(IOTC-WPTT-2008-28 rev)

Preliminary stock assessment of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean by the ADMB based ASPM

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Abstract

An Age-Structured Production Model (ASPM) was used to assess the status of the yellowfin tuna stock (*Thunnus albacares*) (YFT) for the period 1950-2007. The Fortran-based ASPM software previously used has been recoded using AD Model Builder (Otter Research). The sensitivity of the results to different periods of catch and CPUE was investigated. As a result that catch and CPUE in 1968-2007 produced the best estimates. The assessment suggested that YFT stock is now entering the overfishing status after 4 years of high YFT catch in 2003-2006. Projections suggested that if future YFT catches are kept at the 2007 catch level, SSB level will reach the estimated MSY level in a few years. It is therefore recommended that catch and effort not be increased above the 2007 level.

Contents

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1. Introduction

In this paper, we attempted to assess yellowfin tuna (*Thunnus albacares*) (YFT) resources using an age-structured production model as this approach was recommended 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 Ocean is a single stock.

2. Data

We use YFT catch, effort and size data by country (area), gear and year for the period 1950 to 2007, which were from the IOTC's updated database as of October 2008.

3. ASPM

3.1 General features

ASPMs 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. The detail formation of the ASPM is provided in Appendix A.

3.2 Re-coded ASPM by ADMB

Using AD Model Builder (Otter Research) we re-coded the Fortran based ASPMS software made by Restrepo (1997). For details refer to IOTC-WPM-2008-___ .

4. INPUT for the ASPM (ADMB)

In the ADMB based ASPM, we use 5 files, i.e., a *control* file, a *parameter guesses* file, a *biological data* file, an *index* file, a *fishery* file, and a *projection* file. Information needed for these 5 files are as follows:

4.1 Age

We use 8 age classes from age 0 to 7 (a plus group).

4.2 Fishery (fleet type)

In the IOTC database there are 10 fisheries, i.e., LL(TWN), LL(JPN), PS(log), PS(free), GILL, GILL+LL, TROLL, BB(Pole & Line), HAND and OTH. Fig. 1 shows the average age compositions of the catch for these 10 fisheries, based on catch-at-age (CAA) estimated by the IOTC Secretariat. The GILL+LL and HAND fleets have similar CAA compositions (Fig. 1), and therefore these two fisheries were combined in the assessment and defined as GILL(O). Hence we use 8 fisheries in the ASPM analyses. Fig 2 shows the catch trends for each gear for 58 years (1950-2007).

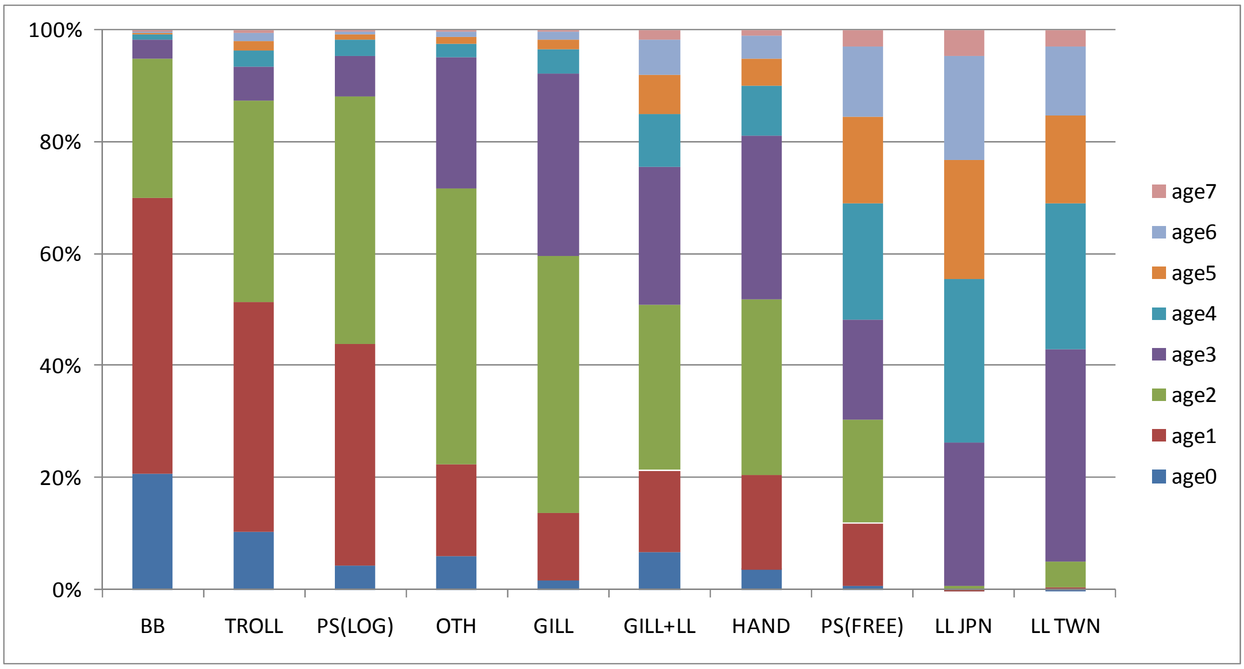


Fig. 1 Average age compositions in 10 fisheries

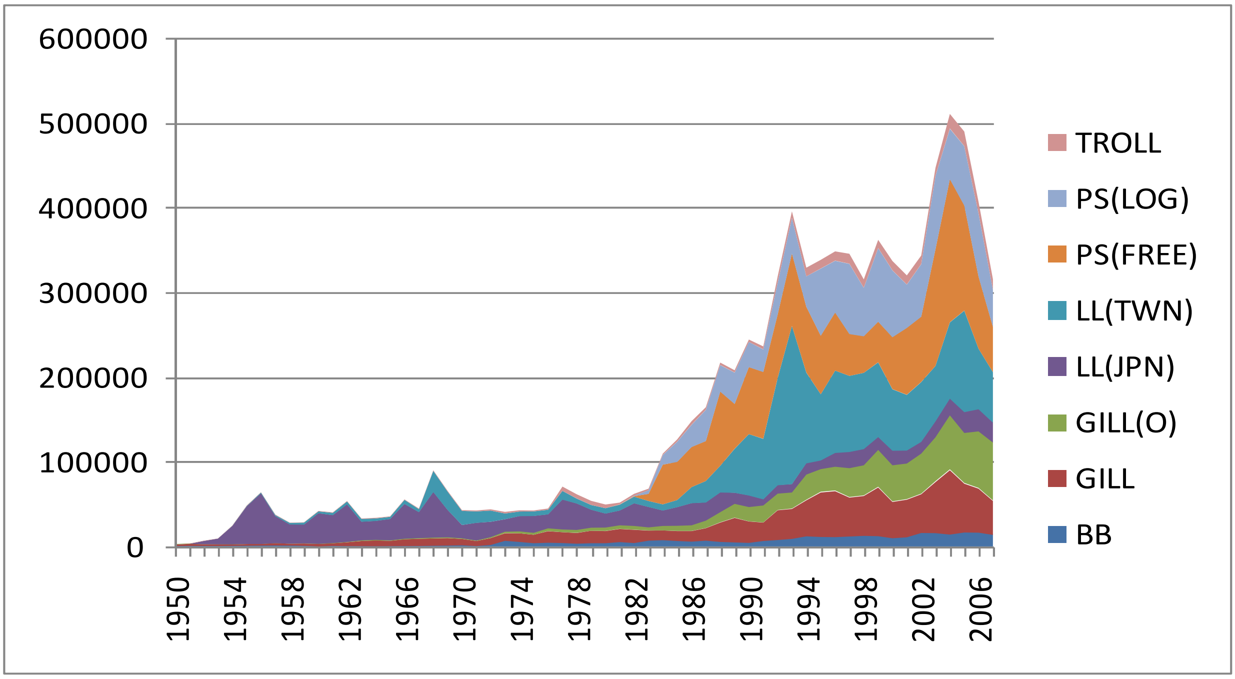


Fig. 2 Catch (in number of fish) trends for the 8 gears (1950-2008) based on the CAA estimated by the IOTC Secretariat.

4.3 Selectivity

Using Separable VPA originally developed by Hunter (1982) and modified by Miyabe (1989), age specific selectivity by fleet was estimated (Fig. 3).

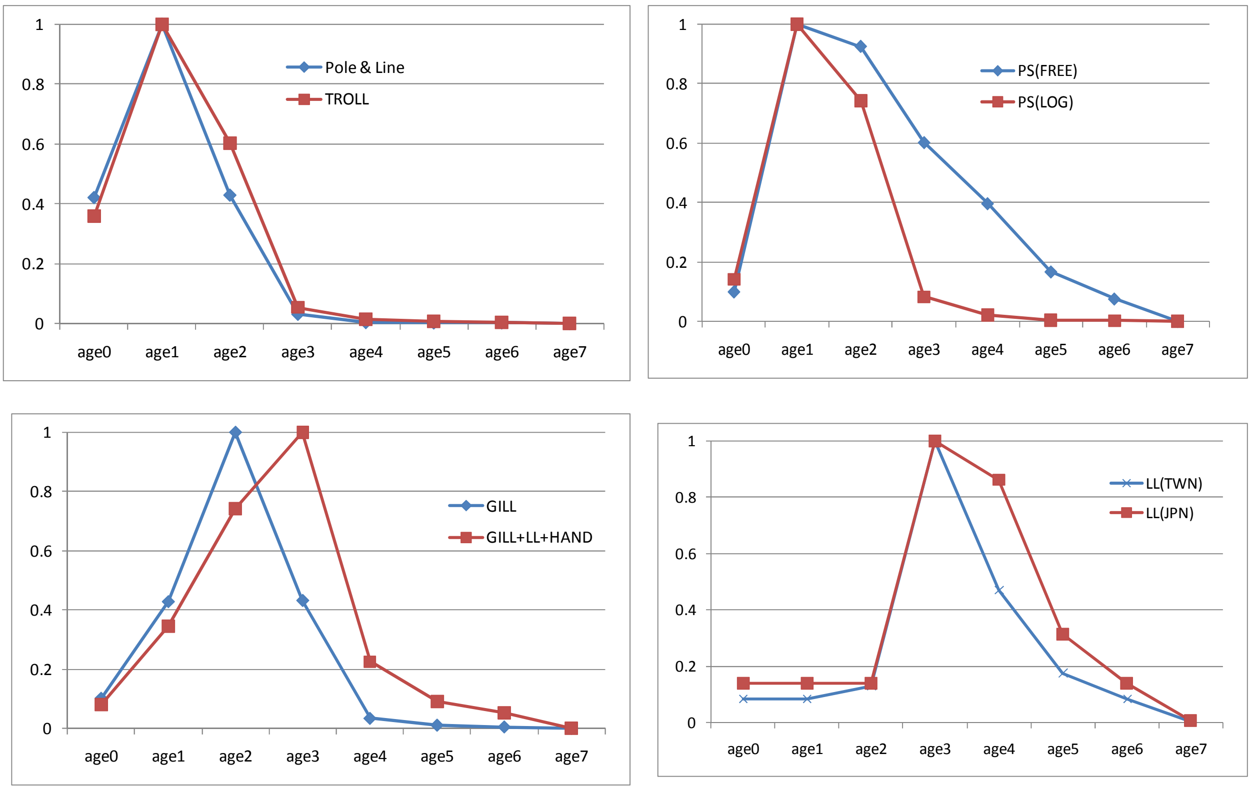


Fig. 3 Estimated selectivity for the 8 gears (fleets)

4.4 Biological parameters

For Biological parameters in the ASPM, three types of age-specific inputs are needed, i.e., natural mortality (*M*), weights (beginning and mid-year) and fecundity.

(1) Natural mortality vector (*M*)

We used *M* vectors used in the 2007 assessment as shown in Table 1.

Table 1 *M* vectors

Age	0	1	2	3	4	5	6	7+
M	0.80	0.6						

(2) Begin- and mid-year weights-at-age

Based on the new growth equation (Paige et al, 2008) and the LW relation (IOTC, 2008), IOTC provided the weight values by age as shown in Table 2.

Table 2 YFT age-weight keys in the Indina Ocaen

Age	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
Weight (kg)	0.38	0.81	1.40	2.15	3.05	4.20	10.62	22.77	34.10	42.99	49.38	53.76	56.68	58.95	59.83	60.62

(3) Fecundity

We assume that fecundity is proportional to the body weights at the middle of each age and also assume 0% fecundity (maturity) for age 0-3.5 and 100% for age 3.5+. Table 3 summarizes this information.

Table 3 Maturity and fecundity of YFT in the Indian Ocean

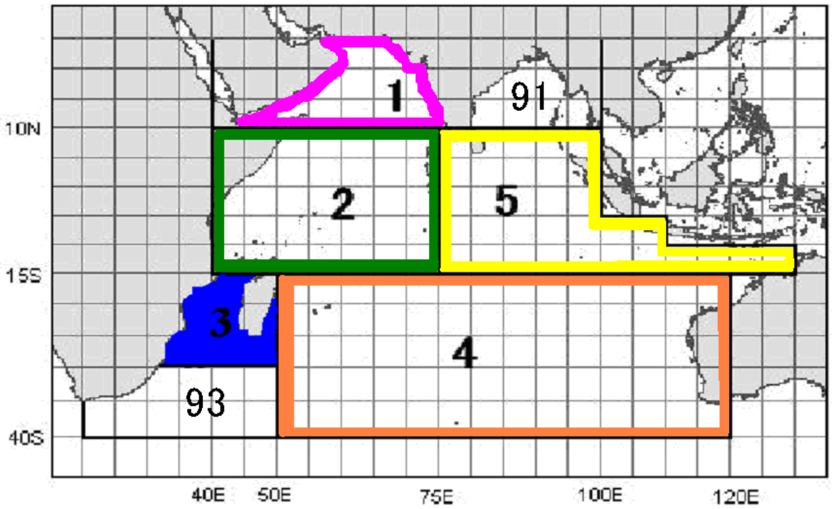
Age	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5+
Maturity (%)	0	0	0	100	100	100	100	100
Fecundity (kg)	0	0	0.00	22.77	42.99	53.76	56.68	60.62

4.5 Abundance Index (AI)

We use the AI based on the Japanese and the Taiwanese GLM-standardized CPUE for the index inputs, which are described in IOTC-WPTT-2008-_____(Okamoto and Shono, 2008) and IOTC-WPTT-2008-____ (Chang et al, 2008) respectively.

(1) Sub areas

For both Japan and Taiwan, same sub areas (2, 3 and 5) are used as in Fig. 3.



Fig, 3 Sub areas for STD CPUE by GLM (Okamoto and Shono, 2008)

4.6 Periods for catch and CPUE

We will attempt different periods of CPUE and catch to evaluate the best periods producing the most reasonable ASPM results.

(1) CPUE (Japan)

There is an unrealistic trend between CPUE and catch for the entire period (1950-2000's) (Fig. 4). We consider that there are two regimes before and after 1980, i.e., (a) the first regime, 1950's – 1970' when CPUE declined drastically while catch remained at a low level and (b) the 2nd regime when the catch drastically increased while CPUE remained constant at a low level.

But if the 2nd regime is shown on a different scale, we can see the more realistic trend between Catch and CPUE (Fig. 5).

Thus we will use the period 1980-2007 as the base case. Then we attempt two periods starting from 1960's (1960-2007) and also from around 1970's (1968-2007) as the sensitivities because these two periods have less decline problem comparing to the one from 1952-2007 and we are interested in the ASPM results for these two periods.

(2) CPUE (Taiwan)

We use the STD CPUE (TWN) (one period: 1979/80-2007) estimated by Chang et al (2008).

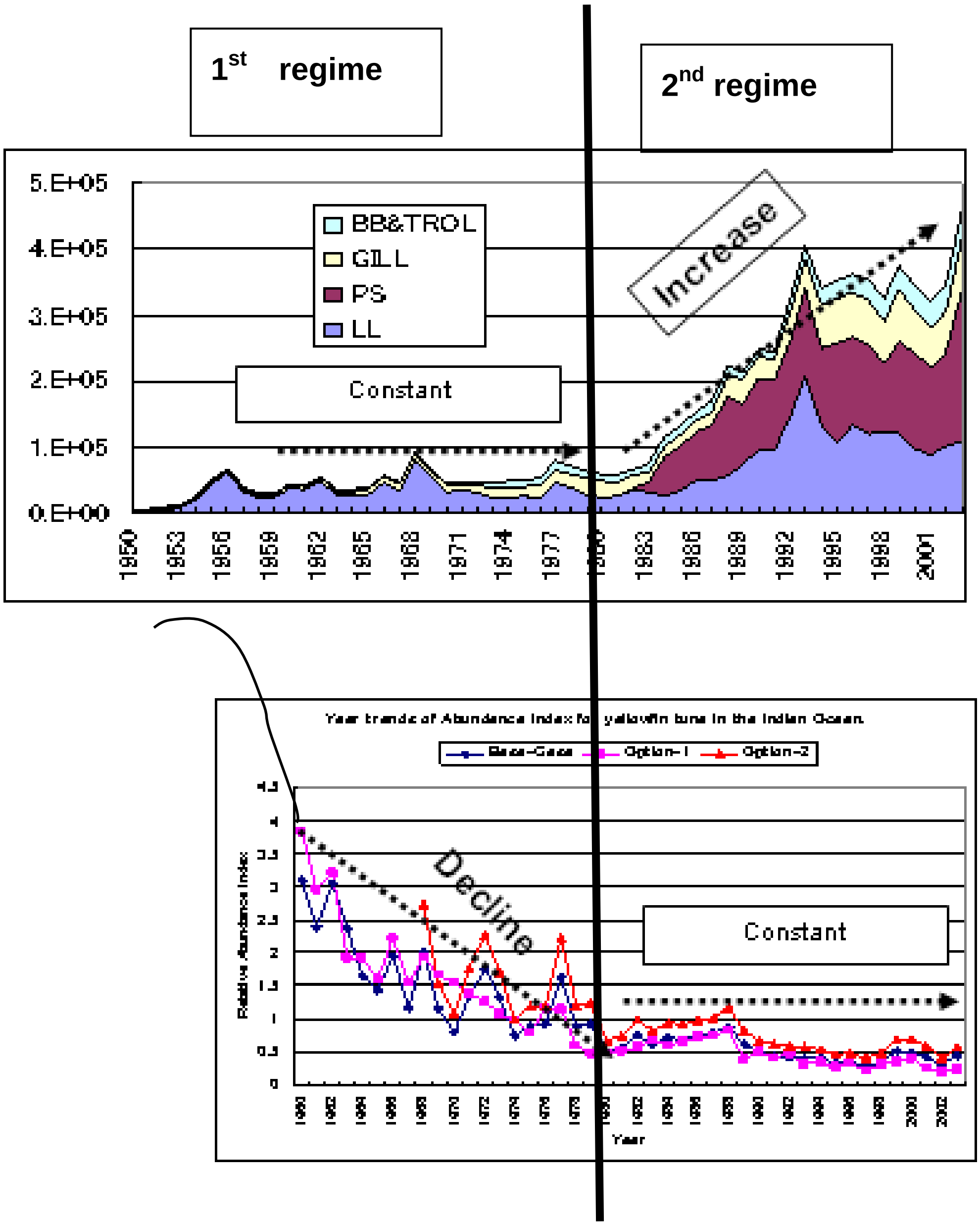
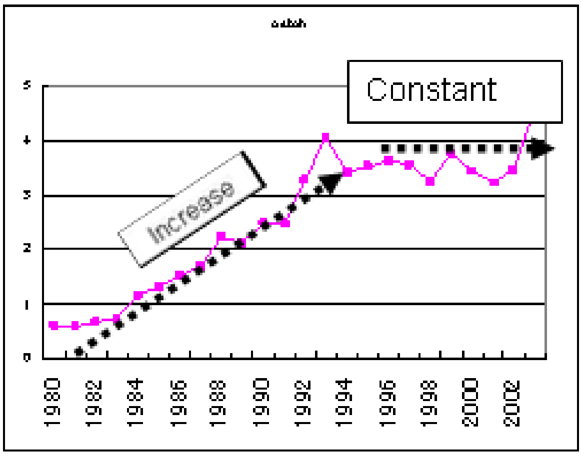


Fig. 4 Unrealistic trend between CPUE and catch (Nishida and Shono, 2007)

Note CPUE (1952-1959) is roughly depicted based on Myers (2005).



