STOCK ASSESSMENT OF YELLOWFIN TUNA (*THUNNUS ALBACARES*) RESOURCES IN THE INDIAN OCEAN BY THE AGE STRUCTURED PRODUCTION MODEL (ASPM) ANALYSES

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ABSTRACT

In this paper, we attempted to assess yellowfin tuna (Thunnus albacares) (YFT) resources using the age-structure production model (ASPM) (1967-2000) as this approach was recommended for the tropical tuna stock assessments in the Indian Ocaen in the recent IOTC ad hoc working party meeting on methods held in IRD, Sète, France 23-27, April, 2001.

INTRODUCTION

In this paper, we attempted to assess yellowfin tuna (*Thunnus albacares*) (YFT) resources using the age-structure production model (ASPM) as this approach was recommended for the tropical tuna stock assessments in the Indian Ocean in the recent 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.

DATA

We use YFT catch and size data by country (area), gear, year and season for 41 years from 1960-2000, which were from the IOTC's updated database (May, 2002 version).

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.

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+.

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. These inputs are decided (or assumed) as follows:

(1) Natural mortality vector (M)

We use two types of M vectors as shown in Table 1. M vector 2 is suggested by Fonteneau.

Table 1 Two N vectors as ASPM input

Age	0	1	2	3	4	5+
M vector 1	0.8	0.8	0.4	0.4	0.4	0.4
M vector 2	1.2	0.8	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 equation (Stequert *et al*, 1995)

$$L_{t(cm)} = 272.7\left(1 - e^{-0.176[t-(-0.266)]}\right)$$

Based on the results of the otolith increment data collected in the (western) Indian Ocean.

L-W relationship (IPTP, 1990)

For fork length < 64 cm : $W = (5.313 \times 10^{-8})l^{2.754}$

For 64cm <=fork length: $W = (1.585 \times 10^{-8})l^{3.045}$

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 (at end)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Length (cm)	34.4	54.5	72.9	89.7	105.1	119.2	132.2	144.0	154.8	164.8	173.9
Weight (kg)	0.91	3.36	7.45	14.0	22.7	33.3	45.6	59.2	73.8	89.3	105.1

(3) 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+
Maturity	0	0	0.5	1	1	1
Fecundity (kg)	0	0	11.4	45.6	73.8	105.1

Catch

Appendix B lists the annual catch by gear based on the IOTC database (May, 2002 version). According to Appendix B, there are eight types of gears including others, which exploit the YFT in the Indian Ocean. In the ASPM analyses, we need to estimate selectivity for each gear. As we don't have enough size data to estimate accurate selectivities for these eight gears, we classify them into four types considering similarities of the age compositions and depths of the gears, which are shown in Table 4 and Fig. 1.

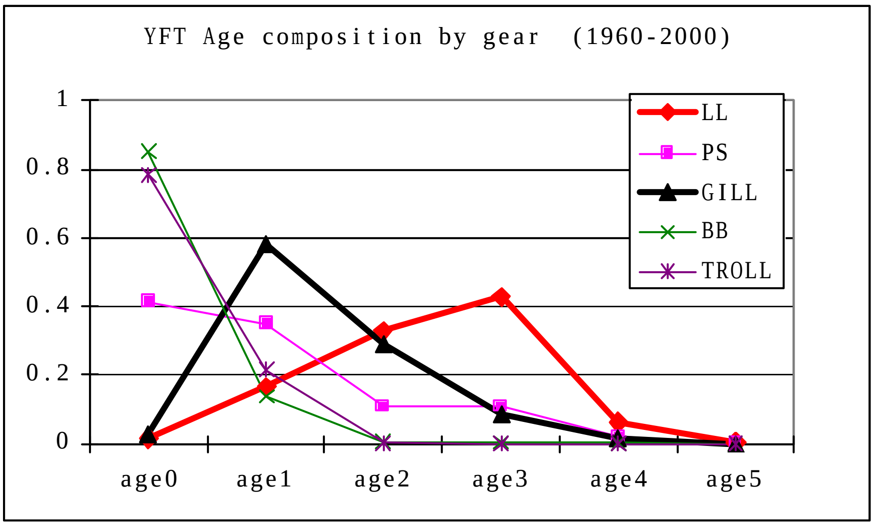


Fig. 1 YFT age compositions by gear based on the IOTC size database (1960-2000).

Table 4 Four gear types, their codes, relevant gears, major age class & size to exploit YFT.

Type (code)	Gear Code	member gears	Depth of the gear	Major age classes for catch
Surface (SUF)	BB_TL	BB, TROLL, LINE, and OTHER (*)	Surface	0
(2) Sub-surface (SUB)	GILL	GILL and OTHER (*)	30m (?)	1
(3) Surface to Sub-surface (SUF_SUB)	PS	PS	Surface to 30 m (?)	0-1
(4) Mid water (MID)	LL	LL, HAND, LINE(*), and OTHER(*)	50-250 m	2-5+

Note (*) for classification of OTHERS : see Table 5..

There are OTHER gears listed in Table 5, which are mainly the combined gears. They are also classified into four categories by considering compositions of combined gear types, which are based on the information provided by Miguel Herrera (IOTC). Using these four gear categories, trends of the YFT catch are re-summarized in Fig. 2 from 1960-2000 as we will use this period for the ASPM analyses. For a reference, Fig. 3 shows the gear compositions of the cumulative YFT catch for 41 years from 1960-2000.

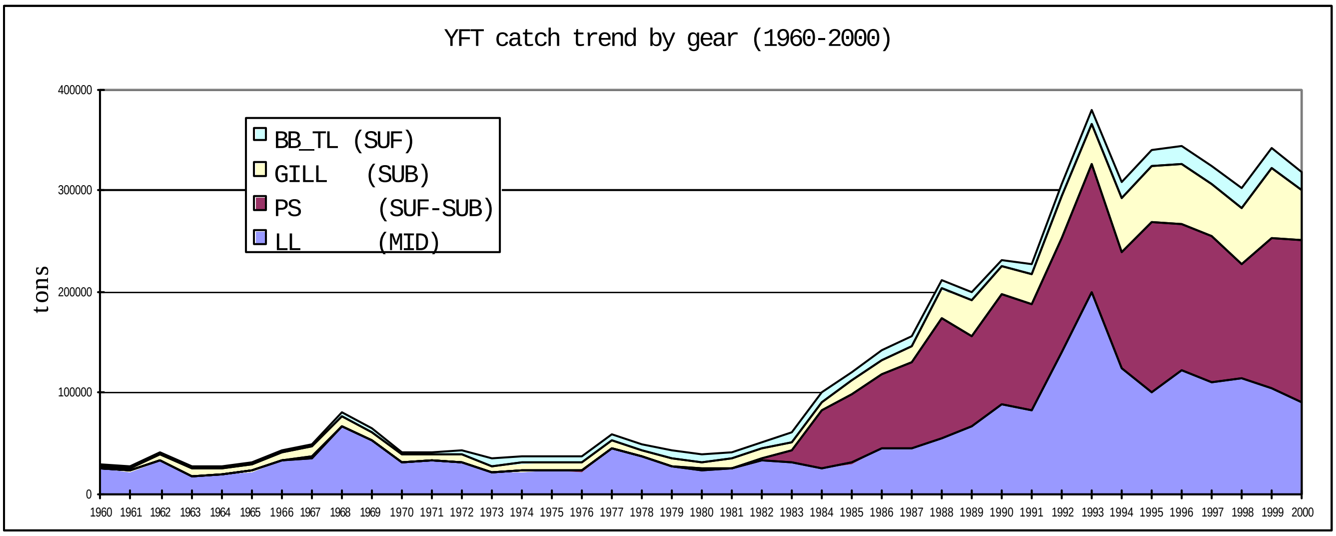


Fig. 2 YFT annual catch trends by FOUR gear category (1960-2000)(tons)

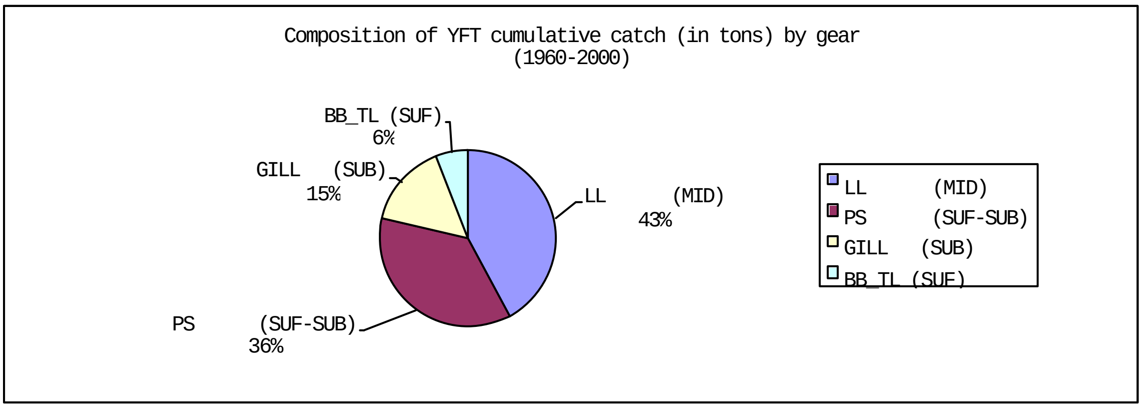


Fig. 3 Gear compositions in the cumulative YFT catch for 41 years from 1960-2000.

Table 5 List of OTHER type of gear and LINE by country, cumulative YFT catch and assigned gear type code defined in Table 4.

IOTC gear category	IOTC country code	Cumulative YFT catch (t) (1950-2000)	Assigned gear type code and their compositions(*)
OTHER	AUS	80	SUF(100%)
OTHER	COM	2,158	SUF(50%) MID(50%)
OTHER	IDN	32,577	SUF(80%),SUB(10%), SUF_SUB(10%)
OTHER	IND	12,298	SUF(33%),SUB(33%), MID(33%)
OTHER	JPN	2	SUF(100%)
OTHER	LKA	142,193	SUB(80%), MID(20%)
OTHER	MDV	27	SUF(100%)
OTHER	MOZ	218	SUF(100%)
OTHER	SYC	2,946	SUF(20%), MID(80%)
OTHER	TZA	1,050	SUB(100%)
OTHER	YEM	15,026	SUB(100%)
OTHER	ZAF	161	SUF(100%)
LINE			SUF(50%), MID(50%)

Note (*): Gear compositions are roughly estimated based on Nishida (1999) and personal communication with Miguel Herrera (IOTC).

