Stock assessment of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean by the age structured production model(ASPM) analyses

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Abstract

We attempted to assess yellowfin tuna (*Thunnus albacares*) (YFT) using the data for 46 years from 1960-2005 by the age-structure production model (ASPM). We use ASPM as the basic method because it was recommended as the optimum approch for the tropical tuna stock assessments in the Indian Ocean during the IOTC ad hoc Working Party on Methods (WPM) meeting at the IRD, Sète, France 23-27, April, 2001. We assumme that YFT in the Indian Ocaen is a single stock.

Contents

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1. Introduction

In this paper, we attempted to assess yellowfin tuna (*Thunnus albacares*) (YFT) using the age-structure production model (ASPM) as the basic method because this approach was recommended as the optimum approach for the tropical tuna stock assessments in the Indian Ocaen in the IOTC ad hoc working party meeting on methods held in IRD, Sète, France 23-27, April, 2001 (Anonymous, 2001). We assumme that YFT in the Indian Ocaen is a single stock.

2. Data

We use YFT catch and size data by country (area), gear, year and season for 46 years from 1960-2005, which were from the IOTC's updated database.

3. ASPM

ASPM have been used in assessments carried out by the International Commission for the Conservation of Atlantic Tunas (ICCAT) in the past, particularly for albacore tuna (*Thunnus alalunga)* in the south Atlantic and bluefin tuna (*Thunnus thynnus*) in the western Atlantic.

Conceptually, ASPMs fall somewhere between simple biomass-based production models (e.g., Schaefer 1957; Prager 1994) and the more data-demanding sequential age-structured population analyses (Megrey, 1989). Typically, simple production models estimate parameters related to carrying capacity, rate of productivity, biomass at the start of the time series, and coefficients that scale indices of abundance to the absolute magnitude of biomass. ASPMs estimate similar parameters but make use of age-structured computations internally, rather than lumped-biomass ones, and directly estimate parameters of a stock-recruitment relationship. Their main advantage over simpler production models is that they can make use of age-specific indices of relative abundance.

In this paper, we used the ASPM software developed by Victor Restrepo (1997) called as ASPMS (stochastic version of ASPM). The detail formation of the ASPM is provided in Appendix A.

4. Period for the ASPM analyses

Although we have 5.5 decades of the data (1950-2005), we use the data for 4.5 decades of the data (1960-2005). The reason to use 4.5 decades of the data are as follows: The fishing grounds in the first decade (1950's) are very limited (Fig. 3), which bring the large CPUE in limited & high concentrated YFT waters. Thus CPUE in inconsistent area (first one decade and the latter 4.5

decades) are statistically not comparable. This problem also brought the missing cells in the CPUE standardization thus we could not get the parameters in the GLM in the past. In addition the q (catchability) has been improving in the past 5.5 decades thus we need to use the recent data to reduce biases by heterogeneities q values. By the same reason we also attempted two newer periods, (a) 48 years (1968-2005) (as from1968 Taiwan CPUE are available) and (b) 26 years (1980-2005).

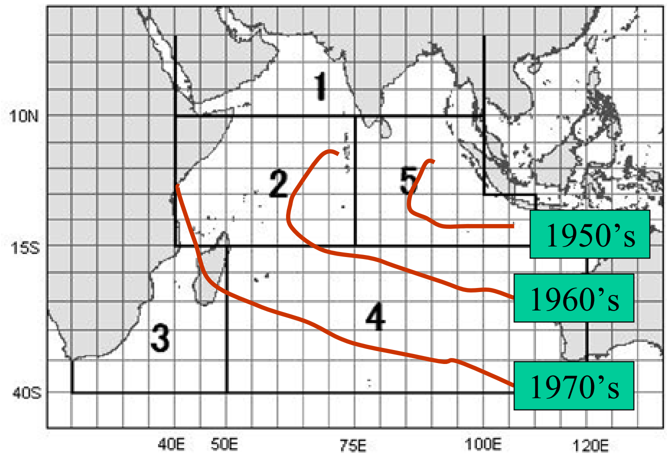


Fig. 3 Evolution of the Japanese LL fishing grounds by decade.

4. INPUT for the ASPM

There are three types of the age specific input data required for the ASPM, i.e., Biological parameters, Catch with selectivity and Index (CPUE). In our YFT ASPM analyses, we use six age classes from age 0-5+.

4.1 Biological parameters

For Biological parameters, three types of age-specific inputs are needed, i.e., natural mortality (M), weights (beginning and mid of the age) and fecundity. <u>As an initial attempt, we use agreed parameters used in the 2005 assessments as below:</u>

(1) Natural mortality vector (M)

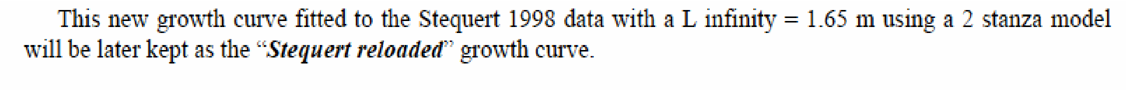
Table 1 M vectors

age	0	1	2	3	4	5	6+
M vector	0.8	0.6	0.6	0.6	0.6	0.6	0.6

(2) Weights at the beginning and the middle of the age

To estimate these parameters, we use the following growth curve and the L-W relationship:

Growth curve

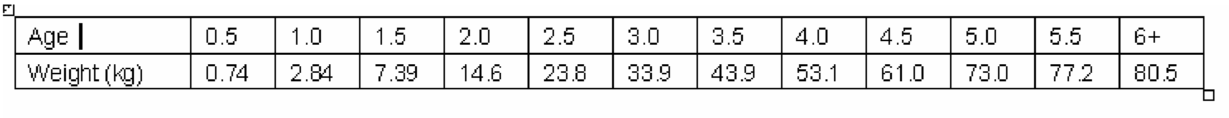

This new growth curve fitted to the Stequert 1998 data with a L infinity = 1.65 m using a 2 stanza model will be later kept as the “*Stequert reloaded*” growth curve.

L-W relationship

$$W=1.585*10^{-5} L^{3.045}$$

As results, we obtained Age-L-W key as shown in Table 2.

Table 2 YFT age-length-weight keys in the Indina Ocaen



Age	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6+
Weight (kg)	0.74	2.84	7.39	14.6	23.8	33.9	43.9	53.1	61.0	73.0	77.2	80.5

(3) Maturity and Fecundity

We assume that fecundity is proportional the body weights at the middle of each age and also assume 0 fecundity (maturity) for age 0-1, 50% for age 2 and 100% for age 3-5+. Table 3 summarizes this information.

