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Comparisons of Time Series Models for the Forecasting of Albacore Commercial Harvest in the Indian Ocean

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ABSTRACT

Time series models were used and compared to forecast commercial catch of albacore in the Indian Ocean. Three time series models, i.e., auto-regressive integrated moving average (ARIMA), regression model with the ARIMA error (RAE) and transfer function noise (TN) models were built. Monthly catch was used as dependent variable and adjusted catch per unit effort (ACPUE) standardized by the general linear model was used as the independent variable in the RAE and TN models. Catch data 1969-1996 were used as the inner simulated period, and 1997 data were used in the outer forecasting period. Six statistical criteria, ME, MPE, MAE, MAPE, RMSE and RMSPE were used to evaluate the performance of the built models. The results indicate that three selected time series models can closely trace the pattern of the yearly periodicity and the fluctuation of the catch series. Time delay did not exist between the catch and the ACPUE series. The bivariate model (TN, RAE) used in the inner simulation and the ARIMA model used in outer forecasting seems sound by the individual comparison of the statistical criteria in the present study. For overall comparison the bivariate RAE model seems best among the three built time series models using in forecasting the albacore catch in the Indian Ocean, but a conservative prediction may be observed during forecasting using RAE.

Key words: *Time series analysis, ARIMA, Transfer Function, Albacore.*

INTRODUCTION

Using time series models to forecast fish population production is a powerful tool for the fishery analysts and managers. It is capable of deriving an appropriate benchmark using to control fishing efforts to maintain the stock and harvest at a viable level (Ulanowicz *et al.*, 1980) and can lead us to make a much more appropriate and direct management decision *in priori* than some other fishery parameters. Further in the recent, Rothschild *et al.* (1996) have introduced the application of time series analysis to fisheries population assessment and modeling.

Among the time series models, Box and Jenkin's time series analysis method (Box and Jenkin, 1976; Jensen, 1985) is the most popular one for the short-term forecast (Lin, 1992). Except the Box-Jenkin's model, autocorrelation analysis, Fourier spectral analysis and maximum entropy spectral analysis have been used for investigating the periodicity of striped bass (Van Winkle *et al.*, 1979). Transfer function noise model is used to stock-recruitment analysis of fishery resource (Noakes, 1987). Some time series models have been compared for the analysis of fishery data (Saila *et al.*, 1981), fishery dynamics (Mendelsohn, 1981; 1987; Liu and Jesen, 1992) and seafood consumption forecasting (Chen and Wang, 1994). Vector autoregression has been used in describing and forecasting the sardin-anchovy complex (Stergiou, 1991). Moreover, time series models have been found (Lin and Lee,

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1976; Stocker and Hilborn, 1981; Stergiou, 1990; Tsai and Chai, 1992; Stergiou and Christou, 1996; Tsai *et al.*, 1996) for uses in catch forecast of many marine and fresh-water species. Saila *et al.* (1980) compared the results of some time series models to analyze fisheries data. However, a few applications for the analysis of tunas and tuna-like species fishery data have been tackled.

Albacore (*Thunnus alalunga*) is one of the target species of tunas and tuna-like species for Taiwanese longline fleets from 1972 onward around the world (Yang, 1979). Particularly, about 90% of the albacore catch produced in the Indian Ocean have almost been taken by Taiwanese since then (Hsu and Liu, 1990).

In the Indian Ocean albacore is mainly exploited by longline, gillnet and purse seine gears. Commercial exploitation commenced in 1952 by the Japanese using longline gear, and then Korean and Taiwanese longline fishery participated on this exploitation in 1957 and 1963, respectively (Hsu and Liu, 1990). Taiwanese used gillnet to target immature albacore in the Indian Ocean from 1983 to 1992, and catch levels taken by gillnet from 1987 to 1992 superceded those made by longline gear. Therefore, Taiwan's fishery data can provide the main and unique frame data structure for any proper study of Indian albacore stock assessment.

Nonetheless, the population studies of albacore in the Indian Ocean are limited in biology and population dynamics. Those are the studies of length-weight relationship (Hsu, 1999), age and growth (Huang *et al.*, 1990), production models assessment (e.g., Chang, 1993; Hsu, 1995), yield per recruit analysis (Lee *et al.*, 1990), life parameters estimation (Chang *et al.*, 1993) and the virtual population analysis (Lee, 1991). However, time series model analysis herein used to forecast the stock production is the first attempt for this fishery. The time series models used in evaluation of a fish stock provide at least three advantages. Those are to consider the underlying stochastic structure of a dynamic system, to simulate the output series of a dynamic system for different sets of input data, and to provide short term forecast of the output variable of a dynamic system (Rothschild *et al.*, 1996).