Selectivity

In estimating the selectivity, we need the catch-at-age (CAA) matrix. To estimate the CAA, we need the age compositions. However, as we don't have enough size data for FOUR types of gears, we will estimate the age compositions by some period (3-5 years). Then we estimate the CAA based on these age compositions. Then, by looking at the similarity of the patterns of age compositions and catch trends among these periods, we will further pool them into a few longer periods during 1960-2000. For each longer period, we estimate one vector of selectivity (see Fig. 4). Appendix C shows the data process to determine such longer periods for the selectivity and also the resultant CAA. Based on these information we estimate the selectivity using the separable VPA by gear. The results are shown in Fig. 4. For the LL, we assume that the selectivity for age 3-5+ to be 1.

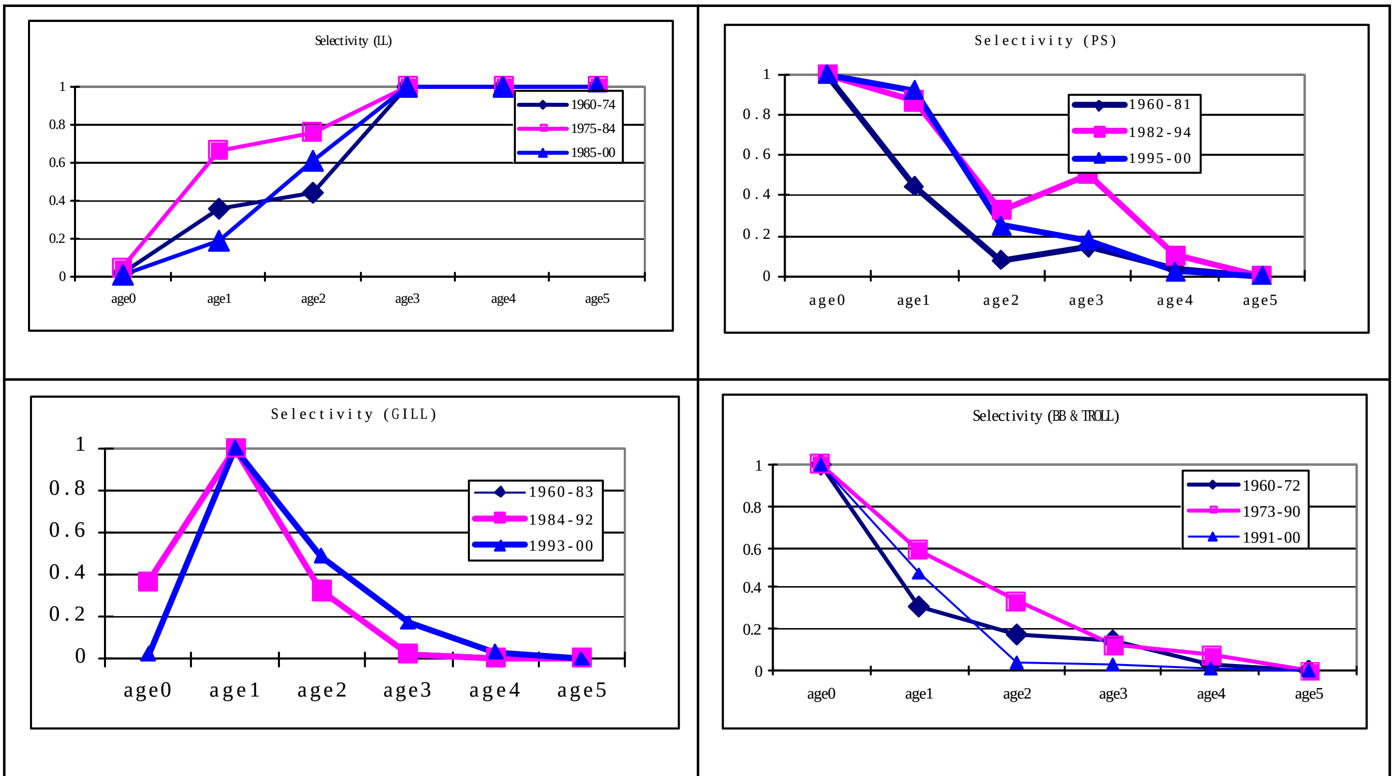


Fig. 4 Estimated Selectivity by gear

Index (LL CPUE)

We use the Japanese and the Taiwanese standardized CPUE by the GLM as the index inputs, which are described in IOTC/WPTT/02/12 (Shono, Okamoto and Nishida, 2002) and IOTC/WPTT/02/30 (Wang and Wang, 2002) respectively. Fig. 5 shows the trends of the estimated CPUE.

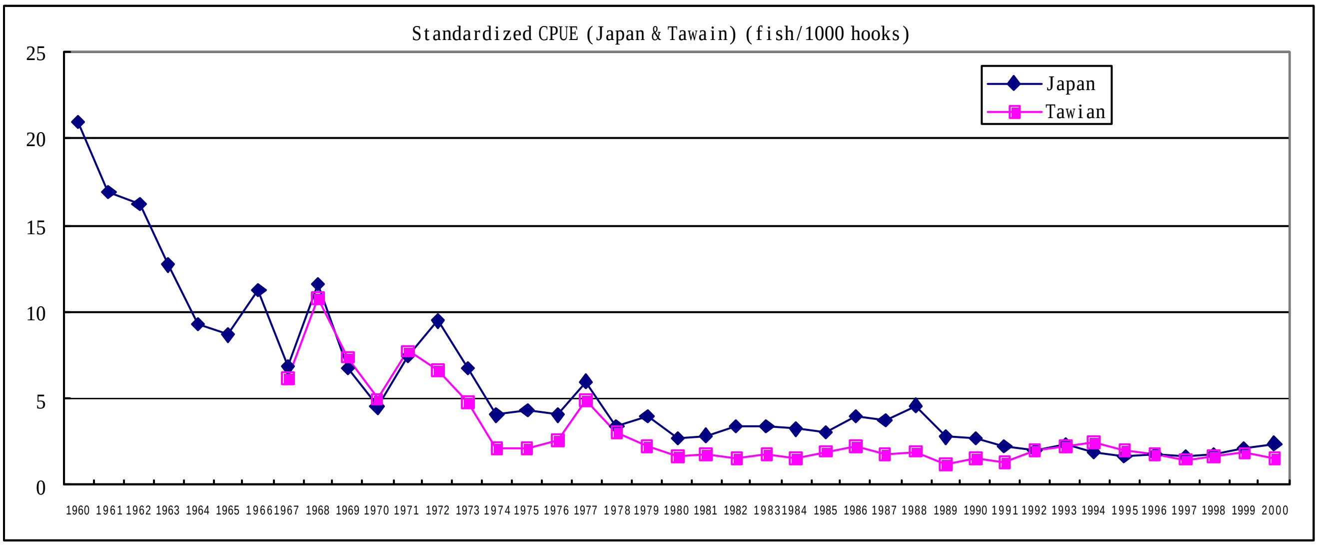


Fig. 5 Trends of the standardized CPUE of Japanese and Taiwanese LL (1960-2000)

5. ASPM RUNS (RESULTS)

Using the input parameters, we attempted various ASPM Runs. As results, we could not get the solutions (ASPM did not converge). This is probably because both CPUE (Fig. 5) and catch trends (Fig. 6) are not properly reflected, i.e., during 1960's CPUE dramatically deceased although catch was constant, while during 1990's, CPUE were constant although catch dramatically increased.