Table 3 Maturity and fecundity of YFT in the Indian Ocean

age	0	1	2	3	4	5	6+
M vector	0.8	0.6	0.6	0.6	0.6	0.6	0.6
Fecundity	0	0	23.8	43.9	61.0	73.0	80.5

4.2 Catch

There are many gear types to exploit YFT in the Indian Ocean. We classified into four classes i.e., LL (longline), PS (purse seine), GILL (gillnet) and BB_TROL (pole & line and troll together) because each gear type catch different age classes (Fig. 4). Fig 5 shows the catch by gear for 51 years from 1950-2005.

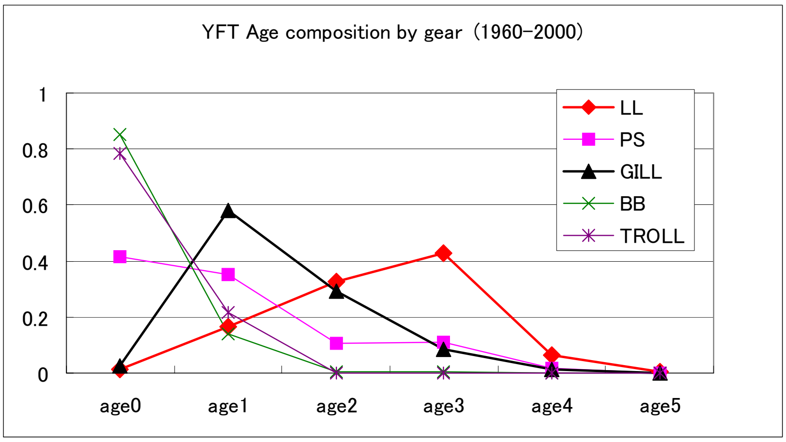


Fig. 4 Age compositions by 5 gear types.

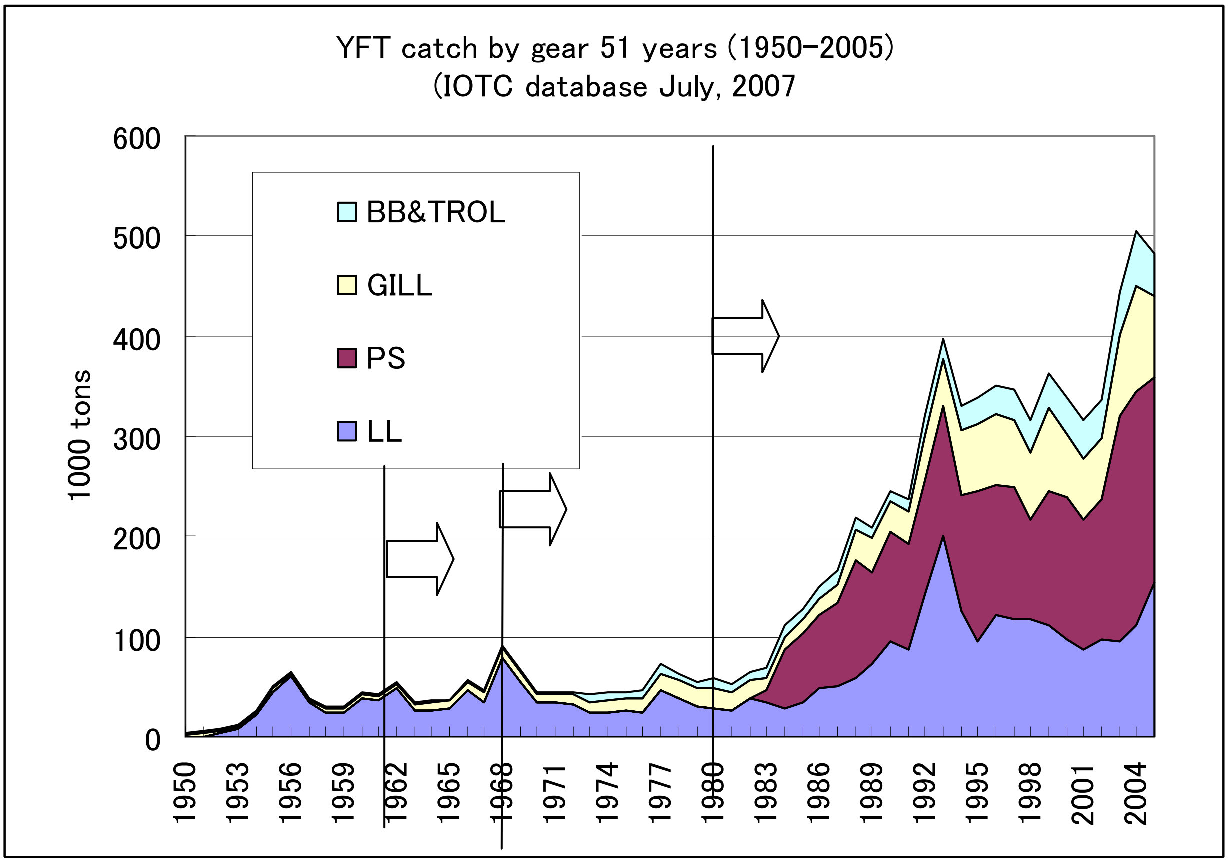


Fig. 5 Catch by gear (1950-2005) and three periods to be used in the ASPM analyses (1960-2005), (1968-2005) and (1980-2005)