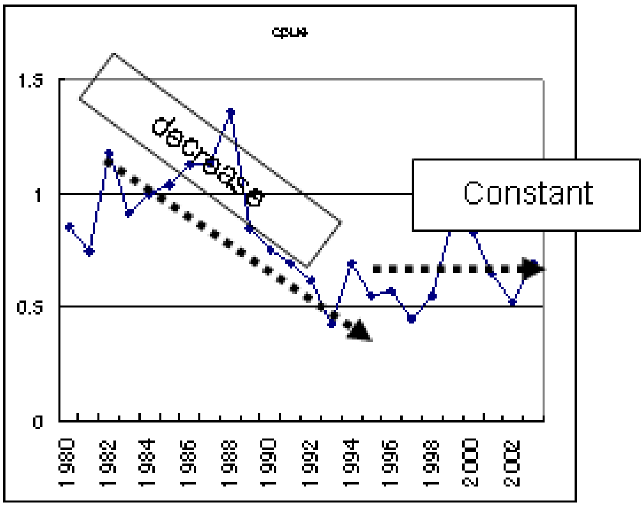


Fig.5 More realistic trend between catch and CPUE (1980's-2009's) (Nishida and Shono, 2007)

(3) Catch

To reflect the periods of CPUE we will attempt 3 periods for the catch, i.e., base case: 1980-2007 and 2 sensitivities (1960-2007 and 1968-2007).

(4) Summary

Table 3 shows the summary of the periods for catch and CPUE that we attempt for the ASPM analyses.

Table 4 Summary of periods on catch and CPUE for ASPM

<table>
<tr><td></td><td>Base case (BC)</td><td colspan="2">Sensitivities (S)</td></tr>
<tr><td>Catch</td><td rowspan="3">BC
1980-2007</td><td rowspan="2">S1
1960-2007</td><td rowspan="2">S2
1968-2007</td></tr>
<tr><td>CPUE(JPN)</td></tr>
<tr><td>CPUE(TWN)</td><td colspan="2">none</td></tr>
</table>

4.7 STD CPUE

(1) Japan

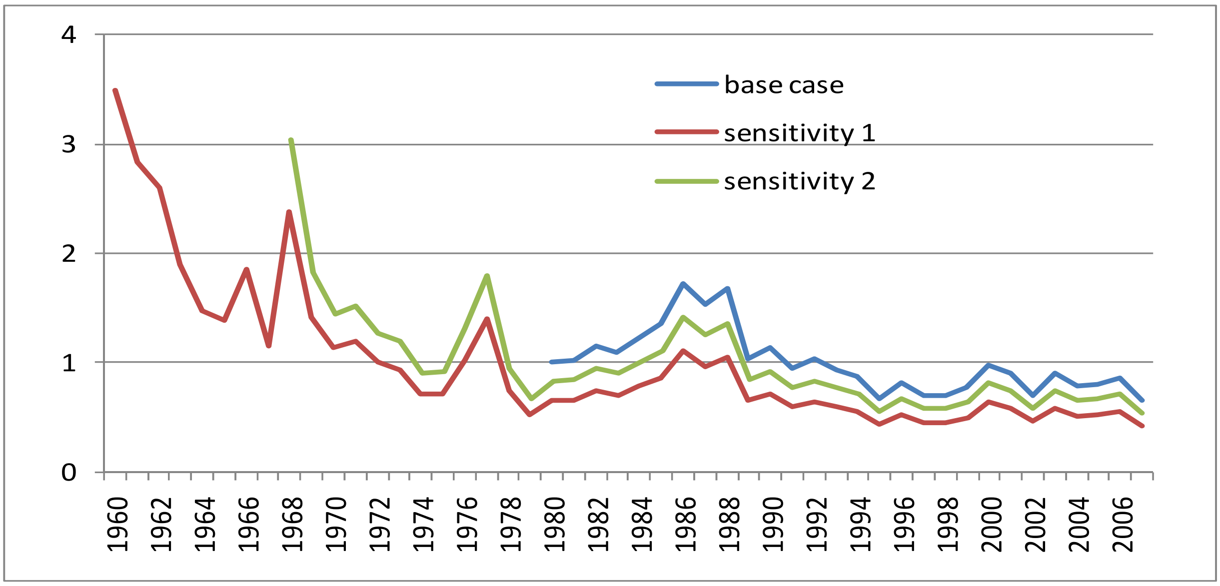


Fig. 6 STD CPUE (JPN) in 3 periods (Okamoto and Shono, 2008)

(one period for the base case and two for sensitivities for the ASPM runs)

(2) Taiwan

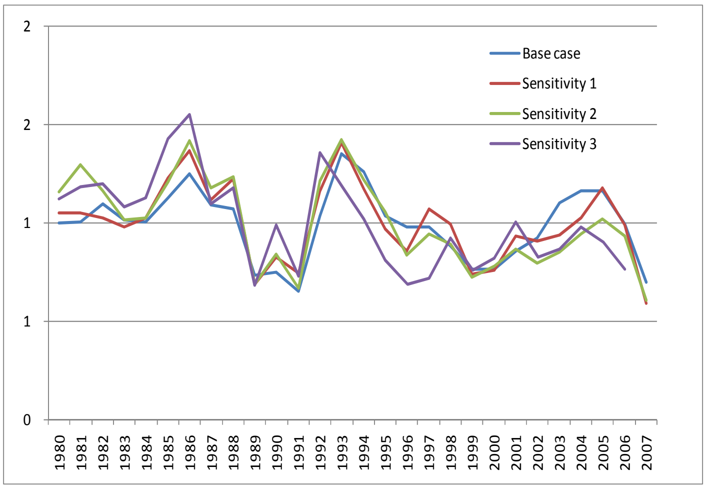


Fig. 7 STD CPUE (TWN) in 1 period with one base case and 3 sensitivities (Table 5)

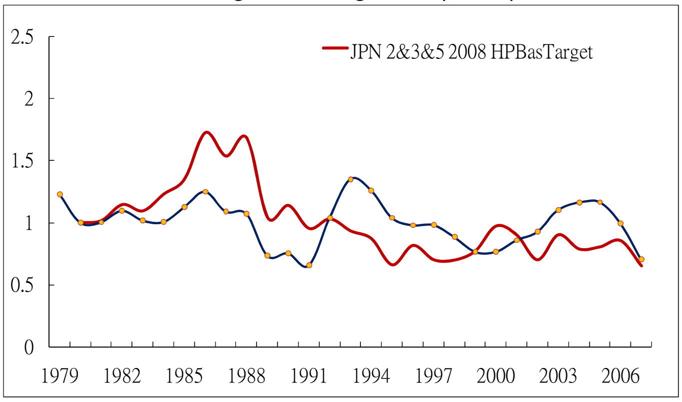
Change et al (2008)

Table 5 Base case and 3 sensitivities for the ASPM (ADMB) runs

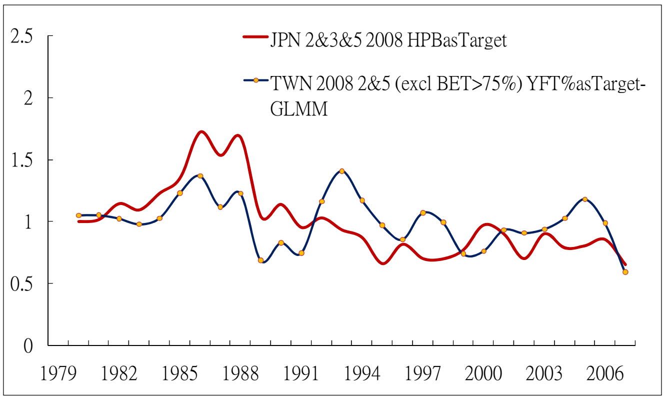
	Targeting correction by	Model
Base case (BC)	YFT ratio	GLM
Sensitivity 1 (S1)		GLMM
Sensitivity 2 (S2)	ALB & BET ratio	
Sensitivity 3 (S3)		GLMM with SST

(3) Comparison between CPUE (JAPAN) and CPUE (TWN) in the base case period (1980-2007)

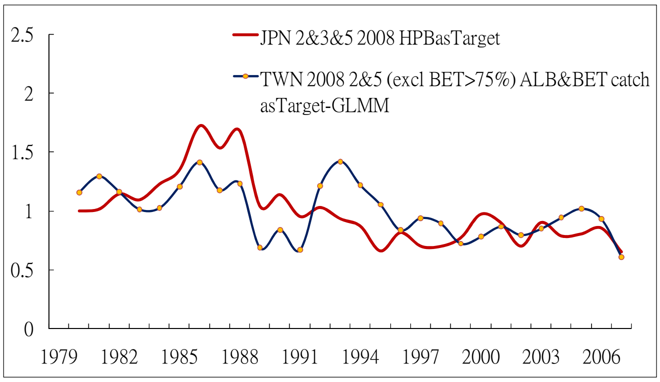
Fig 8. Chang et al (2008)



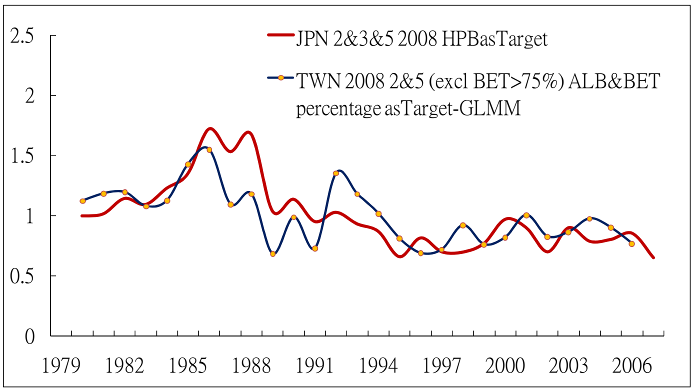
(a) Taiwan base case vs. Japan



(b) Taiwan sensitivity 1 vs. Japan



(c) Taiwan sensitivity 2 vs. Japan



(d) Taiwan sensitivity 3 vs. Japan

5. ASPM runs

Based on the different periods for catch and CPUE (base case and sensitivities) and also CPUE (TWN) with a base case and 3 sensitivities we will attempt 42 different types (scenarios) of ASPM runs considering all possible combinations.

Table 6 shows such scenarios and the results of 42 ASPM runs. As a result we initially found that 5 best scenarios produced based on MSY and SSB values, i.e., from the best scenario they are no. 20, 8, 18, 15 and 9.

However, SSB trends for scenarios 8, 18, 15 and 9 (all in 1950-2007) showed very strange shape (e.g., Fig. 9), thus we dropped out them and selected scenario 20 (1968-2007) for further analyses for the stock status.

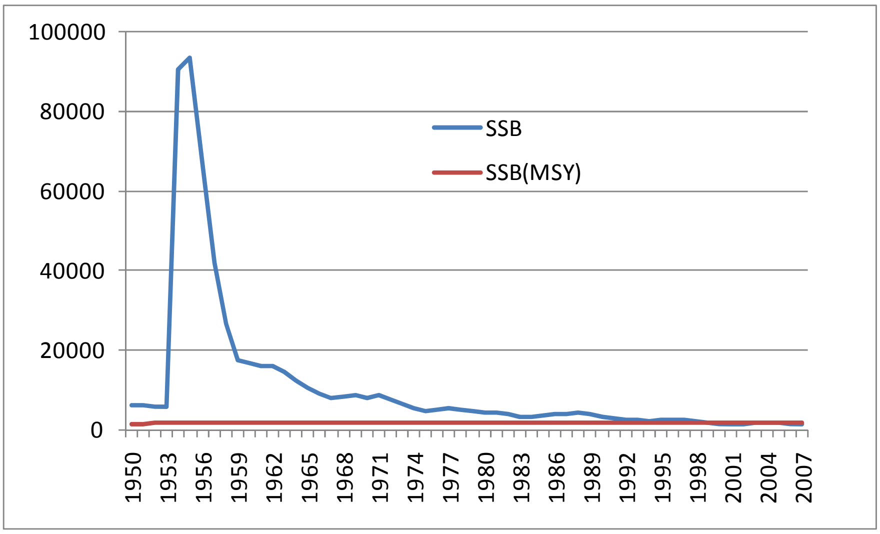


Fig. 9 Problem on the SSB trends if we use the catch data from 1950-2007 which appeared in scenarios 8, 18, 15 and 19. This might be caused by the unrealistic population dynamics relations between CPUE & catch in this period.

Table 6 Results of 42 ASPM (ADMB) runs

Input information in addition to those explained in Sections 41.-4.7

Steepness=0.8 (fixed), B-H SR relation, and

penalty (weighting values) to fit to the objective function (residual sum of squares)

ρ(serial correlation coefficient in the error terms of the S-R model) = 0.00

σ^2 (sigma for the stock-recruitment relationship) = 0.20

σ^2 (sigma for the initial population size) = 0.40

Note BC(base case), S(sensitivity), UR(un realistic), NC(Not converged)

Scenario Number	Catch (3 periods)	Taiwan CPUE (1 period: 1980-2007) & (4 CPUE)	JPN CPUE (3 periods)	R2	LH model	LH cpue	SR fit	MSY (mil. tons)	SSB (mil tons)	Results (1)-(5) Best 5 scenarios
	BC:1980-2007 S1: 1950-2007 S2: 1968-2007	(1) BC: YFT% (GLM) (2) S1: YFT% (GLMM) (3) S2: ALB-BET % (GLMM) (4) S3: ALB-BET% (GLMM w/ SST)	BC:1980-2007 S1: 1960-2007 S2: 1968-2007							
1	S1 (1950-2007)	OFF	S1	NC						
2			S2	0.946	-64	-89	25	0.37	0.59	UR
3			BC	0.988	-68	-93	25	0.36	0.28	UR
4		BC	OFF	0.997	-86	-121	35	Too large		UR
5		S1		NC						
6		S2		0.992	-62	-97	35	1652	33361	UR
7		S3		0.936	-50	-64	15	Too large		UR
8		BC	S1	0.872	-82	-103	21	0.38	1.64	(2)*
9			S2	0.760	-83	-93	11	0.44	3.26	(5)*
10			BC	0.545	-76	-81	5	Too large		UR
11		S1	S1	0.822	-83	-104	22	0.38	0.97	UR
12			S2	0.787	-83	-95	12	0.46	3.16	UR
13			BC	0.632	-76	-83	6	2.15	10.3	UR
14		S2	S1	NC						
15			S2	0.805	-84	-97	12	0.41	2.08	(4)*
16			BC	0.687	-79	-86	7	0.94	11.4	UR
17		S3	S1	NC						
18			S2	0.852	-91	-105	14	0.39	1.89	(3)*
19			BC	0.754	-85	-92	7	0.73	7.82	UR
20	S2 (1968-2007)	OFF	S2	0.934	-64	-83	18	0.36	0.87	(1) (selected)
21			BC	0.989	-68	-94	26	0.37	0.42	UR
22		BC	OFF	0.997	-86	-121	35	148		UR
23		S1		0.999	-801	-803	82	1.62	5.72	UR
24		S2		0.992	-62	-97	35	1542		UR
25		S3		0.936	-50	-65	15	1527		UR
26		BC	S2	0.758	-86	-93	6	0.57	5.71	UR
27			BC	0.547	-77	-81	5	1.78	27.0	UR
28		S1	S2	0.786	-87	-96	8	0.61	6.09	UR
29			BC	0.625	-77	-83	6	3.1	1.48	UR
30		S2	S2	0.801	-88	-97	8	0.50	3.87	UR
31			BC	0.689	-79	-86	7	1.07	13.6	UR
32		S3	S2	NC						
33			BC	NC						
34	BC (1980-2007)	OFF	BS	0.982	-67	-87	20	0.38	0.28	UR
35		BC	OFF	0.959	-65	-81	16	1.52		UR
36		S1		NC						
37		S2		NC						
38		S3		NC						
39		BC	BC	0.540	-75	-79	4	2.93	4.78	UR
40		S1		0.633	-77	-84	6	Too large		UR
41		S2		0.689	-79	-86	7	1.97	28.4	UR
42		S3		0.774	-85	-92	6	0.97	13.4	UR

(*) Scenarios 8, 18, 15 and 19 (1950-2007) were initially 2nd to 4th best results, but it was rated as UR as the estimated SSB showed strange trends.

5.1 Period on Catch and CPUE

To investigate the relation between catch and CPUE for the selected scenario 20, we depicted their trends (Fig. 10).