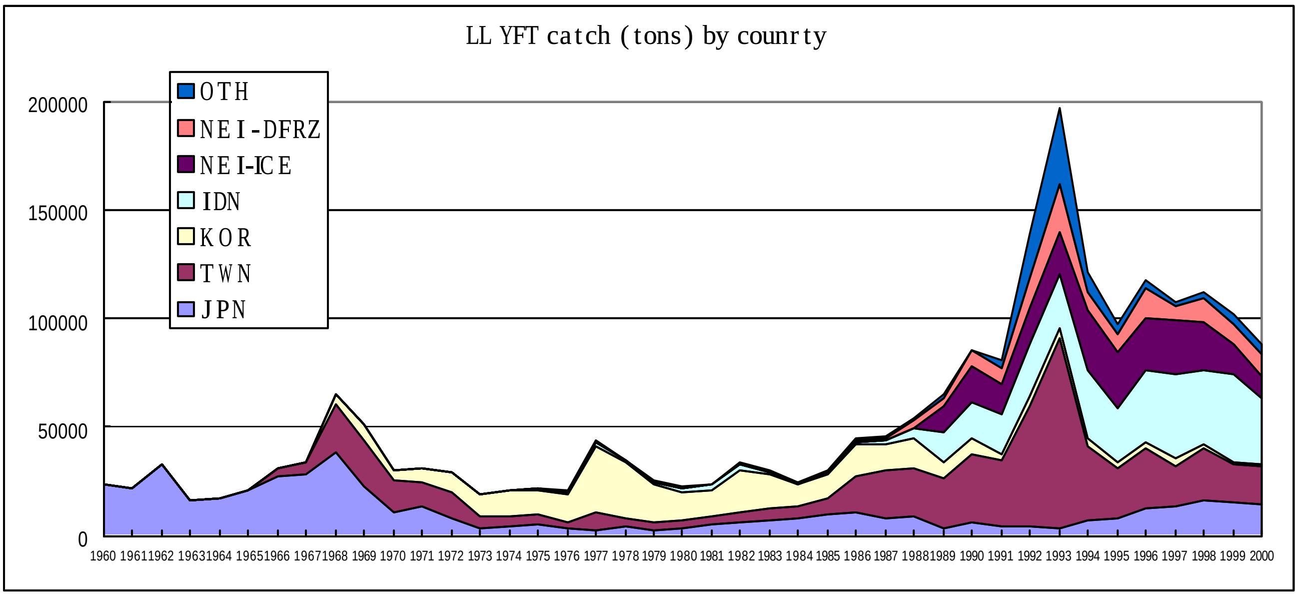


Fig. 6 Trends of the LL catch by country

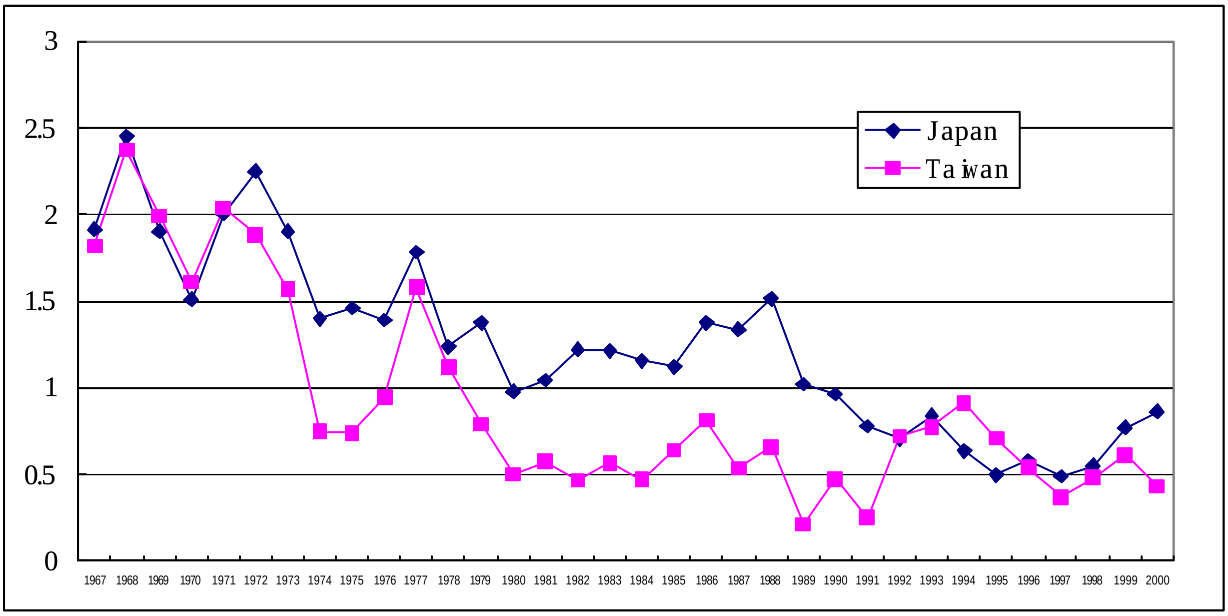


Fig. 7 Trends of the standardized CPUE of Japanese and Taiwanese LL (1967-2000)

Thus, we consider that the period of 1960-2000 is inappropriate. To solve this problem, we decided to omit some years during the sharp decreasing period of the CPUE in 1960's. Then, we re-attempted the ASPM runs with the starting year of 1967 as the Taiwanese CPUE is available from this year (Fig. 7).

As results, we could get the reasonable solutions with the 1967-2000 data set with M 2 vector. Table 6 and Figs. 8-18 summarized the results.

6. DISCUSSION

High LL CPUE levels during the early fisheries developmental period (1950's and 1960's) affect the ASPM analyses as the catch level are not well reflected, i.e., in 1960's even the catch were constant, LL CPUE drastically decreased. Such phenomena have been experienced many studies in the past in all three Oceans for almost all tuna and billfish species.

Because of this problem, we started the analyses from 1960 by omitting the high CPUE seen in the 1950's. But, this problem still remains with the data in 1960's as observed in Figs. 5 & 6. Thus, we further omit years with such high CPUE levels (1960-66). As a result, we could get the reasonable ASPM results. The CPUE series from 1967-2000 are likely realistic because when total catches sharply increased from mid 1980's (Fig. 6), LL CPUE were reflected and gradually decreased (Fig. 7).

As the result of the ASPM Run, we have almost constant recruitment trend in 1990's although there were the huge catch in 1990's. This is probably caused by the possible fact that apparent (estimated) LL CPUE decreasing trends were much slower than in the actual one. Thus, the real recruitment in 1990's is considered to have much more decreasing trend than the estimated one in Fig. 9.

Table 6 Summary of the ASPM INPUT and results

INPUT & Assumptions				
Years analyzed	1960-2000		1967-2000	
Stock (area)	Single stock (whole Indian Ocean)			
Gear types for catch (depth of the gear)	LL (mid water) PS (surface to sub-surface) GILL (sub-surface) BB_TROLL (surface)			
Growth	Stequert *et al* (1995)			
L-W relation	IPTP (1990)			
M vector	M1	M2	M1	M2
Selectivity	Three different selectivities for three different periods are estimated for each gear			
penalty (weighting values) to fit to the objective function (residual sum of squares)	?(serial correlation coefficient in the error terms of the S-R model) = 0.00 s^2 (weighting for the stock-recruitment relationship) = 0.20 s^2 (weighting for the initial population size) = 0.40			
Spawner-Recruit relation	Beverton-Holt model (stochastic option)			
Index (CPUE) (all ages combined)	Japan (Shono et al, WPTT/02/) Taiwan (Wang and Wang, WPTT/02/)			
Results				
Steepness	No convergent	No convergent	No convergent	0.63
-ln (likelihood)				- 79.9
R-squared				0.812
MSY (current catch in 2000)				0.29 million tons (0.32 million tons)
TB(2000)				3.38 million tons
TB(MSY)				1.92 million tons
B ratio(TB)= TB(2000)/TB(MSY)				1.77
SSB(2000)				3.22 million tons
SSB(MSY)				1.88 million tons
B ratio(SSB)= SSB(2000)/SSB(MSY)				1.71
B1 ratio = TB2000/B1				0.63
F(2000)				0.23
F(MSY)				0.33
F(ratio) = F2000/F(MSY)				0.70

Note : TB: Total Biomass, SSB: Spawning Stock Biomass B1: Biomass at the start year

Age	0	1	2	3	4	5+
M vector 1 (M1)	0.8	0.8	0.4	0.4	0.4	0.4
M vector 2 (M2)	1.2	0.8	0.6	0.6	0.6	0.6

Fig. 8 Estimated population size by age (group) (no of fish)

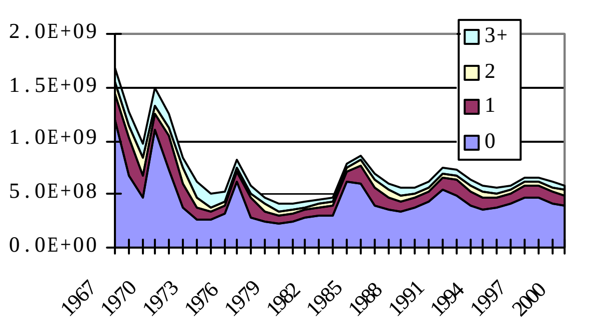
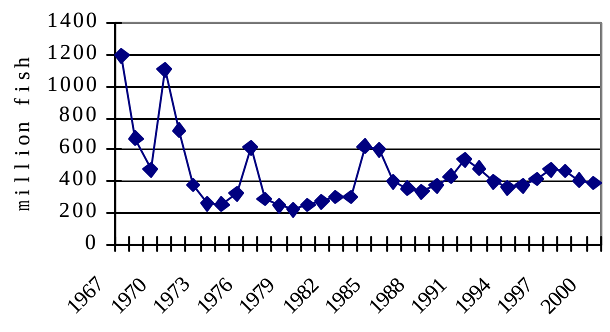


Fig. 9 Trend of the recruitment



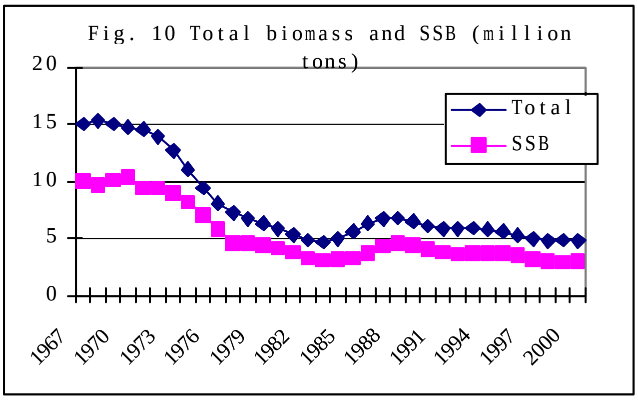


Fig. 10 Total biomass and SSB (million tons)
Total
SSB
20
15
10
5
0
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000

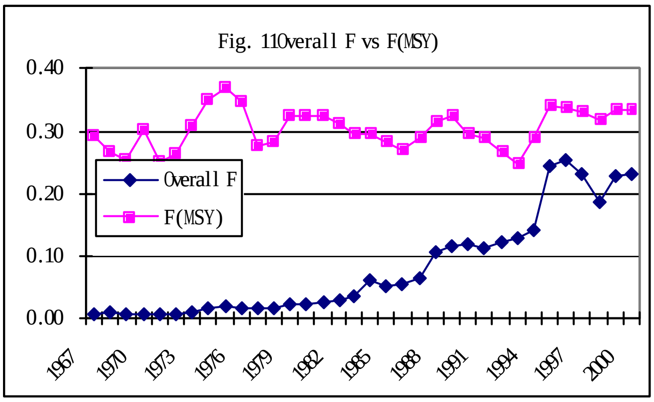


Fig. 11Overall F vs F(MSY)
Overall F
F(MSY)
0.40
0.30
0.20
0.10
0.00
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000

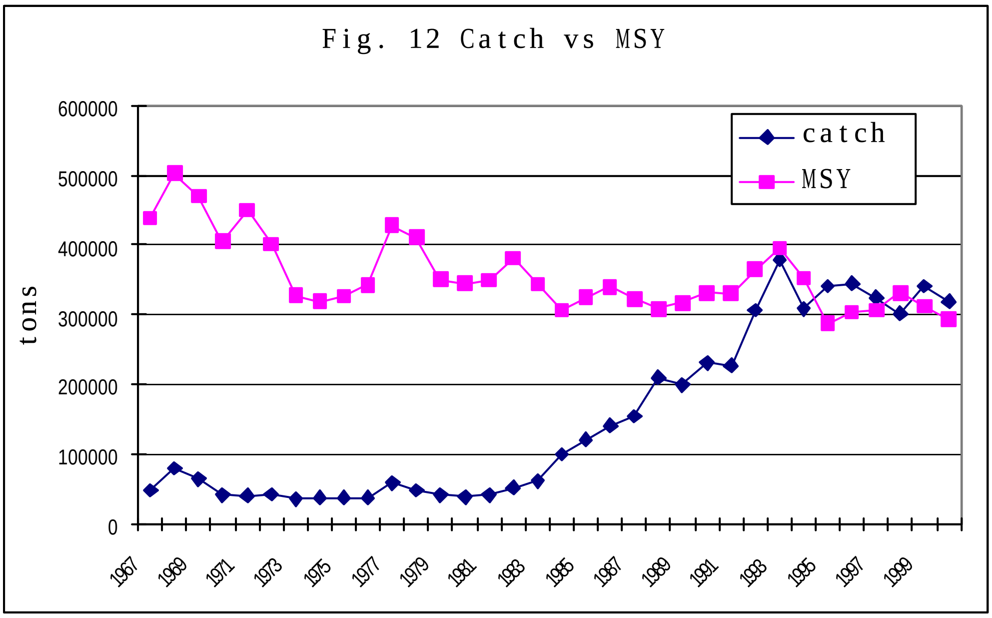


Fig. 12 Catch vs MSY
catch
MSY
tons
600000
500000
400000
300000
200000
100000
0
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999

