on which fisheries scientist one asks.

For example, a biologist might answer that there is little or no influence unless the catch is large relative to the target school, in which case local depletion causes catch per unit effort (CPUE) to decline. Conversely, an economist might maintain that CPUE is an increasing function of effort: as the level of fishing effort increases, fishermen become more adept at finding and catching fish, and consequently average catch rises. Alternatively, one could take the fishermen's perspective and decide that the causation implied in the question is backwards; actually fishing effort has little effect on CPUE. Rather, fishing conditions today determine tomorrow's fishing activities.

These are three reasonable yet conflicting answers to the question. Although presented in a very stylized fashion, each answer has significant implications for the modeling and regulation of commercial fishing industries.

For example, if CPUE is not a function of effort, then CPUE can be forecast by regulators without simultaneously forecasting effort. This might be done towards the end of a fishing season to determine a possible closing date. On the other hand, if CPUE does depend to some extent on the level of effort, CPUE cannot be accurately predicted without incorporating into the forecasting process those economic variables that influence effort.

Perhaps of more interest to modelers is whether each species in a multiple species fishery can be regulated independently. If the CPUE for one species is influenced by the effort for a different species, then the two species must be simultaneously modeled and regulated.

In general, if there are strong influences of fishing effort on CPUE then the modeling and regulatory process can be severely complicated. (A lengthy elaboration of these points and similar issues is presented in Phillips 1982.) In this paper I present the results of an empirical analysis attempting to statistically determine the extent of CPUE and effort interactions in the San Pedro, California, anchovy and mackerel fishery, where "effort" is operationally defined as the boat-days dedicated to fishing for a given species.

The results suggest that there are definite positive interactions between fishing effort for anchovy (and mackerel) and CPUE for anchovy (and mackerel). The results also suggest some cross-effects between species. Although there is a slightly positive effect of fishing effort on CPUE, particularly for mackerel, the major effect seems to be of CPUE on fishing effort.

[Manuscript received April 5, 1983.]

DATA AND METHODOLOGY

The investigation was performed using data provided by the California Department of Fish and Game. Each day, agents of the Department of Fish and Game collect records of each commercial sale of oceanic fish in California. These records, collected at the docks, include the prices paid, the weight, and the species of fish involved. Because of the vast number of data collected, there is a substantial lag before the data are available for statistical analysis. Therefore, I used observations from the 1974, 1975, and 1976 fishing seasons.

From the raw data, I extracted daily sales by those San Pedro fishermen who earned at least 75% of their annual revenues from mackerel and anchovy. This defined a working fleet of about 30 vessels. I then aggregated these daily observations into a new data base reflecting the entire fleet's daily activities. No individual vessel's data were analyzed except in the aggregated form.

The resulting data base had 684 fishing days in the total sample. These were divided into an "in-sample" and a "postsample" group. The in-sample group of 488 observations was used for statistical estimation, and the postsample group of 196 observations was used to evaluate alternative statistical models.

The four relevant series, anchovy CPUE and fishing effort and mackerel CPUE and fishing effort, were used to fit ARIMA models using Box-Jenkins univariate modeling techniques (Box and Jenkins 1976). These estimated models were used to filter the series into "prewhitened" data. Using the estimated ARIMA models, I removed the trends and serial correlation, leaving four series-satisfying tests for white noise.

Next, I estimated cross-correlograms between the prewhitened CPUE and prewhitened effort series and used them to tentatively identify the presence of feedback and the direction of "causation"[1] between the series. The analysis in this step provides a statistical basis for answering "how today's effort influences tomorrow's catch."

RESULTS

Using the daily data, I identified univariate time series models for anchovy and mackerel effort and CPUE. In each case, the suggested model was a low-order autoregressive model. Following the Box-Jenkins algorithm for modeling such series, I estimated several alternate autoregressive, moving average, and mixed models for each series. I estimated the equations over the initial 488 observations and computed the forecast performance over the final 196 observations. The models performing best in terms of minimizing the mean-squared forecast error are the autoregressive models reported in Table 1.

