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First attempt of stock assessment using Stock Synthesis III (SS3) for the Indian Ocean albacore tuna (*Thunnus alalunga*)

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Executive summary

Stock assessment for the Indian Ocean albacore tuna based on the Stock Synthesis III (SS3) was attempted with consideration of available information on catch, abundance indices and length frequency up to 2010. A total of five fisheries were defined. Three independent CPUE series (Japan, Taiwan and Korea) were available for tuning indices. Quarterly length compositions from the different fisheries contributed to the likelihood in addition to the populations indices. The Several biological and ecological parameters such as the growth curves, length-weight relationship, natural mortality and steepness were assumed to be known (see main text of this paper) when optimizing the likelihood. Results based on the three independent incompatible CPUE series produced unreasonable results. Therefore, a CPUE series for Taiwanese longline fishery, in which fishing operation and fishing ground have been stable and its catch accounts for a large extent of total catch in the Indian Ocean, was employed in the base case scenario. Also, the weighted average of Japanese and Taiwanese CPUEs was also used in sensitivity tests.

In a base case scenario (here natural mortality=0.2207, steepness=0.8 and SD of recruitment deviation=0.2), the current F/F_{MSY} and SSB/SSB_{MSY} were estimated as 1.657 and 0.844, respectively. A current SB(2010)/SB(1950) ratio was at 0.186, and the level of MSY was assessed as 28,093 (t). The figures become more optimistic when the abundance index was replaced with the averaged one; the current F/F_{MSY} and SSB/SSB_{MSY} were respectively 1.242 and 1.268 and MSY was 30,296 (t). The estimated stock indices were sensitive to changes in the value of steepness, natural mortality, the extent of recruitment deviation and abundance indices, but the outcome of this exercise provides some implications to the interpretation of the albacore stock, in which some of key biological parameters are unknown and have uncertainty, because other stock assessment methods failed to provide comprehensive sensitivity tests due to lack of convergence in optimization.

Run	CPUE	Natural Mortality (M)	Steepness (h)	Recruitment deviation (σR)	F_{2010}/F_{MSY}	SSB_{2010}/SSB_{MSY}	SSB_{2010}/SSB_{1950}	MSY
1	Taiwanese CPUE only	0.2207	0.6	0.2	2.614	0.563	0.171	23,135 t
2	Taiwanese CPUE only	0.2207	0.7	0.2	2.113	0.667	0.176	25,291 t
3 (base)	Taiwanese CPUE only	0.2207	0.8	0.2	1.657	0.844	0.186	28,093 t
4	Taiwanese CPUE only	0.2207	0.9	0.2	0.997	1.349	0.264	36,444 t
5	Taiwanese CPUE only	0.4	0.8	0.2	1.657	0.844	0.186	28,093 t
6	Taiwanese CPUE only	0.2207	0.8	0	0.469	2.994	0.612	59,074 t
7	Taiwanese CPUE only	0.2207	0.8	0.4	1.477	0.913	0.201	30,533 t
8	Weighted average of JPN and TWN CPUEs	0.2207	0.7	0.2	1.546	1.011	0.267	27,162 t
9	Weighted average of JPN and TWN CPUEs	0.2207	0.8	0.2	1.242	1.268	0.281	30,296 t

Given this preliminary nature of our assessments, the results presented in this paper may not be useful for giving management advice itself, but we do believe that this first attempt could give an opportunity to compare with results by other stock assessment methods and also to discuss possible and reasonable sets of parameters and scenarios used in our future assessment.

In addition, the work would be a possible kick-off for future improvement toward management advice and also a basis of developing operating models (OMs) in the management strategy evaluations (MSEs).

1. Introduction

Commercial fishery for albacore tunas have been operated in the Indian Ocean since early 1950s. After the exploitation by Japanese longline fishery, Korean and Taiwanese longline fisheries started their operations in 1954 and 1965, respectively. Drift nets were also employed for the albacore fishery from mid-1980s to 1992, when the practice of drift net fishing was banned. Recently, Taiwanese longline catch has largely accounted for more than half of the total catch in this region. It should be noted that the albacore fishing ground has been shifting to southern Eastern Indian Ocean to avoid operations in Somalian waters, which have been infested by pirates.