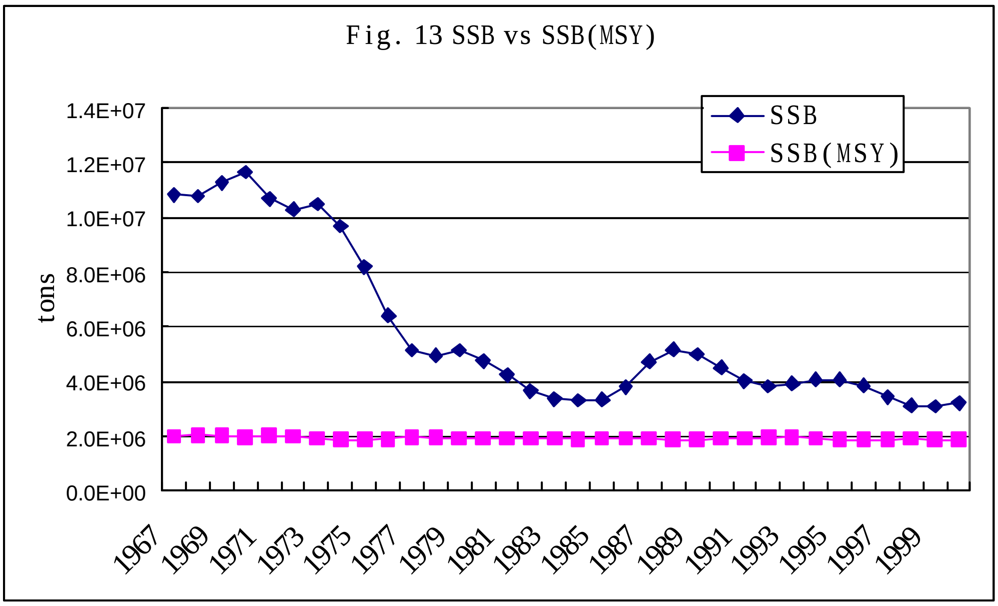


Fig. 13 SSB vs SSB(MSY)
SSB
SSB(MSY)
tons
1.4E+07
1.2E+07
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999

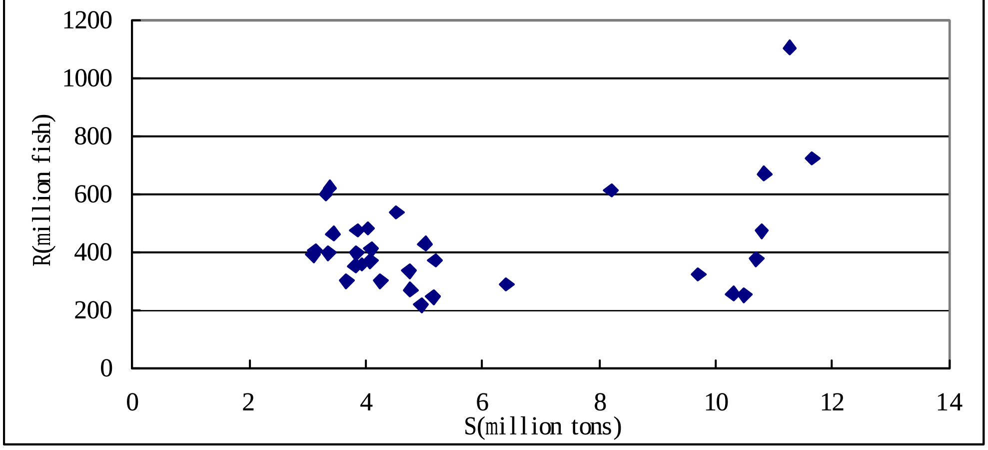


Fig. 14 Spawner(S)-Recruit(R) relation

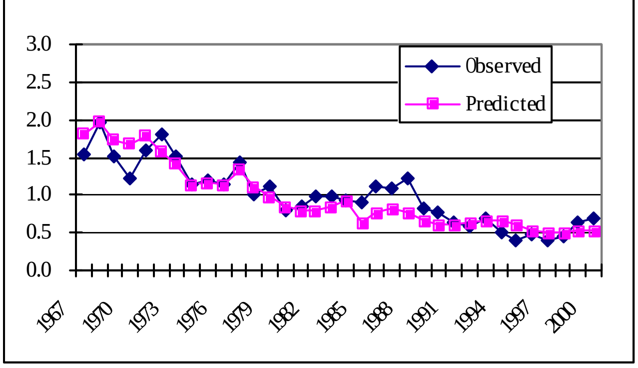


Fig. 15 Obsevred vs Predicted CPUE (Japan)

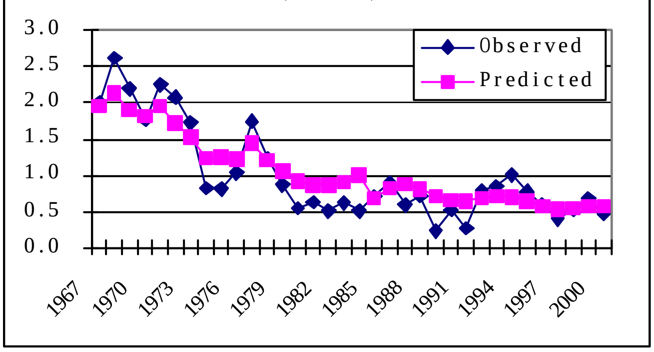


Fig. 16 Observed vs Predicted CPUE (Taiwan)

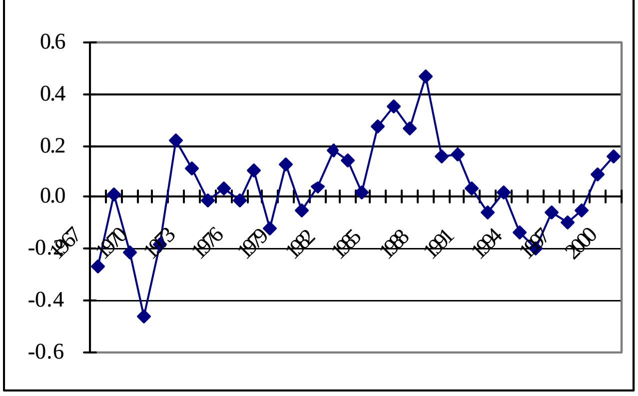


Fig. 17 Residual of Japanese CPUE

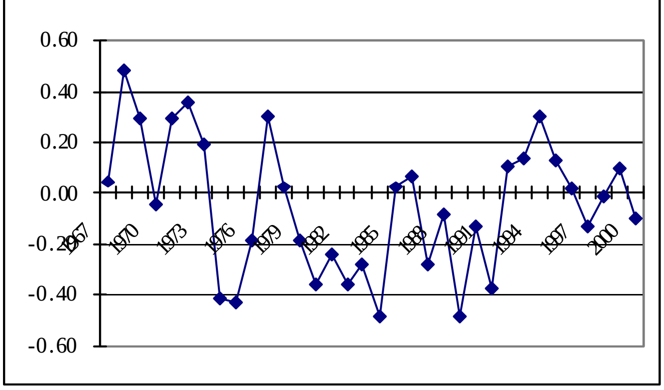


Fig. 18 Residual of CPUE (Taiwan)

As a conclusion, although we likely have the underestimated ASPM results, the YFT stock status is about the optimum yield level as the MSY is the 0.29 millions and the current catch level is the 0.32 million tons.

Table 1 shows simple comparisons of YFT assessments the past three studies. Estimated adult (age 2+) population sizes in 1988 are compared.

Table 1 Simple comparisons of YFT assessments among three studies in the past.

	Method	Analyzed period	Estimated population of the adult YFT (age 2+) in 1988 (million fish)
Nishida and Kishino (1991)	Immature–adult dynamic model (similar approach to the ASPM)	1971-88	15
Nishida (1995)		1971-92	20
Nishida and Shono (2002)	ASPM	1967-00	12

We have rather lower estimates than those in the first two studies. This is because the current study include the huge catch in 1990's, which make the population dynamics more realistic and population estimates lower. Hence, the estimates in the current study are likely more robust one.

Considering the possible fact that the estimates in this study are much more robust than those in the past but they are considered to be under-estimated, it is likely that the current catch level (0.32 million tons) are beyond the real MSY level, which is much larger than the estimated one in this study (0.29). Hence, if we keep to continue this level of the catch, we will also expect the situation like BET (see IOTC/02/35 by Nishida *et al*, 2002). This means that to keep the current catch level can not guarantee to maintain the SSB and Total biomass (TB) producing the MSY level in the near future.

Considering the over-fishing status of BET, the optimum or possible over-fished status of YFT and the multi-species fisheries nature including BET and YFT in the Indian Ocean, <u>it is strongly recommended for the tuna fishing nations in the region to consider some management measures to reduce catch and/or effort in order to secure the sustainable yield of both YFT and BET for the long future</u>.

ACKNOWLEDGEMENTS

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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

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

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 a and ß are not easy to guess. For this reason, the ASPM uses a different parameterization, following (Francis 1992). It consists of defining a “steepness” parameter, t, 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., $R = tR_0$ when $S = g/5$, where g 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 $(S/R)_{F=0}$,

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

a and ß are given by

$$a = \frac{4t \ R_0}{5t - 1} \qquad (5)$$

and

$$b = \frac{g(1-t)}{5t - 1} \qquad (6)$$

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

$$SPR_{crash} = \frac{(S/R)_{crash}}{(S/R)_{F=0}} = \frac{b/a}{g/R_0} = \frac{1-t}{4t} \qquad (7)$$

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 ? and t are chosen to minimize the negative log-likelihood,

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

where *I* 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 $s_{i,t}^2$ 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:

$$\hat{I}_{i,t} = q_i \sum_a N_{a,t} u_{a,i} w_i \qquad (9)$$

where ? 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, $s_{i,t}^2$. If all the values for all indices are given equal weight, they can be set to

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

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:

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

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

So far, the presentation of the method has indicated that parameters ? and t (or, equivalently, a and ß) are estimated directly in the search, and the parameters q_i and $s_{i,t}^2$ 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 an equilibrium 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 t and ?. 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)

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

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

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

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

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

That is, recruitment is estimated as deviations from a virgin level. Instead of estimating ? and t directly as parameters, the model estimates ? and all the $n_{t.}$. 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

$$R_{t+1} = \frac{aS_t}{b+S_t}e^{e_{t+1}} \qquad (15)$$

with $e_{t+1} = re_t + h_{t+1}$, $|r| < 1$, the ? have zero expectation and variance equal to s_h^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):

$$-\ln(L_2) = \frac{n_t}{2}\ln(s_h^2) - \frac{1}{2}\ln(1-r^2) + \frac{1}{2s_h^2}\left[(1-r^2)e_1^2 + \sum_{t=2}^{n_t}(e_t - re_{t-1})^2\right] \qquad (16)$$

Where the residuals would be computed as

$$e_{t+1} = \ln(N_{1,t+1}) - \ln(R_{t+1}) = \ln(N_{1,t+1}) - \ln\left(\frac{aS_t}{b + S_t}\right) \quad (17)$$

Computation of the first residual would depend on the initial conditions. For example, in a virgin state, it would be $e_1 = \ln(N_{1,1}) - \ln(R_0)$.

