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Nonequilibrium Production Model of Yellowfin Tuna in the Central and Western Pacific

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Introduction

Western Pacific yellowfin tuna are caught by the purse seine, longline, and pole and line fleets of distant-water fishing nations (DWFNs) and Pacific Island Countries. The yellowfin are also caught by ringnet, purse seine and handline in the Philippines and by pole and line in eastern Indonesia (SPC 1990). The total catch (Figure 1) has increased from 90,916 MT in 1970 to 394,704 MT in 1992 (WPYRG 1994). Hampton and Lewis (1993) mentioned that the yellowfin tuna catch has almost doubled in the last ten years, with most of the increase occurring since 1988. This rapid increase in catch has caused concern about the status of the stock.

The most recent appraisal of the yellowfin stock using an equilibrium production model was performed by Suzuki et al. (1989). Hampton (1992) and Hampton and Lewis (1993) assessed the current yellowfin status by using tag attribution models. The purpose of this paper is to assess the yellowfin stock status by using a nonequilibrium stock-production model, ASPIC (A Surplus-Production model Incorporating Covariates) (Prager 1991, 1992, 1993, 1994).

Data Sources and Analysis Method

The total catches by country and by year for the period 1970-1992 were obtained from WPYRG (1994). The data used for standardized effort are shown in Table 1.

Because the effort must be standardized before being input into the ASPIC production model, each of the six effort data sets were standardized individually by the general linear model (GLM), which was similarly used by Sun and Yeh (1993a, 1993b, 1994). The main effect variables were year, month and area.

Do them separately

Because ASPIC allows multiple data-series with different units to be incorporated during fitting, a total of nine data-series were constructed. Each data series represented one of the following categories of fishery: Japanese longline, Taiwanese longline, all other longline, Japanese purse seine, Taiwanese purse seine, U.S. purse seine, all other purse seine, Japanese pole and line, and all other pole and line.

The category "all other longline fisheries" included those countries for which the effort data was unavailable. Countries represented by this category included Korea, Philippines, Indonesia, et cetera. The combined countries' effective effort was determined by use of the formula

$$f_i = \frac{\sum_{j=1}^{k} Y_{ij}}{CPUE_i}$$

where Y_{ij} is the yearly catch of each fishery j of the k country and $CPUE_i$ is the standardized CPUE of Taiwanese longline fishery for year i. This estimate was coupled with ΣY_i and was used in the construction of this separate data-series.

The category "all other purse seine fisheries" included the countries Korea, Philippines, Russia, et cetera. The combined countries' effective effort was calculated by means of the same model as mentioned above, but the $CPUE_i$ used was the standardized CPUE of the Japanese purse seine fishery.

The category "all other pole and line fisheries" included the countries of Indonesia, Papua New Guinea, et cetera. These combined countries' effective effort was also calculated using the above formula, but the $CPUE_i$ used was that of the Japanese pole and line fishery.

These nine data-series were compiled separately, and each consisted of the total catch and effective effort of its respective category. The complete data-series were input into ASPIC simultaneously. The model then estimated the following management benchmarks (Prager 1991, 1992, 1993, 1994):

MSY	maximum sustainable yield
B_{MSY}	stock biomass at MSY
F_{MSY}	fishing mortality at MSY
$F_{0.1}$	management benchmark
$Y_{0.1}$	equilibrium yield at $F_{0.1}$
B-ratio	ratio of B_t to B_{MSY}
F-ratio	ratio of F_t to F_{MSY}

Also, a bootstrapping procedure of 1000 trials was used independently to assess the variability of the estimated parameters, adjust for estimation bias and compute approximate bias-corrected confidence intervals according to the method of Efron and Gong (1983).

Results and Discussion

The model and management parameter estimates (Table 2) from ASPIC were:

r =1.49/year,
K =1,800,000 MT,
MSY =670,700 MT,
B_{MSY} =900,000 MT,
F_{MSY} =0.745, .062/mo.
$F_{0.1}$ =0.671, and
$Y_{0.1}$ =664,000 MT.