During the third Working Party for temperate tuna (WPTmT3) held last year, an assessment using a production model (ASPIC, Prager 2004) was conducted (Nishida and Matsumoto 2011). Due to contradictory trends between Japanese and Taiwanese standardized CPUE series, the convergence was not easily carried out, and therefore a result based only Taiwanese CPUE series with a likely assumption on the initial depletion (B/K in 1980 was fixed at 0.9) was used for the management advice. The WPTmT3 and the 14th Scientific Committee (SC14) recognized that i) recent catches have been above MSY, ii) recent fishing mortality exceeds FMSY (F2010/FMSY > 1) and iii) there is a moderate risk that total biomass is below BMSY (B2010/BMSY ≈ 1). Also, an estimate of MSY was 29,900 t (21,500–33,100 t), which is smaller than the current amount of catch 43,711 t.

However, since no other kinds of assessment were conducted last year, the WPTmT3 and SC14 therefore recommended at least two other methods of assessment be carried out during this intercessional period. To meet this request, we here report on results of our first attempt of stock assessment using Stock Synthesis III (SS3) for the Indian Ocean albacore tuna. This paper is a kind of companion paper with other two papers by our colleagues using different approaches, ASPIC (Matsumoto et al. 2012) and an age-structured production model (ASPM, Nishida et al. 2012), to give a ground for comparison of results from broad spectrum of complexity of models.

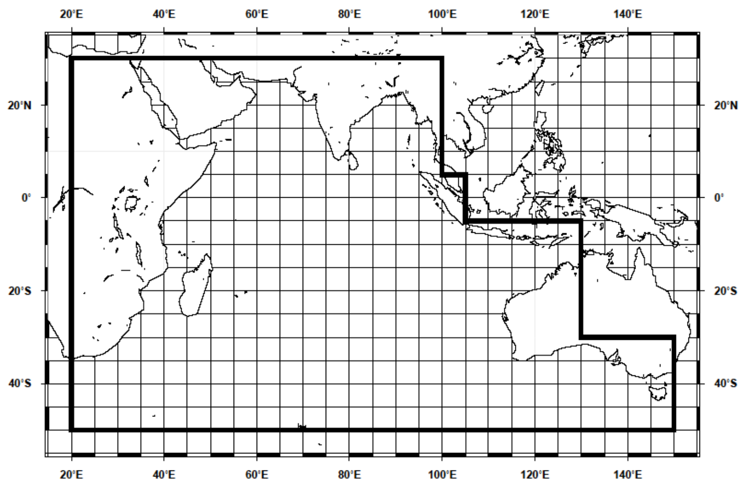


Figure 1. Geographical area for the stock assessment. No area separation was considered in this assessment.

2. Data

2.1 Catch statistics

Quarterly catch for the albacore tunas were summarized by year and fishery with a unit of metric tonnage. The span of years is from 1950 to 2010 (not to 2011 because of unavailability of catch information in 2011). A well-organized file of the dataset, "ALB_SA_20120523.xls", was kindly prepared and provided by the IOTC Secretariat (downloaded from a website of IOTC, http://www.iotc.org/English/meetings/wp/wptmtcurrent.php) in a timely manner. Five fisheries (fleets) were defined as follows. Annual and quarterly tends in total catch by fishery are shown in Figure 2.

Definition of fisheries

Fishery 1: Japanese longline(LL), including Korean and other countries Japan type longline (JPN_LL, 1952-2010)
Fishery 2: Taiwanese longline, including Indonesian and other countries Taiwan type longline (TWN_LL, 1954-2010)
Fishery 3: Taiwanese Drift gill net (Drift, 1982-2010)
Fishery 4: Purse Seine (PS, 1982-2010)
Fishery 5: Others (Others, 1950-2010)