Note that a and ß 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 ? (refer to equations. (4), (5), and (6)). Our approach is to replace a and ß 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

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

$$e_{t+1} = \ln(N_{1,t+1}) - \ln\left(\frac{4R_0 S_t t}{t(5S_t - g) - S_t + g}\right) \quad (19)$$

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

$$\sum_{t=2}^{n_t-1}\left[\ln(N_{1,t+1}) - \ln\left(\frac{4R_0 S_t t}{t(5S_t - g) - S_t + g}\right) - r\ln(N_{1,t}) + r\ln\left(\frac{4R_0 S_{t-1} t}{t(5S_{t-1} - g) - S_{t-1} + g}\right)\right]^2 \quad (20)$$

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

It remains to be mentioned what to do about the parameters ? and s_h^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 s_h^2 values will result in lower stochasticity in recruitment, while higher s_h^2 values will allow recruitment to fluctuate more widely in order to better fit the index data. A value of ?=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 ? and s_h^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 ?, 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

$$N_{2,1} = R_0 e^{v_0} e^{-M_1} \quad (21a)$$

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

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 ?. This could be accomplished with the term

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

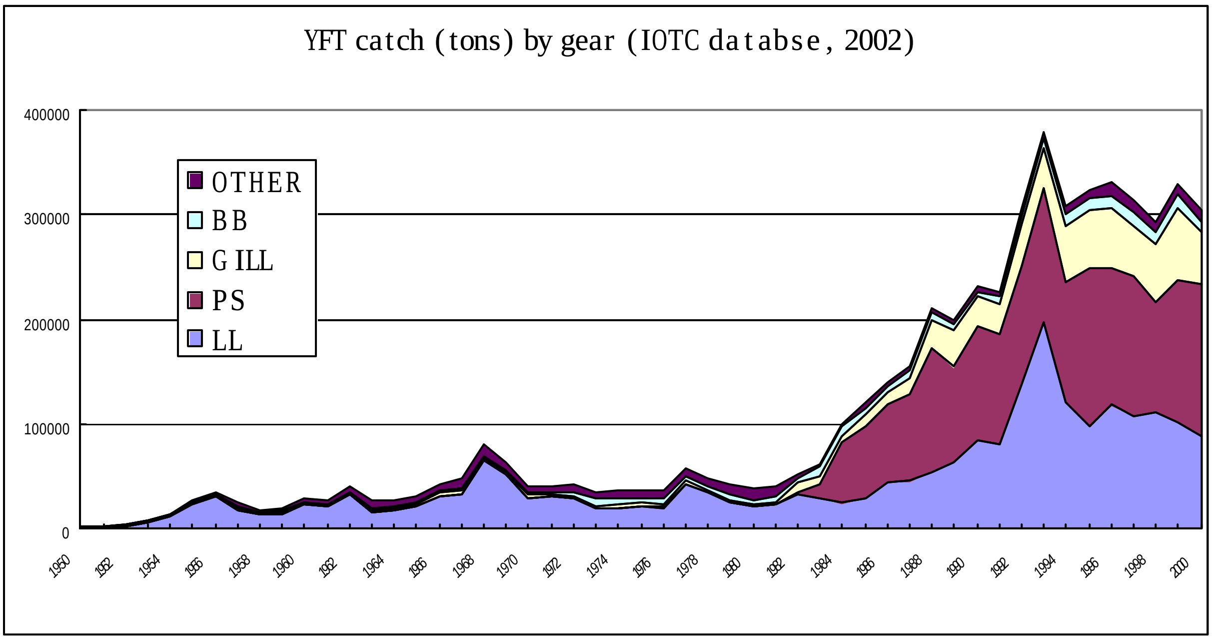
where s_v^2 is a variance value to be fixed by the analyst.

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 (s_h^2, s_v^2 and possibly $s_{i,l}^2$), the log-likelihood components could be given different emphases (l) to obtain model estimates by minimizing:

$$-\ln(L_T) = -\ln(L_1) - l_2\ln(L_2) - l_3\ln(L_3) \qquad (23)$$

APPENDIX B YFT CATCH IN THE INDIAN OCEAN (1950-2000)

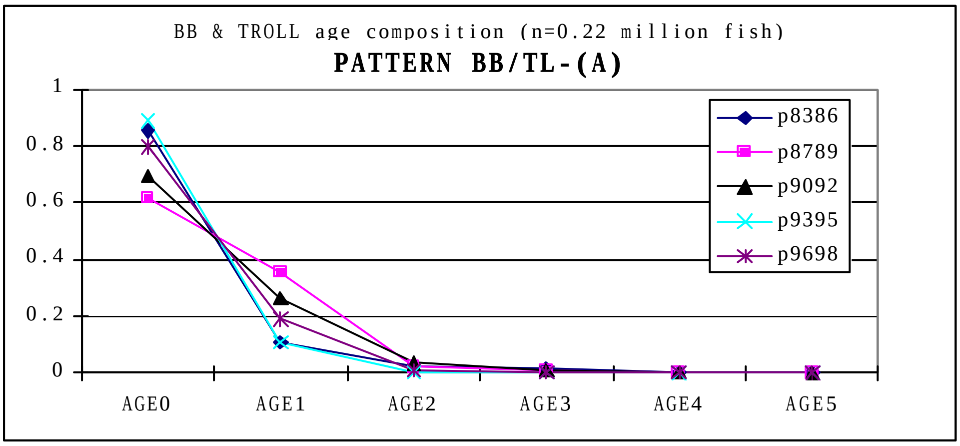
	Gear								
	BB	GILL	HAND	LINE	LL	OTHER	PS	TROL	total
1950	1500	351	0	0	0	100	0	79	2030
1951	1500	351	0	0	0	300	0	79	2230
1952	1500	351	0	0	3240	400	0	79	5570
1953	1500	535	0	0	5957	400	0	0	8392
1954	1500	552	0	0	11693	400	0	79	14224
1955	2000	569	0	0	24103	400	0	79	27151
1956	2000	535	0	0	30869	1600	0	79	35083
1957	2000	1372	0	0	18059	3500	0	79	25010
1958	2000	686	0	0	13777	2400	0	79	18942
1959	2000	686	0	0	14836	2600	0	79	20201
1960	1000	836	0	0	23796	3300	0	79	29011
1961	1500	753	0	0	21562	3700	0	79	27594
1962	1500	1188	0	0	33006	5300	0	79	41073
1963	1500	1757	0	0	15911	8400	5	79	27652
1964	1500	2442	0	0	17300	6000	22	79	27343
1965	1000	2643	0	0	20900	6700	12	79	31334
1966	1500	3530	0	0	31300	6500	0	79	42909
1967	1700	3429	0	0	34221	9200	0	158	48708
1968	1700	3446	0	0	65154	9700	0	237	80237
1969	1800	3112	0	0	51593	7600	0	237	64342
1970	2282	2827	0	0	29735	6600	0	331	41775
1971	1381	2306	0	0	31194	5500	0	573	40954
1972	2511	2750	0	0	29220	7700	0	575	42756
1973	7401	2162	0	0	19135	6286	0	636	35620
1974	6159	2965	0	0	20675	7070	21	725	37615
1975	4732	3272	0	0	21729	6955	39	632	37359
1976	5218	3070	0	0	20834	7359	56	802	37339
1977	4897	2743	0	0	43543	6874	107	684	58848
1978	3822	1598	0	0	34796	6976	289	806	48287
1979	4396	2762	0	0	25348	8589	187	1044	42326
1980	4368	1275	0	0	22221	9182	211	974	38231
1981	5946	1958	0	0	23366	8876	342	912	41400
1982	5000	9183	0	0	33517	1691	1301	895	51587
1983	8120	8138	5	0	30109	1224	12777	948	61321
1984	8482	6126	1	0	24799	956	58437	891	99692
1985	6961	9902	2	0	29947	4289	68904	709	120714
1986	6206	12006	44	0	45079	3879	73566	398	141178
1987	7378	14982	44	0	45594	2357	83951	474	154780
1988	5944	27390	49	0	54246	3238	118728	571	210166
1989	5526	34931	2118	0	64646	711	89875	1766	199573
1990	4932	26952	2251	0	85786	764	108811	1728	231224
1991	7028	28260	2132	0	80421	889	105787	1828	226345
1992	8029	39709	1348	0	139002	867	112927	4164	306046
1993	9275	38068	1720	0	196991	951	128185	3897	379087
1994	12383	52196	1988	0	121738	962	114815	4415	308497
1995	11768	54076	1904	0	97779	952	152347	4456	323282
1996	11501	55953	2019	0	118255	8153	131319	4396	331596
1997	12167	48631	1926	0	107643	5013	133530	4472	313382
1998	12994	54747	1780	287	112470	2229	104026	4664	293197
1999	13594	68946	1779	485	101654	1397	136137	4649	328641
2000	10773	48356	1938	592	87792	1747	146934	5823	303955



APPENDIX C PREPARATORY WORKS FOR THE CATCH-AT-AGE AND SELECTIVITY

(1) SURFACE (*BB & TROLL)*

Period	(1)	(2)	(3)	(4)(*)	(5)(*)	(6)(*)
	Sample size (n)	Pattern of age composition of catch (see Fig.x)	Mean weight (kg)	Catch (tons)	Catch (1000 fish) =(4)/(3)	Sampling rate (%) = (1)/10*(5)
1960-82	0	*BB_TL-(A)(assumed)*	*2.87(assumed)*	99,427	34,644	0
1983-86	6,937	BB_TL-(A)	2.87	38,076	13,267	0.05%
1987-89	4,035		4.09	24,365	5,957	0.07%
1990-92	3,973		3.86	27,952	7,241	0.06%
1993-95	144,165		1.75	46,549	26,599	0.54%
1996-98	64,091		2.58	54,921	21,287	0.30%
1999-00	0	*BB/TL-(A)(assumed)*	*2.58(assumed)*	35,716	13,843	0



Annual CAA (BB/TROLL) by pattern of age composition and period (in 1000 fish)