TABLE 1

Let B denote the "backwards" operator such that $y^{t-1} = B^i \cdot y^t$. Let MCPUE denote mackerel CPUE, let ACPUE denote anchovy CPUE, let ME denote mackerel effort, and let AE denote anchovy effort. Let the prefix R denote "residual" to identify the prewhitened variables. The univariate linear models of the series minimizing means squared forecasting error are the following models. (Standard errors are reported.)

ACPUE

$$(1 - \underset{(0.03575)}{0.5951849B} - \underset{(0.03746)}{0.1121908B^3} + \underset{(0.04512)}{0.1161364B^7} - \underset{(0.04396)}{0.1093452B^6})\mathrm{ACPUE}^t = 13.95966 + \mathrm{RACPUE}^t$$

In sample: $N = 488$

$R^2 = 0.42426$

$\bar{R}^2 = 0.41949$

s.e. $= 20.97673$

$F = 88.98047$

AE

$$(1 - \underset{(0.0458)}{0.5687526B} - \underset{(0.04371)}{0.1719947B^6} + \underset{(0.04464)}{0.0935268B^5} - \underset{(0.04347)}{0.13414B^3} + \underset{(0.05281)}{0.05610872B^2})\mathrm{AE}^t = 3.244975 + \mathrm{RAE}^t$$

In sample: $N = 488$

$R^2 = 0.37908$

$\bar{R}^2 = 0.37264$

s.e. $= 6.91751$

$F = 58.854$

MCPUE

$$(1 - \underset{(0.04588)}{0.3984744B} - \underset{(0.04195)}{0.1424534B^6} - \underset{(0.04306)}{0.1072012B^7})\mathrm{MCPUE}^t = 3.84161 + \mathrm{RMCPUE}^t$$

In sample: $N = 488$

$R^2 = 0.1883$

$\bar{R}^2 = 0.18327$

s.e. $= 10.33098$

$F = 37.42624$

ME

$$(1 - \underset{(0.04675)}{0.455493B} + \underset{(0.04772)}{0.0697266B^2} - \underset{(0.05507)}{0.1670767B^6} - \underset{(0.04972)}{0.199367B^7})\mathrm{ME}^t = 1.089719 + \mathrm{RME}^t$$

In sample: $N = 488$

$R^2 = 0.31849$

$\bar{R}^2 = 0.31285$

s.e. $= 4.05084$

$F = 56.43089$

[1]Using the concept of causality in the mean proposed by Granger (1969), fishing effort is said to "cause" CPUE if the mean squared forecasting error is less when the information set used for forecasting includes past values of both CPUE and effort than when the information set only includes past values of CPUE. In this application, if there is significant correlation between past value of prewhitened effort and present values of prewhitened CPUE, one tentatively identifies effort as "causing" CPUE. Note that the identification is only tentative and is relative to the particular information set used. With more information, the apparent causation might be eliminated. Two recent application papers discuss the finer details of causality testing and should be reviewed by interested practitioners: Ashley and Granger (1979), and Ashley et al. (1980).

The residuals from the estimated equations are the prewhitened variables. By construction, they approximately satisfy white noise criteria and with the estimated models contain the same information as the original data series. The next step in my analysis was to compute the cross-correlograms presented in Table 2. The correlograms show several interesting—and unexpected—relations between the series. I will first discuss the anchovy results and then the mackerel

With respect to anchovies, curiously, the only statistically significant correlations, besides at the zero lag, are at approximately ±1 week. A possible explanation for the significance of the −7 lag (ρ = 0.10742), is that the fishermen use more sophisticated forecasts based, perhaps, on additional information such as weather and lunar cycles. It does not seem reasonable that fishing a week ago improves fishing today while intervening fishing activity does not significantly affect CPUE. I propose that the −7 term reflects the fishermen's wider information set rather than a biological causal mechanism. The +6 and +7 lags are also significant: today's CPUE is positively correlated with fishing effort a week from now. This is consistent with the San Pedro fishermen's tendency to change nets at weekly intervals.