Therefore, the present study is to use the time series methods for forecasting the albacore catch in term of abundance indices represented by catch per unit effort of Taiwanese longline fishery, which is the most significant fishery in the Indian Ocean (Hsu and Liu, 1990). While three different time series models were used, the results will be compared by error investigation in order to evaluate the appropriateness of using these models in forecast.

MATERIAL AND METHODS

1. Data used

The fishery-dependent data of Taiwanese longline fishery are composed of aggregated monthly 5x5 degree catch and effort series from 1967 to 1997. These data used in the current analysis were abstracted from the databases of Institute of Oceanography, National Taiwan University from 1967 to 1994, and from Oversea Fisheries Development Council (a funded organization of Council of Agriculture) for the rest. Total albacore catch in the Indian Ocean was adopted from Anon. (1997). The time series catch and effort data from 1968 to 1996 were used to build the models. Data for 1997 were used to attest the forecast from those models. Though it may take a risk on evaluating the model validity, we can achieve the objective of model comparison in using a longer time series data set to fit those models and using only 1997 actual catch for forecasting detection.

2. Standardization of catch per unit effort

The standardized abundance indices represented by catch per unit effort were pursued from nominal catch per unit effort (NCPUE), that is the catch divided by corresponding fishing effort, by means of general linear model (GLM) involving year, quarter, sub-area and target species factors. The GLM model is expressed by:

$$\ln(NCPUE+1)=\mu+Y_i+M_j+S_k+T_l+\varepsilon_{ijkl} \quad (1)$$

where the constant 1 was added into the nominal catch per unit effort in order to avoid logarithmic transformation of the zero catch. μ is the overall mean; Y_i is the year effect; M_j is the month effect; S_k is the sub-area effect; T_l is the target species effect; and error structure (ε_{ijkl}) of the current GLM was assumed simply as normal distribution with zero mean and σ standard deviation. Where the interaction terms among used factors were not considered and are lumped into the error term in the present study.

The dense distribution of albacore in the Indian Ocean locates between 15°S and 35°S. A dividend was made by 15°S to account for the spatial heterogeneity in according to the density (Lee, 1991; Chang, 1993). Moreover, to account for the target transferred from albacore to bigeye tuna in different space and time, the target species effect was considered by proportion being catch of albacore to the catch of bigeye tuna. As a consequence, the standardized CPUE was obtained, then, the effective effort was estimated by the catch divided by standardized CPUE. Furthermore, the monthly standardized CPUE (ACPUE) series was obtained by the monthly catch divided by the monthly effective effort.

3. Building of time series models

Three time series models were built with the abundance indices to identify their feasibility in short-term catch forecasting of albacore in the Indian Ocean. The first time series model is autoregressive integrated moving average model (ARIMA), the second is a regression model with ARIMA error model (RAE), and the third is transfer function noise model (TN). Different properties, postulates and constraints of those models can be referred to Box and Jenkins (1976), Wei (1990), Pole *et al.* (1994) and Power and Steele (1995). Among these models, the annual catches were used as dependent variable in corresponding with the standardized annual abundance indices. Seemingly, autocorrelation occurred among the annual abundance index, and the coefficient of autocorrelation was investigated to point out the time lag.

The ARIMA model is

$$Y_t = \frac{\theta(B)}{\phi(B)} a_t \quad (2)$$

The RAE model is

$$Y_t = X_t + \frac{\theta(B)}{\phi(B)} a_t \quad (3)$$

, and the TN model is

$$Y_t = \frac{\omega(B)}{\delta(B)} X_{t-b} + \frac{\theta(B)}{\phi(B)} a_t \quad (4)$$

where Y_t is the natural logarithmic transformation of catch series for month t; X_t is the natural logarithmic transformation of standardized catch per unit effort (ACPUE) for month t with b-month lags, $b = 1, 2, \cdots, k$; $\theta(B)$ is the moving average polynomial; $\phi(B)$ is the autoregressive polynomial; $\omega(B)$ is the nominate polynomial; $\delta(B)$ is the denominate polynomial, and a_t is an identical and independent error structure with normal distribution of zero mean and unit variance. Box and Jenkins (1976) and Lin (1992) provided the detailed procedures of model building for those time series models.

4. Models evaluation

The AIC (Akaike's Information Criterion) and SBC (Schwartz's Bayesian Criterion, Schwartz, 1978) were used to model selection to determine the orders. Moreover, when the time series model was selected, six criteria are computed to evaluate the appropriateness of models during models' simulation and forecasting. Those are mean error (ME), mean percentage error (MPE), mean absolute error (MABE), mean absolute percent error (MABPE), root mean square error (RMSE), and root mean square percent error (RMSPE).