Pattern	Period	YR	AGE0	AGE1	AGE2	AGE3	AGE4	AGE5
A	p6082	1960	416.0	51.6	12.1	7.4	0.4	0.0
A	p6082	1961	588.5	73.1	17.1	10.4	0.5	0.0
A	p6082	1962	612.2	76.0	17.8	10.9	0.5	0.0
A	p6082	1963	612.2	76.0	17.8	10.9	0.5	0.0
A	p6082	1964	612.2	76.0	17.8	10.9	0.5	0.0
A	p6082	1965	487.4	60.5	14.2	8.6	0.4	0.0
A	p6082	1966	636.0	79.0	18.5	11.3	0.5	0.0
A	p6082	1967	719.0	89.3	20.9	12.8	0.6	0.0
A	p6082	1968	742.5	92.2	21.6	13.2	0.6	0.0
A	p6082	1969	796.0	98.8	23.1	14.1	0.7	0.0
A	p6082	1970	940.4	116.8	27.3	16.7	0.8	0.0
A	p6082	1971	744.8	92.5	21.6	13.2	0.6	0.0
A	p6082	1972	1176.3	146.0	34.2	20.9	1.0	0.0
A	p6082	1973	2645.0	328.4	76.8	46.9	2.2	0.0
A	p6082	1974	2249.3	279.3	65.4	39.9	1.9	0.0
A	p6082	1975	1650.0	204.9	47.9	29.3	1.4	0.0
A	p6082	1976	1877.8	233.1	54.6	33.3	1.6	0.0
A	p6082	1977	1910.9	237.2	55.5	33.9	1.6	0.0
A	p6082	1978	1732.7	215.1	50.3	30.7	1.5	0.0
A	p6082	1979	2163.9	268.6	62.9	38.4	1.8	0.0
A	p6082	1980	2055.4	255.2	59.7	36.5	1.7	0.0
A	p6082	1981	2146.2	266.5	62.4	38.1	1.8	0.0
A	p6082	1982	2051.6	254.7	59.6	36.4	1.7	0.0
A	p8386	1983	2857.0	354.7	83.0	50.7	2.4	0.0
A	p8386	1984	2861.6	355.3	83.1	50.8	2.4	0.0
A	p8386	1985	2634.7	327.1	76.5	46.7	2.2	0.0
A	p8386	1986	2587.9	321.3	75.2	45.9	2.2	0.0
A	p8789	1987	1398.5	805.8	45.0	16.9	2.8	0.0
A	p8789	1988	1169.2	673.7	37.6	14.1	2.4	0.0
A	p8789	1989	1104.2	636.3	35.5	13.3	2.2	0.0
A	p9092	1990	4658.7	1763.1	228.2	52.4	13.5	0.0
A	p9092	1991	6208.5	2349.6	304.1	69.8	18.0	0.0
A	p9092	1992	8523.8	3225.8	417.5	95.9	24.7	0.0
A	p9395	1993	6745.3	814.9	18.5	12.1	1.8	0.1
A	p9395	1994	8590.2	1037.7	23.6	15.4	2.3	0.1
A	p9395	1995	8295.6	1002.1	22.8	14.9	2.3	0.1
A	p9698	1996	5686.4	1364.3	60.4	27.4	6.4	0.0
A	p9698	1997	5591.2	1341.5	59.4	27.0	6.2	0.0
A	p9698	1998	5664.6	1359.1	60.2	27.3	6.3	0.0
A	p9900	1999	5754.7	1380.7	61.1	27.8	6.4	0.0
A	p9900	2000	5263.0	1262.7	55.9	25.4	5.9	0.0

(2) SUB-SURFACE (GILL)

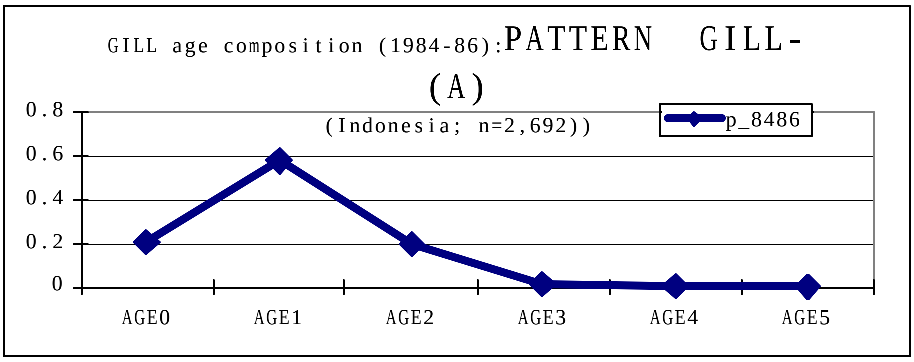
Indonesia type (smaller mesh size)

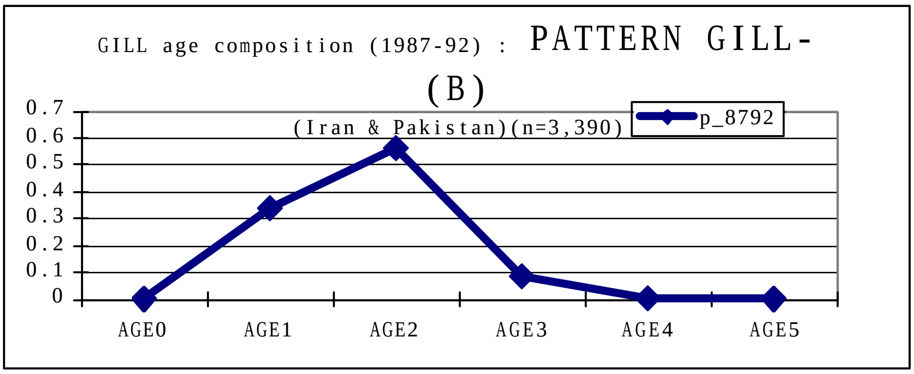
Period	(1)	(2)	(3)	(4)	(5)	(6)
	Sample size (n) (un-raised)	Pattern of age composition of catch (see Fig.x)	Mean weight (kg)	Catch (tons)	Catch (1000 fish) = (4)/(3)	Sampling rate (%) = (1)/10*(5)
1960-83	0	*GILL-(A) (substituted)*	10.02	3,911	390	0
1984-86	2,692	GILL-(A)		1,163	116	2.3%
1987-92	0	*GILL-(A) (substituted)*		1,625	162	0
1993-96	0			1,624	162	0
1997-00	0			2,239	223	0

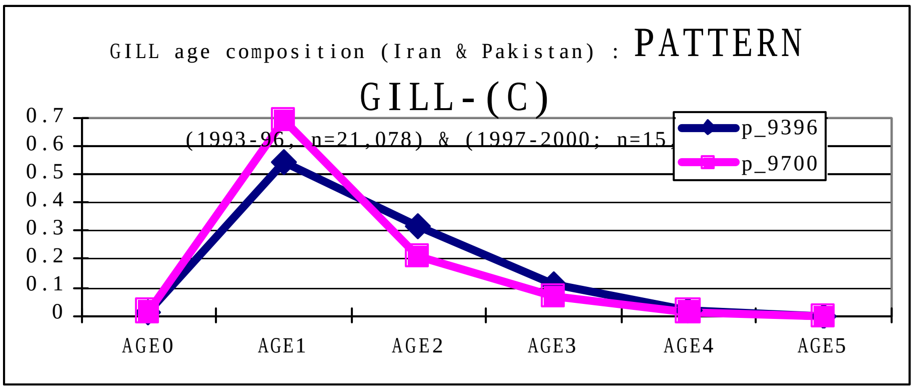
Iran, Pakistan, Oman, Sri Lanka and Others (larger mesh size)

Period	(1)	(2)	(3)	(4)(*)	(5)(*)	(6)(*)
	Sample size (n) (Iran & Pakistan) (**)	Pattern of age composition of catch (see Fig.x)	Mean weight (kg)	Catch (tons)	Catch (1000 fish) =(4)/(3)	Sampling rate (%) = (1)/10*(5)
1960-83	0	*GILL-(B)*	19.71	176,987 (124,800)	8,980 (6,331)	0 (0)
1984-86	0	*(substituted)*		31,303 (27,569)	1,588 (1,399)	0 (0)
1987-92	3,390	GILL-(B)		176,325 (132,870)	8,945 (6,741)	0.04 (0.05)
1993-96	21,078	GILL-(C)	17.52	204,398 (112,381)	11,667 (6,414)	0.18 (0.33)
1997-00	15,719	GILL-(D)	14.01	224,709 (131,189)	16,039 (9,364)	0.10 (0.17)

(*) no. for Iran + Pakistan (**) probably un-raised







Annual CAA (GILL) by pattern of age composition and period (in 1000 fish)

PATTERN GILL-(A) : Indonesia (smaller mesh size)

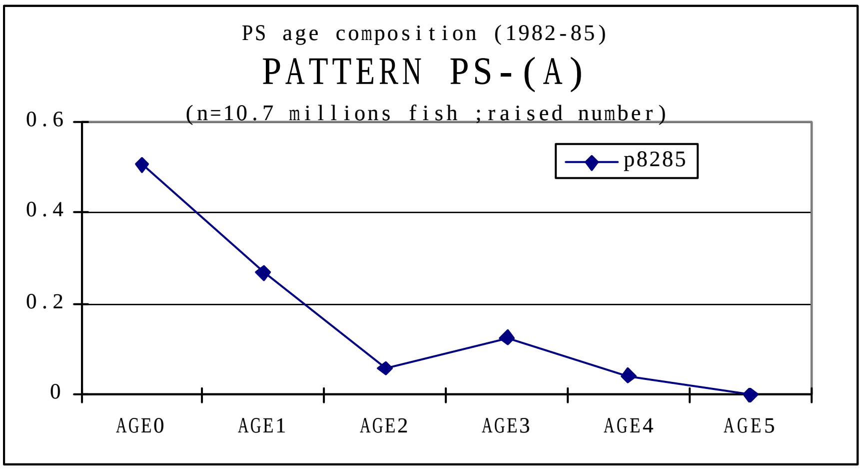
GILL-(B), (C), (D) : Iran, Pakistan, Oman, Sri Lanka and Others (larger mesh size)