The computed ordinary and bias-corrected point estimates of MSY (Table 3) were 670,700 MT and 675,100 MT, respectively, with an 80% confidence interval of 481,700-700,000 MT. The total mortality rate (Figure 2) increased slowly and steadily from 0.076 in 1972 (the annual values of the first two years, 1970 and 1971, were omitted due to extreme imprecision) to 0.261 in 1992. This figure is still far below the model's F_{MSY} of 0.745.

Figure 3 shows the trajectory of the point estimates of relative biomass (B_t/B_{MSY}) which decreased slowly and steadily in the past two decades. (The first five years were omitted due to extreme imprecision). In Figure 4, the trajectory of the point estimates of relative fishing mortality (F_t/F_{MSY}) indicates the trend is a stable and slow increase. (The first two years are once again omitted due to extreme imprecision.) The bias-corrected point estimates of relative biomass and fishing mortality, along with the nonparametric 80% confidence intervals from the bootstrapping procedure of 1000 trials are shown in Figures 5 and 6.

Based on the above analyses, the conclusions are optimistic. The current status of the yellowfin tuna stock in the western Pacific appears to be a state of moderate exploitation.

Strictly meeting all assumptions in production modeling is rarely successful. However, as mentioned by Prager (1992), the ASPIC framework provides a flexible format for production modeling. Other than its inherent flexibility, the ASPIC approach exhibits at least three strong advantages: (1) It is a true non-equilibrium model. (2) The model retains true population persistence. (3) The model does not form a regression between two quantities (i.e. effort and CPUE). In addition, as noted by Christopher and Farber (1994), ASPIC allows for multiple data series with different effort units to be incorporated simultaneously during fitting, and the model can also handle missing data points from one or more series. Because the ASPIC modeling is realistic and practical, we should continue to use this technique as one of the means for monitoring the status of stocks of the western Pacific yellowfin tuna.

Acknowledgements

We would like to thank Gary Sakagawa and Al Coan of the SWFSC for releasing the US purse seine data, and Ziro Suzuki of the NRIFSF for authorizing SPC to release the Japanese data. Thanks are also extended to Antony Lewis and Peter Williams of SPC, who helped in distributing the Japanese data.

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Table 1. Data sources and contents used in the ASPIC production model analysis for the western Pacific yellowfin. All the data are in the form of year, month and 5°x5° unit area.

Country	Gear type	Period	Type of effort	Type of catch	Source*
Japan	Longline	1981-92	hooks	no. of fish	SPC[1]
	Purse seine	1970-92	days	weight (MT)	SPC[1]
	Pole and line	1981-91	days	weight (MT)	SPC[1]
Taiwan	Longline	1967-92	hooks	no. of fish	NTU
	Purse seine	1983-92	days	weight (MT)	SPC & NTU
US	purse seine	1988-92	days	weight (MT)	SWFC

* SPC[1]: Released by South Pacific Commission under the authorization of Dr. Suzuki (NRIFSF)
NTU: National Taiwan University.
SPC: South Pacific Commision.
SWFC: Southwest Fisheries Science Center.

Table 2. Estimated management parameters and benchmarks for the ASPIC production model fitted to nine fisheries for yellowfin tuna in the Central and Western Pacific Ocean.