Therefore, monthly catch data and standardized catch per unit effort from 1969 to 1996 were used as the inner period simulation, and those of 1997 were used for the outer period forecasting purpose. For stabilizing time series data of catches and abundance indices, natural logarithm was taken for these data before the analysis was done to avoid seasonal fluctuation and to reduce the variance (Jensen, 1985; Lin, 1992).

RESULTS

1. Standardized catch per unit effort series

The nominal catch per unit effort (NCPUE) was adjusted by general linear model (GLM, equation 1). The ANOVA table of fitting GLM was shown in Table 1, showing that 87% of the variability could be taken for the model (R^2=0.868). The results also indicated that more than half of the variability could explain the effect regarding to target species.

The trend of standardized catch per unit effort (ACPUE, illustrated in Fig. 1(a)) shows more stationary than that of NCPUE, and the periodical fluctuation is observed from ACPUE series more obviously. The effective fishing effort obtained from dividing catch by ACPUE indicated that the effective fishing effort departed from nominal fishing effort from 1985 afterward (Fig. 1(b)). This may explain that the fishing efforts directed to bigeye tuna other than albacore (say, deep longline effort) occurred from the year in 1985. The result evidenced that the ACPUE is able to represent the trend of albacore abundance in the Indian Ocean and is appropriate for the present analysis.

2. Auto-correlation and cross-correlation function analyses

The auto-correlation function (ACF) plot showed that one-lag auto-correlation and 12-lag seasonal auto-correlation catch were investigated between the natural logarithmic transformation of catches and ACPUE (Figs. 2(a) and 2(b)). Similarly, the cross-correlation function (CCF) showed that a simultaneous fluctuation was observed between natural logarithmic transformation for catches and ACPUE (Fig. 2(c)). However, the TN model does not consider the time delay effect.

3. Time series models

The three time series models were fitted as:

(1) The ARIMA model:

$$\ln(catch_t)(1-B^{12}) = \frac{(1-0.86B^{12})}{(1-0.67B)(1-0.19B^6)} a_t, \qquad (2')$$

where the fit of the ARIMA model gives that standard error (SE) is equal to 0.51, AIC is 521, and SBC is 536 on ARIMA (12,6).

(2) The RAE model:

$$\ln(catch_t)(1-B^{12}) = 1.04\ln(ACPUE_t)(1-B^{12})$$

Table 1. The ANOVA of standardizing catch per unit effort by the general linear model with the effects on year, month, sub-area and target species.

Sources	DF	Sum of squares	Mean square	F value	Pr>F
Model	43	29143.8659	677.7643	2549.58	0.0001
Year	30	3014.2471	100.4749	377.96	0.0001
Month	11	398.9610	36.2692	136.44	0.0001
Sub-area	1	14976.7813	14976.7813	56338.94	0.0001
Target Species	1	10753.8765	10753.8765	40453.42	0.0001
Error	16615	4416.8246	0.2658		
Corrected total	16658	33560.6905			
R-square	C.V.	Root MSE	CPUE mean		
0.8684	39.8235	0.5156	1.2947		