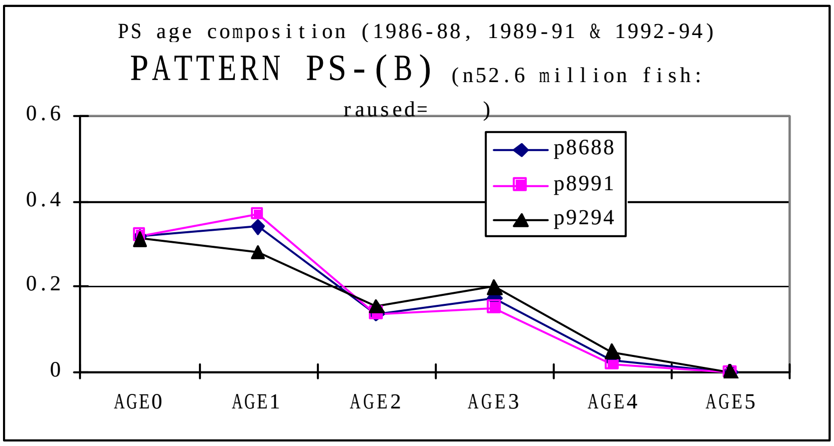
Pattern	period	year	AGE0	AGE1	AGE2	AGE3	AGE4	AGE5
A	6083	1960	1.6	4.6	1.6	0.1	0.0	0.0
A	6083	1961	2.1	5.8	1.9	0.2	0.0	0.0
A	6083	1962	2.5	6.9	2.3	0.2	0.0	0.0
A	6083	1963	2.5	6.9	2.3	0.2	0.0	0.0
A	6083	1964	2.5	6.9	2.3	0.2	0.0	0.0
A	6083	1965	2.9	8.1	2.7	0.2	0.1	0.0
A	6083	1966	2.9	8.1	2.7	0.2	0.1	0.0
A	6083	1967	2.9	8.1	2.7	0.2	0.1	0.0
A	6083	1968	2.9	8.1	2.7	0.2	0.1	0.0
A	6083	1969	3.3	9.2	3.1	0.3	0.1	0.0
A	6083	1970	2.5	6.9	2.3	0.2	0.0	0.0
A	6083	1971	2.5	6.9	2.3	0.2	0.0	0.0
A	6083	1972	4.1	11.6	3.9	0.3	0.1	0.0
A	6083	1973	4.0	11.4	3.8	0.3	0.1	0.0
A	6083	1974	3.1	8.7	2.9	0.2	0.1	0.0
A	6083	1975	0.6	1.7	0.6	0.0	0.0	0.0
A	6083	1976	1.2	3.4	1.1	0.1	0.0	0.0
A	6083	1977	4.0	11.2	3.8	0.3	0.1	0.0
A	6083	1978	5.7	16.1	5.4	0.5	0.1	0.0
A	6083	1979	8.9	25.0	8.4	0.7	0.2	0.0
A	6083	1980	7.3	20.4	6.9	0.6	0.1	0.0
A	6083	1981	0.6	1.6	0.5	0.0	0.0	0.0
A	6083	1982	5.4	15.3	5.1	0.4	0.1	0.0
A	6083	1983	4.7	13.2	4.4	0.4	0.1	0.0
A	8486	1984	3.4	9.5	3.2	0.3	0.1	0.0
A	8486	1985	7.9	22.3	7.5	0.6	0.1	0.0
A	8486	1986	12.5	35.4	11.9	1.0	0.2	0.0
A	8792	1987	7.6	21.3	7.2	0.6	0.1	0.0
A	8792	1988	7.2	20.4	6.9	0.6	0.1	0.0
A	8792	1989	1.9	5.3	1.8	0.1	0.0	0.0
A	8792	1990	3.9	11.1	3.7	0.3	0.1	0.0
A	8792	1991	6.4	18.0	6.0	0.5	0.1	0.0
A	8792	1992	6.4	18.0	6.0	0.5	0.1	0.0
A	9396	1993	7.7	21.6	7.3	0.6	0.1	0.0
A	9396	1994	7.3	20.5	6.9	0.6	0.1	0.0
A	9396	1995	8.0	22.6	7.6	0.6	0.1	0.0
A	9396	1996	10.4	29.2	9.8	0.8	0.2	0.0
A	9700	1997	11.5	32.3	10.9	0.9	0.2	0.0
A	9700	1998	11.1	31.4	10.5	0.9	0.2	0.0
A	9700	1999	11.7	32.9	11.1	0.9	0.2	0.0
A	9700	2000	11.7	32.9	11.1	09	0.2	0.0
B	6083	1960	32.9	92.7	31.2	2.6	0.6	0.1
B	6083	1961	34.5	97.3	32.7	2.7	0.6	0.1
B	6083	1962	51.6	145.4	48.9	4.1	0.9	0.2
B	6083	1963	83.3	235.0	79.0	6.6	1.5	0.3
B	6083	1964	70.5	198.7	66.8	5.6	1.3	0.3
B	6083	1965	77.6	218.7	73.5	6.2	1.4	0.3
B	6083	1966	85.1	240.1	80.7	6.8	1.5	0.3
B	6083	1967	106.6	300.5	101.0	8.5	1.9	0.4
B	6083	1968	111.0	312.8	105.1	8.8	2.0	0.4
B	6083	1969	89.1	251.3	84.5	7.1	1.6	0.3
B	6083	1970	77.8	219.4	73.7	6.2	1.4	0.3
B	6083	1971	63.2	178.2	59.9	5.0	1.1	0.2
B	6083	1972	82.9	233.6	78.5	6.6	1.5	0.3
B	6083	1973	65.1	183.4	61.6	5.2	1.2	0.2
B	6083	1974	81.5	229.8	77.2	6.5	1.5	0.3
B	6083	1975	89.2	251.5	84.5	7.1	1.6	0.3
B	6083	1976	89.7	252.7	85.0	7.1	1.6	0.3
B	6083	1977	76.3	215.0	72.3	6.1	1.4	0.3
B	6083	1978	61.4	173.2	58.2	4.9	1.1	0.2
B	6083	1979	80.2	226.1	76.0	6.4	1.5	0.3
B	6083	1980	71.0	200.3	67.3	5.7	1.3	0.3
B	6083	1981	84.4	238.0	80.0	6.7	1.5	0.3
B	6083	1982	95.2	268.4	90.2	7.6	1.7	0.3
B	6083	1983	84.5	238.2	80.1	6.7	1.5	0.3
B	8486	1984	65.3	184.1	61.9	5.2	1.2	0.2
B	8486	1985	127.5	359.5	120.8	10.1	2.3	0.5
B	8486	1986	133.4	376.1	126.4	10.6	2.4	0.5
B	8792	1987	161.3	454.6	152.8	12.8	2.9	0.6
B	8792	1988	301.8	850.8	286.0	24.0	5.5	1.1
B	8792	1989	370.1	1043.5	350.7	29.4	6.7	1.3
B	8792	1990	286.3	807.1	271.3	22.8	5.2	1.0
B	8792	1991	299.6	844.5	283.9	23.8	5.4	1.1
B	8792	1992	418.6	1180.2	396.7	33.3	7.6	1.5
C	9396	1993	28.1	1197.7	694.7	240.3	38.3	0.2
C	9396	1994	38.4	1637.4	949.7	328.5	52.4	0.3
C	9396	1995	39.7	1694.6	982.9	340.0	54.2	0.3
C	9396	1996	42.7	1823.9	1057.9	365.9	58.3	0.3
D	9700	1997	54.6	2490.1	750.2	239.3	54.6	0.0
D	9700	1998	60.2	2747.3	827.7	264.0	60.2	0.0
D	9700	1999	75.5	3447.1	1038.5	331.2	75.5	0.0
D	9700	2000	53.6	2444.7	736.5	234.9	53.6	0.0

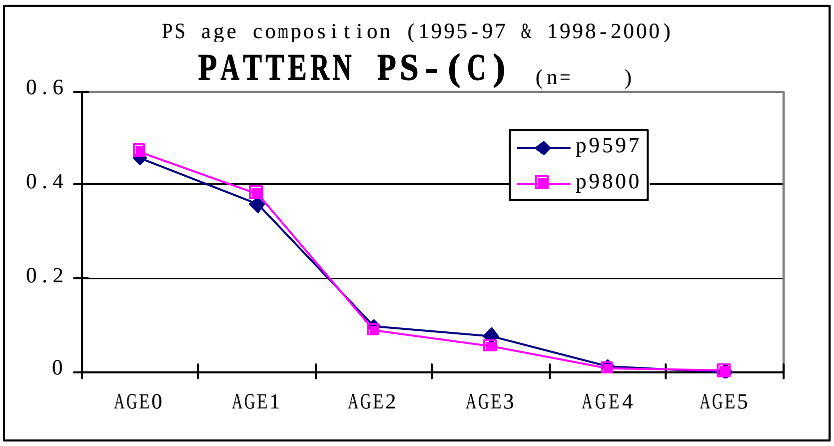
(3) SURFACE to SUB-SURFACE (PS)

Period	(1)(*) Sample size (1000 fish) (raised number)	(2) Pattern of age composition of catch (see Fig.x)	(3) Mean weight (kg)	(4) Catch (tons)	(5) Catch (1000 fish) =(4)/(3)	(6) (raised) sampling rate (%) = (1)*100/(5)
1960-81	0	PS-(A)(substituted)	12.7(**)	2,999	236	0
1982-85	10,667	PS-(A)	12.7	141,818	11,167	95.5%
1986-88	15,993	PS-(B)	16.1	276,851	17,196	93.0%
1989-91	20,860		14.5	304,493	21,000	99.3%
1992-94	15,742		18.8	355,965	18.934	83.1%
1995-97	37,654	PS-(C)	9.6	457,414	47,647	79.0%
1998-00	42,402		8.2	422,070	51,472	82.4%

Note (*) Samples are primarily from Spain and France. (**) average weight during 1982-85 are substituted.