4.3 Abundance Index (AI) (Fig.6) : Japan (Okamoto et al, 2007: IOTC-2007-WPTT-XX).

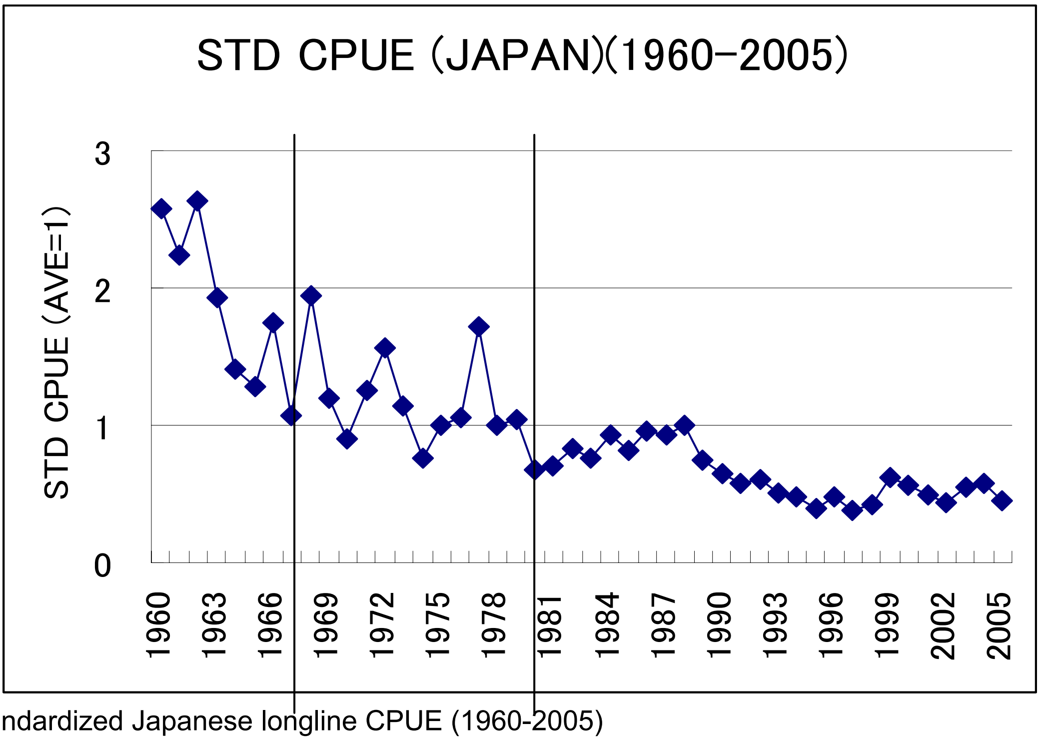
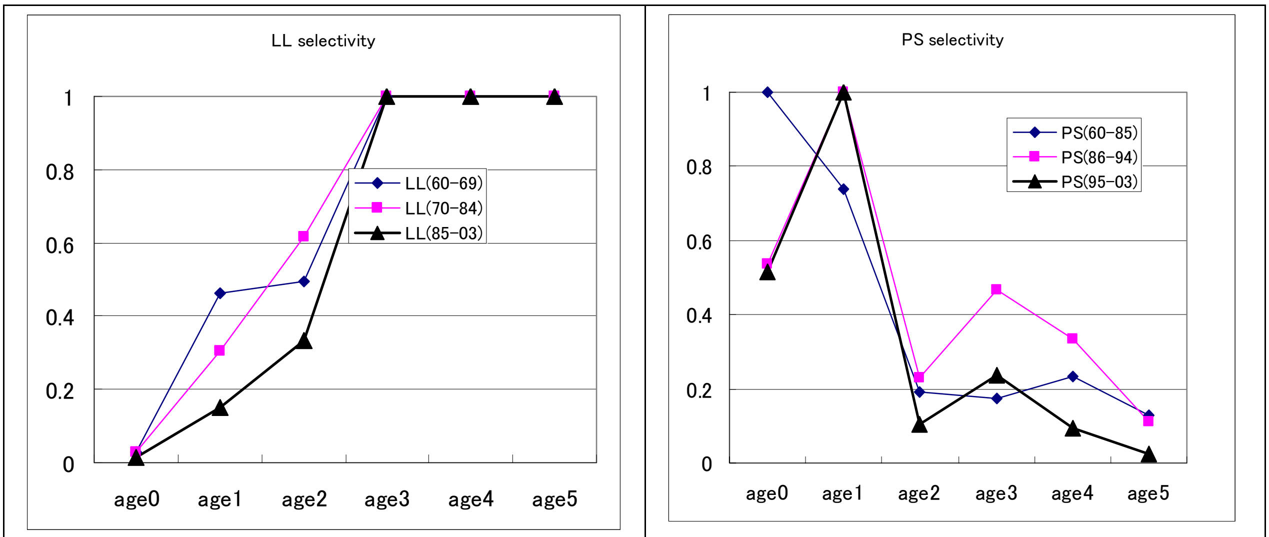


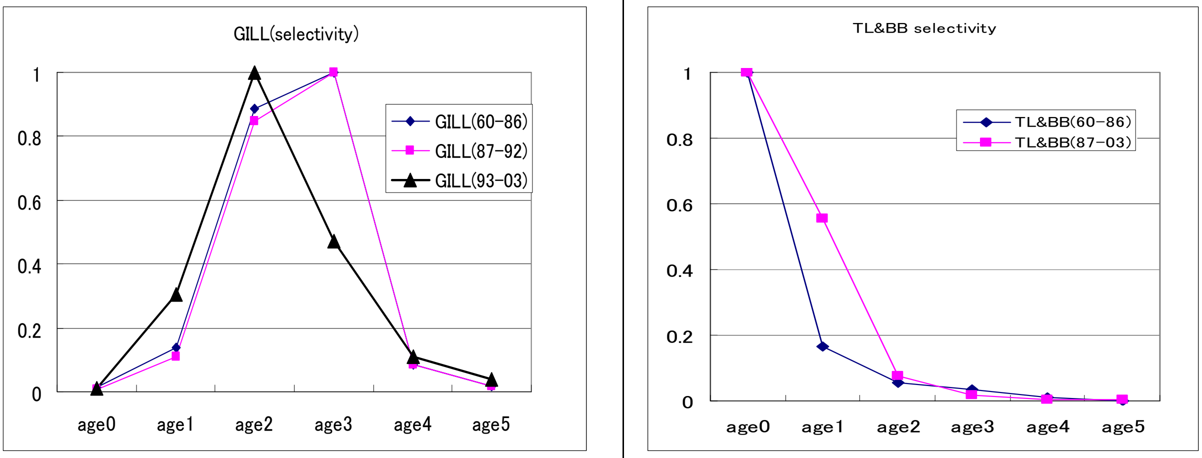
Fig. 6 Standardized Japanese longline CPUE (1960-2005)