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate
B1R	Biomass ratio in 1970	3.587E-01
K	Maximum stock biomass	1.800E+06
r	Intrinsic rate of increase	1.490E+00
....	Catchability coefficients by fishery:	
q(1)	Simulated Fishery #1 -- Taiwan longline	4.887E-08
q(2)	Simulated Fishery #2 -- Japan longline	4.911E-08
q(3)	Simulated Fishery #3 -- Other longline	4.265E-08
q(4)	Simulated Fishery #4 -- Taiwan purse seine	1.059E-06
q(5)	Simulated Fishery #5 -- Japan purse seine	5.053E-07
q(6)	Simulated Fishery #6 -- US purse seine	2.547E-06
q(7)	Simulated Fishery #7 -- Other purse seine	7.540E-07
q(8)	Simulated Fishery #8 -- Japan pole and line	9.698E-08
q(9)	Simulated Fishery #9 -- Other pole and line	9.587E-08

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	
MSY	Maximum sustainable yield	6.707E+05	
Bmsy	Stock biomass at MSY	9.000E+05	
Fmsy	Fishing mortality at MSY	7.452E-01	
F(0.1)	Management benchmark	6.707E-01	
Y(0.1)	Equilibrium yield at F(0.1)	6.640E+05	
B-ratio	Ratio of B(1993) to Bmsy	1.665E+00	
F-ratio	Ratio of F(1992) to Fmsy	3.503E-01	
....	Fishing effort at MSY in units of each fishery:		
fmsy(1)	Simulated Fishery #1 -- Taiwan longline	1.525E+07	f(0.1) = 1.372E+07
fmsy(2)	Simulated Fishery #2 -- Japan longline	1.518E+07	f(0.1) = 1.366E+07
fmsy(3)	Simulated Fishery #3 -- Other longline	1.747E+07	f(0.1) = 1.573E+07
fmsy(4)	Simulated Fishery #4 -- Taiwan purse seine	7.036E+05	f(0.1) = 6.332E+05
fmsy(5)	Simulated Fishery #5 -- Japan purse seine	1.475E+06	f(0.1) = 1.327E+06
fmsy(6)	Simulated Fishery #6 -- US purse seine	2.925E+05	f(0.1) = 2.633E+05
fmsy(7)	Simulated Fishery #7 -- Other purse seine	9.883E+05	f(0.1) = 8.895E+05
fmsy(8)	Simulated Fishery #8 -- Japan pole and line	7.684E+06	f(0.1) = 6.916E+06
fmsy(9)	Simulated Fishery #9 -- Other pole and line	7.773E+06	f(0.1) = 6.996E+06

Table 3. Estimated management parameters and benchmarks for the ASPIC production model fitted to nine fisheries for yellowfin tuna in the Central and Western Pacific Ocean. The bootstrapped results were based on 1000 trials.