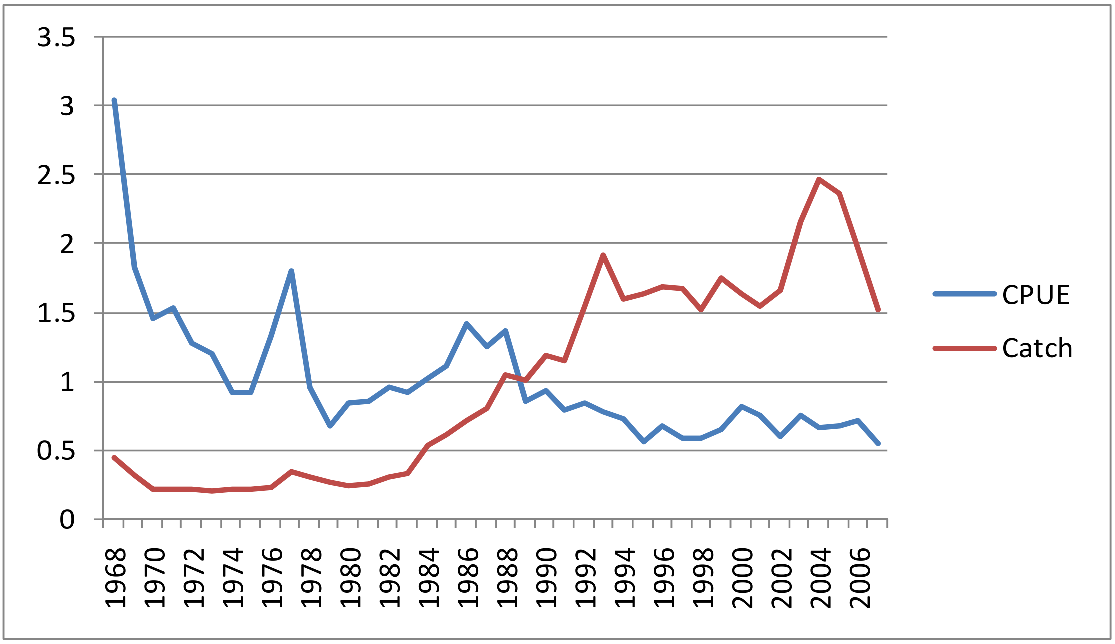


Fig. 10 Relations between catch vs. CPUE in Scenario 20.

General observations on the periods of catch and CPUE as follow::

(1) Catch (1950-2007) (S1) and also 1980-2007 (base case) did not produce realistic results.

(2) Catch (1968-2007) (S2) produced reasonable results.

(3) It is worth to attempt catch (1960-2007) in the future.

(3) STD CPUE (JPN) and Catch in 1968-2007 produced the best result.

(4) STD CPUE (TWN) did not produced reasonable results.

5.2 Stock status

Table 7 and Fig. 10 describe the results of the best scenario 20.

Table 7 Summary of ASPM for the best scenario 20.

		Scenario 20
Catch period		S2 (1968-2007)
CPUE period		Japan(S2):1968-2007
Catch vs. MSY	MSY (mil. tons)	0.36
	Current catch (2007) (mil. tons)	0.30
	Ave catch (past 5 years)	0.42
	Catch/MSY (2007)	0.89
	Catch/MSY (past 5 years)	1.40
F vs. F(MSY)	F (2007)	
	F (MSY)	
	Current F ratio (2007)	0.88
	Ave F ratio (past 5 years)	1.22
SSB vs. SSB(MSY)	SSB (2007)	0.87
	SSB (MSY)	1.42
	SSB ratio (2007)	0.61
	SSB ratio (past 5 years)	1.07

Based on the scenario 20, the status of the stock is likely entering to the overfishing status after the high YFT catch for 4 years (2003-2006). This is based on various stock indicators shown in Fig. 10 and Table 6.

- If we look at only the 2007 results, the stock status is likely not too serious.
- However if we look at the results in the recent 5 years including high YFT catch periods (2003-2006), the stock indicators show the serious sign, i.e., Catch/MSY=1.40 and F ratio=1.22 , SSB ratio=1.07

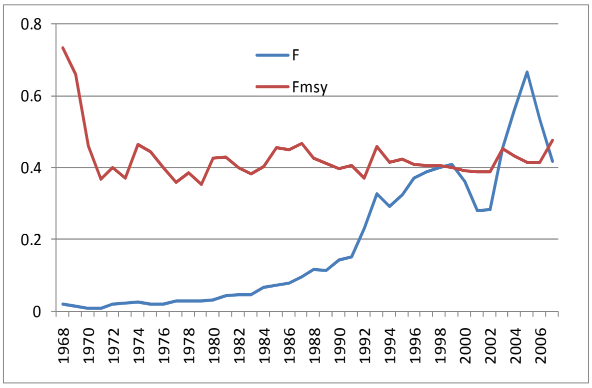
5.3 Projections

Fig 12 shows 20-year projection results for two cases for Scenario 20, (a) first case is to use the 2007 catch level for all gears and (b) 2nd case is for the 5 years average of the recent catch (2003-2007) including 2003-2006 high YFT catch.

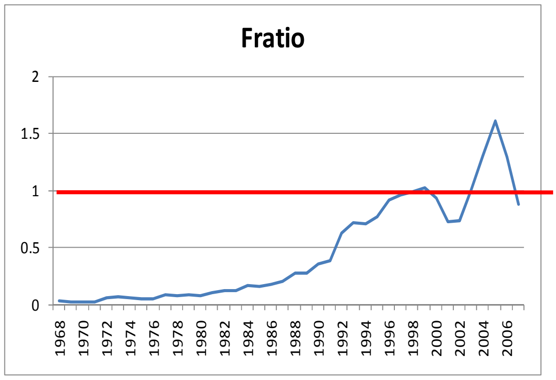
The results suggest that if future catches are kept at the 2007 level (about 300,000 tons) the YFT stock easily recovers to above MSY level, while if we keep the 5 years high catch level (440,000 tons) the YFT stock can maintain the a little below the SSB (MSY) level.

As a conclusion, it is suggested that catch and effort levels should not be increased above the 2007 level.

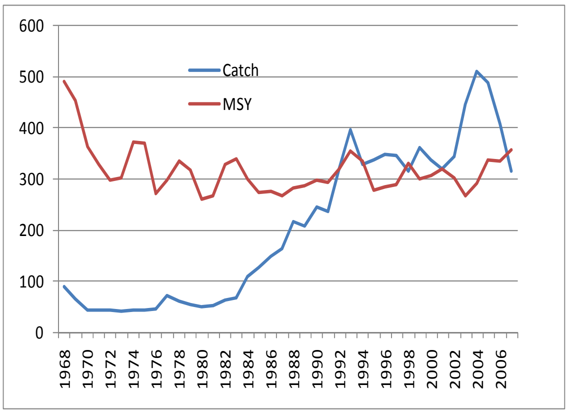
Scenario 20 Catch: S1(1968-2007) and CPUE: JPN S2 (1968-2007)



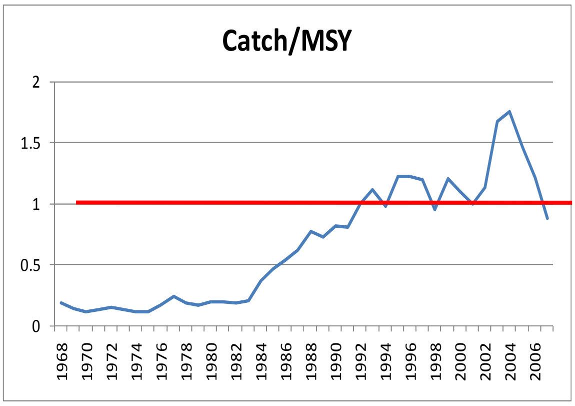
(1) F vs. Fmsy



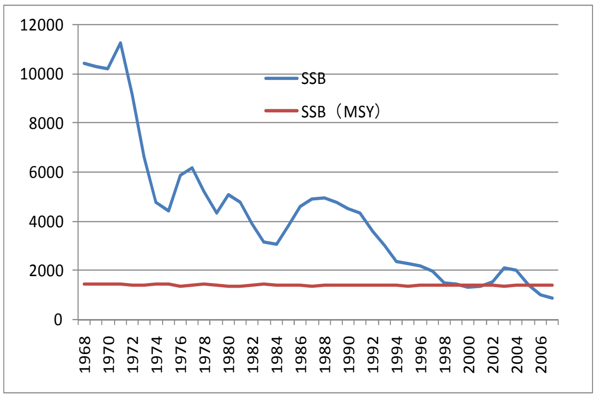
(2) F ratio



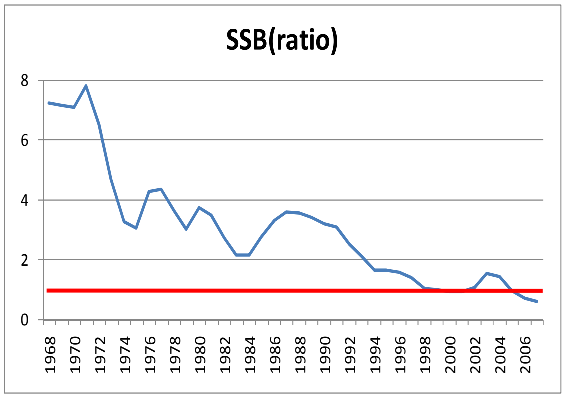
(3) Catch vs. MSY (1,000 t)



(4) catch/MSY



(5) SSB vs SSB (MSY) (1,000 t)



(6) SSB ratio

Fig. 10 Results of the best ASPM scenario 20

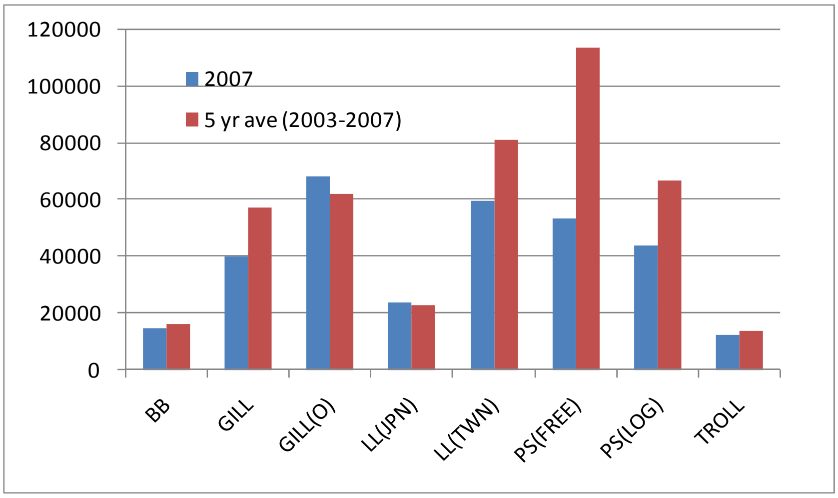


Fig. 11 Two catch levels for the projection, i.e., (a) 2007 level and (b) recent 5 year ave level (2003-2007). NB: 2003-2006 were high YFT years.

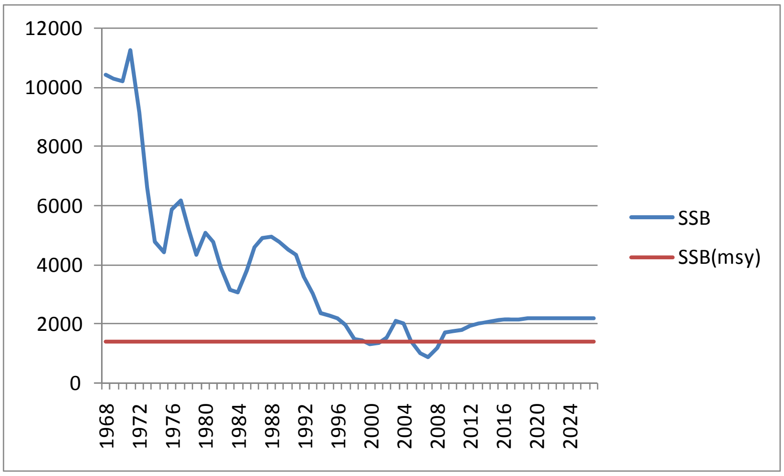


Fig 12(a) Results of the projection (t) when same catch levels for all gears in 2007 were continued

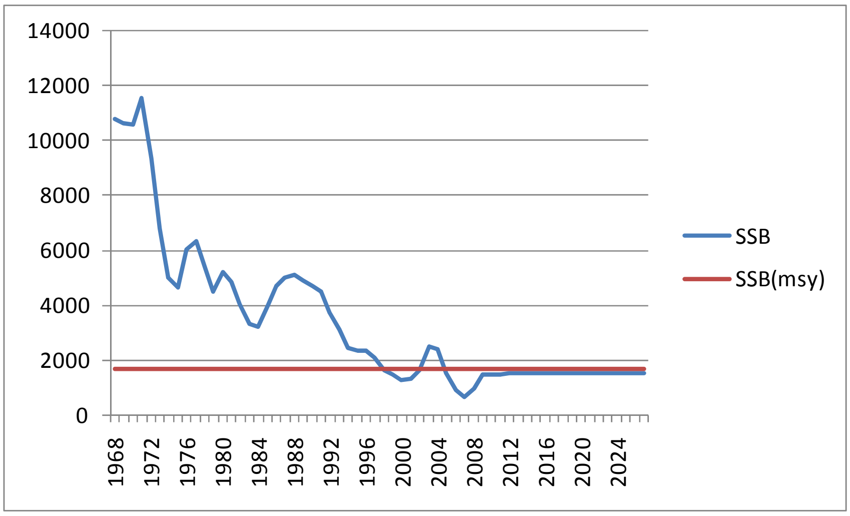


Fig 12(b) Results of the projection (t) when ave catch in recent 5 years (2003-2007) for all gears were continued. NB: 2003-2006 were high YFT years.

Acknowledgements

I sincerely thank to Dr Rebecca Rademeyer (University of Cape Town) to recode the Fortran ASPM by ADMB. Thanks for WPTT e-mail circulations members for the fruitful discussion which gave many hints in conducting useful ASPM analyses. Many appreciation for Miguel Herrera (IOTC) for providing essential data and also for Prof. Dough Butterworth (Cape Town University, South Africa) to help in developing the ADMB based ASPM.

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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 $(N_{l,t+1}$ 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,

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

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 $\sigma_{i,t}^2$ 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

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

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:

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

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,

$$N_{1,1} = R_0 \qquad (12a)$$

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

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

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)

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

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

$$Y_F = R_F (Y/R)_F \qquad (13c)$$

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

$$N_{1,t} = R_0 e^{\nu} \tag{14}$$

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 ν_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

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

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):

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

Where the residuals would be computed as

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

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

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

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

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

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

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

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

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

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

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

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 (σ_η^2,σ_v^2 and possibly $\sigma_{i,l}^2$), the log-likelihood components could be given different emphases (λ) to obtain model estimates by minimizing:

$$-\ln(L_T)=-\ln(L_1)-\lambda_2\ln(L_2)-\lambda_3\ln(L_3) \quad (23)$$

Addendum

IOTC-2008-WPTT10-28(add)

2nd ASPM runs

Reviews :

1st RUN (42 scenarios)

- Paige Growth eq.
- M 0.8 (age 0) 0.6 (age 1 or older) (last SA)
- Catch period (3) (1950-, 1968- and 1980-)
- CPUE period Japan (3)

  (1960-2007, 1968-2007 & 1980-2007)
- CPUE Taiwan (4) (1980-2007)
- LL selectivity : dome shape
- Steepness =0.8 (fixed)

Results of 1st RUN
(best scenario : 20)

- Optimum period

  Catch 1968-2007

  CPUE 1968-2007 (Japan)

No good results

longer or shorter period

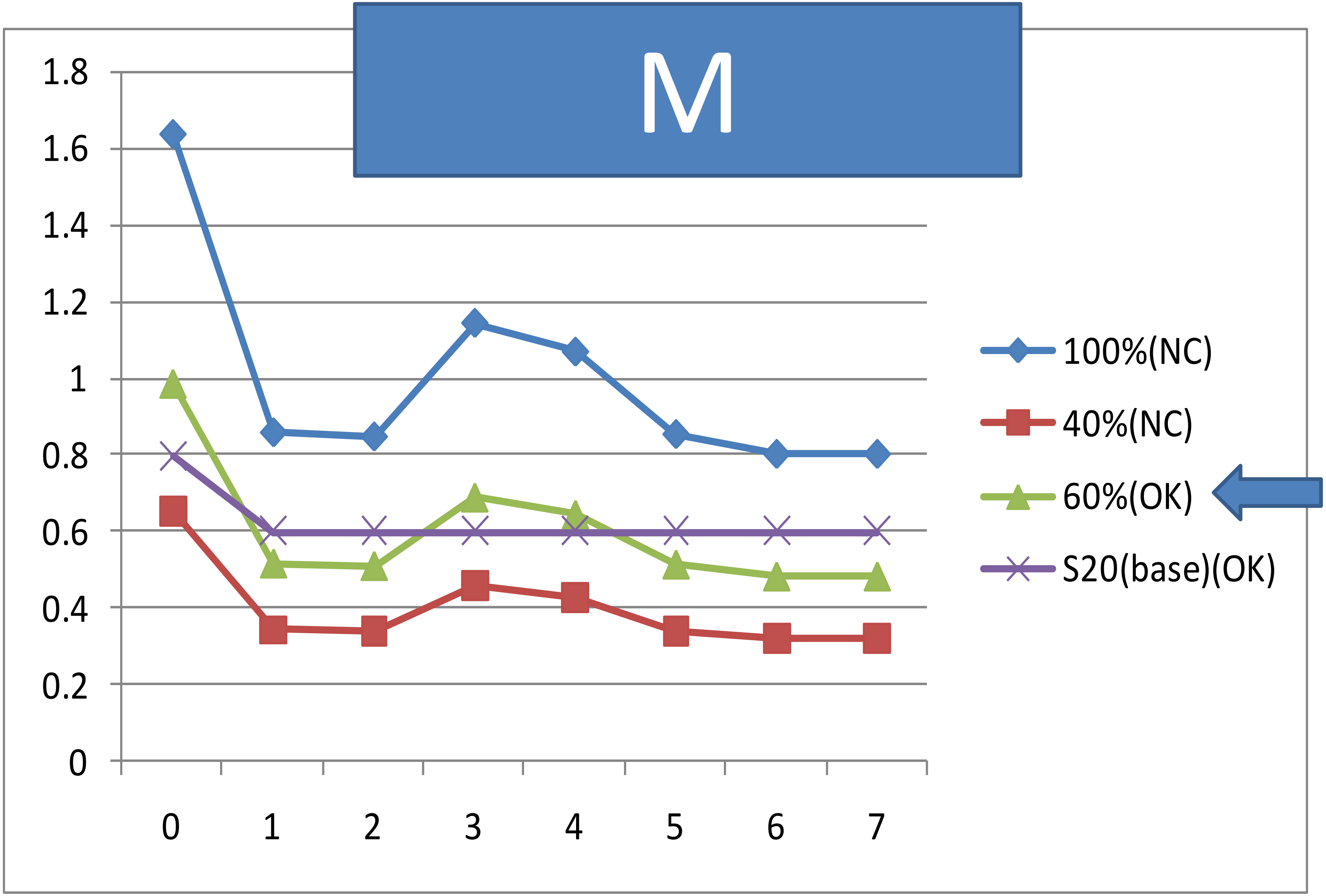
- Catch (1950-2007 or 1980-2007)
- CPUE Japan (1960-2007 or 1980-2007)

  all Taiwan (1980-2007)