4.4 Selectivity (Fig.7)



(a) LL

(b) PS



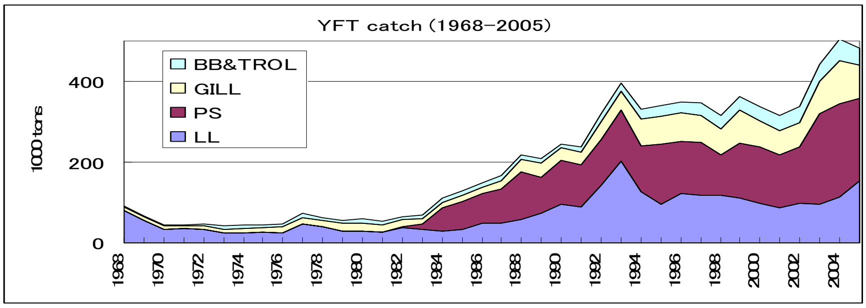
(c) GILL

(d) BB & TROLL

Fig. 7 Selectivity by gear

5. ASPM three runs (Results)

INPUT

Area	Whole Indian Ocean
Catch by gear	

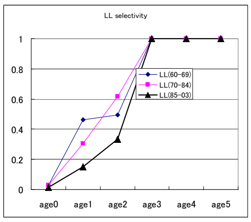
M & Fecundity by age

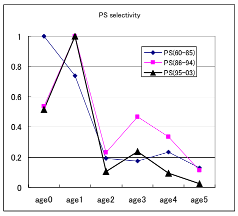
age	0	1	2	3	4	5	6+
M vector	0.8	0.6	0.6	0.6	0.6	0.6	0.6
Fecundity	0	0	23.8	43.9	61.0	73.0	80.5

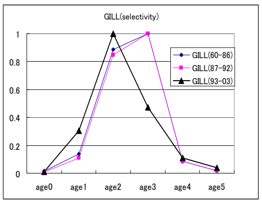
Age-weight key

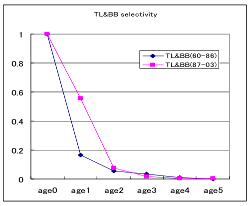
Age	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6+
Weight (kg)	0.74	2.84	7.39	14.6	23.8	33.9	43.9	53.1	61.0	73.0	77.2	80.5

Selectivity

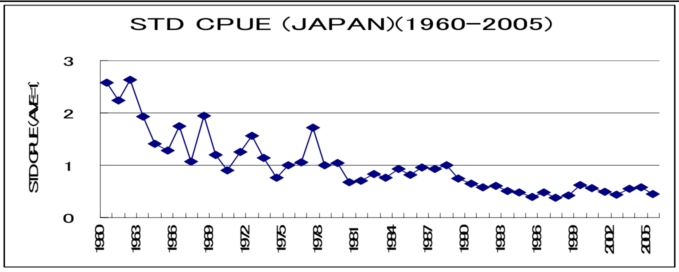








STD CPUE (Japan)



	1960-2005	1968-2005	1980-2005

RESULTS

Run no➔	1	2	3
R2	0.96	0.88	0.96
-log (LL)	-102	-78	-81
MSY(mt)	0.28	0.27	0.31
Catch (2005)	0.48		
F(MSY)	0.47	0.48	0.45
F(2005)	0.84	0.75	0.52
F(ratio)	1.8	1.6	1.0
SSB(virgin)(mt)	6.0 (1960)	4.2 (1968)	2.7 (1980)
SSB(MSY)(mt)	0.90	0.89	1.02
SSB(2005)(mt)	0.98	1.04	1.55
SSB(2005/MSY)	1.1	1.2	1.5
Depression SSB(2005/virgin)	16%	25%	57%
Total B(virgin)(mt)	9.9 (1960)	6.5 (1968)	4.5 (1980)
Total B(2005) (mt)	1.5	1.7	2.3
Depression TB(2005/virgin)	15%	26%	51%

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Appendix A Formulation of the ASPM

The deterministic formulation, for ease of presentation, precedes the formulation for the stochastic model. A Beverton and Holt (1957) type of stock recruitment relationship (SRR) is assumed here. Note, however, that other forms could be implemented following the same basic procedure outlined here.

Deterministic formulation

The deterministic model is essentially like that of (Punt 1994), which was based on ideas presented by Hilborn (1990). It consists of a forward population projection,

$$N_{1,t+1} = f(S_t) \qquad \text{for age 1} \qquad (1a)$$

$$N_{a+1,t+1} = N_{a,t}e^{-z_{a,t}} \qquad \text{for other ages except the "plus" group, and} \qquad (1b)$$

$$N_{p,t+1} = N_{p-1,t}e^{-z_{p-1,t}} + N_{p,t}e^{-z_{p,t}} \qquad \text{for the plus group, } p, \qquad (1c)$$

where $f(S)$ *is* a stock-recruitment function (explained below), *a* and *t* index age and year, and age 1 is, for simplicity, assumed here as the age of recruitment. *Z* denotes the total age and year-specific mortality rate, which is the sum of natural mortality (M_a, an assumed input value) and fishing mortality, *F*. In the (Restrepo *in press*) implementation*, F* is calculated based on total yields, weights at age $(\overline{W}_{a,t})$, and age –specific selectivities that are input and assumed exact, for up to five fisheries. This is accomplished by solving for the fishery-specific multipliers $(F_{g,t})$ of the input selectivities ($s_{g,a,t}$) that result in the observed yields (*Y*), given the estimates of stock sizes:

$$Y_{g,t} = \sum_{a=1}^{p} F_{g,t} s_{g,a,t} \overline{w}_{a,t} N_{a,t} U_{a,t} \qquad \text{with}$$

$$U_{a,t} = \frac{\left[1 - e^{-\sum_g F_{g,t} s_{g,a,t} - M_a}\right]}{\sum_g F_{g,t} s_{g,a,t} + M_a} \qquad (2)$$

Thus, the population projection is conditioned on known yields. The Beverton and Holt SRR can be described by the equation

$$R_{t+1} = f(S_t) = \frac{\alpha S_t}{\beta + S_t}, \qquad (3)$$

where *R* is the number of recruits $(N_{1,t+1}$ in eq.1a) and *S* is the reproductive output, namely the product of numbers times maturity times fecundity, summed over all ages. For simplicity, we hereafter refer to *S* as “spawning biomass”, which is often used as a proxy for reproductive output.