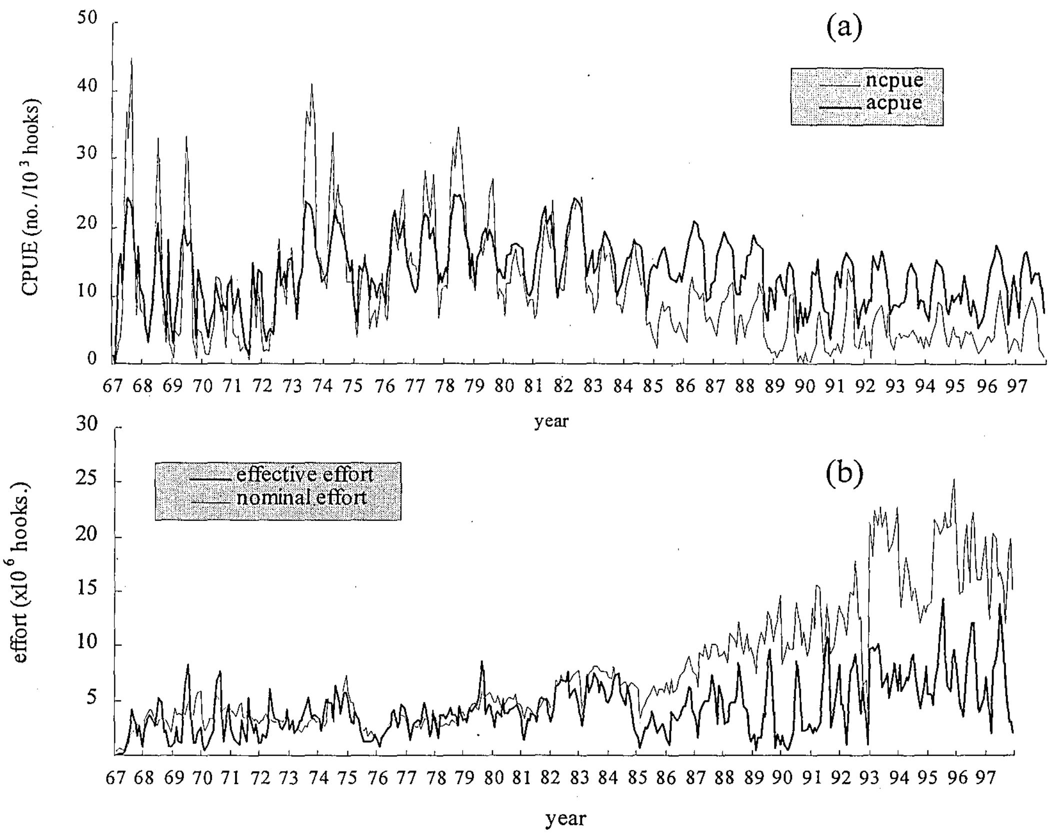

Fig. 1. The comparisons of (a) nominal and adjusted catch per unit effort (NCPUE vs. ACPUE, respectively); (b) nominal and effective fishing efforts during 1969-1996.

$$+\frac{(1\text{-}0.85B^{12})}{(1\text{-}0.63B)(1\text{-}0.21B^{6})}\,a_t, \qquad (3')$$

where the fit of the RAE model gives that SE is equal to 0.42, AIC is 394, and SBC is 410 on RAE(12,6).

(3) The TN model:

$$\ln(\text{catcht}_t)(1\text{-}B_{12})$$
$$= 0.03+1.04\ln(\text{ACPUE}_t)(1\text{-}B^{12})$$
$$+\frac{(1\text{-}0.93B^{12})}{(1\text{-}0.63B)(1\text{-}0.21B^{6})}\,a_t, \qquad (4')$$

where the fit of the TN model gives that SE is equal to 0.41, AIC is 390, and SBC is 409 on TN(12,6).

The 12-month difference was used to eliminate the seasonal effect of the time series after taking natural logarithm. The disturbance terms were identified with one-month and 6-month auto-regressive polynomial and 12-month moving average polynomial. The TN model did not consider the time delay effect as stated previously.

Fig. 3 indicates the residual distributions of the three fitted models. The residual frequency illustrates that the normal distribution seems met for fitted by ARIMA as the model errors were assumed as NID $\sim(0,\sigma^2)$. In contrast, the residuals for fitted by RAE and TN seem not fixed the assumption that the errors follow normal distribution. Nonetheless, we consider that those three models be acceptable with large deviations for the representing monthly catch of albacore in the Indian Ocean.