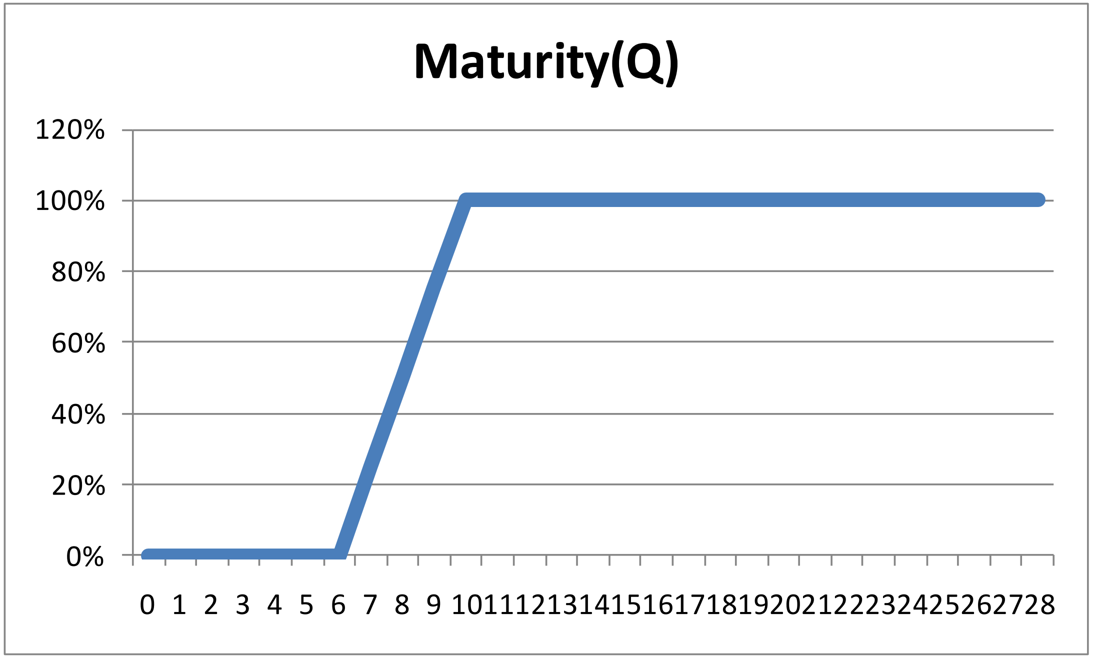
2^{nd} run (40 scenarios)

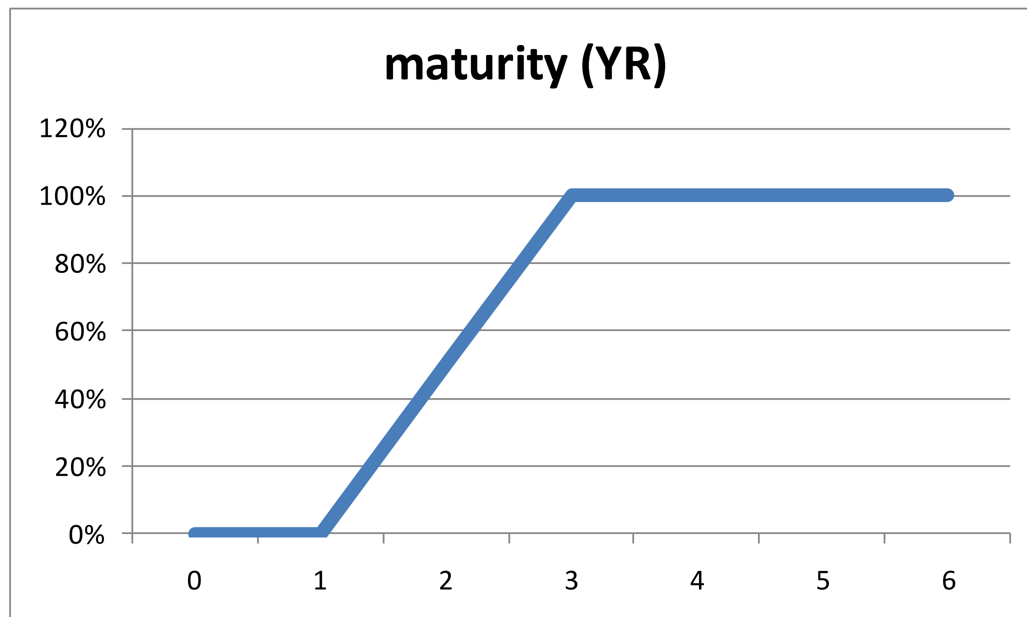
- Growth **(AF vs. Paige)**
- LL selectivity **(Dome vs. Flat top)**
- Selectivity **(estimated vs. Fixed=0.8)**
- CPUE (5)

  Japan (1) vs. [Japan(1)+Taiwan (4)]
- Catch period (1960-2007 vs. 1968-2007)


M
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
100%(NC)
40%(NC)
60%(OK)
S20(base)(OK)

Maturity schedule (MF-CL)





RESULTS

Table 7 Results of 40 extended ASPM (ADMB) runs (1968-2007)

Note S(selectivity), UR(un realistic), NC(Not converged) LS(Low Steepness value)

No	steepness	LL Selectivity (shape)	Growth	CPUE Japan(1) Taiwan(4)	Steep-Ness	R2	LH model	LH cpue	SR fit	MSY (mil. tons)	SSB (mil tons)	Results
1	Estimated	Dome	P	J	No convergence							
2				J+T(BC)								
3				J+T(S1)	0.39	Low selectivity						
4				J+(TS2)	0.36							
5				J+(TS3)	0.41							
6			AF	J	0.98	High selectivity and Unrealistic estimates						
7				J+T(BC)								
8				J+T(S1)								
9				J+(TS2)								
10				J+(TS3)								
11		Flat	P	J	No convergence							
12				J+T(BC)	0.41	Low selectivity						
13				J+T(S1)	No convergence							
14				J+(TS2)								
15				J+(TS3)								
16			AF	J								
17				J+T(BC)								
18				J+T(S1)								
19				J+(TS2)								
20				J+(TS3)								

Note S(selectivity), UR(un realistic), NC(Not converged)   LS(Low Steepness value)

No	steepness	LL Selectivity (shape)	Growth	CPUE Japan(1) Taiwan(4)	Steep-Ness	R2	LH model	LH cpue	SR fit	MSY (mil. tons)	SSB (mil tons)	Results
21	Fixed (0.8)	Dome	P	J	0.8	0.85	-96	-108	11	0.35	2.30	BC(S20)
22				J+T(BC)		0.91	-106	-119	12	0.39	1.11	OK(best)
23				J+T(S1)		No convergence						
24				J+T(S2)								
25				J+(TS3)								
26			AF	J		0.86	-59	-66	7	0.35	0.63	UR
27				J+T(BC)		No convergence						
28				J+T(S1)								
29				J+(TS2)								
30				J+(TS3)								
31		Flat	P	J		No convergence						
32				J+T(BC)		0.91	-104	-118	13	0.46	1.83	UR
33				J+T(S1)		0.83	-82	-94	11	0.36	0.40	UR
34				J+(TS2)		0.85	-87	-100	11	0.37	0.35	UR
35				J+(TS3)		0.85	-97	-100	11	0.37	0.35	UR
36			AF	J		No convergence						
37				J+T(BC)								
38				J+T(S1)								
39				J+(TS2)								
40				J+(TS3)								

Results

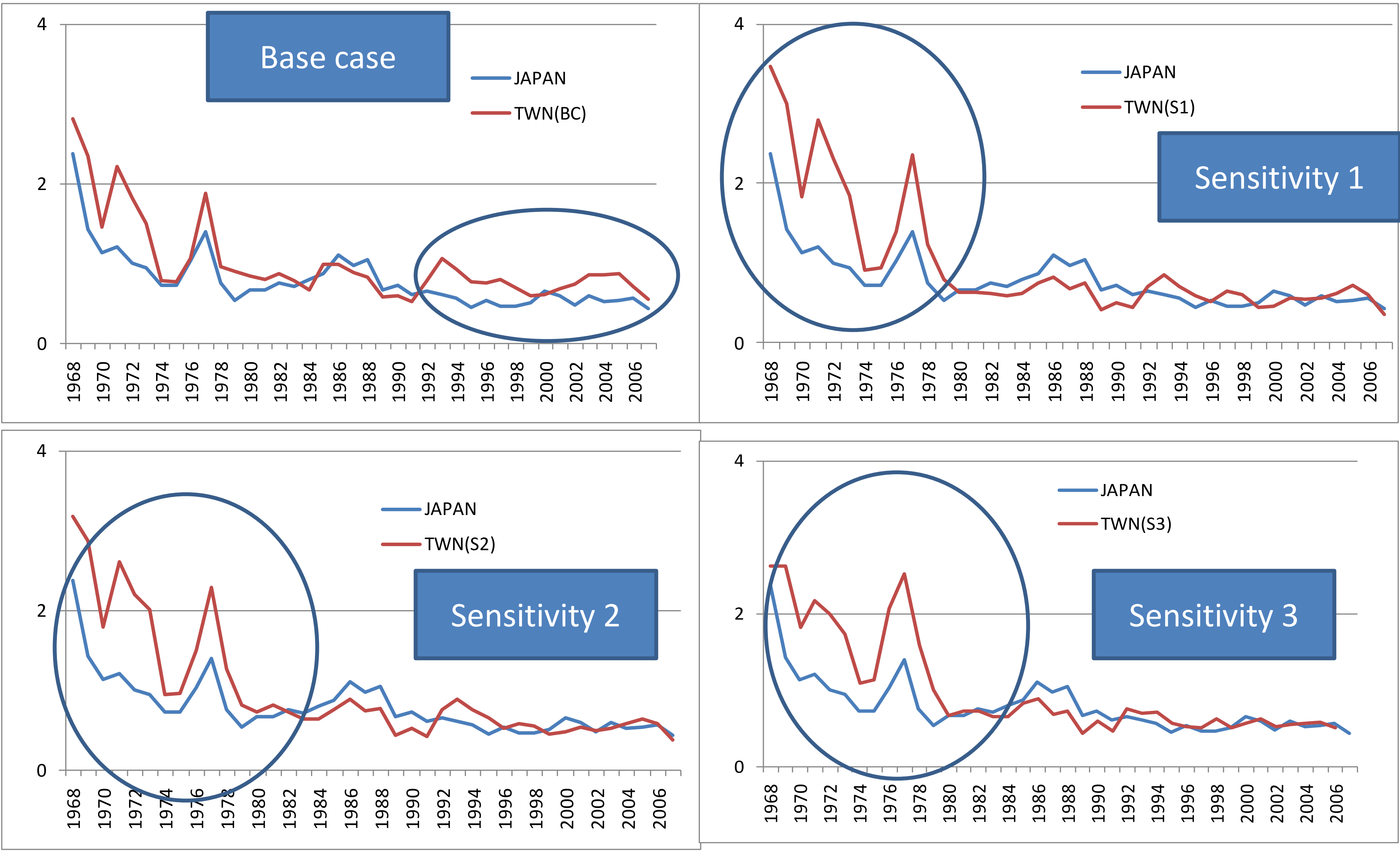
Optimum parameters

- Selectivity **Fixed=0.8**
- LL selectivity **Dome shape**
- Catch period **(1960-2007 & 1968-2007)**
- Growth : **Paige**

Best scenario in the 2nd Run (22→21)

- **CPUE (1968-2007)**

Scenario 22: Japan + Taiwan (base case)
Scenario 21 : Japan (Scenario 20 in 1st run)

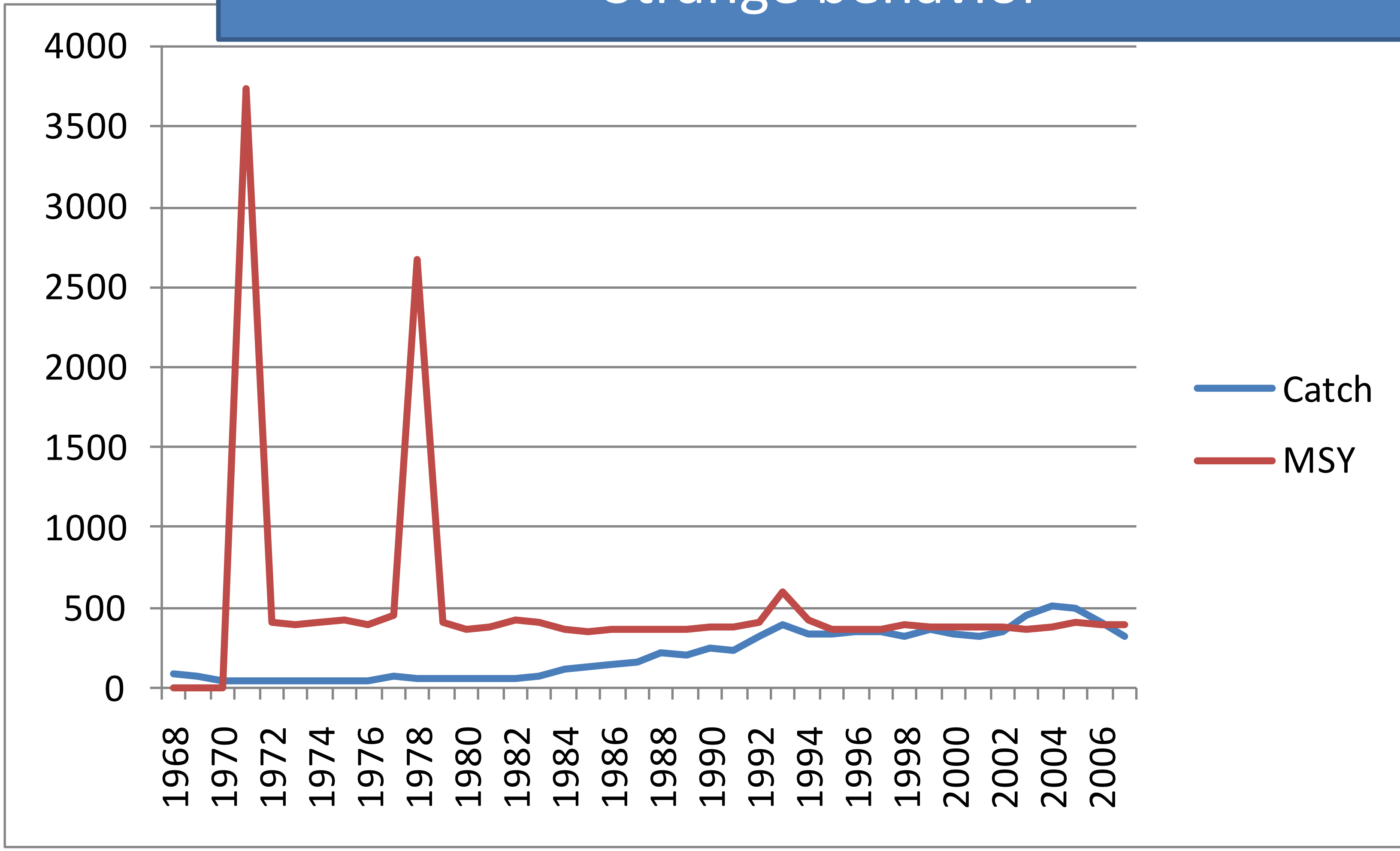


Large discrepancies before 1980 except base case
(but base case has a large discrepancies in recent years)

- **But Strange relation in Scenario 22 (although converged)**

➔ **Not selected**

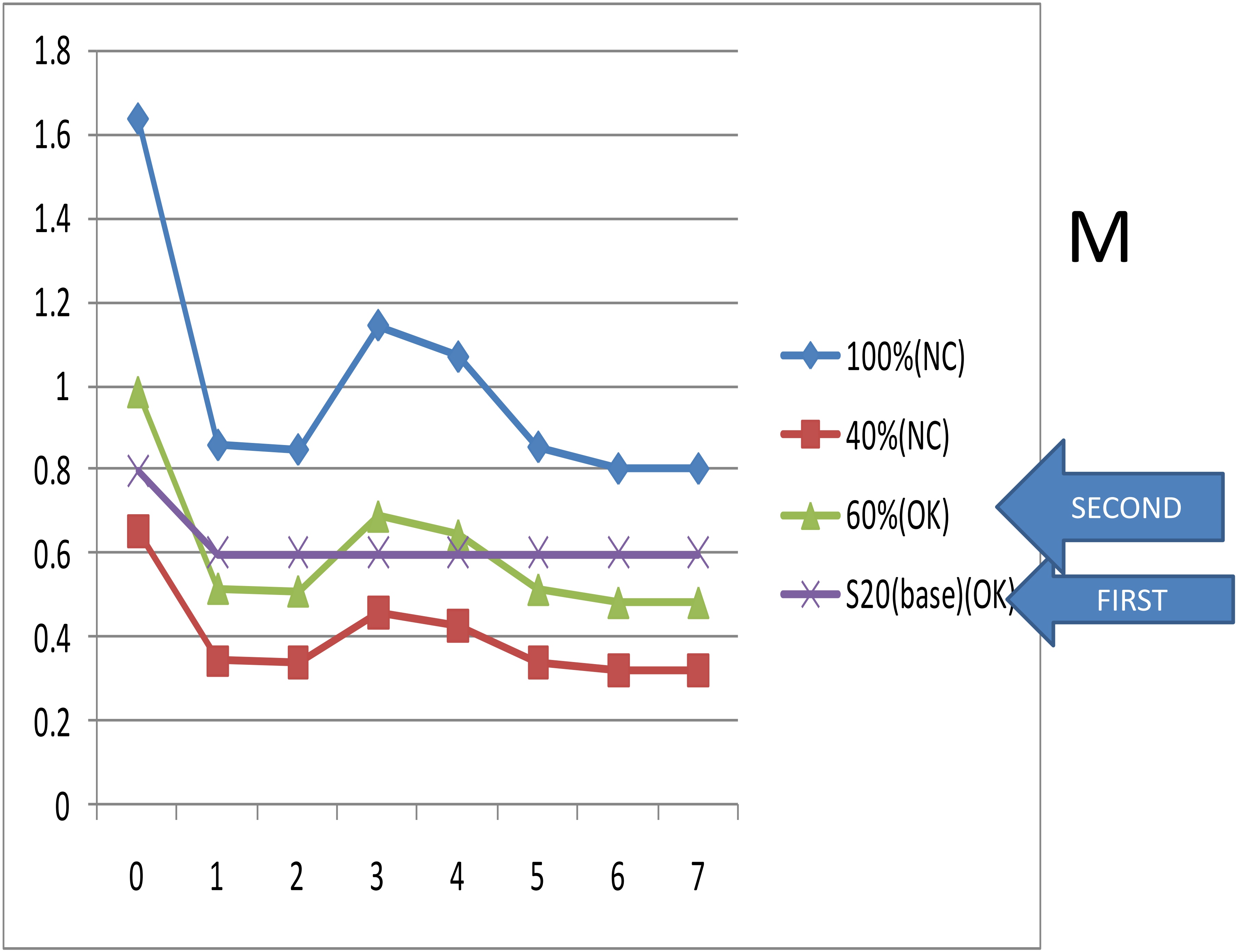
Scenario 22 (Japan & Taiwan CPUE)
Strange behavior