TABLE 2

$\mathrm{Corr}(RAE_{t+k}, RACPUE)$	N = 488 k =	$\mathrm{Corr}(RME_{t+k}, RMCPUE)$
0.10742	−7	0.01030
−0.03183	−6	−0.07330
−0.02469	−5	−0.06093
−0.01882	−4	0.04897
0.04895	−3	0.01888
−0.04371	−2	0.03568
0.08566	−1	0.17200
0.57756	0	0.37698
0.03401	1	0.13095
0.05562	2	0.03926
−0.01367	3	0.07514
0.05800	4	0.00360
−0.00516	5	−0.07646
0.12612	6	0.10683
0.10017	7	0.02349

95% critical value $\approx 2\sigma \approx \frac{2}{\sqrt{n}} = 0.09053$

The mackerel cross-correlations suggest a different explanation for that fishery. As with the anchovy, there is a significant positive correlation at about a week lead (ρ_6 = 0.10683), consistent with fishing effort transferring into the fishery after the usual week delay. However, there are two other statistically significant correlations, both positive and at ±1 day. The highly significant −1 lag (ρ_{-1} = 0.17200) is consistent with learning explanations and seems to refute short-term depletion hypotheses. The significant lag at +1 (ρ_1 = 0.13095) may be in response to the higher value of mackerel relative to anchovy: when mackerel CPUE seems to increase, more fishermen want to participate in the fishery.

As an additional experiment, I computed the cross species-effort/CPUE cross-correlations (Table 3). Besides the significant zero lag correlations, there was one other significant correlation in each cross-correlogram. The correlation between today's mackerel CPUE and the anchovy fishing effort 5 days hence is significantly negative (ρ_5 = −0.1049), perhaps reflecting the anchovy fishermen who stop fishing, change nets, and enter the mackerel fishery on lead 6 or 7 as seen above. The only significant nonzero lag correlation between mackerel effort and anchovy CPUE is at the −7 lag (ρ_{-7} = 0.1211). I have no story to explain why mackerel fishing a week ago is related to higher anchovy CPUE today.

TABLE 3

$\mathrm{Corr}(RAE_{t+k}, RMCPUE_t)$	N = 488 k =	$\mathrm{Corr}(RME_{t+k}, RACPUE_t)$
0.02707	−7	0.12110
−0.02909	−6	−0.07682
−0.08135	−5	0.02977
+0.01047	−4	0.00909
−0.01614	−3	0.03507
−0.02851	−2	0.03460
0.05008	−1	0.04919
0.20184	0	0.32219
0.04682	1	0.06772
0.02192	2	−0.06894
0.02107	3	0.04975
0.00281	4	−0.02038
−0.10490	5	−0.03269
0.04736	6	0.04031
0.05832	7	0.00545

95% critical value $\approx 2\sigma \approx \frac{2}{\sqrt{n}} = 0.09053$

CONCLUSION

The data suggest that there are statistically significant interactions between past values of fishing effort for mackerel and anchovy and the current values of mackerel and anchovy CPUE. Consequently, models of this fishery may need revision to reflect the underlying multiple species structure. An interesting area for future research would be to incorporate additional information into the underlying information set—especially spotter plane and meteorological data—to see if the cross-correlations remain significant.

ACKNOWLEDGMENTS

This research was performed at the National Marine Fisheries Service, Southwest Fisheries Center in La

Jolla, California. I would particularly like to thank Dr. Daniel Huppert for encouragement and helpful comments throughout the entire study.

LITERATURE CITED

Ashley, R. A., and C. W. J. Granger. 1979. Time series analysis of residuals from the St. Louis model. J. Macroeconomics 1(4):373-394.

Ashley, R. A., C. W. J. Granger, and R. Schmallensee. 1980. Advertising and aggregate consumption: an analysis of causality. Econometrica 48:1149-1167.

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

Granger, C. W. J. 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica 37:424-438.

Phillips, G. M. 1982. Regulatory issues in a multiple species fishery: the case of San Pedro. Ph.D. dissertation, University of California, San Diego.