4. Models evaluation

The expected catches obtained from

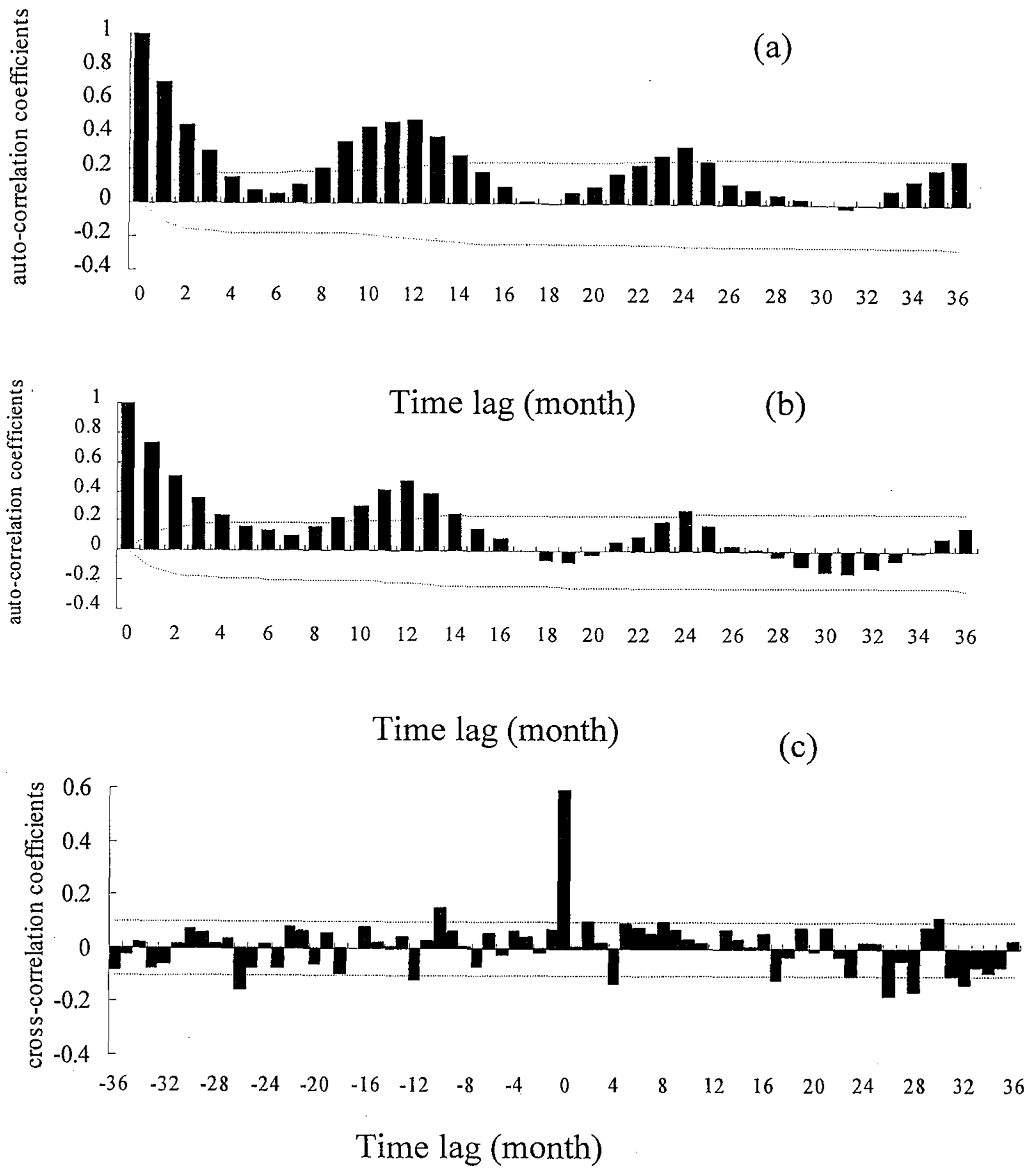

Fig. 2. Auto-correlation plots of the (a) catch and the (b) adjusted catch per unit effort (ACPUE) series and the (c) cross-correlation plot of the pre-whitened ACPUE and catch series. The series all have been taken natural logarithm and dot lines indicate 95% confidence interval.

inner simulation for 1969-1996 and outer forecasting for 1997 using the three fitted models are illustrated in Fig. 4 in comparison with the observed catches. The comparison indicates that the catch trends from those three models are very similar and all follow the observed ones.

The evaluation criteria of the inner simulation and outer forecasting for the selected time series models are obtained as Table 2 in the present analyses. It was apparent that in average the simulations fitted better for the inner period than the outer period forecasting for those models.