Formulation (3) is not very desirable for estimation because starting values of the parameters α and β are not easy to guess. For this reason, the ASPM uses a different parameterization, following (Francis 1992). It consists of defining a “steepness” parameter, τ, which is the fraction of the virgin recruitment (R_0) that is expected when *S* has been reduced to 20% of its maximum (i.e., $R = \tau R_0$ when $S = \gamma / 5$, where γ is the virgin biomass). The SRR can thus be defined in terms of steepness and virgin biomass, two parameters that are somewhat easier to guess initial values. For a Beverton-Holt relationship, virgin biomass should generally be of similar magnitude to the largest observed yields, while steepness should fall somewhere between0.2and1.0, with higher values indicating higher capacity for the population to compensate for losses in spawning biomass with increases in the survival of recruit. Nothing that equilibrium recruitment at virgin biomass can be computed as the ratio of virgin spawning biomass to spawning biomass per recruit in the absence of fishing $(S/R)_{F=0}$,

$$R_0 = \frac{\gamma}{(S/R)_{F=0}} \tag{4}$$

α and β are given by

$$\alpha = \frac{4\tau\ R_0}{5\tau - 1} \tag{5}$$

and

$$\beta = \frac{\gamma(1-\tau)}{5\tau - 1} \tag{6}$$

The spawning potential ratio*, SPR,* is measured by the spawning biomass per recruit obtained under a given *F,* divided by that under *F*=0 (Goodyear 1993). A useful benchmark for management is the *SPR* corresponding to the slope of the *SRR* at the origin, i.e., at the point when the stock is expected to "crash". From equations (4) to (6) it follows that this SPR_{crash} is given by

$$SPR_{crash} = \frac{(S/R)_{crash}}{(S/R)_{F=0}} = \frac{\beta/\alpha}{\gamma/R_0} = \frac{1-\tau}{4\tau} \tag{7}$$

Hence, in a deterministic sense, any fishing mortality that results in an *SPR* lower than SPR_{crash} is not sustainable.

Fitting the model requires finding the values of the **SRR** parameters that best explain the trends in indices of abundance, given the observed yields and other inputs. For a set of initial conditions ($N_{a,t}$ for all ages in *t*=1), equations (1) and (3) are used to project the population forward, with the fishing mortalities being calculated conditional on observed yields, by equation (2). Values of the parameters γ and τ are chosen to minimize the negative log-likelihood,

$$-\ln(L_1) = \sum_i \left[\frac{n_i}{2} \sum \ln\left(\sigma^2_{i,t}\right) + \sum_t \frac{1}{2\sigma^2_{i,t}} \left(I_{i,t-}\hat{I}_{i,t}\right)^2 \right] \tag{8}$$

where í denotes each available index. The last term is for the squared differences between observed and predicted indices (these could be in logarithmic units if a lognormal error is assumed), and $\sigma^2_{i,t}$ are variances whose computation is explained below. The predicted indices are obtained as the summation of stock sizes, times an input index selectivity, *u*, over all ages:

$$\hat{I}_{i,t} = q_i \sum_a N_{a,t} u_{a,i} \omega_i \tag{9}$$

where ω indicates some input control as to whether the index is in numbers or biomass (in which case the product being summed include weight at age), and whether computations are for the start or middle of the year. The parameters q_i scale each index to absolute population numbers (or biomass) and their maximum likelihood values can be obtained analytically by setting the derivative of equation (8) with respect to q_i equal to zero, and solving for the q_i.

There are several options for handling the variances, $\sigma^2_{i,t}$. If all the values for all indices are given equal weight, they can be set to

$$\sigma^2_{i,t} = \sum_i \left[\frac{1}{n_i} \sum_t \left(I_{i,t} - \hat{I}_{i,t}\right)^2 \right] \tag{10}$$

or, if all values within an index are to have equal weights but each index is weighted depending on how it is fitted by the model (maximum likelihood weighting)then:

$$\sigma^2_{i,t} = \frac{l}{n_i} \sum_t (I_{i,t} - \hat{I}_{i,t})^2 \tag{11}$$

Alternatively, the variances could be input for each value, based on external information.

So far, the presentation of the method has indicated that parameters γ and τ (or, equivalently, α and β) are estimated directly in the search, and the parameters q_i and $\sigma^2_{i,t}$ are obtained indirectly or externally The remaining requirement to complete the estimation procedure has to do with the initial conditions. This can be handled in various ways and perhaps the easiest is to assume that the initial age composition corresponds to anequilibrium one in virgin state. For this to be approximately valid, the time series of yield data should be extended as far back in time as possible, preferably to the onset of fishing. In this case,

$$N_{1,1} = R_0 \tag{12a}$$

$$N_{a,1} = N_{a-1,1} e^{-M_{a-1}} \quad \text{for ages } a = 2 \text{ to } p-1, \text{and} \tag{12b}$$

$$N_{p,1} = \frac{N_{p-1,1} e^{-M_{p-1}}}{(1 - e^{-M_p})} \quad \text{for the plus group.} \tag{12c}$$

An alternative consists of estimating the equilibrium recruitment in year *t* =1 as an additional parameter and solving for the initial age composition that produces a spawning biomass that results in that recruitment given τ and γ. Several other options exist, but it appears that none will generally be superior unless there is adequate relative abundance information for the start of the time series. A useful option may be to “fix” the initial age composition at same scaled fraction of the virgin one, and to conduct sensitivity trials for that choice.

The computation of statistics such as maximum sustainable yield (*MSY*) and related benchmarks (e.g. S_{MSY}, F_{MSY}) is straightforward once the parameters for the *SRR* have been obtained. Shepherd (1982) describes the procedure used to compute equilibrium yield curves from a *SRR*, together with yield-per-recruit and spawning biomass-per-recruit calculations. Conditional on a given *F* (including an overall selectivity pattern), equilibrium spawning biomass, recruitment and yield are computed as (for the Beverton and Holt SRR)

$$S_F = \alpha (S/R)_F - \beta \quad , \tag{13a}$$

$$R_F = \frac{S_F}{(S/R)_F} \quad , \text{ and} \tag{13b}$$

$$Y_F = R_F (Y/R)_F \tag{13c}$$

where $(S/R)_F$ and $(Y/R)_F$ are the spawning biomass and yield per recruit values resulting from exploitation at F. To search for *MSY* –related statistics, this procedure is built into an algorithm to obtain the desired target, e.g. to find the maximum Y_F as the estimates of *MSY.* Note that, if the selectivity pattern changes over time, then the computed MSY-related values will also change as a result of changes in the per-recruit computations.

Stochastic formulation

A stochastic ASPM requires that a recruitment value be estimated for every year. If this were attempted without constrains on the possible recruitment values, while simultaneously estimating the SRR, the application would be over-parameterized in most real situations. In this work, we have chosen to estimate the recruitments as lognormal deviations from the equilibrium SRR, assuming that these deviations follow a first-order autoregressive process.