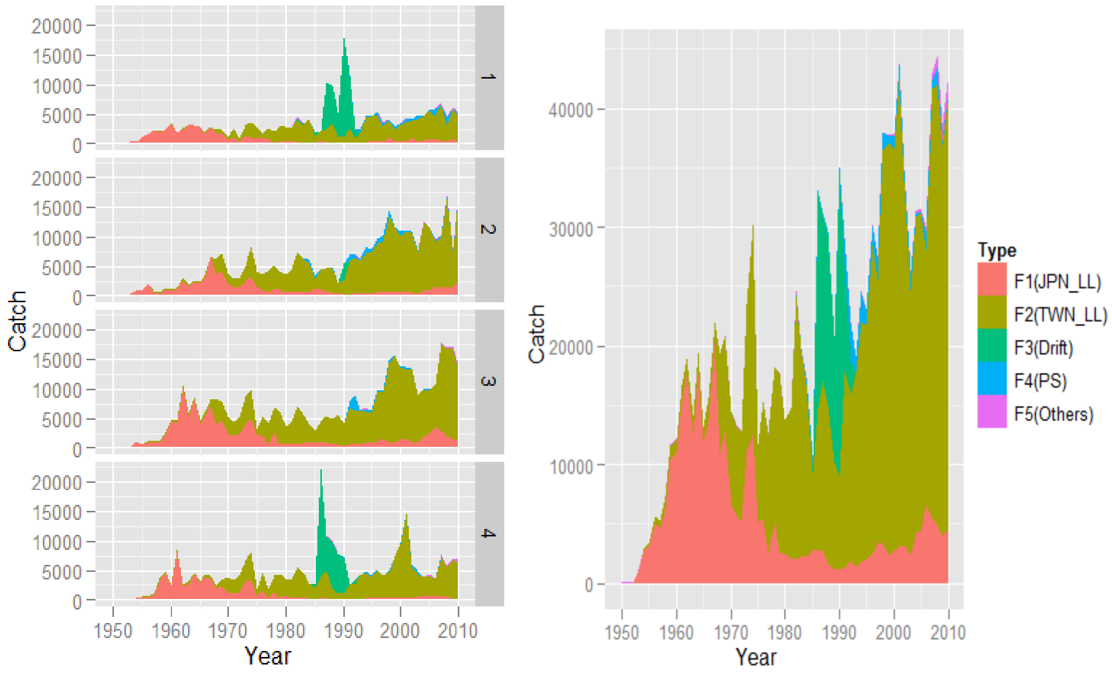


Figure 2. Annual and quarterly trends of total catch for albacore tuna by fishery.

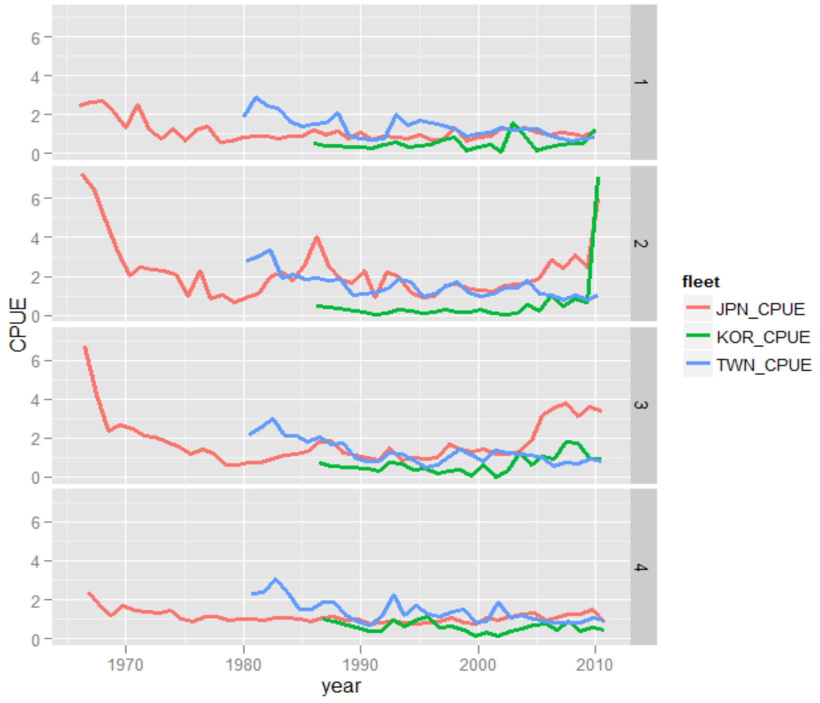
2.2 Relative abundance indices (CPUE series)

Quarterly standardized CPUE series for Japanese, Korean and Taiwanese fishery were available for this analysis. The indices were estimated through analyses with generalized linear models. The quarterly CPUE trends are shown in Figure 3.