RESULTS OF BOOTSTRAPPED ANALYSIS

Param name	Bias-corrected estimate	Ordinary estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Inter-quartile range	Relative IQ range
B1ratio	3.475E-01	3.587E-01	3.22%	2.321E-01	5.384E-01	1.475E-01	0.424
K	1.821E+06	1.800E+06	-1.16%	1.800E+06	1.800E+06	2.263E+01	0.000
r	1.464E+00	1.490E+00	1.82%	9.565E-01	1.609E+00	3.031E-01	0.207
q(1)	4.383E-08	4.887E-08	11.50%	3.944E-08	5.358E-08	8.247E-09	0.188
q(2)	4.390E-08	4.911E-08	11.84%	3.422E-08	5.643E-08	1.100E-08	0.250
q(3)	3.856E-08	4.265E-08	10.62%	3.130E-08	4.587E-08	7.670E-09	0.199
q(4)	9.594E-07	1.059E-06	10.40%	6.981E-07	1.251E-06	2.871E-07	0.299
q(5)	4.642E-07	5.053E-07	8.85%	3.951E-07	5.502E-07	7.810E-08	0.168
q(6)	2.338E-06	2.547E-06	8.98%	1.691E-06	3.097E-06	7.137E-07	0.305
q(7)	6.771E-07	7.540E-07	11.35%	5.861E-07	8.233E-07	1.085E-07	0.160
q(8)	8.756E-08	9.698E-08	10.77%	6.887E-08	1.129E-07	2.229E-08	0.255
q(9)	8.634E-08	9.587E-08	11.05%	7.093E-08	1.115E-07	2.248E-08	0.260
MSY	6.751E+05	6.707E+05	-0.65%	4.817E+05	7.000E+05	9.503E+04	0.141
Bmsy	9.105E+05	9.000E+05	-1.16%	8.999E+05	9.000E+05	1.131E+01	0.000
Fmsy	7.319E-01	7.452E-01	1.82%	4.782E-01	8.047E-01	1.515E-01	0.207
fmsy(1)	1.675E+07	1.525E+07	-8.98%	1.340E+07	1.954E+07	3.284E+06	0.196
fmsy(2)	1.679E+07	1.518E+07	-9.60%	1.279E+07	2.218E+07	5.019E+06	0.299
fmsy(3)	1.921E+07	1.747E+07	-9.02%	1.493E+07	2.310E+07	3.985E+06	0.207
fmsy(4)	7.708E+05	7.036E+05	-8.73%	5.746E+05	1.069E+06	2.615E+05	0.339
fmsy(5)	1.598E+06	1.475E+06	-7.70%	1.280E+06	1.933E+06	3.231E+05	0.202
fmsy(6)	3.195E+05	2.925E+05	-8.44%	2.216E+05	4.529E+05	1.034E+05	0.324
fmsy(7)	1.081E+06	9.883E+05	-8.61%	8.821E+05	1.268E+06	2.035E+05	0.188
fmsy(8)	8.466E+06	7.684E+06	-9.23%	6.391E+06	1.127E+07	2.355E+06	0.278
fmsy(9)	8.570E+06	7.773E+06	-9.30%	6.521E+06	1.068E+07	2.405E+06	0.281
F(0.1)	6.587E-01	6.707E-01	1.63%	4.304E-01	7.242E-01	1.364E-01	0.207
Y(0.1)	6.683E+05	6.640E+05	-0.65%	4.769E+05	6.930E+05	9.408E+04	0.141
B-ratio	1.668E+00	1.665E+00	-0.21%	1.508E+00	1.680E+00	5.534E-02	0.033
F-ratio	3.471E-01	3.503E-01	0.92%	3.329E-01	5.337E-01	6.447E-02	0.186
f0.1(1)	1.508E+07	1.372E+07	-8.08%	1.206E+07	1.758E+07	2.955E+06	0.196
f0.1(2)	1.511E+07	1.366E+07	-8.64%	1.151E+07	1.996E+07	4.517E+06	0.299
f0.1(3)	1.728E+07	1.573E+07	-8.12%	1.344E+07	2.079E+07	3.586E+06	0.207
f0.1(4)	6.938E+05	6.332E+05	-7.86%	5.171E+05	9.623E+05	2.353E+05	0.339
f0.1(5)	1.438E+06	1.327E+06	-6.93%	1.152E+06	1.740E+06	2.908E+05	0.202
f0.1(6)	2.875E+05	2.633E+05	-7.60%	1.994E+05	4.076E+05	9.303E+04	0.324
f0.1(7)	9.733E+05	8.895E+05	-7.75%	7.939E+05	1.141E+06	1.832E+05	0.188
f0.1(8)	7.619E+06	6.916E+06	-8.31%	5.752E+06	1.014E+07	2.119E+06	0.278
f0.1(9)	7.713E+06	6.996E+06	-8.37%	5.869E+06	9.615E+06	2.164E+06	0.281