The population projection equations are as in equation (1), except that recruitment is estimated as

$$N_{1,t} = R_0 e^{v} \qquad (14)$$

That is, recruitment is estimated as deviations from a virgin level. Instead of estimating γ and τ directly as parameters, the model estimates γ and all the $v_{t.}$. R_0 is computed from equation (4). These are essentially all parameters that would be needed to project the population forward and compute the log-likelihood in equation (8). The AR [1] process is incorporated by assuming that the recruitment estimates thus obtained vary around the expected stock recruitment relationship as

$$R_{t+1} = \frac{\alpha S_t}{\beta + S_t} e^{\varepsilon_{t+1}} \qquad (15)$$

with $\varepsilon_{t+1} = \rho\varepsilon_t + \eta_{t+1}$, $|\rho| < 1$, the η have zero expectation and variance equal to σ_η^2. In equations (14) and (15) we distinguish between recruitment values estimated as parameters ($N_{1,t}$) and those predicted from the estimated stock-recruitment relationship (R_t). The negative log-likelihood for these residuals would be (Seber and Wild 1989):

$$-\ln(L_2) = \frac{n_t}{2}\ln(\sigma_\eta^2) - \frac{1}{2}\ln(1 - \rho^2) + \frac{1}{2\sigma_\eta^2}\left[(1-\rho^2)\varepsilon_1^2 + \sum_{t=2}^{n_t}(\varepsilon_t - \rho\varepsilon_{t-1})^2\right] \qquad (16)$$

Where the residuals would be computed as

$$\varepsilon_{t+1} = \ln(N_{1,t+1}) - \ln(R_{t+1}) = \ln(N_{1,t+1}) - \ln\left(\frac{\alpha S_t}{\beta + S_t}\right) \qquad (17)$$

Computation of the first residual would depend on the initial conditions. For example, in a virgin state, it would be

$$\varepsilon_1 = \ln(N_{1,1}) - \ln(R_0).$$

Note that α and β in equations (15) and (17) could be computed from knowledge of virgin biomass and steepness (see equations (5) and (6)). However, only the former is being estimated directly as a parameter. To include steepness as an additional parameter to be directly estimated by the search would confound the information contained in R_0 and γ (refer to equations. (4), (5), and (6)). Our approach is to replace α and β in the *SRR* of equation (17) by a function of those parameters being estimated in the search, and steepness. From equations (5) and (6) it follows that

$$R_{t+1} = \left(\frac{4R_0 S_t \tau}{\tau(5S_t - \gamma) - S_t + \gamma} \right), \text{ such that} \qquad (18)$$

$$\varepsilon_{t+1} = \ln(N_{1,t+1}) - \ln\left(\frac{4R_0 S_t \tau}{\tau(5S_t - \gamma) - S_t + \gamma}\right) \qquad (19)$$

We take advantage of this relationship in order to solve for τ, nothing that, for a given ρ and σ_η^2, equation (16) will be at a minimum when

$$\sum_{t=2}^{n_t-1}\left[\ln(N_{1,t+1})-\ln\left(\frac{4R_0S_t\tau}{\tau(5S_t-\gamma)-S_t+\gamma}\right)-\rho\ln(N_{1,t})+\rho\ln\left(\frac{4R_0S_{t-1}\tau}{\tau(5S_{t-1}-\gamma)-S_{t-1}+\gamma}\right)\right]^2 \qquad (20)$$

is also at a minimum. Thus, in every iteration in the search, a subprocedure is invoked to minimize (20) with respect to τ. Having thus calculated the steepness (and, consequently, α and β), the log-likelihood of equation (16) is added to the overall objective function.

It remains to be mentioned what to do about the parameters ρ and σ_η^2. In theory, there is a potential for these to also be estimated. In practice, however, it is unlikely that data will contain so much information as to determine the relative contribution from recruitment variability with respect to the variability in the index values (see equations (8) and (16)). In our limited experience with this model, it appears that these values should be controlled by the analyst in much the same way as contributions to the likelihood from different data sources are weighted externally in other assessment methods (e.g., Deriso et al.1985). Lower σ_η^2 values will result in lower stochasticity in recruitment, while higher σ_η^2 values will allow recruitment to fluctuate more widely in order to better fit the index data. A value of ρ=0 would assume no autocorrelation between successive recruitment deviations. Empirical studies such as those of Beddington and Cooke (1983) and Myers et al. (1990) may yield information about likely ranges of values for ρ and σ_η^2 for species groups. Reported values for these parameters (Myers et al.1990) are quite variable across species.

Estimating the initial conditions for the stochastic model can be problematic, as with the deterministic model. Estimating the age structure in year 1 would not generally be an option as the model would easily become highly over-parameterized unless there were age-specific relative abundance data for the start of the series. Thus, using a long time series of data extending to the onset of fishing, and assuming an initial equilibrium state at γ, remains a useful option. Other alternatives are also possible. In this paper we examine one in which we calculate a stable age structure (with only natural mortality) resulting from a pre-series recruitment that is fixed. That is, we fix $v_{t=0}$ and set the starting population sizes as

$$N_{2,1}=R_0e^{v_0}e^{-M_1} \qquad (21\text{a})$$

$$N_{a,1}=N_{a-1,1}e^{-M_{a-1}} \quad \text{for ages } a = 3 \text{ to } P\text{-}1\text{, and} \qquad (21\text{b})$$

the plus group is calculated as in equation (12c). This alternative allows the initial age structure to be either higher or lower than that corresponding to an equilibrium virgin state. The parameter $v_{t=0}$ could potentially be estimated in the search procedure as well. If it is, it may be desirable to place a penalty on how much it can alter the initial biomass, say, away from γ. This could be accomplished with the term

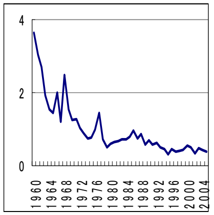
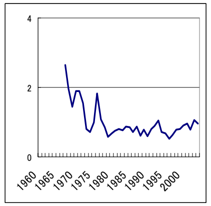
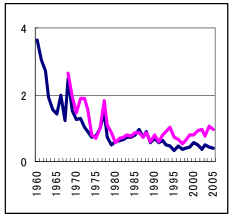
$$-\ln(L_3)=\frac{\ln(\sigma_v^2)}{2}+\frac{(\ln(S_1)-\ln(\gamma))^2}{2\sigma_v^2} \qquad (22)$$

where σ_v^2 is a variance value to be fixed by the analyst.