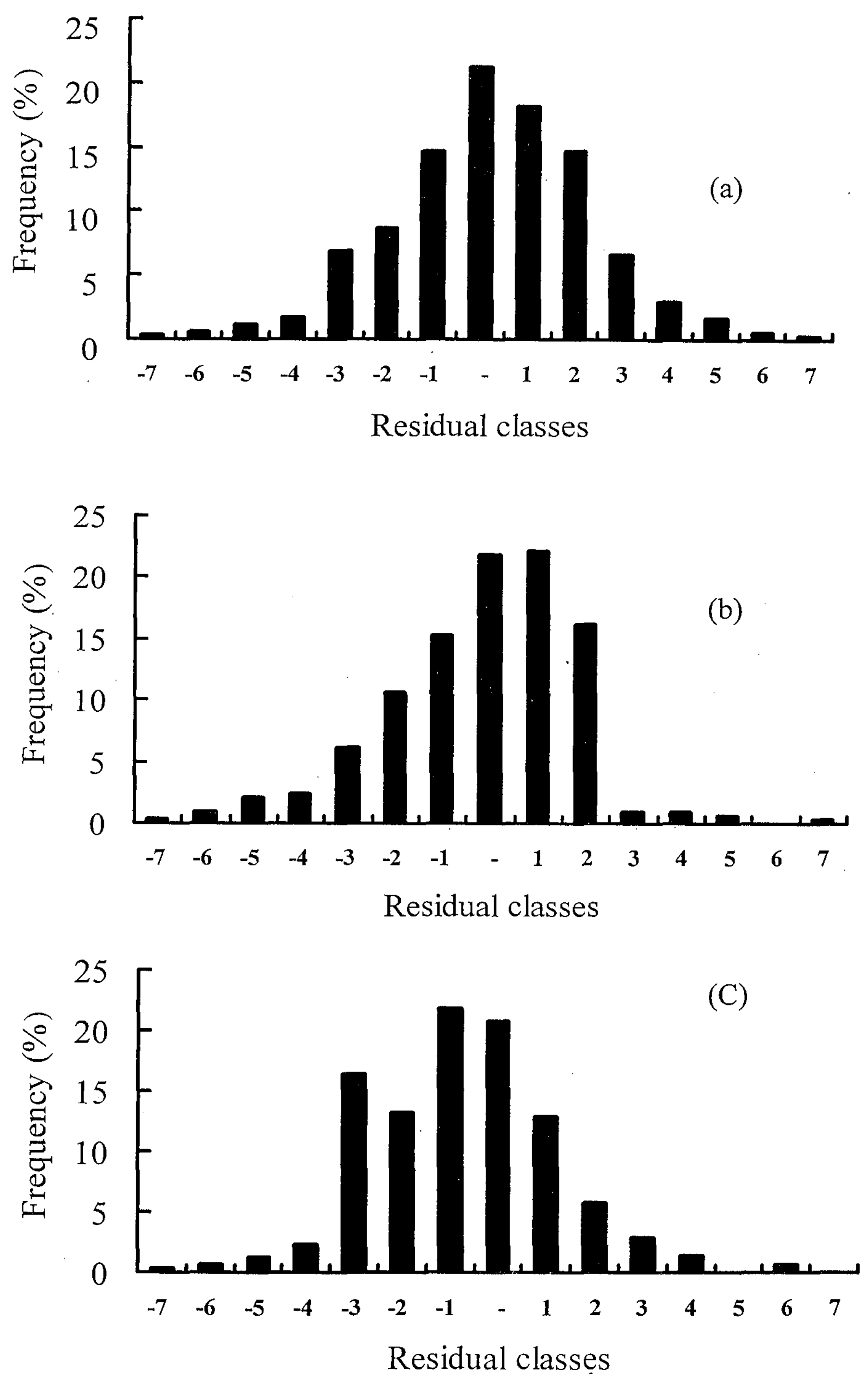

Fig. 3. The residual frequency distributions of the three fitted models to illustrate the NID (0, σ^2) assumption for those models with the catch data of albacore in the Indian Ocean. The residuals (scaled by 1000) are estimated by the differences of the predictions from (a) ARIMA model, (b) RAE model and (c) TN model and observed catches.

