APPLICATION OF AN INTEGRATED VERSION OF FOX'S MODEL TO THE YELLOWFIN AND BIGEYE TUNA FISHERIES

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SUMMARY

This paper explores a simple non-equilibrium approach to the Fox production model with a linear fitting procedure. The model was applied to data on yellowfin and bigeye tuna fisheries. A formulation of the model and fitting procedure is provided. This integrated versions of the Fox model performs well on the data used, providing realistic biological parameter estimates, and seems to be a valuable management tool for these fisheries.

RESUME

Le présent document explore une approche simple en conditions de non équilibre au modèle de production de Fox, avec un processus d'ajustement linéaire. Le modèle a été appliqué à des données sur les pêcheries d'albacore et de thon obèse. Une description du modèle et du processus d'ajustement est fournie. Cette version intégrée du modèle de Fox fonctionne bien avec les données utilisées, fournit des estimations réalistes des paramètres biologiques, et semble être un outil intéressant pour la gestion de ces pêcheries.

RESUMEN

Este documento explora un enfoque simple de no equilibrio al modelo de producción de Fox, con un procedimiento de ajuste lineal. El modelo se aplicó a datos de las pesquerías de rabil y patudo. Se facilita una formulación del modelo y procedimiento de ajuste. Esta versión integrada del modelo Fox funciona bien con los datos usadas, facilitando estimaciones realistas de parámetros biológicos y parece un valioso instrumento de ordenación para estas pesquerías.

1. INTRODUCTION

The models based on the analysis of the annual catch-effort time series are traditionally known as surplus production models. Production models may take several possible forms and the literature contains several proposed, improvements and generalisation of this kind of models (Schaefer, 1954,1957; Pella and Tomlinson 1969; Fox 1970; Walter and Hilborn 1976; Schnute 1977, 1985; Deriso 1980; Uhler 1980; Csirke and Caddy 1983; Roff 1983; Lleonart and Salat 1989; Prager 1994).

A major issue in parameter estimation with production models is whether to assume equilibrium condition and use the simple, usually linear, estimators or assume nonequilibrium condition and use more complex, often nonlinear, dynamic estimators. Equilibrium assumption is rarely satisfied and usually leads to a biased parameter estimates (Mohn 1980, Hilborn 1992).

Dynamic estimators have been derived for the Schaefer and the Pella and Tomlinson production models (Pella and Tomlinson 1969, Schnute 1977). Both require nonlinear estimation methods, but for the Schaefer model, the dynamic estimator has a good linear approximation (Schnute 1977). This author points out that a problem with his model is that the predicted variable, $\overline{U}_{i+1}$, appears on both sides of the regression equation and is not clear which term should be regressed on ($\ln(\overline{U}_{i+1} / \overline{U}_i)$ or $(\overline{U}_{i+1} + \overline{U}_i /2)$).

Clarke et al (1992), with a similar approach of Schnute model, developed a dynamic estimator version for the Fox model, termed Integrated Fox model (IFox). This is a simple logarithmic autoregressive model that regress Ln(Ui) on Ln(Ui-1) and effort.

The purpose of this paper is to examine the usefulness of the IFox model and to gauge its utility in providing realistic assessment for yellowfin and bigeye tuna fisheries. The results should not be considered as an analysis of the actual status of those stocks.

2. METHODS

General formulation for this integrated model is provided in the appendix A. The fitting procedure suggested by Yoshimoto and Clarke (1993) is used (appendix B).

Catch and effort data, from ICCAT (1994), were used for YFT and catch and effort data provided by Pereira (pers. comm.) were used for bigeye (Table 1). For both stocks is considered the hypothesis of a single stock in the entire Atlantic.