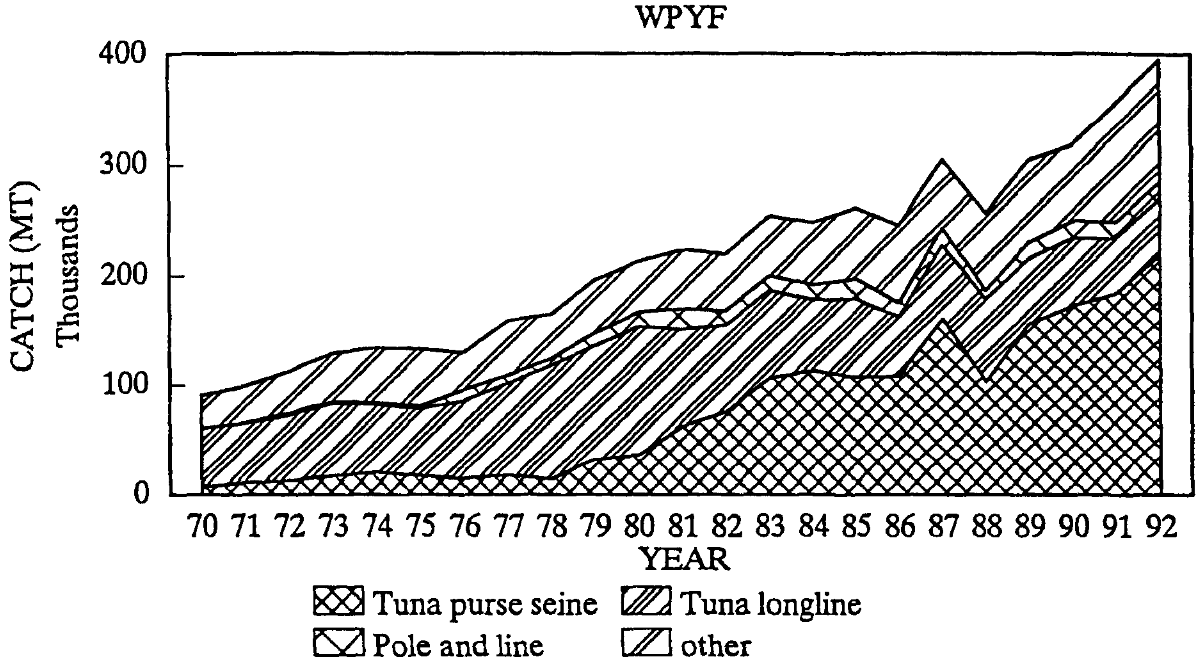

Figure 1. Total catch by gear of yellowfin tuna from the western Pacific Ocean, 1970-92.