Estimation of the stochastic model parameters for any given data set then requires several choices associated with how much recruitment can fluctuate around its deterministic predictions and about the initial conditions. In addition to choices about variances ($\sigma_\eta^2, \sigma_v^2$ and possibly $\sigma_{i,l}^2$), the log-likelihood components could be given different emphases (λ) to obtain model estimates by minimizing:

$$-\ln(L_T)=-\ln(L_1)-\lambda_2\ln(\mathrm{L}_2)-\lambda_3\ln(L_3) \qquad (23)$$

Addendum to IOTC-2007-WPTT9-12 (result of the final ASPM runs) (steepness 0.8 fixed)

<table>
<tr><th>input</th><th>Run 4</th><th>Run 5</th><th>Run 6</th><th>Run 7</th><th>Run 8</th><th>Run 9</th><th>Run 10</th><th>Run 11</th></tr>
<tr><td colspan="9">Biological parameter :
[M] 0.8 for Age 0 and 0.6 for Age 1-6+, [Growth] Stequert reloaded, [LW] $W=1.585*10^{-5} L^{3.045}$</td></tr>
<tr><td>Yr</td><td colspan="4">1960-2005</td><td colspan="4">1968-2005</td></tr>
<tr><td>CPUE</td>
<td>Japan tropical (area 2&5)
 </td>
<td>Taiwan (whole area)
 </td>
<td>J (area 2&5) +T (whole)
 </td>
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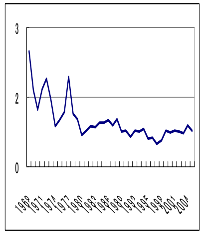 </td>
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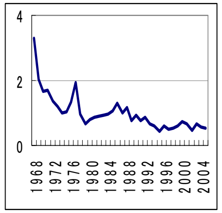 </td>
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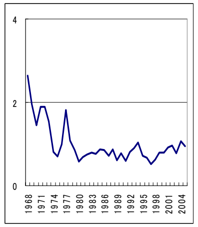 </td>
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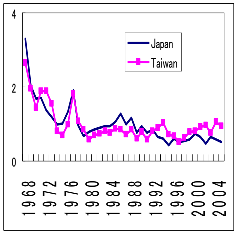
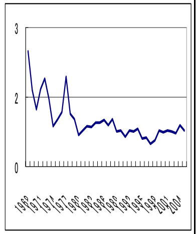
 </td>
<td>Combined J+T
 </td></tr>
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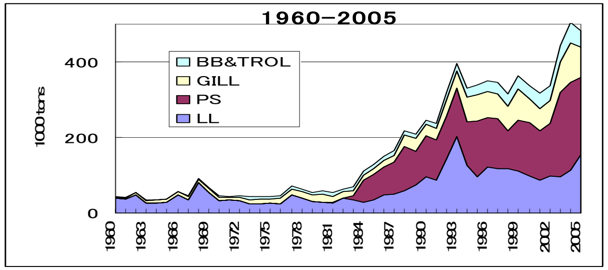
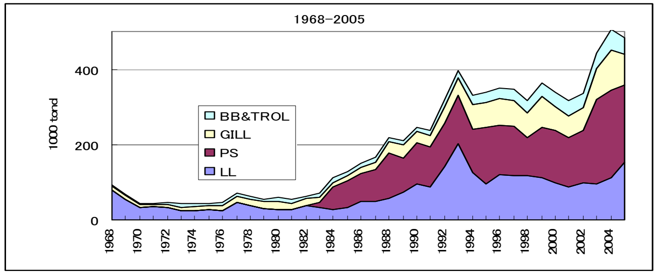
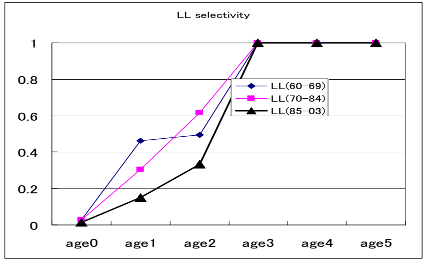
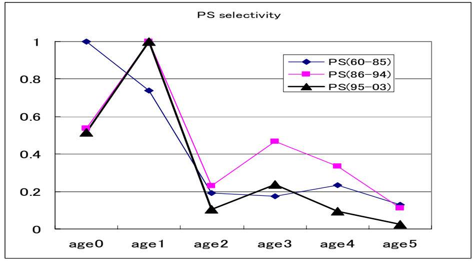
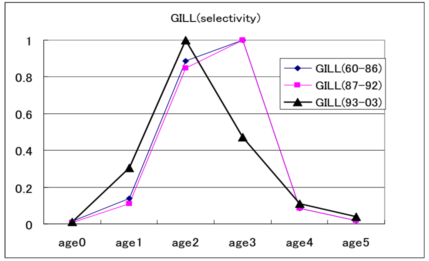
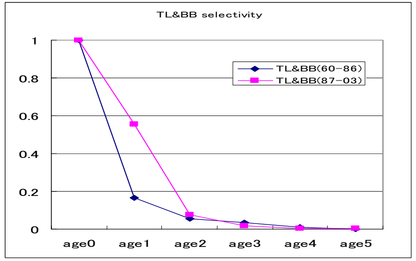
<td colspan="4"> </td>
<td colspan="4"> </td></tr>
<tr><td>Age WT</td><td colspan="8">
<table>
<tr><td>Age</td><td>0.5</td><td>1.0</td><td>1.5</td><td>2.0</td><td>2.5</td><td>3.0</td><td>3.5</td><td>4.0</td><td>4.5</td><td>5.0</td><td>5.5</td><td>6+</td></tr>
<tr><td>Weight (kg)</td><td>0.74</td><td>2.84</td><td>7.39</td><td>14.6</td><td>23.8</td><td>33.9</td><td>43.9</td><td>53.1</td><td>61.0</td><td>73.0</td><td>77.2</td><td>80.5</td></tr>
</table>
</td></tr>
<tr><td>SELECTIVITY</td>
<td colspan="2"> </td>
<td colspan="2"> </td>
<td colspan="2"> </td>
<td colspan="2"> </td></tr>
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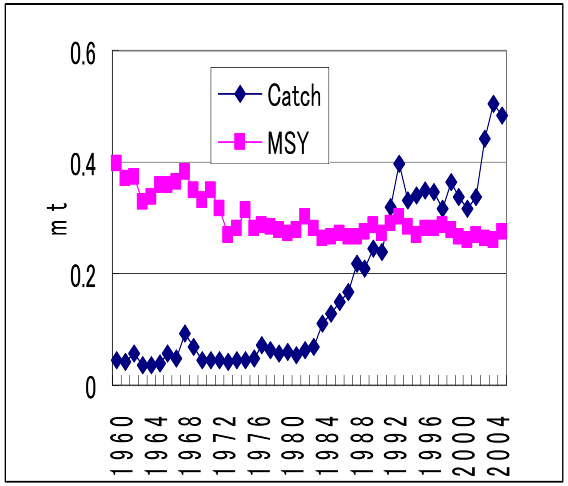
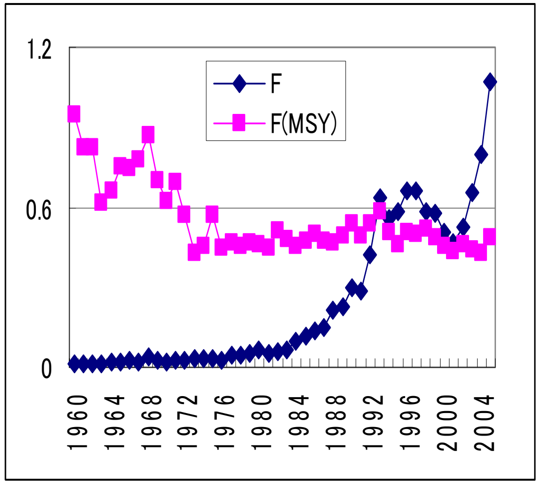
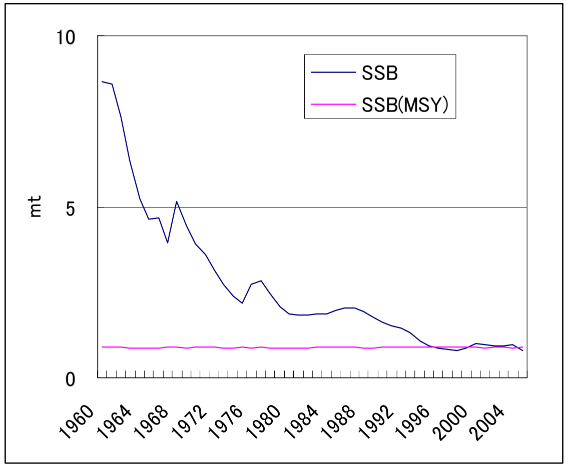
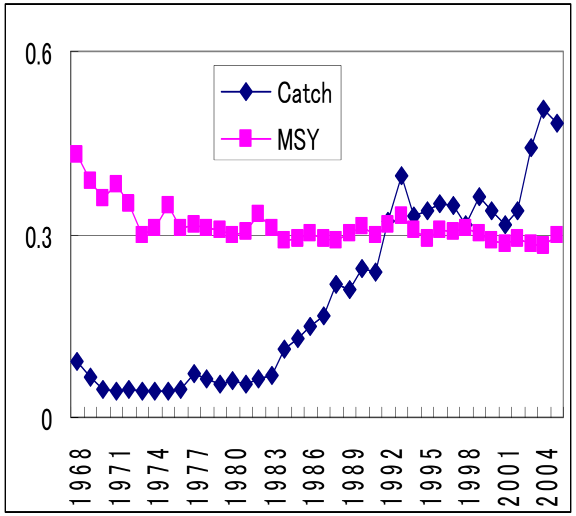
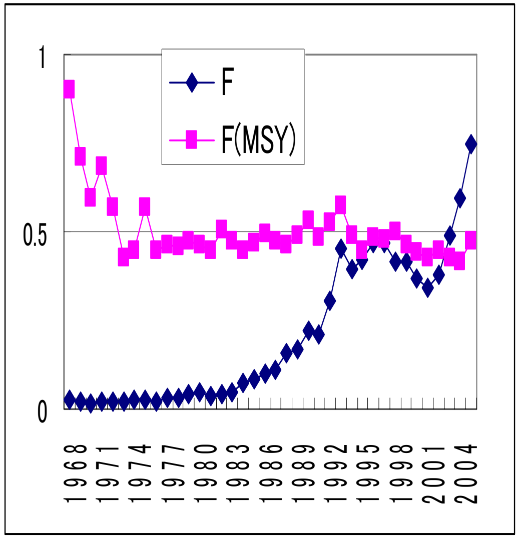
RESULTS