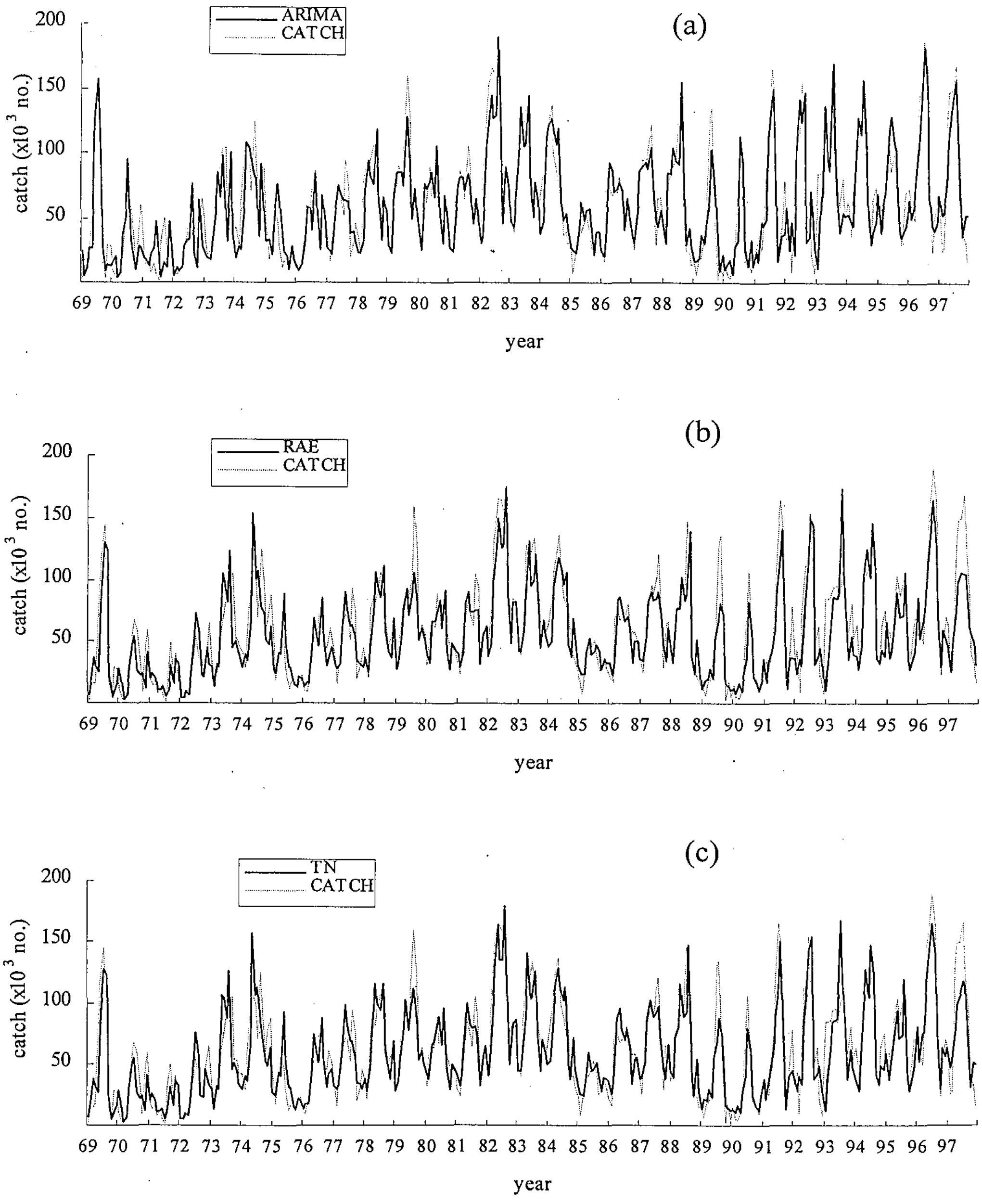

Fig. 4. The inner simulation (1969-1996) and the outer forecasting (1997) for the three time series models, (a) ARIMA, (b) RAE and (c) TN vs. the actual catches.

For the inner simulation, the results of three kinds of mean errors (ME, MABE and RME) indicate that TN model is fitted better than the others. However, the results of percent errors (MPE, MABPE and RMSPE) show that RAE is the best fit with smallest percent error among the three models. For the outer forecasting, the results of three mean errors depict that ARIMA is the best fit with the smallest errors among the three models. But it is similar to the results of inner simulation, RAE could provide the

Table 2. The six statistical test criteria for the inner simulation and the outer forecasting of the three built time series models.

Model	ME	MPE (%)	MABE	MABPE (%)	RMSE	RMSPE (%)
ARIMA						
Simulation	2203.93	-19.6001	15863.63	47.3840	20965.36	116.0050
Forecast	1508.02	-32.7135	21437.09	51.9141	25794.83	82.3095
RAE						
Simulation	5118.64	-6.1850	15052.14	34.8849	20301.86	59.5741
Forecast	17549.51	-4.1214	29224.75	40.7452	34390.06	47.4004
TN						
Simulation	2591.19	-11.3611	14964.71	36.0573	20075.77	62.9824
Forecast	12390.00	-20.5996	29111.10	54.3331	33171.06	77.0233

smallest percent deviation in forecasting.

DISCUSSION

1. Standardized catch per unit effort (ACPUE) and effective fishing effort

Though the current ACPUE was displayed as monthly basis, the results of standardized ACPUE obtained in the present study show discrepancies with those made by Chang (1993) and Hsu (1995) that the ACPUE was also derived by GLM algorithm. This may come from that in the present study only the fishing efforts directed to albacore are considered to derive the ACPUE, but not in the reported previously. As the consequence, the slope of the ACPUE during the period between 1984 and 1991 tends to most slightly decrease among the three derived series represented for periods 1968-1983, 1984-1991 and 1992-1997, respectively.

Furthermore, the effective fishing effort series (Fig. 1(b)) was calculated based on the new derived ACPUE. The effective fishing effort series has departed significantly from the nominal series since 1985. This result could be attributed to the introduction of deep longline fishing type. Lin *et al.* (2000) has evidenced the importance of partitioning fishing efforts for different fishing types before standardization has been made. The results of ACPUE and effective fishing effort derived from the present study have achieved this purpose.

2. Time series model building

The ACF analysis indicated that the logarithm of ACPUE and catch itself show positive auto-correlation with 12-month lag for the time series data (Figs. 2(a) and 2(b)). This result evidences in advance that the albacore fishing for Taiwanese longline fishery in the Indian Ocean apparently has seasons of heavy and light operation (Hsu and Liu, 1990; 1991). Also the cross-correlation between logarithm of ACPUE and catch illustrates a high correlation among the corresponding data (Fig. 2 (c)). Therefore, the ACF was not normalized as shown in Fig. 2(a) and Fig. 2(b), that the periodical fluctuation (with 12-month cycle) seems coincident for the tendency between ACPUE and catch. This also indicates that the ACPUE may represent the abundance and the catch is related to the abundance index (ACPUE) as shown in the albacore fishery in the Indian Ocean.