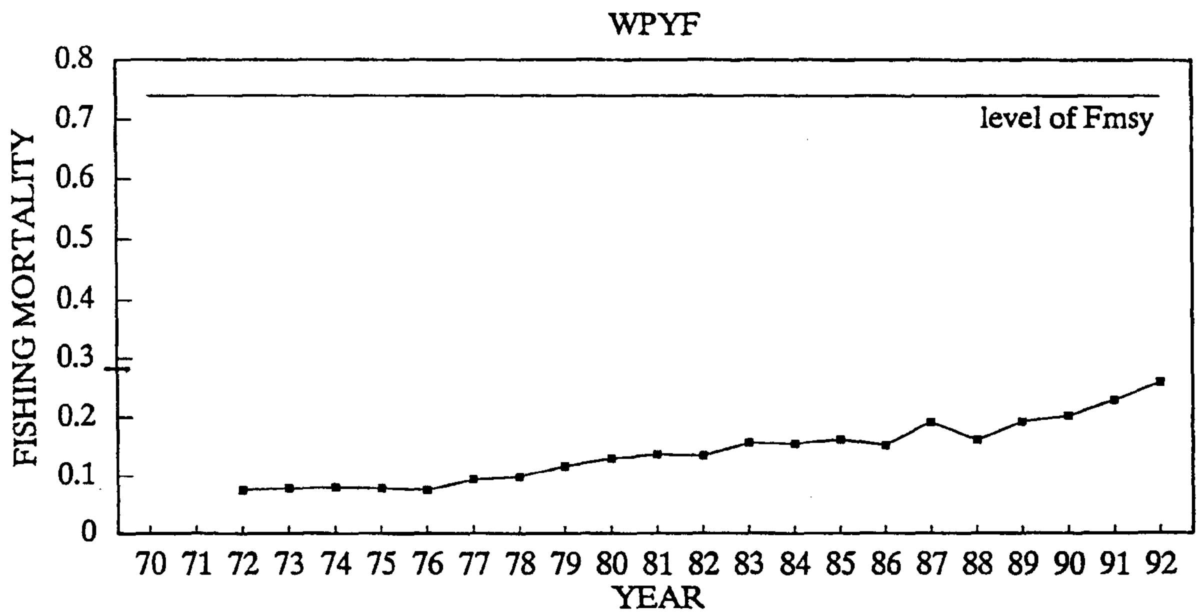

Figure 2. Estimated annual total fishing mortality from the fitted ASPIC model.

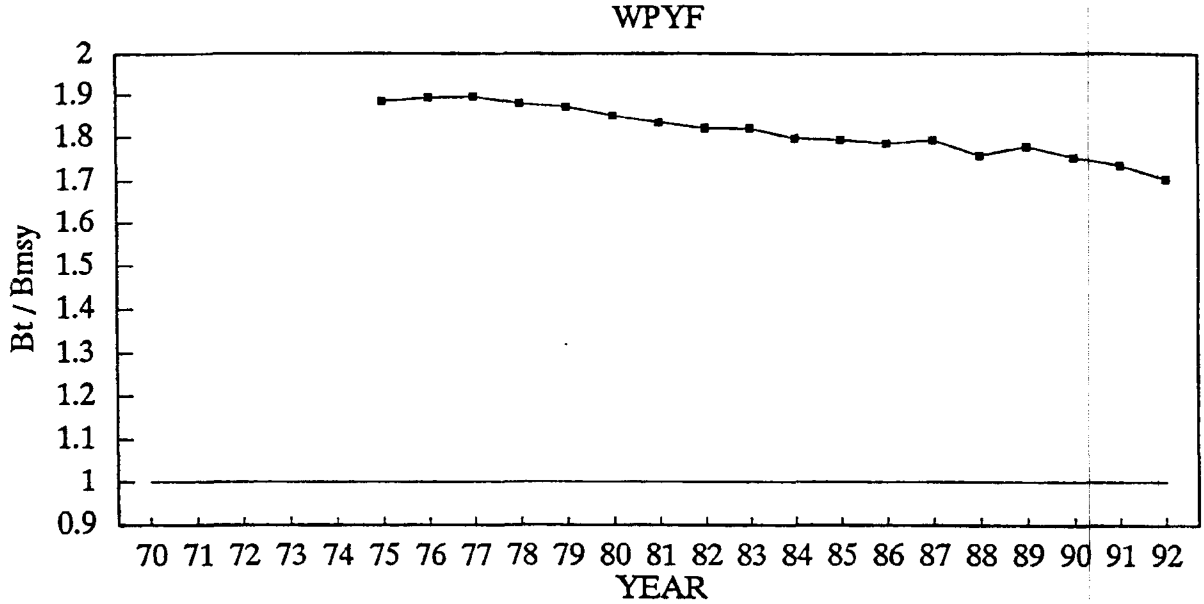

Figure 3. Annual relative biomass ($=B_t/B_{msy}$) from the fitted ASPIC model. Annual values for the first five years are omitted due to extreme imprecision.