Among two different Japanese CPUE series and the associated standard errors (SEs) given in Matsumoto et al. (2012), we used those based on the lognormal assumption as authors' recommendation. For Taiwanese and Korean CPUE series, we respectively used the estimates given by Lee et al. (2012a) and Lee et al. (2012b) up to 2010.

<u>Definition of surveys</u>

Survey 1: Standardized quarterly CPUE series for Japanese Longline fishery
(JPN_CPUE, from 1966 to 2010)
Survey 2: Standardized quarterly CPUE series for Taiwanese Longline fishery
(TWN_CPUE, from 1980 to 2010)
Survey 3: Standardized quarterly CPUE series for Korean Longline fishery
(KOR_CPUE, from 1986 to 1987 and from 1990 to 2010)



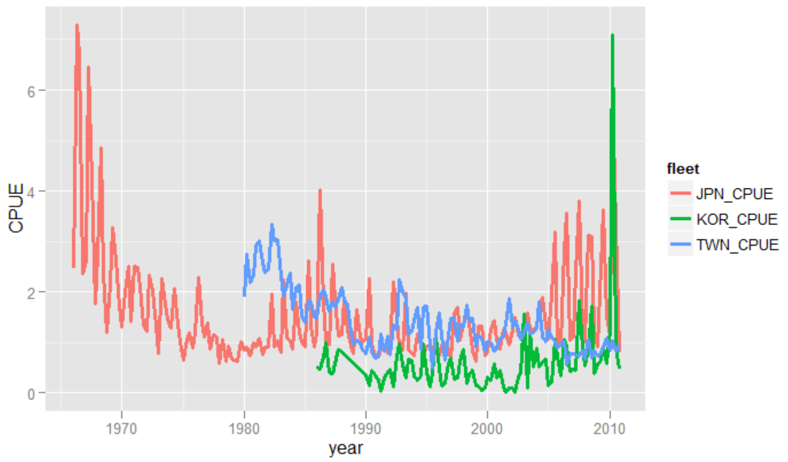


Figure 3. Trends in the Japanese, Taiwanese and Korean standardized CPUE series.

It should also be remarked that these standardized CPUE series may not reflected with the true population trend if there are some changes in fishing ground and catchability across years, possibly due to changes in primary target species. This issue is relevant to the rapid decline in earlier period prior to 1970 and recent increase for the Japanese CPUE series. It might also be relevant to the discrepancy in very recent trends between the three CPUE series. This warrants further discussion under the Working Party how to handle the series.

2.3 Length Frequency data (size composition)

Proportional length frequency data by quarter (1-4) and by fishery (defined above), processed by the IOTC secretariat, are employed (“ALB_SA_20120523.xls”). The size of bin in length is fixed at 2cm and its span is 30-140cm. There are no actually measured length composition data for Fishery 3, but we used frequency data which the secretariat inferred from data existing from other fleets or strata by assuming a fixed sample size, 100 (see section 3.3.2).

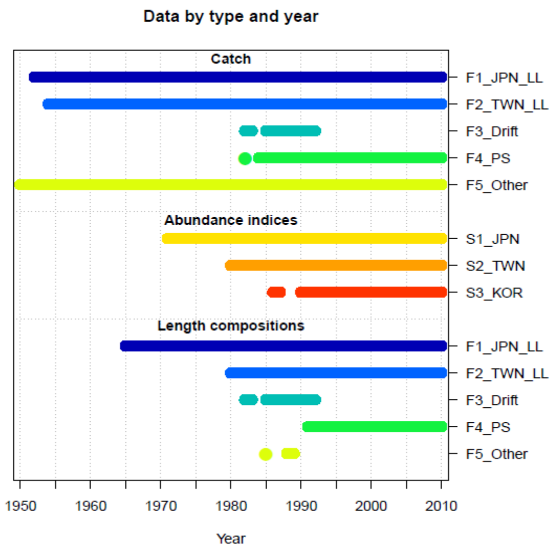


Figure 4. Time spans of the available data

2.4 Tagging data

No tagging data were utilized at this stage but we would like to try any exercises upon request.