3. RESULTS AND DISCUSSION

The results for each stock are given in the same format. The observed data used in the assessments are presented in Table 1 and the estimates of a number of management-related quantities from the assessment method in Table 2. The stability of some of this parameters was test, applying the bootstrap method and results are presented in Table 3. For each stock two figures (Fig. 1 and 4) are provided showing the catch-rate time series with the fits obtained from the estimation method and catch effort data with the equilibrium catch-effort curve obtained from the IFox model. Note that because the lack of freedom the IFox model, which have 1 year time lag, could not obtained estimates of cpue (UP) for the first four years. Predictions for the years 1973-92 and 1965-92 were obtained for YFT and BET respectively. Additional figures are provided showing the prediction error on cpue (Fig. 2) and the estimates of r, q, and K (Fig. 3).

For the first years of data the estimates of r, k and q for BET and K and q for YFT are unrealistic, negative values, for both stocks (Fig. 3), but despite this fact the model predicted cpue accurately (Fig 1). The percent prediction errors, for both stocks, (Fig. 2) suggest that the model is an accurate predictor (<20% error for UP and <30% for UPC). According to Theil's U-statistic test the model is considered useful for forecasting purposes (Theil's U-statistic = 0.544 for YFT and 0.39 for BET).

Considering the regression on all years of data, the model provided positive and reasonable biological parameters and biological reference points (Table 2). The results of the bootstrap analysis (Table 3) suggest that those parameters are stable, low variability.

According to this assessment the fishery for both stocks is considered approximately fully exploited with the actual effort and catch close to the optimal values (Table 1 and 2, Fig. 4). This results are quite similar to those obtained at 1993 SCRS (ICCAT, 1994).

4. CONCLUSION

The model performs well to the data used, providing realistic biological parameters estimates, and passed the Theil's U-statistic when predicting cpue. The model seems to be a valuable management tool for these fisheries.

The assessment of this stocks by ICCAT has been based on effort-averaging method of Fox (1975) and observation error method, ASPIC (Prager, 1992). The effort-averaging and processor error methods have been criticised in the literature as usually leading biased and imprecise parameter estimates (Roff and Fairbain 1980, Polacheck et al 1993). An observed error structure can be applied to the IFox model and the author has work in progress. However, from this analysis, there appears no reason why IFox should not be applied to yellowfin and bigeye tuna fisheries.

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APPENDIX A

MODEL FORMULATION

Under the condition that exploitation occurs, the instantaneous rate of change of the stock biomass can be described by the general differential equation:

$$1/B\ dB/dt = g(B_i) - F_i \qquad (1)$$

where 1/B dB/dt is the instantaneous rate of change in biomass, $g(B_i)$ the instantaneous rate of natural growth and $-F_t$ the instantaneous rate of removal by fishery.

For a given interval Ti (Ti=ti+1-ti), during which Fi remain constant, we can compute the change in biomass from one point ti to another ti+1, integrating (1):

$$\mathrm{Ln}\ Bi+1 - \mathrm{Ln}\ Bi = \int_{ti}^{ti+1} g(Bi)\ dt - Fi\ Ti \qquad (2)$$

Consider the approximation $\overline{g(B)}\ Ti = \int_{ti}^{ti+1} g(Bi)\ dt$ and $\overline{g(Bi)} = g(\overline{B})$ equation (2) can be written as:

$$\mathrm{Ln}\ Bi+1 - \mathrm{Ln}\ Bi = g(\overline{B})\ .\ Ti - Fi\ .Ti \qquad (3)$$

where $\overline{B}$ is a mean biomass during the time interval Ti, and Bi and Bi+1 are instantaneous values of the biomass at the beginning period t+1 and t, respectively. Since such instantaneous values are typically not observed in the data, it is useful to make $\overline{B}i$ as the geometric mean of the instantaneous biomass at the beginning of period t and t+1, as approximations suggested by Schnute (1977), then:

$$2\ \mathrm{Ln}\ \overline{B}i = \mathrm{Ln}\ Bi + \mathrm{Ln}\ Bi+1 \qquad (4)$$

If (3) is added for years Ti and Ti+1, during which Ti=Ti+1=T=constant, we obtain:

$$\mathrm{Ln}\,\overline{B}i+1 - \mathrm{Ln}\overline{B}i = \frac{T}{2}.\left[g(\overline{B}i) + g(\overline{B}i+1)\right] - \frac{T}{2}.\left[Fi + Fi+1\right] \tag{5}$$

Cadima (pers. comm.) points out that equation (5) can be considered as a very general equation of the integrated models of Schaefer (Schnute 1977) and Fox (Yoshimoto and Clark 1993).