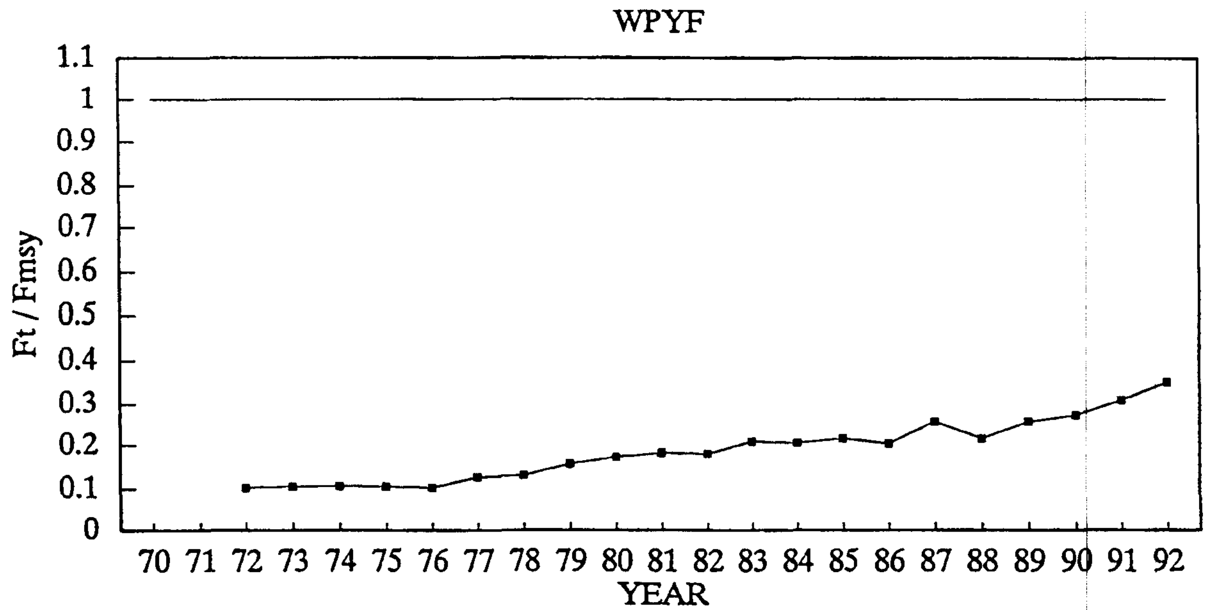

Figure 4. Annual relative fishing mortality ($=F_t/F_{msy}$) from the fitted ASPIC model. Annual values for the first two years are omitted due to extreme imprecision.