As a result
Same scenario
(20 in 1st Run and 21 in 2nd Run)
was selected
(out of 82 scenarios) → robust

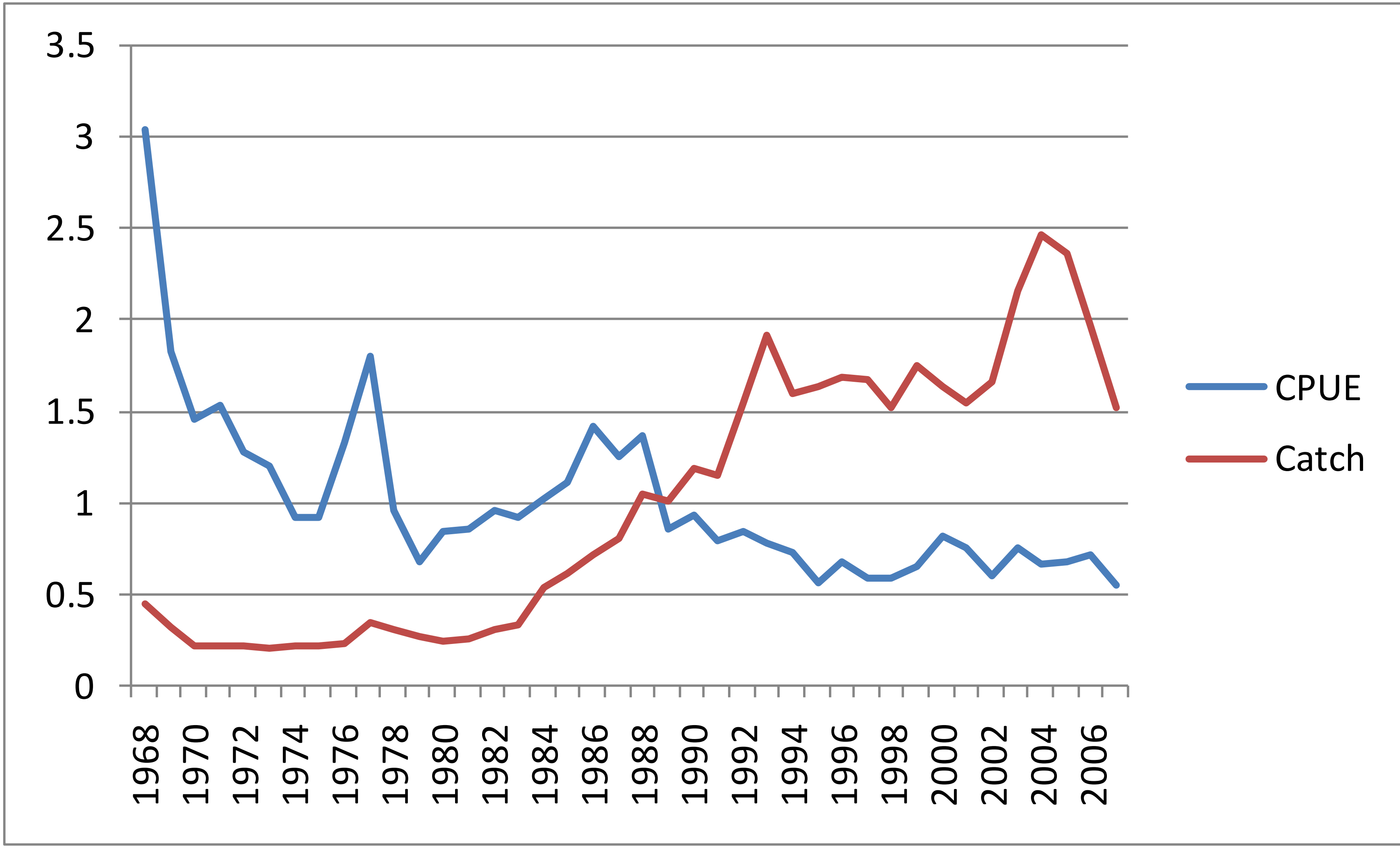
- **FIRST (Scenario 20) R2=0.93(selected)**
- SECOND (scenario 21) R2=0.85

Difference is only M vector

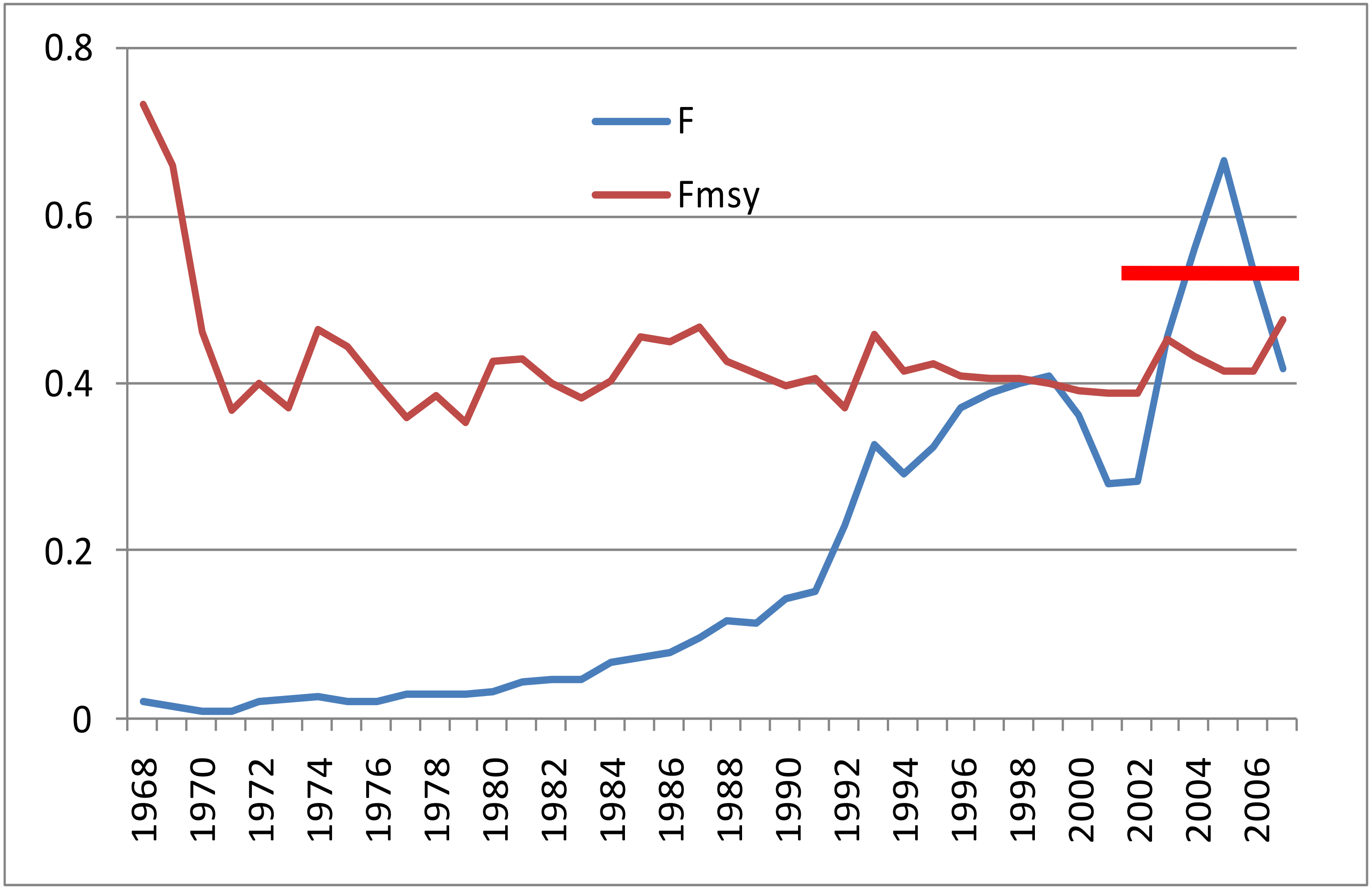


1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
100%(NC)
40%(NC)
60%(OK)
S20(base)(OK)
M
SECOND
FIRST

Scenario 20 (1st Run) :CPUE (Japan) vs. Catch

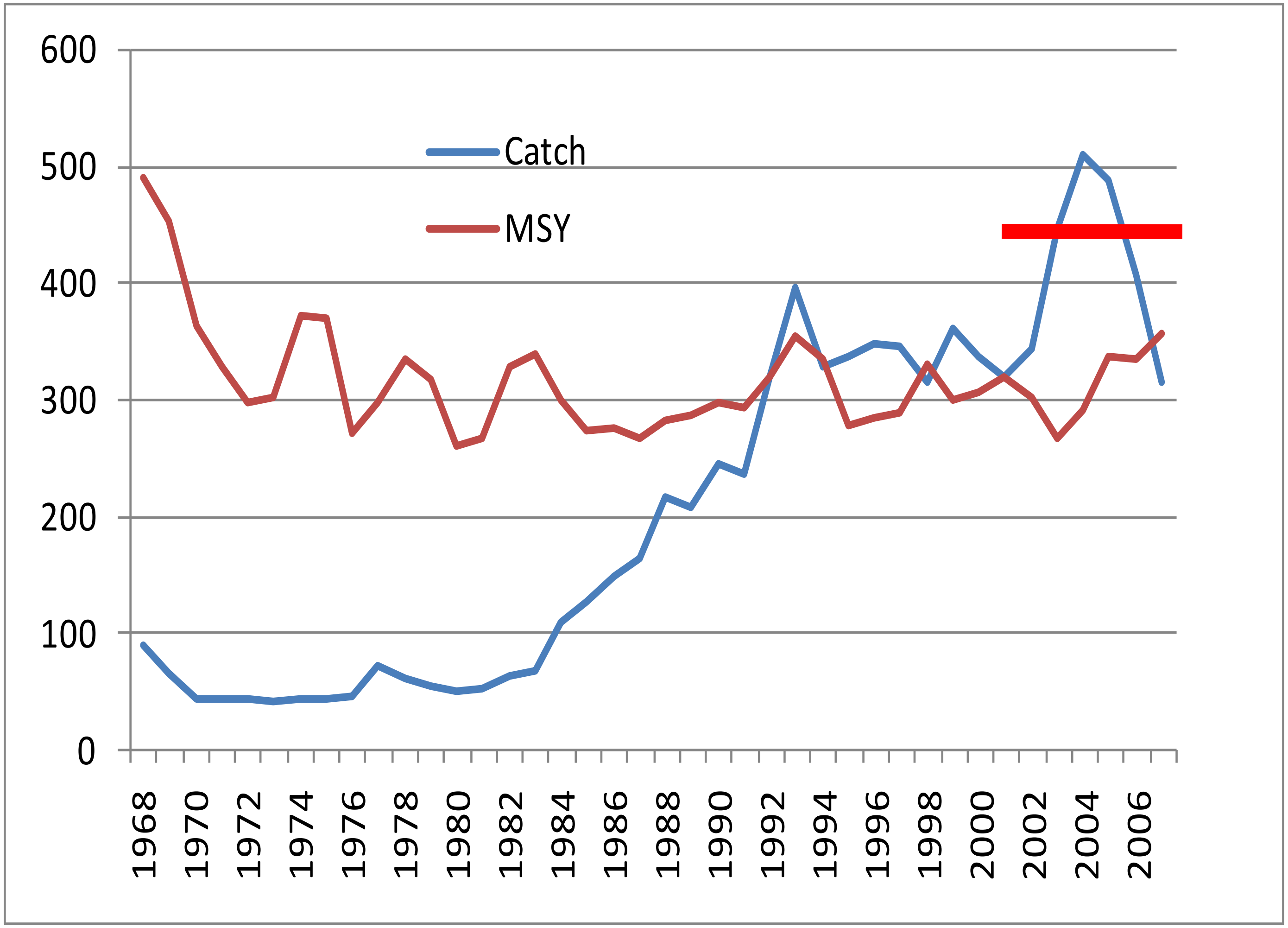


F(MSY)= 0.47, F(2007)=0.42, F(ave 03-07)=0.53

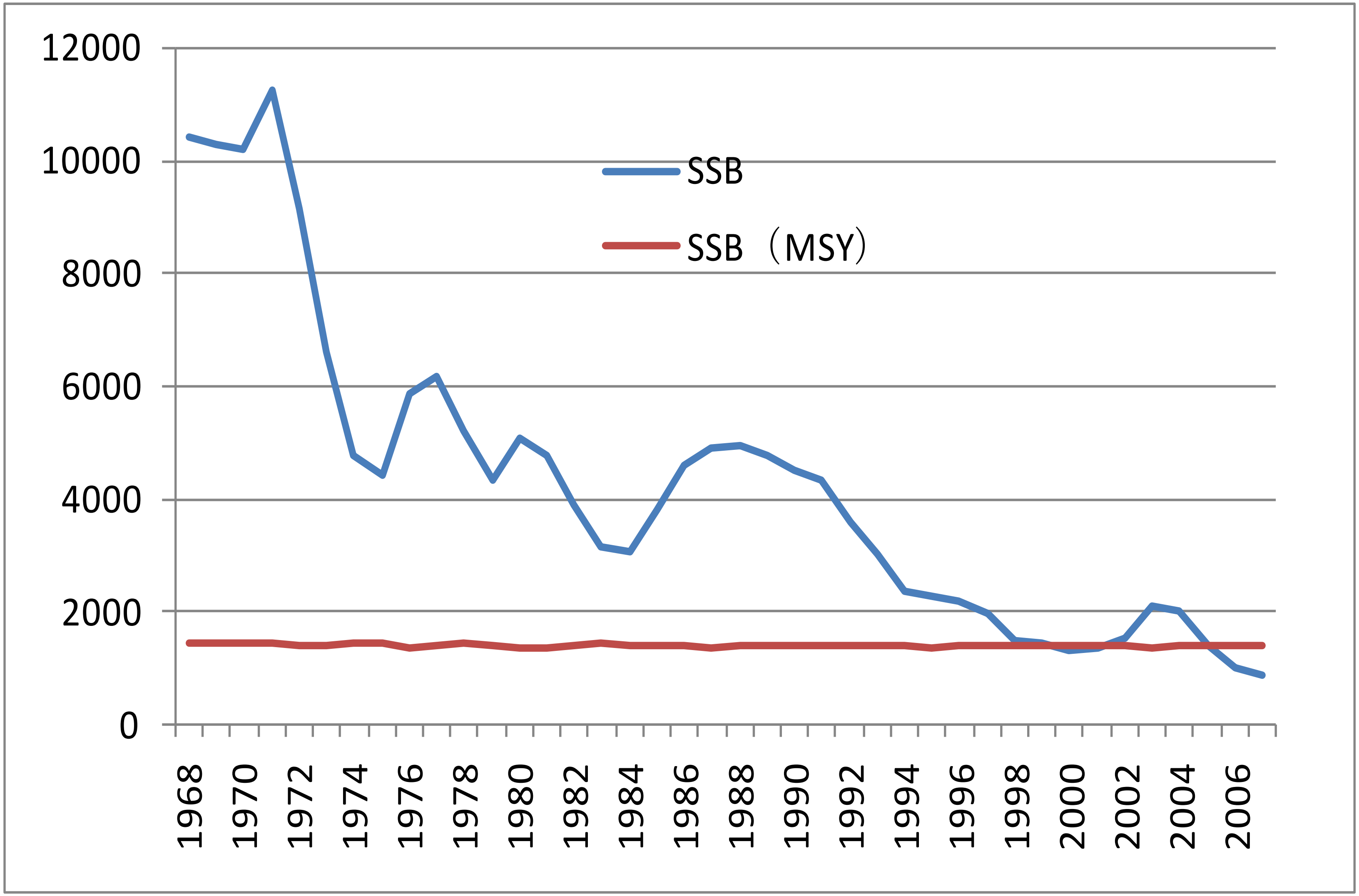


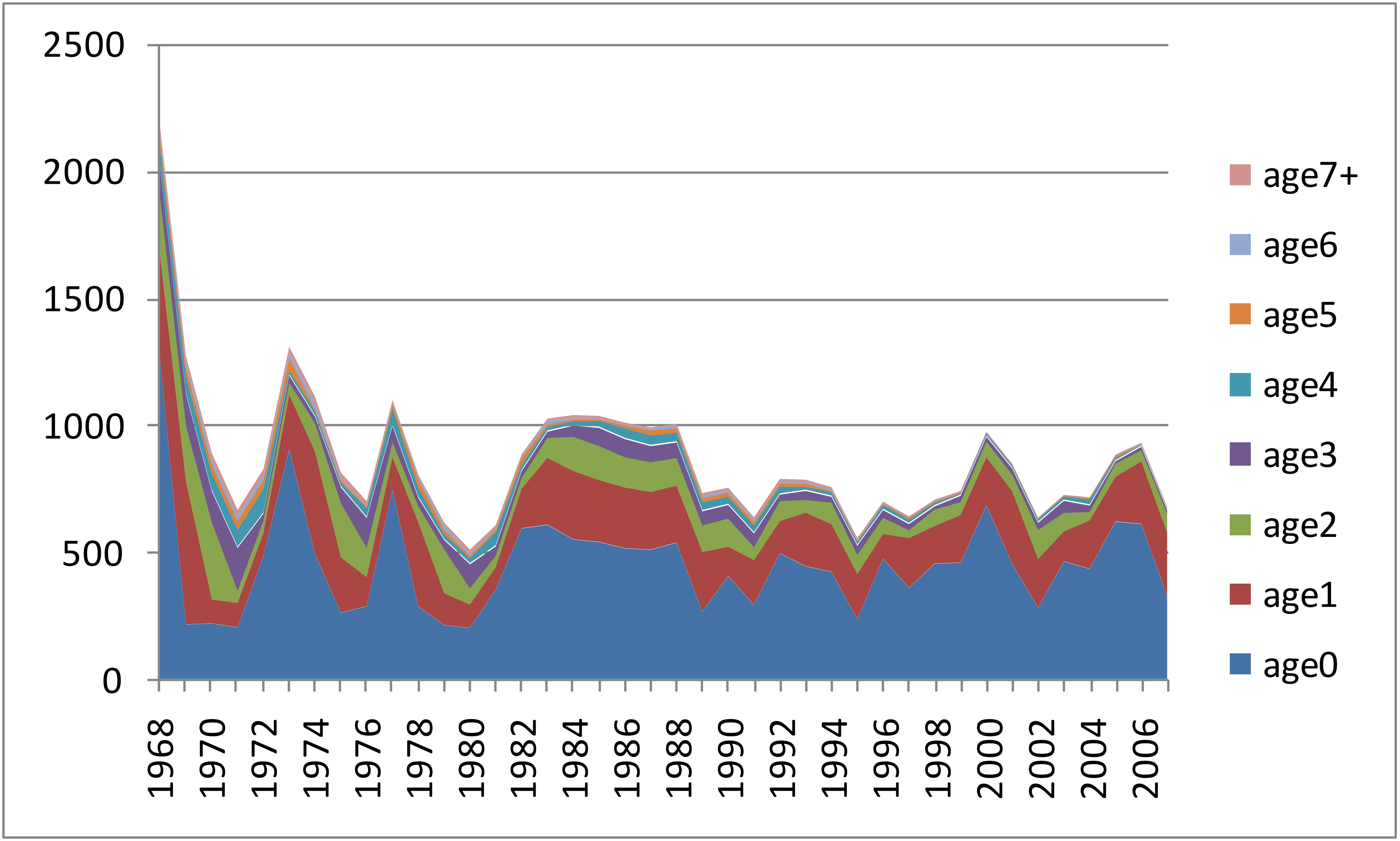
F ratio (2007)=0.89, F ratio (ave 03-07)=1.22