For the basic Fox model has been proposed for the instantaneous rate of natural growth, $g(\overline{B}t)$, a function of the form:

$$g(\overline{B}t) = r\,\mathrm{Ln}\,\frac{K}{\overline{B}t} \tag{6}$$

Substitution of (6) in (5), after a little algebraic manipulation, gives:

$$\mathrm{Ln}\,\overline{B}i+1 = \frac{2Tr}{2+Tr}\,\mathrm{Ln}\,K + \frac{2-Tr}{2+Tr}.\mathrm{Ln}\,\overline{B}i - \frac{T}{2+Tr}.(Fi+Fi+1) \tag{7}$$

By adopting the common assumption that $\overline{B}i = \frac{\overline{U}i}{q}$ and FiTi=q.fi, we transform (7) into terms of indices of biomass and effort, or:

$$\mathrm{Ln}\,\overline{U}i+1 = \frac{2Tr}{2+Tr}\,\mathrm{Ln}(qK) + \frac{2-Tr}{2+Tr}.\mathrm{Ln}\,\overline{U}i - \frac{q}{2+Tr}.(fi+fi+1) \tag{8}$$

Equation (8) can be used to obtain three parameters by regression of one variable on two:

$$\mathrm{Ln}(\overline{U}i+1) = b_1 + b_2.\mathrm{Ln}(\overline{U}i) - b_3.(fi+fi+1) \tag{9}$$

where:

$$r = \frac{2(1-b_2)}{(1+b_2)} \qquad q = -\frac{4b_3}{1+b_2} \qquad K = -\frac{(1+b_2)}{4b_3}.e^{\frac{b_1}{(1-b_2)}} \tag{10}$$

and the CPUE for year i+1 can be obtain by:

$$U_{i+1} = e^{(b_1+b_2\ln(Ui)-b_3\,(f_i+f_{i+1}))} \tag{11}$$

APPENDIX B

FITTING THE MODEL

1 - IFox approach make annual predictions for year i using only information prior that year. Ordinary least squares regression is applied using catch and effort data for the first i-1 year's and estimates the parameters r, q and k, for year i, using the results of that regression. A prediction of the cpue is made for year i+1, with (11).

A regression is then performed for the first i years for the prediction of year i+1, and this procedure is continued until a prediction is made for the last year of available data of the fishery.

2 - The predicted (UP) and observed (Ui) cpue are compared to determine the predicted power:

$$100.\ |Ui - UPi|/Ui$$

3 - The predictive ability of the model is tested by using Theil's U-statistic (UT):

$$UT = \sqrt{\frac{\sum_{i=k}^{N}(Ui-UPi)^2}{\sum_{i=k}^{N}(Ui-Ui-1)^2}}$$

4 - Biological reference points are estimated using the biological parameters r, q and K, (Cadima 1992), from the regression of all years of data for a fishery.

5 -The stability of the parameters is test using the bootstrap method with resampled residuals (Efron and Tibshirani ,1986).

Yoshimoto et Clarke (1993) proposed the Durbin-h-statistic and Durbin-t-statistic test for detection of autocorrelation and Cochrane-Orcutt procedure for autocorrelation correction, for the estimation of the biological parameters. The author run this tests for YFT and BET as suggested. Since no autocorrelation was detected, the results have been ignored here by simplicity.