	Run 4	**Run 5**	**Run 6**	**Run 7**	**Run 8**	**Run 9**	**Run 10**	**Run 11**
Period	**1960-1980**				**1968-2005**			
CPUE	**Japan (area 2&5)**	**Taiwan (whole area)**	**J +T (two cpue)**	**Combined J+T**	**Japan tropical (area 2&5)**	**Taiwan (whole area)**	**J +T (two cpue)**	**Combined J+T**
R2	0.97	0.97	0.94	0.97	-73	0.93	0.85	0.91
-log(LL)	-95	-94	-134	-102	0.90	-79	-108	-81
MSY (mt)	**0.27**	0.37	0.59	0.33	**0.30**	0.42	0.34	0.34
Catch (2005)(mt)	**0.48**							
F(MSY)	0.49	0.44	0.44	0.45	0.47	0.44	0.45	0.45
F(2005)	1.07	0.26	0.24	0.39	0.75	0.22	0.40	0.37
F(ratio)	**2.18**	0.59 (too optimistic)	0.55 (too optimistic)	0.87	**1.60**	0.50 (too optimistic)	0.89	0.82
SSB(virgin) (mt)	8.64	4.16	20.9	3.61	6.95	9.97	8.02	6.41
SSB(MSY) (mt)	0.89	1.26	1.97	1.09	0.98	1.41	1.13	1.12
SSB(2005) (mt)	0.79	3.20	3.39	2.10	1.12	3.76	2.07	2.18
SSB ratio (2005/MSY)	**0.89**	2.54 (too optimistic)	1.72 (too optimistic)	1.93 (too optimistic)	**1.15**	2.55 (too optimistic)	1.82 (too optimistic)	1.95 (too optimistic)
Depression SSB (2005/virgin)	**9%**	77%	16%	58%	**16%**	38%	26%	34%
Comments	**Likely realistic**	**Likely too optimistic**	**Likely too optimistic**	**Likely too optimistic**	**Likely realistic**	**Likely too optimistic**	**Likely too optimistic**	**Likely too optimistic**

	Catch vs MSY	F vs.F(MSY)	SSB vs SSB(MSY)
Run 4	Msy=0.27 mt  	Fratio =2.18  	SSB ratio =0.89 (below MSY) 
Run 8	MSY=0.30 mt  	Fratio =1.60  	SSB ration=1.15 (above MSY)