MSY=360 (thousand tons)
C(2007)=330,   C(2003-2007)=420



SSB(MSY)=1.42 (mil. tons)
SSB(2007)(ratio) =0.61



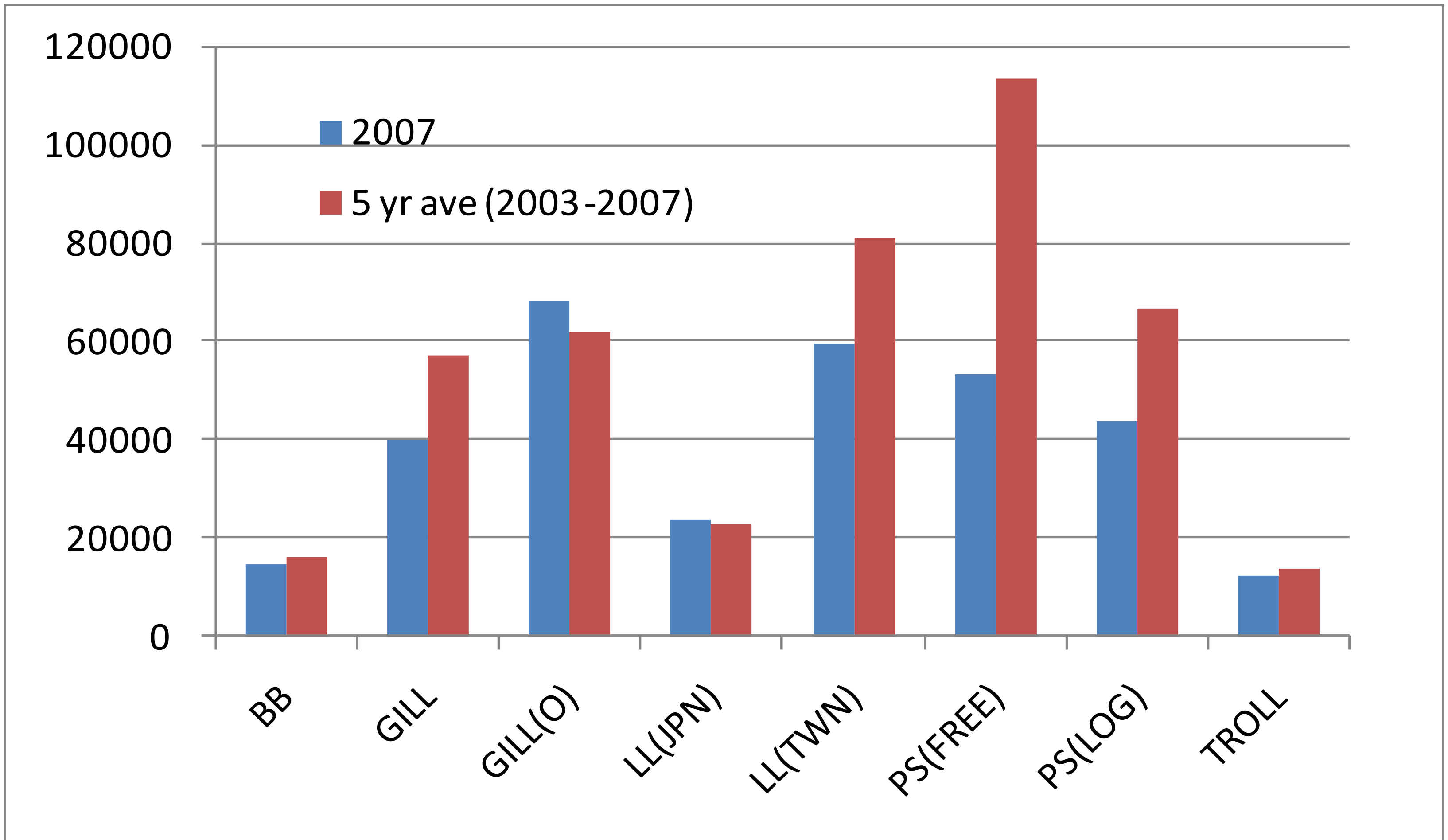


Million fish

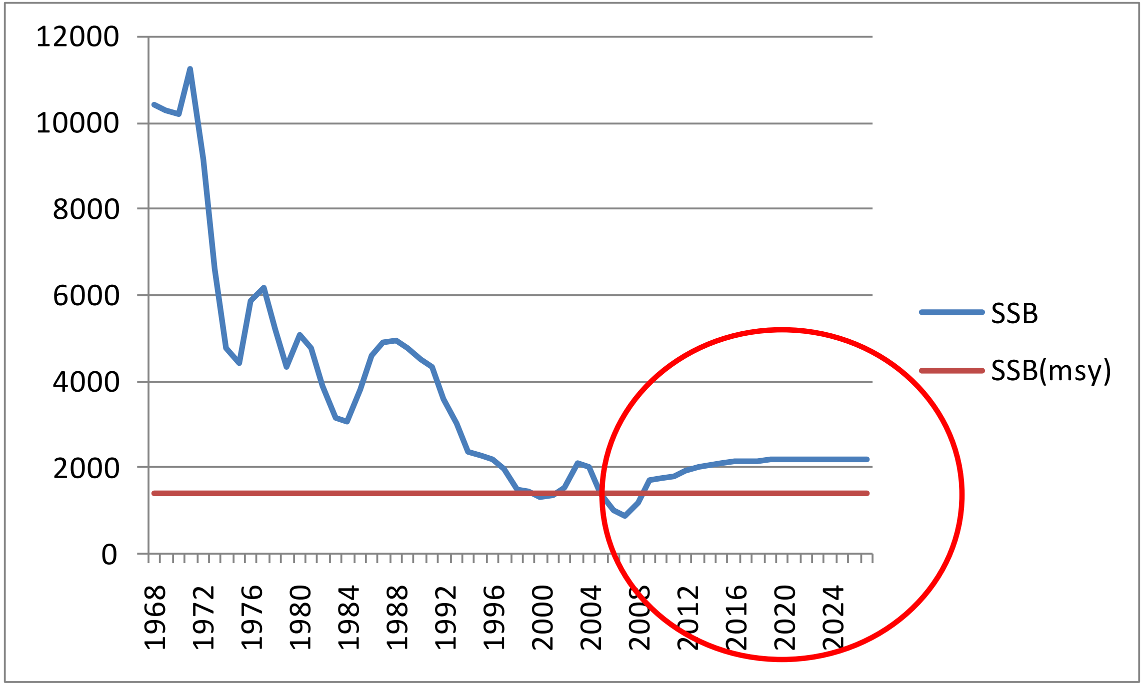
Diagnosis & other plots

(Angannuzzi)

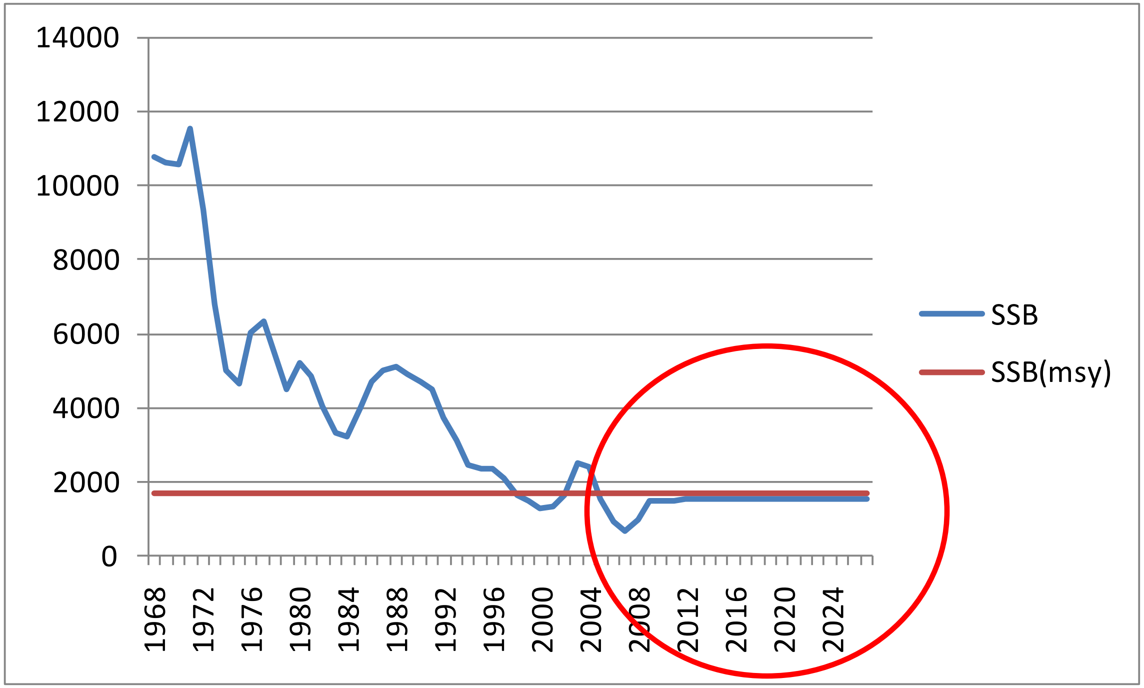
Future projection: two scenarios (1) catch (2007) (2) Ave catch (2003-2007)



SCENARIO 1
C(2007)



SCENARIO 2
C(ave 2003-07)



Summary (1)

Optimum parameters based on 82 ASPM runs

- Period : **CPUE (1968-), Catch (1960's-)**
- LL Selectivity : **dome shape**
- Selectivity : **Fixed=0.8**
- CPUE : **Japan (1968-2007)**

  ➔Taiwan base case CPUE is getting better !

  ➔ Taiwan CPUE should be **1968-**
- M : **60% of MF-CL or**

  age 0 (0.8) and age 1- (0.6)

Summary (2)

Stock status

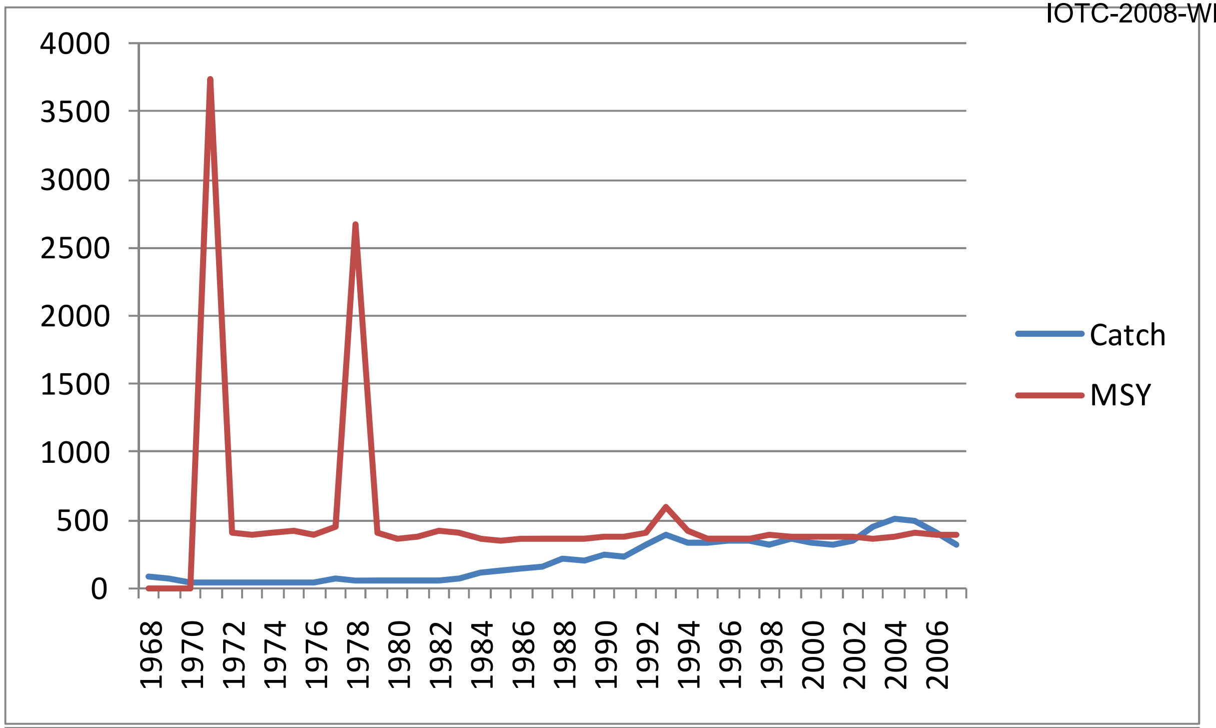
- Based on the stock indicators in the final results, IO YFT stock is are now likely entering to the overfishing status after 4 years high YFT catch in 2003-2006.

Revised

ASPM results

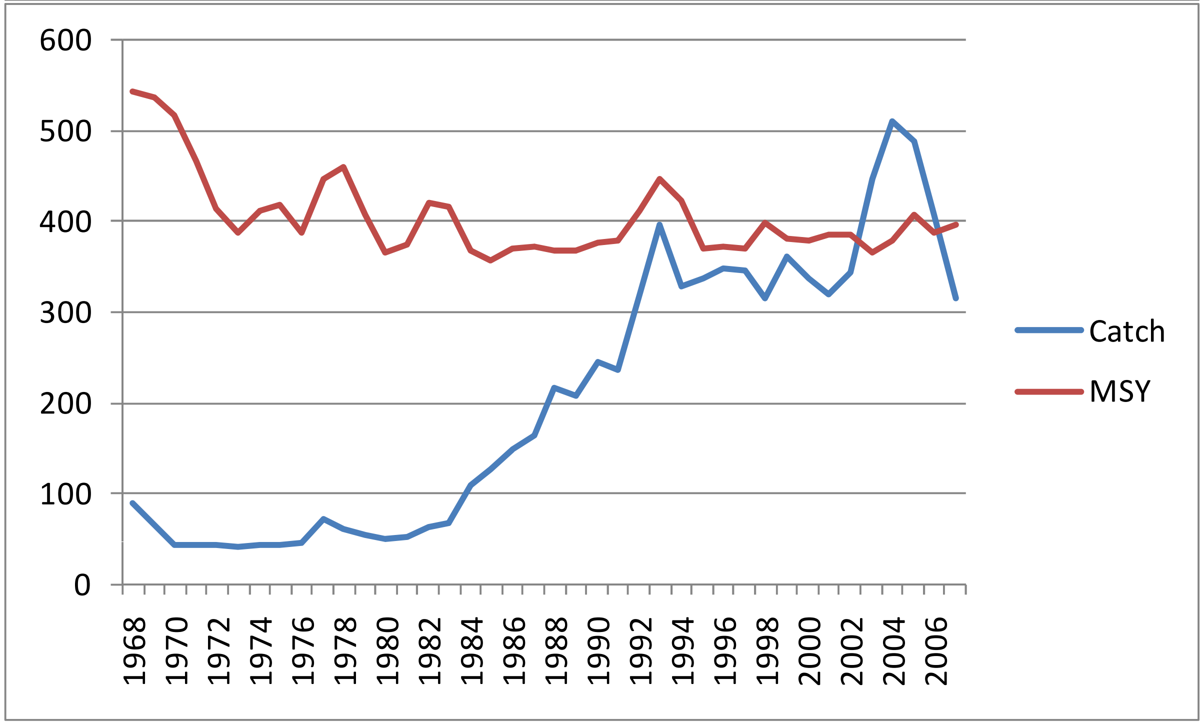
IOTC-2008-WPTT10-28(rev)

2nd runs :
Scenario 22
(JPN & TWN CPUE)
Strange behavior



Program revised

→ OK



Re-run 2 other finalists using the revised ASPM program

Scenario 20 (1st run)(M:0.6 & 0.8)
Scenario21 (2nd run)(M:60% of MFCL)
both CPUE (Japan only)

Same results

Note
Screening criteria
(1st 42 runs & 2nd 40 runs)