Table 1 - Catch, effort and catch-rate data for YFT and BET considered for the assessments

YEAR	YFT CATCH (1000 MT)	YFT EFFORT (fish. days)	YFT CPUE	BET CATCH (1000 MT)	BET EFFORT (10 hooks)	BET CPUE
61				17	164	0.1
62				23	254	0.09
63				26	267	0.1
64				24	270	0.09
65				39	477	0.08
66				25	221	0.11
67				25	312	0.08
68				23	245	0.09
69	93	12.8	7.24	34	508	0.07
70	73	15.9	4.6	41	592	0.07
71	73	18	4.07	55	845	0.07
72	94	17.5	5.34	46	816	0.06
73	95	18.3	5.18	56	758	0.07
74	107	22.6	4.72	64	965	0.07
75	125	24.8	5.04	61	1047	0.06
76	123	26.6	4.63	45	900	0.05
77	129	25.2	5.11	54	701	0.08
78	131	26.1	5	52	744	0.07
79	125	30.5	4.11	45	620	0.07
80	125	34.5	3.63	63	803	0.08
81	151	38.8	3.88	67	1175	0.06
82	160	49.2	3.25	74	1257	0.06
83	160	55.6	2.88	60	1037	0.06
84	111	50.2	2.22	69	1201	0.06
85	149	41.7	3.58	74	1293	0.06
86	134	33	4.07	59	1092	0.05
87	135	36	3.74	49	781	0.06
88	128	36.8	3.48	58	978	0.06
89	154	30.4	5.07	68	1459	0.05
90	173	36.8	4.71	71	1544	0.05
91	166	55.4	3.01	71	1613	0.04
92	152	52.6	2.89	72	1579	0.05

Table 2. Estimates of a number of management quantities obtained by the IFox model for YFT and BET.

	r	q	K	YMAX	Bmax	Fmax	Umax	tmax	Y0.1	B0.1	F0.1	U0.1	t0.1
YFT	2.62	0.043	160	154.52	58.86	2.63	2.53	61	150.44	73.24	2.05	3.15	48
BET	3.59	0.0019	53.69	70.85	19.75	3.59	0.04	1878	68.98	24.58	2.80	0.05	1468

Table 3. Bootstrap estimates of the means, standard deviations (SD) and coefficients of variation (CV) of parametrs and biological reference points for YFT and BET, when applying the IFox model

	Mean	SD	CV
		YFT	
r	2.84	1.0817	0.38
q	0.0467	0.0183	0.39
K	166.447	55.665	0.33
YMAX	155.43	10.116	0.07
Fmax	2.84	1.0817	0.38
Bmax	61.23	20.478	0.33
tmax	61.63	7.9904	0.13
Umax	2.54	0.1178	0.07
		BET	
r	3.93	1.70	0.43
q	0.002	0.0009	0.44
K	56.65	20.99	0.37
YMAX	71.07	2.96	0.04
Fmax	3.93	1.70	0.43
Bmax	20.84	7.72	0.37
tmax	1890	132.42	0.07
Umax	0.04	0.0013	0.03