Three selected functions are applicable in the present analysis. Among those models, the RAE and TN have very similar expression in function with very close statistics (see RESULTS section for the detail). For the RAE and TN models, an identical and independent distribution for error structure term, i.e., a_t, is necessary, besides, the dependence between variables X_t and a_t

should be satisfactory to delineate the colinearity (Lin, 1992). The pre-whiting term is not as significant as expected. Thus, The pre-whiting X_t term in the TN model was made such that the results of RAE and TN models were similar to use the albacore catch and ACPUE data in the present study. Therefore, the eligibility in using RAE and TN models to forecast the catch of albacore in the Indian Ocean is the same.

3. Simulation and forecasting

Commonly there are several adequate models that can be used to represent a series (Wei, 1990). The ultimate choice of a model may depend on the AIC (Akaike, 1976), and SBC (Schwartz, 1979) in the present study. And the inner simulation and outer forecasting are evaluated by the goodness of fit (the residual mean square). Although the AIC tends to overestimate the order of autoregression (Shibata, 1976) and BIC (Bayesian Information Criterion, Akaike, 1978; 1979) is less likely to overestimate the order, we use AIC and SBC as the evaluation criteria herein. This is because the AIC and SBC are much more irrespective than standard error (SE) somewhat in selecting the best model.

Our main purpose herein the present study is to forecast albacore catch values in a short-term future period. Therefore, in the present study, we used AIC and SBC for the best model selection, then, six criteria regarding to residual mean squares were used an alternative criteria for attesting simulation and forecasting errors. The orders of three models are selected as in equations (2'), (3') and (4'). Those models were used to simulate internally and to forecast externally the catch data. There are in discrepancies of the results between evaluation by mean errors and by mean percent errors. Our favorite choice is to consider the result by mean percent errors, because an additive normal error was assumed. Thus, the RAE may be the best choice to use in forecasting the albacore catch in the Indian Ocean. Furthermore, the result of residual analysis showed that the RAE had the most skewness appearance among the three resultant models. The RAE equation may be in violation of the error assumption the most. The forecasting by RAE may cause a large deviations with much more conservative (predicted low catch) than the others. This is the reason why we consider RAE is the favorite one.

Usually the bivatiate models provide more forecasting information than univariate ones (Lin, 1992), but it is much more parsimonious in parameter estimation for the univariate models than bivariate ones. How to select a best time series model to forecast catch is pretty tricky for a short-term prediction of the fish production. First of all, a good and accurate catch and effort should be required. Next, the forecast is not very reliable for long term prediction. The forecasts are usually statistically valid only for the next season of an output series, due to increasing prediction error as the forecasts continue into the future (Rothschild *et al.*, 1996). Cryer (1986) also presents a detail discussion of forecast and associated prediction error estimation procedure. We used time series models to forecast continuously 12 months albacore production, this operation may cause the large errors obtained in the present analysis. And the white noises may exist in either catch or catch per unit effort that may not be eliminated sufficiently by means of standardization. All of those should be investigated in future for appropriately using time series models to predict a short term fish production.

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印度洋長鰭鮪商業性漁獲預測之時序列模式的比較

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本研究比較不同時間序列模式用來預測印度洋長鰭鮪之漁獲量。以月別漁獲量爲因變數及經一般線性模式法校正後的月別單位努力漁獲量爲自變數，建立三類時間序列模式，分別爲：自我回歸整合移動平均模式、回歸模式涵自我回歸整合移動平均誤差項及轉換函數模式。月別漁獲量序列分別以 1968-1996 年爲內部模擬區間及 1997 年爲外部預測區間。六種統計決策值分別用來比較三類模式的預測能力。

結果顯示，三類時間序列模式皆能模擬漁獲量序列的年內季節變動性和年間的震盪，且時間延遲並不存在於月別漁獲量和其相對的月別標準化單位努力漁獲量之間。個別的統計誤差決策值比較顯示，在內部模擬區間，雙變量模式略優於單變量模式；在外部預測區間，單變量模式則較優於雙變量模式。但全部統計百分誤差決策值比較之下，雙變數之回歸模式涵自我回歸整合移動平均誤差項則在預測印度洋長鰭鮪漁獲量上似較優於單變數之自我回歸整合移動平均模式，但具有較保守的預測值。

關鍵詞：時間序列分析，自我回歸整合移動平均模式，轉換函數模式，長鰭鮪。

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