CAA PS (Surface –Sub surface fisheries) (in 1000 fish)

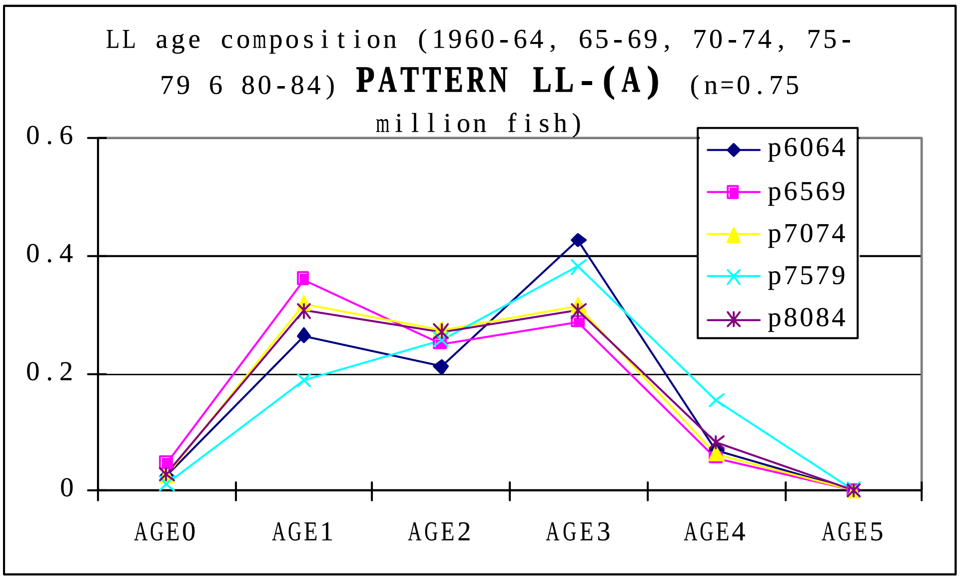
Pattern	Period	YR	AGE0	AGE1	AGE2	AGE3	AGE4	AGE5
PS-(A)	p6081	1960	1.6	0.8	0.2	0.4	0.1	0.0
PS-(A)	p6081	1961	2.0	1.1	0.2	0.5	0.2	0.0
PS-(A)	p6081	1962	2.4	1.3	0.3	0.6	0.2	0.0
PS-(A)	p6081	1963	2.6	1.4	0.3	0.6	0.2	0.0
PS-(A)	p6081	1964	3.3	1.7	0.4	0.8	0.3	00
PS-(A)	p6081	1965	3.3	1.7	0.4	0.8	0.3	0.0
PS-(A)	p6081	1966	2.8	1.5	0.3	0.7	0.2	0.0
PS-(A)	p6081	1967	2.8	1.5	0.3	0.7	0.2	0.0
PS-(A)	p6081	1968	2.8	1.5	0.3	0.7	0.2	0.0

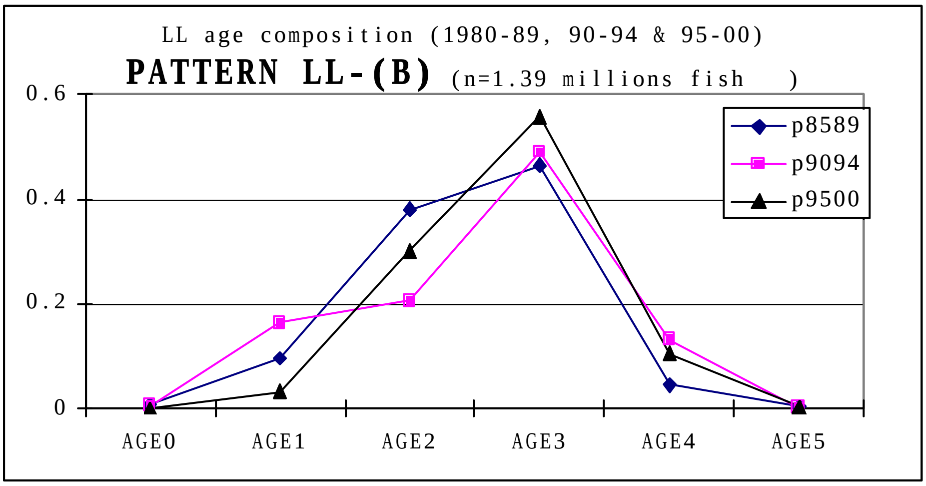
PS-(A)	p6081	1969	3.2	1.7	0.4	0.8	0.3	0.0
PS-(A)	p6081	1970	2.4	1.3	0.3	0.6	0.2	0.0
PS-(A)	p6081	1971	2.4	1.3	0.3	0.6	0.2	0.0
PS-(A)	p6081	1972	4.0	2.1	0.5	1.0	0.3	0.0
PS-(A)	p6081	1973	3.9	2.1	0.5	1.0	0.3	0.0
PS-(A)	p6081	1974	3.8	2.0	0.4	1.0	0.3	0.0
PS-(A)	p6081	1975	2.1	1.1	0.2	0.5	0.2	0.0
PS-(A)	p6081	1976	3.4	1.8	0.4	0.8	0.3	0.0
PS-(A)	p6081	1977	8.1	4.3	0.9	2.0	0.7	0.0
PS-(A)	p6081	1978	17.0	9.0	2.0	4.2	1.4	0.0
PS-(A)	p6081	1979	16.0	8.5	1.9	4.0	1.3	0.0
PS-(A)	p6081	1980	15.4	8.2	1.8	3.8	1.3	0.0
PS-(A)	p6081	1981	14.1	7.5	1.7	3.5	1.2	0.0
PS-(A)	p8285	1982	55.9	29.7	6.5	14.0	4.6	0.1
PS-(A)	p8285	1983	510.7	271.0	59.6	127.6	42.5	0.7
PS-(A)	p8285	1984	2323.3	1233.1	271.3	580.4	193.3	3.2
PS-(A)	p8285	1985	2744.6	1456.7	320.5	685.6	228.3	3.8
PS-(B)	p8688	1986	1458.8	1563.5	629.3	805.2	127.3	3.3
PS-(B)	p8688	1987	1661.6	1780.8	716.7	917.1	145.0	3.7
PS-(B)	p8688	1988	2348.0	2516.5	1012.8	1296.0	204.9	5.3
PS-(B)	p8991	1989	1992.1	2301.0	850.8	942.5	110.3	1.9
PS-(B)	p8991	1990	2411.9	2785.8	1030.1	1141.1	133.5	2.3
PS-(B)	p8991	1991	2344.9	2708.5	1001.5	1109.5	129.8	2.2
PS-(B)	p9294	1992	1880.9	1689.8	932.0	1203.5	295.7	5.4
PS-(B)	p9294	1993	2135.1	1918.2	1057.9	1366.1	335.7	6.1
PS-(B)	p9294	1994	1912.4	1718.1	947.6	1223.7	300.7	5.5
PS-(C)	p9597	1995	8067.4	6298.7	1717.5	1364.5	190.5	3.5
PS-(C)	p9597	1996	6860.4	5356.3	1460.5	1160.4	162.0	3.0
PS-(C)	p9597	1997	6860.4	5356.3	1460.5	1160.4	162.0	3.0
PS-(C)	p9800	1998	6446.2	5210.3	1201.8	726.9	93.8	5.4
PS-(C)	p9800	1999	8529.9	6894.5	1590.2	961.9	124.1	7.2
PS-(C)	p9800	2000	9270.4	7493.1	1728.3	1045.4	134.9	7.8

(4) MIDWATER (LL)

Period	(1)(*) Sample size (1000 fish)	(2) Pattern of age composition of catch (see Fig.x)	(3) Mean weight (kg)	(4) Catch (tons)	(5) Catch (1000 fish) =(4)/(3)	(6) Sampling rate (%) = (1)*100/(5)
1960-64	182	LL-(A)	31.6	116,375	3,683	4.9%
1965-69	198		25.6	210,388	8,218	2.4%
1970-74	144		27.7	136,282	4,920	2.9%
1975-79	112		36.4	153,020	4,204	2.7%
1980-84	113		28.8	138,764	4,818	2.3%
1985-89	1,247	LL-(B)	34.5	242,053	7,016	17.8%
1990-94	55		38.2	633,380	16,581	0.3%
1995-00	92		40.5	641,735	15,845	0.6%

Note (*) Samples are primarily from Japan (1960-2000), Taiwan (1985-88) and Korea (1998-2000).





CAA (MIDWATER: LL)

Pattern	Period	Year	AGE0	AGE1	AGE2	AGE3	AGE4	AGE5
A	p6064	1960	19.6	203.7	163.0	330.2	54.2	0.7
A	p6064	1961	17.9	185.5	148.5	300.7	49.4	0.6
A	p6064	1962	27.3	283.7	227.0	459.8	75.5	0.9
A	p6064	1963	14.1	146.0	116.8	236.6	38.9	0.5
A	p6064	1964	14.8	153.6	122.9	249.0	40.9	0.5
A	p6569	1965	40.2	310.8	216.0	248.2	48.0	0.1
A	p6569	1966	59.0	456.5	317.3	364.6	70.5	0.1
A	p6569	1967	65.3	505.2	351.1	403.5	78.0	0.1
A	p6569	1968	121.7	941.6	654.4	752.1	145.4	0.3
A	p6569	1969	96.2	744.7	517.6	594.8	115.0	0.2
A	p7074	1970	30.1	357.6	307.5	354.0	70.5	0.4
A	p7074	1971	31.3	371.9	319.8	368.1	73.4	0.4
A	p7074	1972	29.7	353.3	303.8	349.7	69.7	0.4
A	p7074	1973	19.7	233.8	201.1	231.4	46.1	0.2
A	p7074	1974	21.4	254.2	218.7	251.7	50.2	0.3
A	p7579	1975	8.4	120.2	164.5	243.2	98.7	1.9

A	p7579	1976	8.1	115.7	158.3	234.0	94.9	1.8
A	p7579	1977	16.2	232.4	318.0	469.9	190.7	3.6
A	p7579	1978	13.0	186.7	255.5	377.6	153.2	2.9
A	p7579	1979	9.7	138.7	189.7	280.4	113.8	2.2
A	p8084	1980	24.2	254.8	226.1	255.5	69.4	1.1
A	p8084	1981	26.0	273.7	242.9	274.4	74.5	1.2
A	p8084	1982	34.4	361.8	321.1	362.7	98.5	1.6
A	p8084	1983	30.6	322.2	285.9	323.0	87.7	1.4
A	p8084	1984	25.1	264.7	234.9	265.4	72.1	1.1
B	p8589	1985	5.7	84.1	331.7	404.5	40.0	4.0
B	p8589	1986	8.6	126.7	499.3	609.0	60.2	6.1
B	p8589	1987	8.7	128.1	505.0	615.9	60.9	6.2
B	p8589	1988	10.4	152.4	600.8	732.7	72.5	7.3
B	p8589	1989	12.7	187.1	737.7	899.7	89.0	9.0
B	p9094	1990	12.9	378.0	473.8	1131.8	305.4	2.7
B	p9094	1991	12.1	354.4	444.3	1061.3	286.4	2.5
B	p9094	1992	20.6	602.5	755.4	1804.4	486.9	4.3
B	p9094	1993	29.2	853.1	1069.5	2554.7	689.4	6.1
B	p9094	1994	18.2	531.2	665.9	1590.7	429.2	3.8
B	p9500	1995	1.8	81.3	741.1	1372.1	258.6	6.5
B	p9500	1996	2.2	100.0	912.0	1688.4	318.2	8.0
B	p9500	1997	2.0	90.4	824.4	1526.4	287.6	7.2
B	p9500	1998	2.0	93.6	853.5	1580.1	297.8	7.5
B	p9500	1999	1.8	84.5	770.8	1427.1	268.9	6.7
B	p9500	2000	1.6	73.4	669.3	1239.2	233.5	5.9