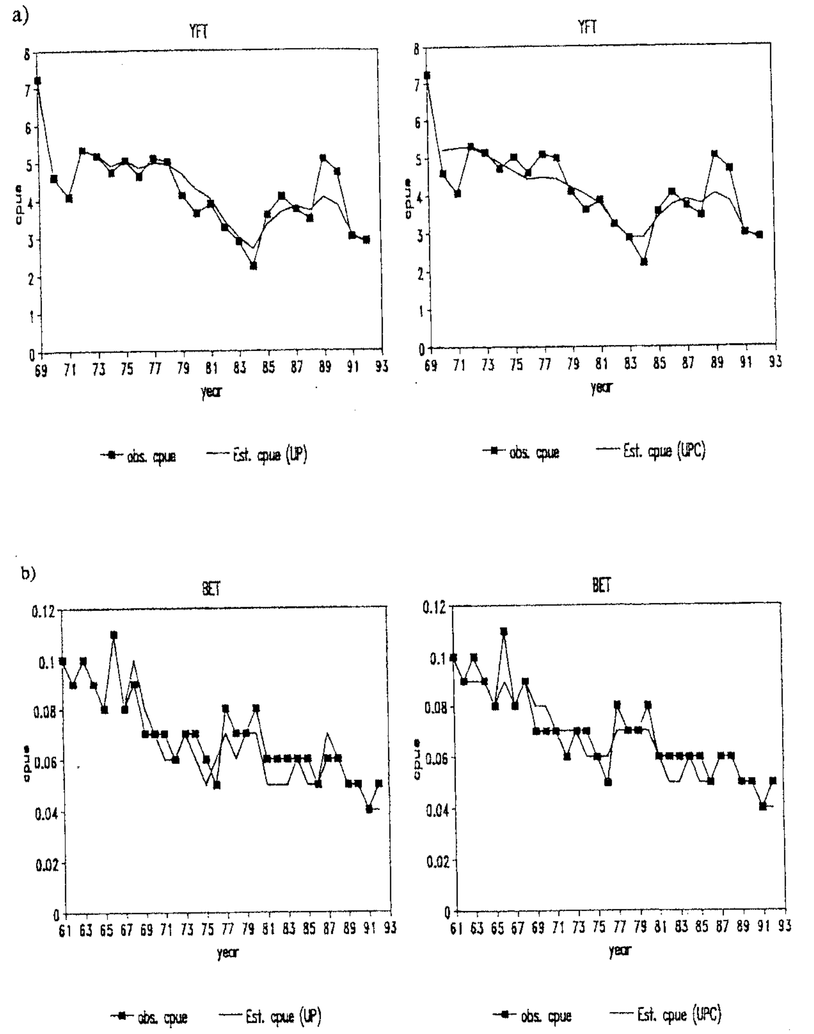

FIG. 1. Catch rate time series for a) yellowfin and b) bigeye tuna with the fits obtained from IFox model.
UP - Predicted cpue using parameters from the regression on the i years prior that one
UPC - Predicted cpue using parameters from the regression performed on all years of data avaible.

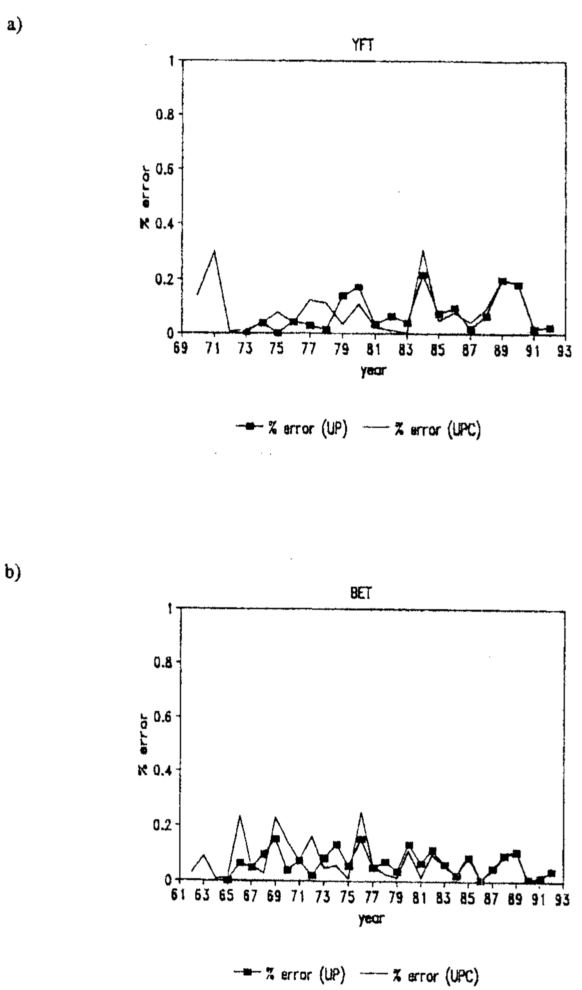

FIG. 2. Prediction error on cpue (%) estimated by IFox model for a) YFT and b) BET.