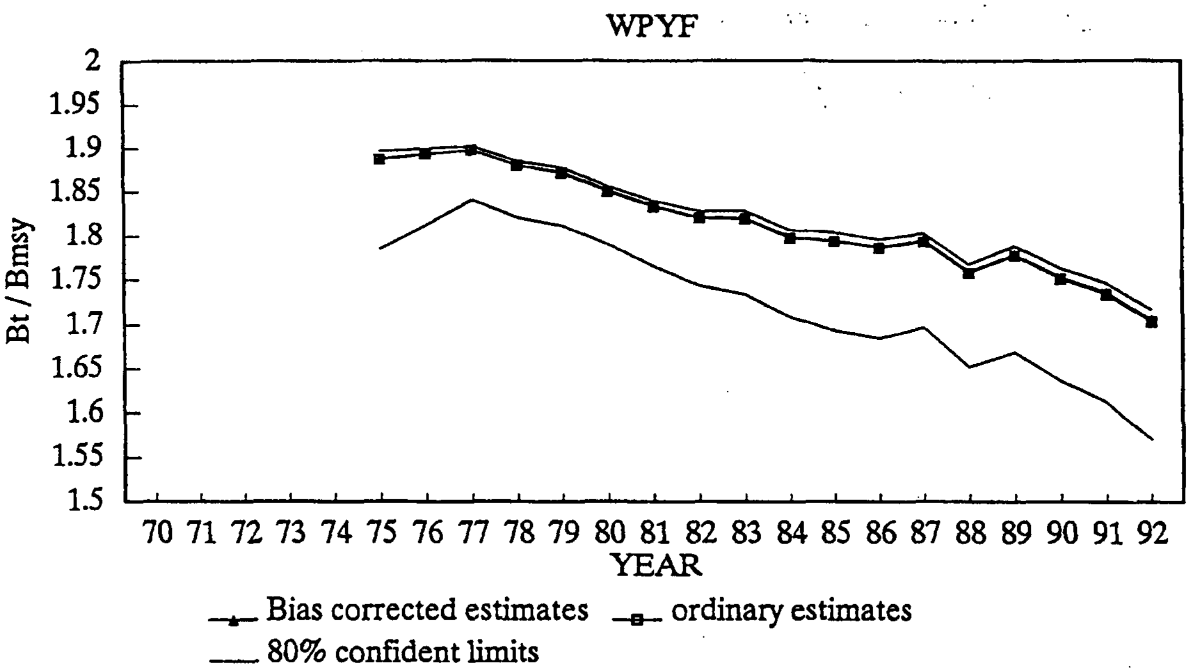

Figure 5. Bootstrapped annual relative biomass from the fitted ASPIC model. Confidence intervals are based on 1000 trials. Annual values for the first five years are omitted due to extreme imprecision.

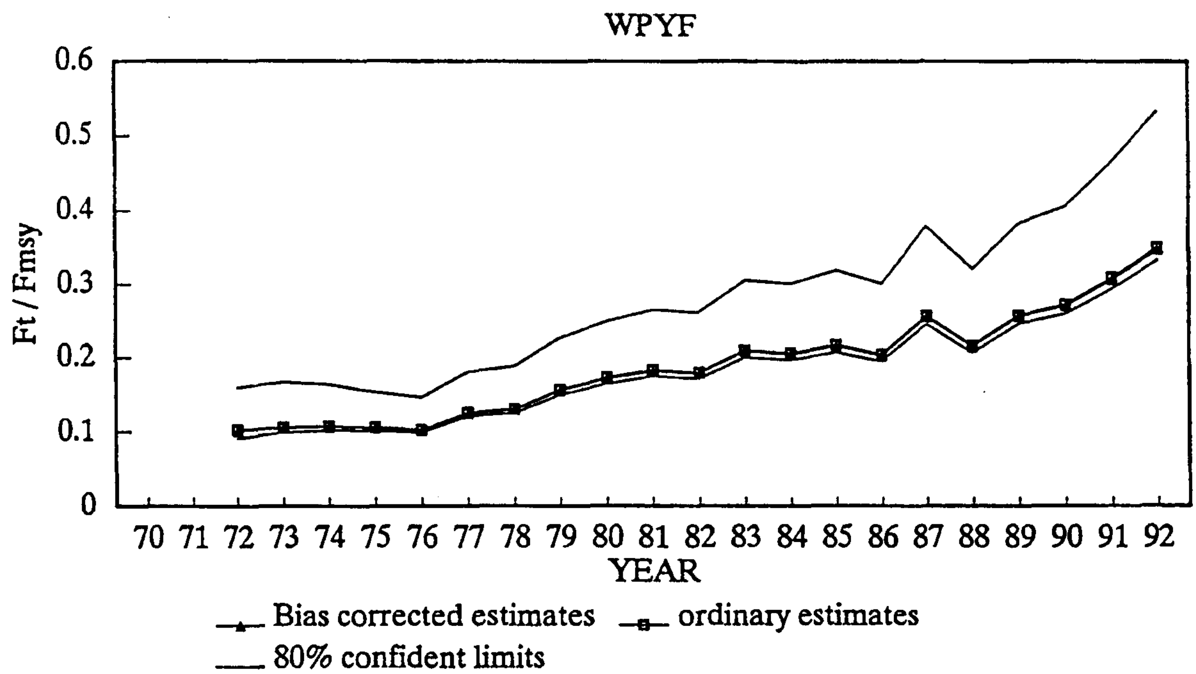

Figure 6. Bootstrapped annual relative fishing mortality from the fitted ASPIC model. Confidence limits are based on 1000 trials. Annual values for the first two years are omitted due to extreme imprecision.