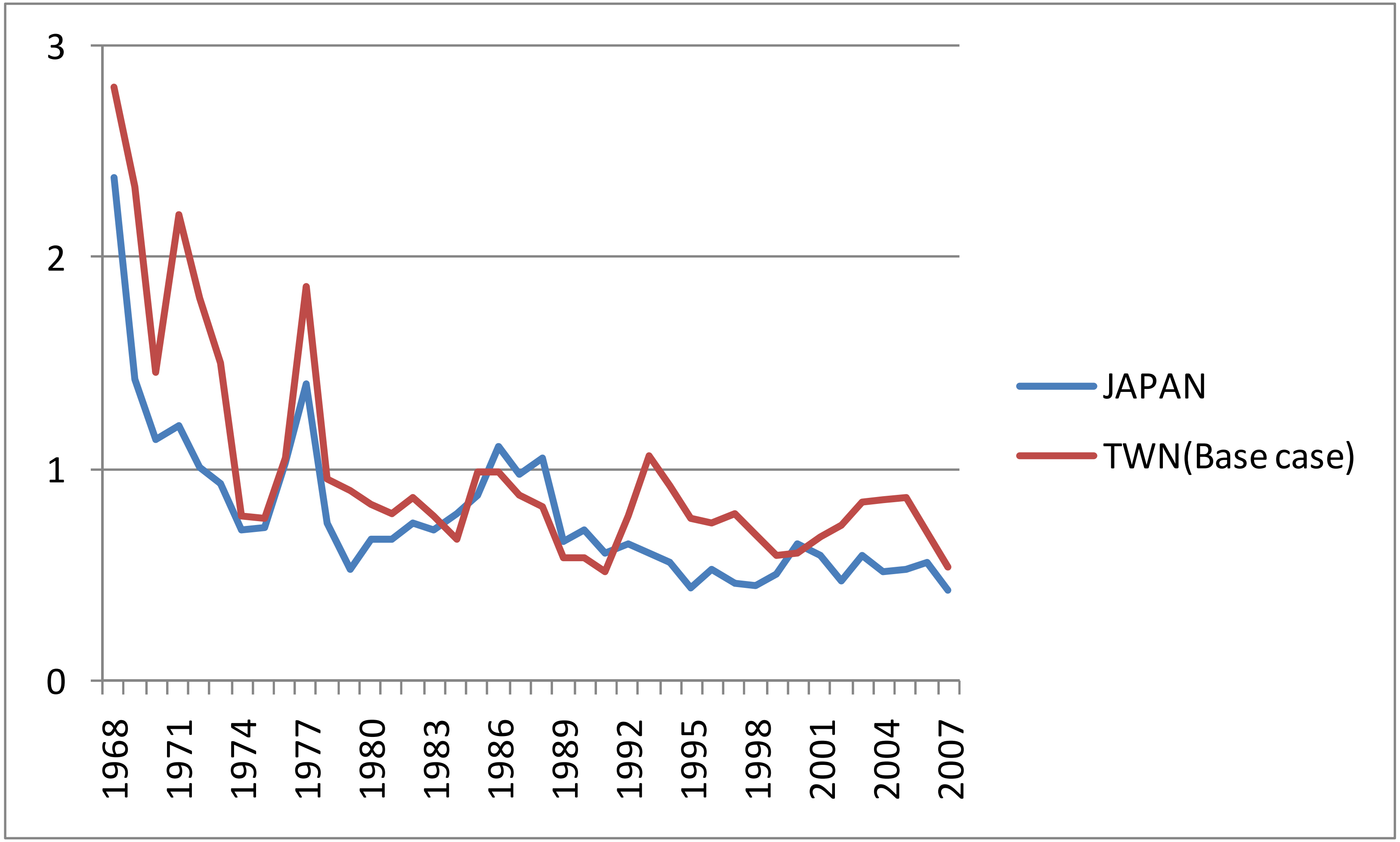
- 0.2 <= MSY <= 0.6 (million tons)
- 0.5 <=SSB(2007) <= 5.0 (million tons)

Re-evaluation of 3 finalists

Run	S. No.	M	CPUE	r2	MSY (**)	Catch (*)	F(ratio) 2007	F(ratio) Ave 03-07	SSB (ratio) 2007	SSB (ratio) Ave 03-07
1st	20	0.6 0.8 (**)	JPN	0.93	0.36	0.33 (2007) 0.42 (ave: 03-07)	0.88	1.22	1.07	0.61
							(pessimistic)			
2nd	21	60% of MFCL	JPN	0.86	0.35		0.62	0.83	1.23	1.40
	22		JPN+ TWN (BC)	0.91	0.39		0.52	0.72	1.32	1.37
							(optimistic)			

(*) million tons

(**) 0.8(age 0) & 0.6 (age 1-) (ICCAT) used last SA (2007)



TWN CPUE high level → optimistic results

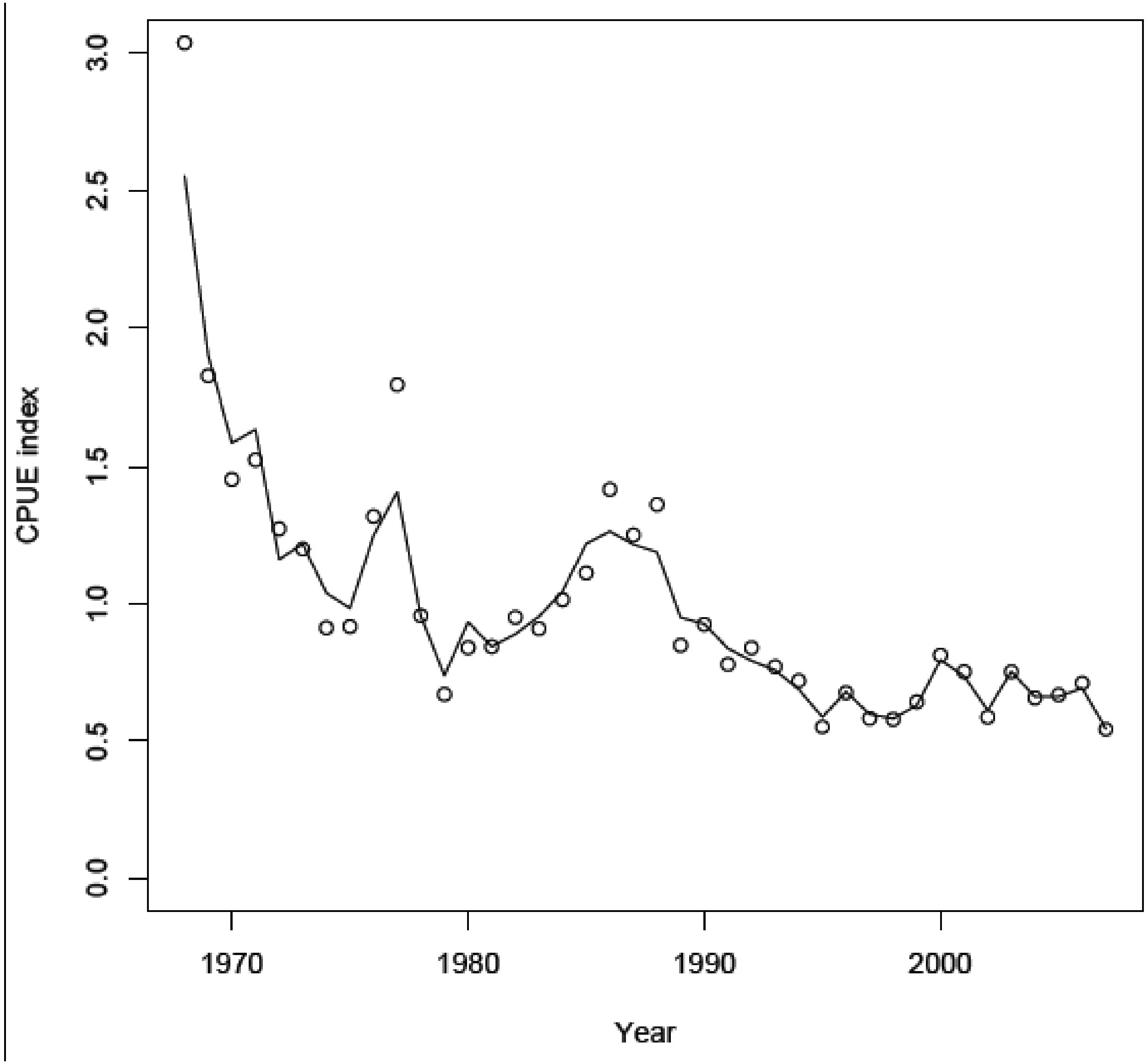
pulses unstable trends → still some reservation

As a result
Scenario 20 (1st Run) (CPUE JPN) was selected among 82 scenarios

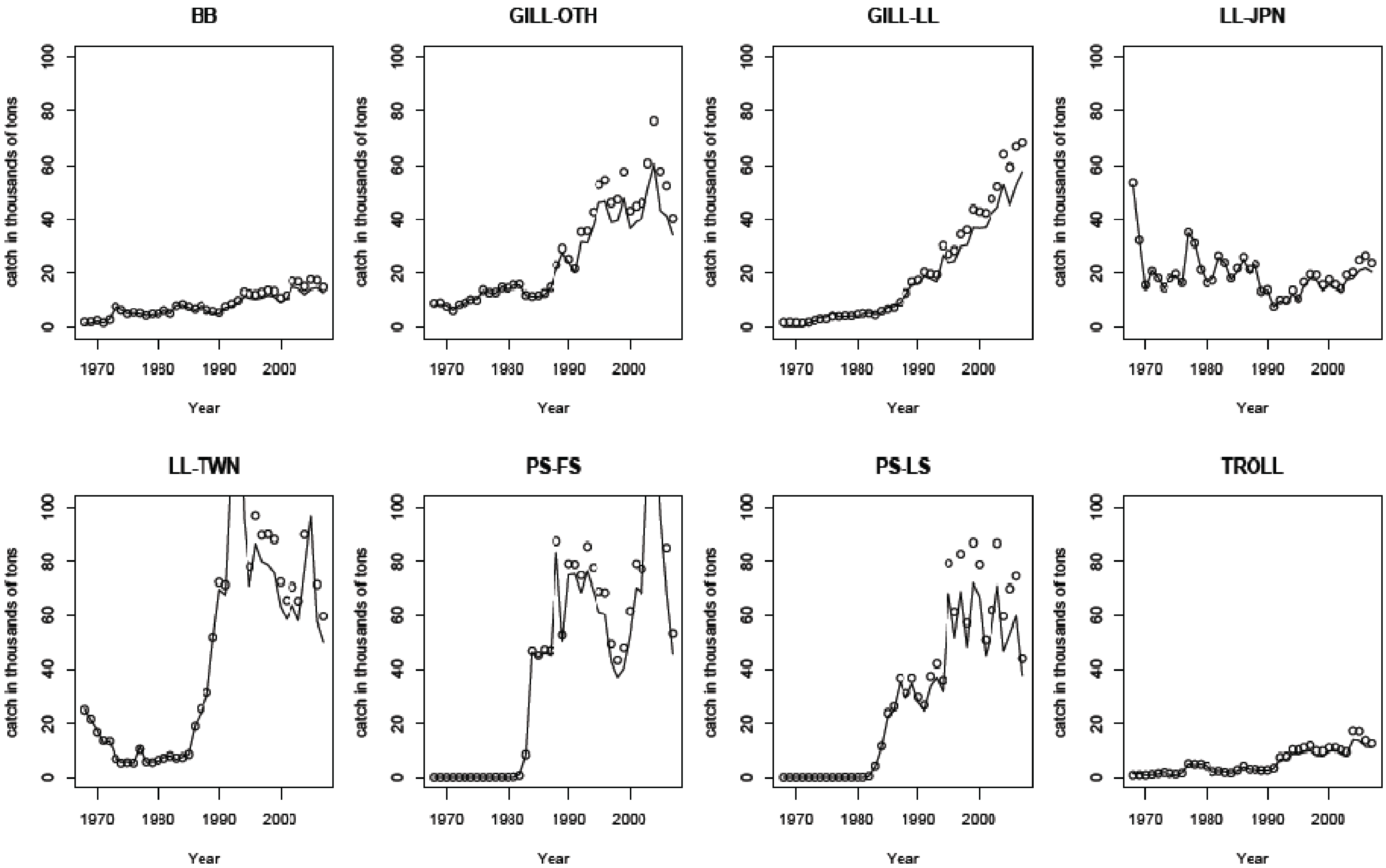
- **LL selectivity** **dome shape**
- **Growth** **Paige & Polacheck (2008)**
- **M (ICCAT)** **0.8 (age 0) and 0.6 (age 1-)**
- **Steepness** **Fixed=0.8**
- **Catch & CPUE (JPN) : 1968-2007**

Plots
(Diagnosis & results)

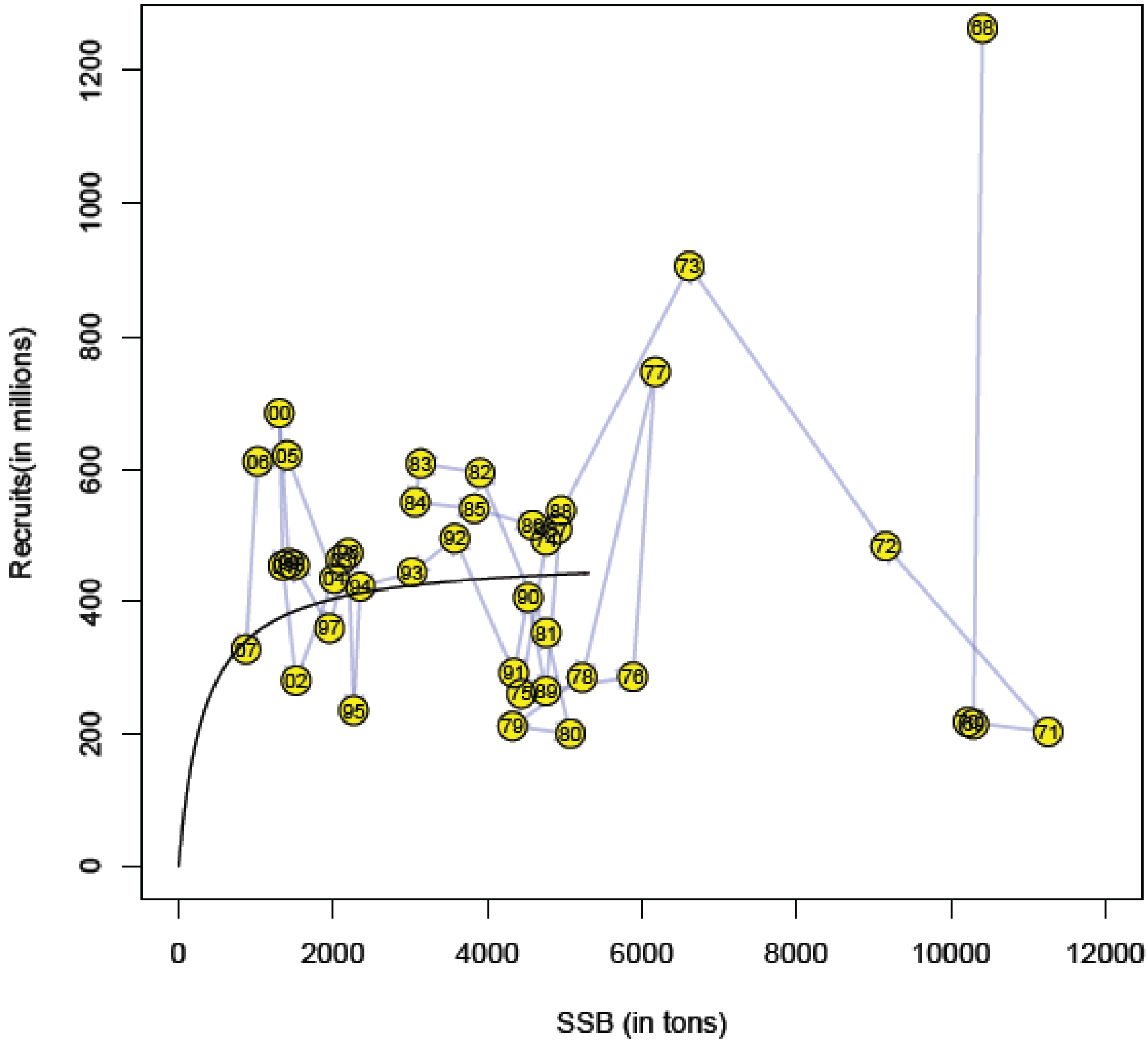
CPUE (observed vs. predicted)



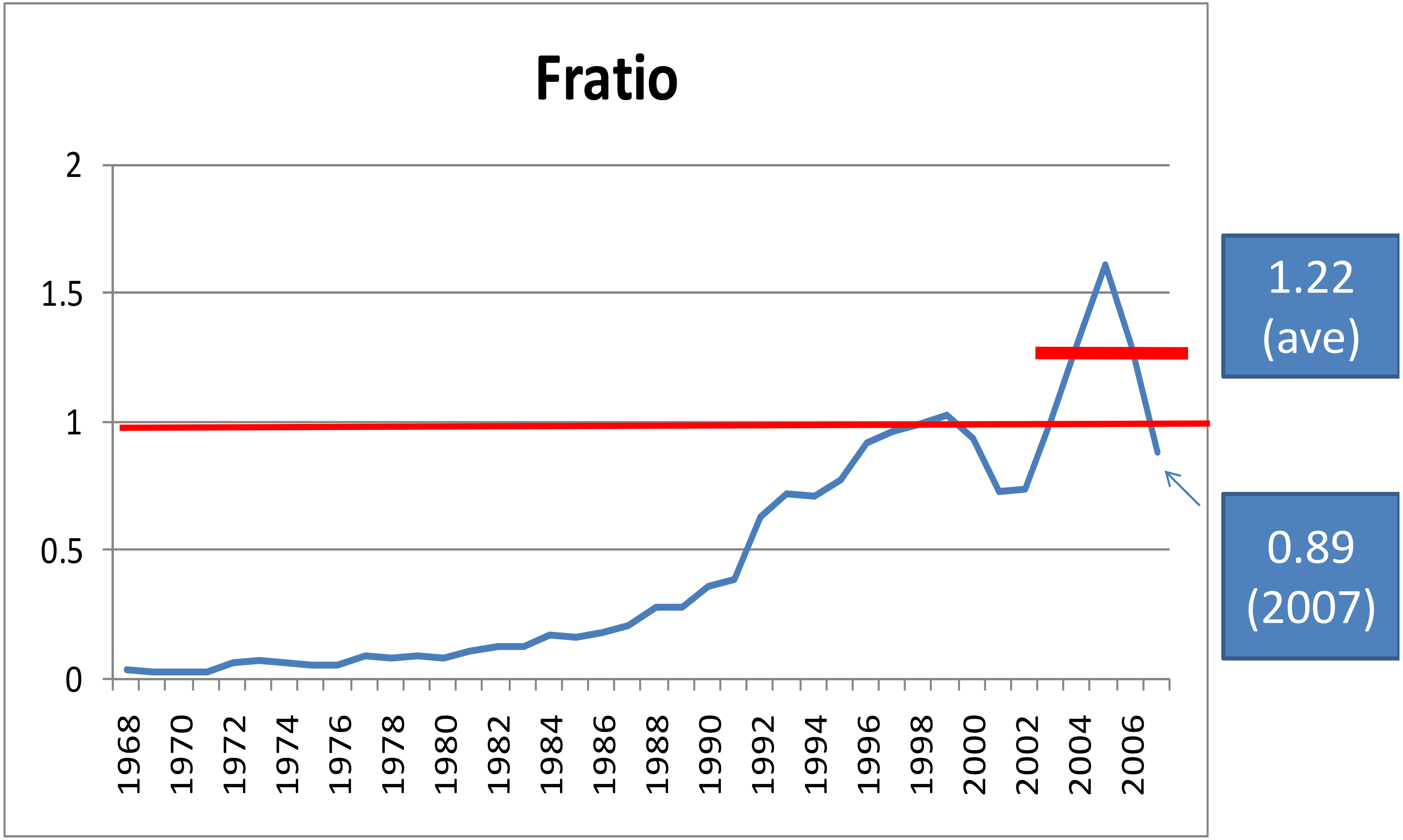
Catch (observed vs. predicted)