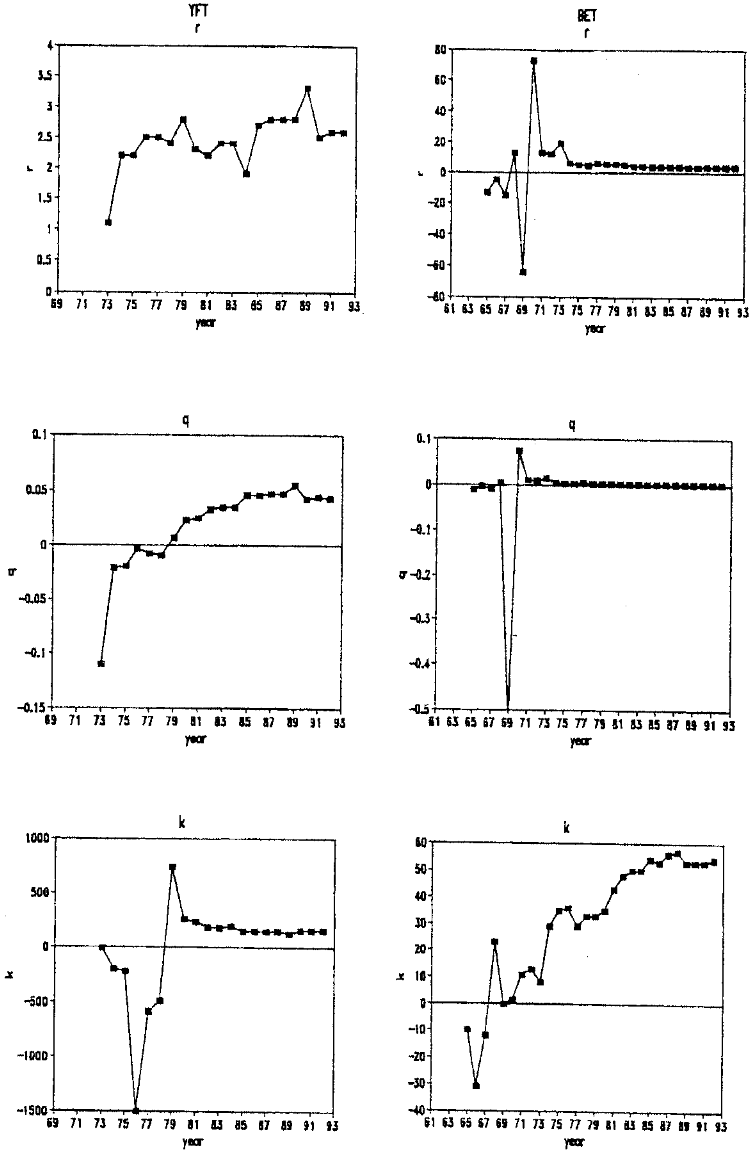

FIG. 3. Estimates of r, q, and K obtained from IFox model for YFT and BET

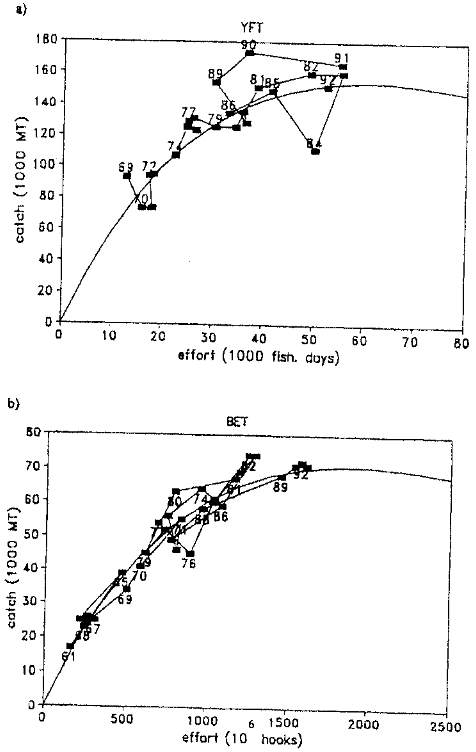

FIG. 4. Catch and effort data for a) YFT and b) BET with the equilibrium catch-effort curve obtained from IFox model