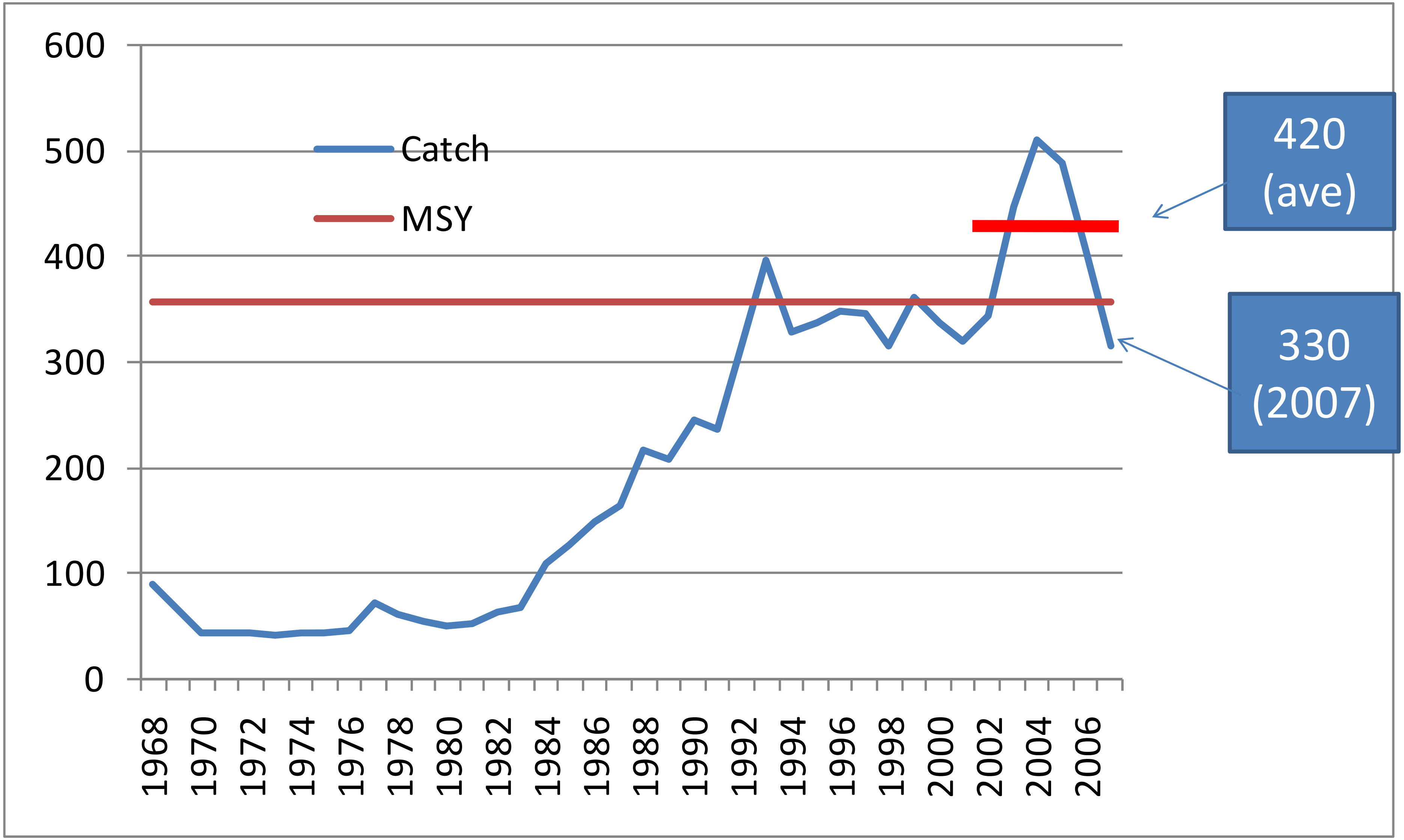
SR (observed vs. predicted)

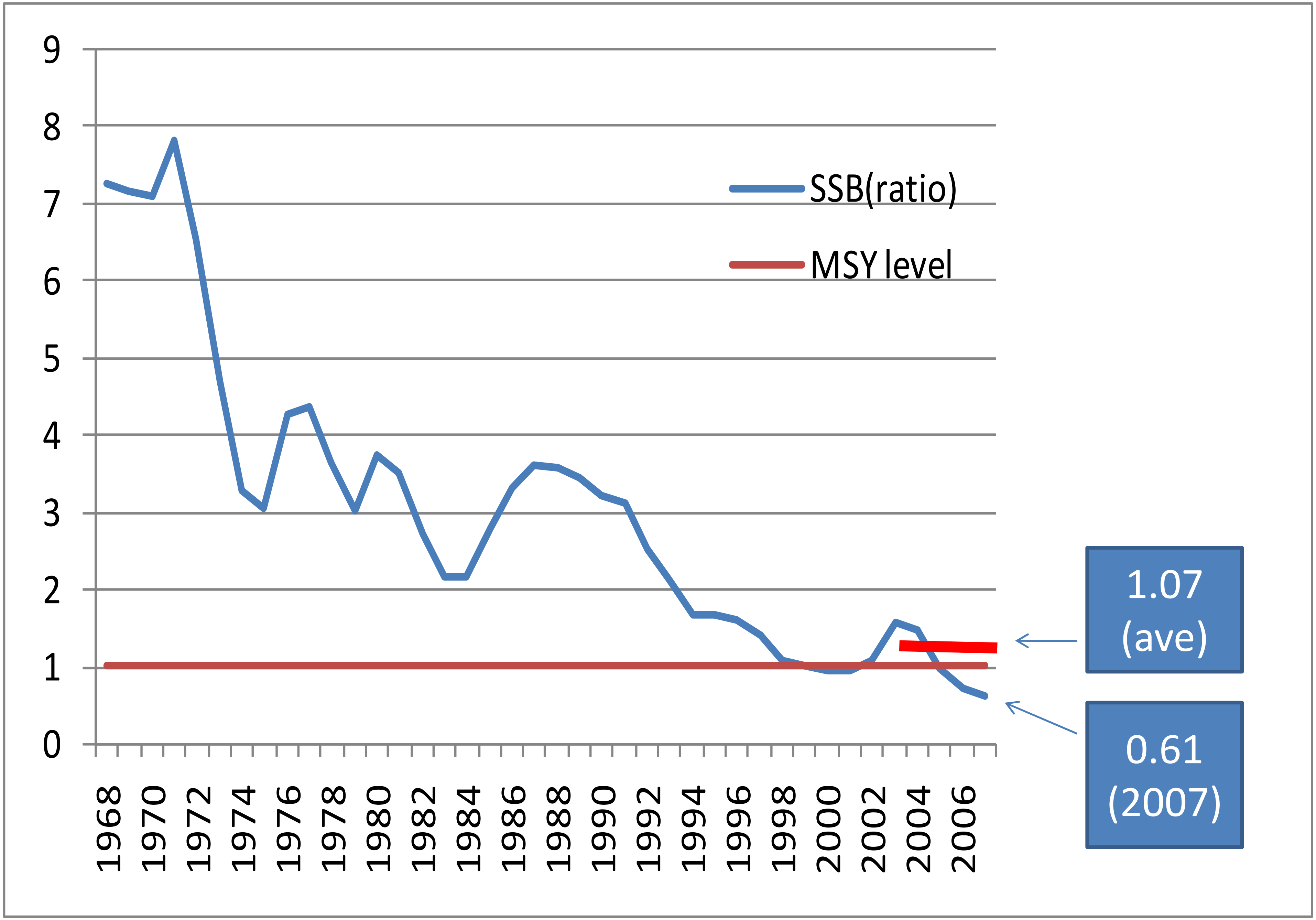


F vs F(MSY)


Fratio
2
1.5
1
0.5
0
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
1.22
(ave)
0.89
(2007)

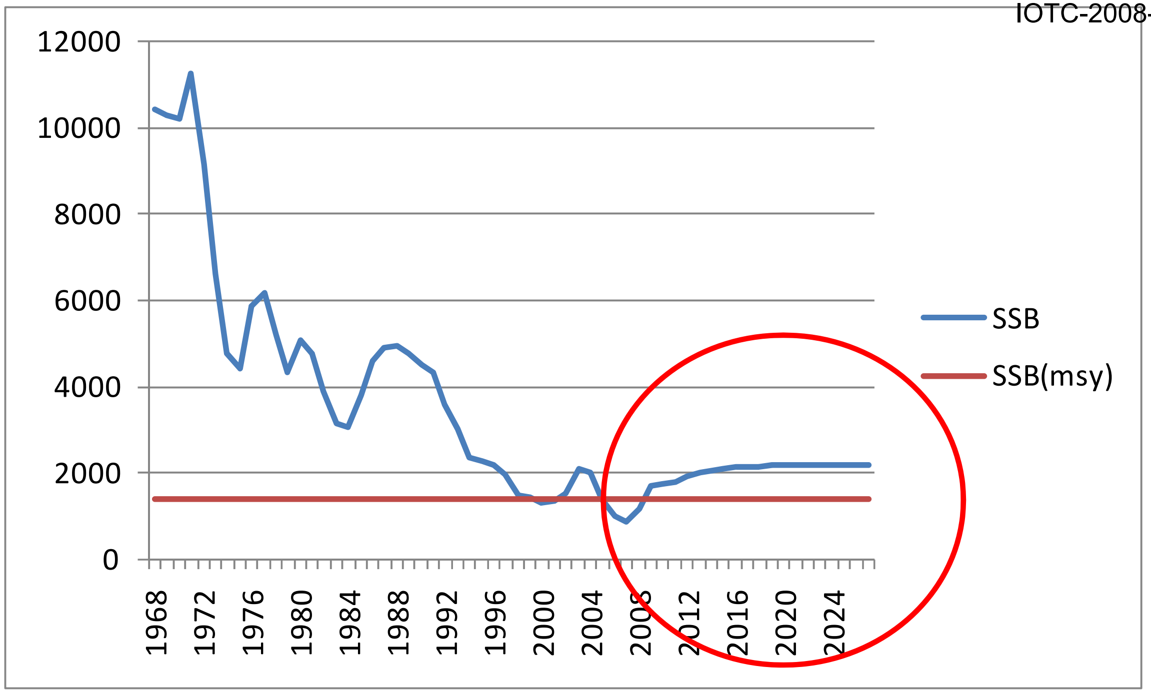
Catch vs. MSY(360 thousand tons)



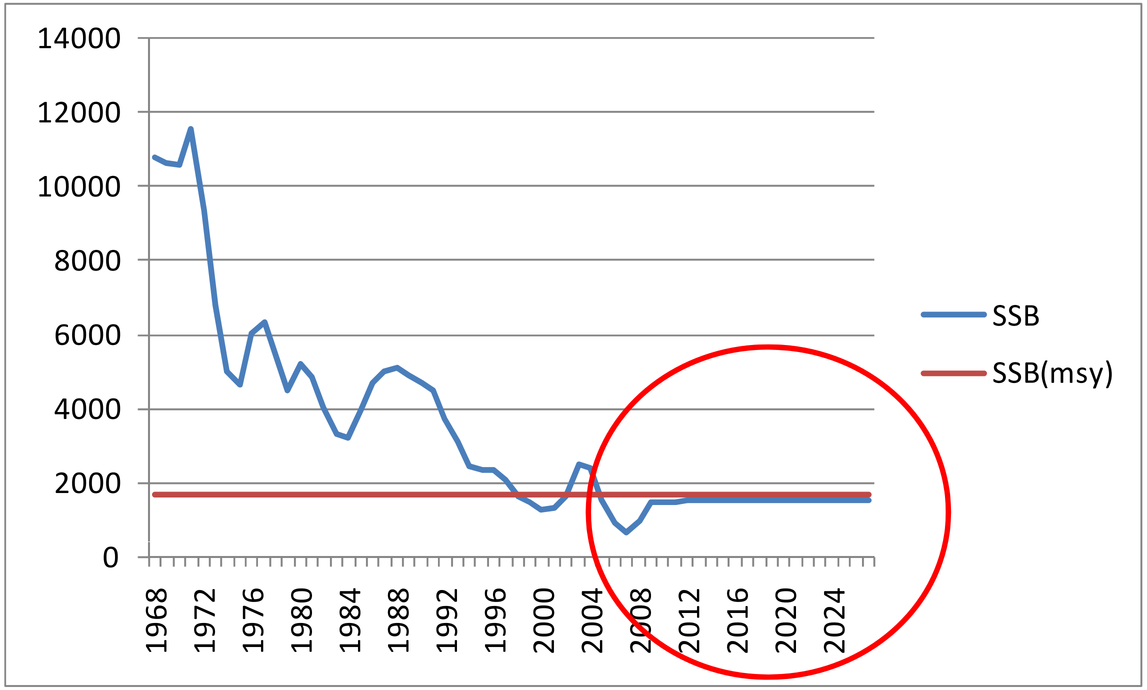

9
8
7
6
5
4
3
2
1
0
SSB(ratio)
MSY level
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
1.07
(ave)
0.61
(2007)

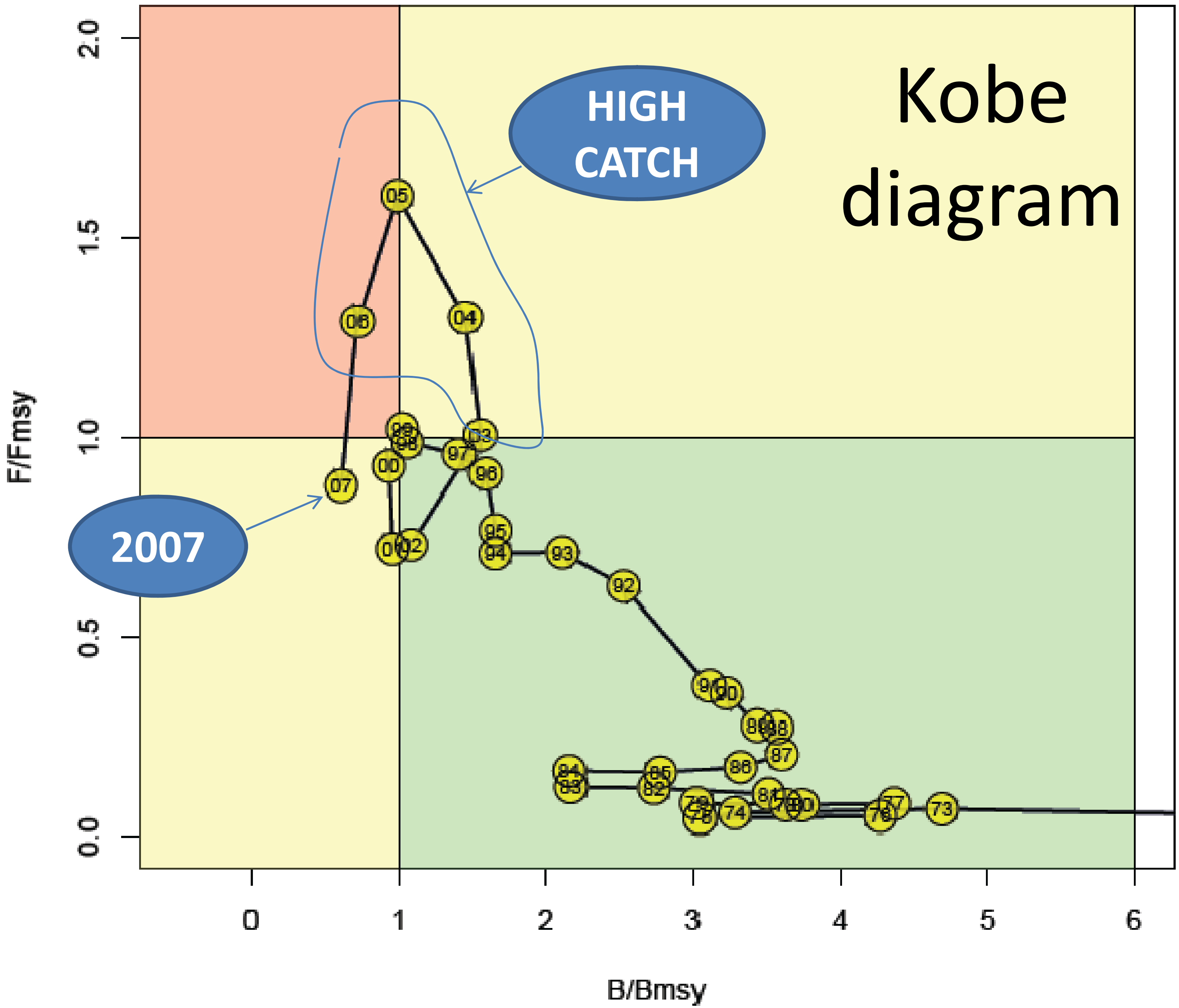
SSB Projection

SCENARIO 1
Catch(2007)
330 ,000 t
expect quick recovery



SCENARIO 2
Catch
(ave 2003-07)
420,000 t




Kobe diagram
HIGH CATCH
2007
F/Fmsy
B/Bmsy
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6

Summary

- Based on the stock indicators in Scenario 20 (1st run), IO YFT stock is are now likely entering to the overfishing status after 4 years high YFT catch in 2003-2006.

- Based on the projection and the expected continuous lower catch partially due to the Pirate MPA off Somalia may help to recover YFT ??

future ASPM

- CAA=> selectivity (SVPA) (now)
- next version:

  CAA=> estimate selectivity within ASPM

Mini integrated model w/o tagging data

Useful…

→ quick SA

→ evaluation of INPUT parameters (scenarios)

→ Cross check SA results ↔ (MFCL & SS3)