3. Methods

3.1 Software

The analysis in this paper was performed with a well-known software, Stock Synthesis 3 (version 3.23b) developed by Dr. Methot (see Methot 2009). The executable file is downloadable from a website http://nft.nefsc.noaa.gov/SS3.html.

For graphical presentation, a package "r4ss" (http://code.google.com/p/r4ss/) for R was utilized.

3.2 Specification

Main assumptions made for this analysis (say “a base case scenario”) are summarized in Table 1 below. Regarding the effective sample sizes, those assessed by the first run with a max sample size, 1000, are utilized in the second run.

No area definition was assumed (i.e. the whole region was aggregated as the unique area).

3.2.1 Time period and data handling:

Basically, the full period from 1950-2010 was covered, but we need to reach agreement on which period is suitable for the assessment given the lessons learnt from the last year’s ASPIC assessment.

Also, time blocking might be another issue to be agreed under the working party; especially we have to consider any changes in target species etc.

3.2.2 Basic biological parameters:

1) **Sex structure**: two genders with 1:1 sex ratio. The number of gender groups was set at 1.

2) **Natural mortality**: For the Indian Ocean albacore tuna, a constant value of M=0.2207 (/year) over ages, estimated by Lee and Liu (1992) using longline fishery data, is available. This value was used in the base case. However, a greater value M=0.456 (/year) is available for the South Atlantic and Mediterranean Seas (ICCAT 2011), and M=0.3 and 0.4 were respectively used for the North and South Pacific as input values for assessment (e.g. Watanabe et al. 2006, Hoyle 2008, 2011), and therefore we consider 0.4 as an alternative value to be tested in our sensitivity test.

3) **Growth formula**: The following von Bertalanffy curve estimated by direct information on an age(othlith)-length relationship was employed (Lee and Yeh 2007) for the consistency with Nishida et al (2012).

$$L_t = L_\infty(1-e^{-K(t-t_0)}) \text{ with } L_\infty = 147.5, K = 0.126, t_0 = -1.89$$

This is not a sex-specific curve. Also, parameters were actually estimated using the samples taken in the South Atlantic. Other estimates for growth parameters are also available for the Indian Ocean tuna. For example, Huang et al. (1990) provided the following formula;

$$L_t = L_\infty(1-e^{-K(t-t_0)}) \text{ with } L_\infty = 128.13, K = 0.162, t_0 = -0.897$$

We conducted a sensitivity test using this formula.

4) **Length-weight relationship**: The following sex-specific allometric curves were available (e.g. Lee and Kuo, 1988),

$$W = aL^b \text{ with } a = 4.183\times10^{-5},\ b = 2.8222\,(\text{female}),\ a = 3.383\times10^{-5},\ b = 2.8676\,(\text{male}),$$

but for the consistency with Nishida et al (2012), we used the following formula.

$$W = aL^b \text{ with } a = 5.691\times10^{-5},\ b = ,$$

5) **Age-at-maturity**: This is somewhat vague information for the Indian Ocean albacore tuna, but it is said the sexual maturity would start at age 5 rates (e.g. IOTC 2012). We therefore tentatively assumed the maturity rate as follows;

Mat0: 0 for Age <=3, 0.25 for Age=4, 0.5 for Age=5, 0.75 for Age=6 and 1 for Age>=7.

As in the case of natural mortality rate, there is some other information that the maturity could start at earlier ages than the above (see Hoyle and Davies 2008, ICCAT 2011). Taking account for this sort of information, we could consider another different scenario as sensitivity test (but not yet tried).

Mat1: 0 for Age <=3, 0.5 for Age=4 and 1 for Age>=5.

6) **Fecundity**: This is assumed to be proportional to the spawning biomass.

7) **Longevity**: There is information on this only for the Pacific Ocean albacore (10 years) and a closer

estimate, 8 years, is also provided for the Indian Ocean stock (IOTC 2012). Given this situation, we assume tentatively 10 years for the longevity of the Indian Ocean albacore.

3.2.3 Population dynamics and fishery

1) **Stock-recruitment relationship**: A standard Beverton-Holt relationship was assumed. It might be hard to estimate the steepness parameter (h), so we fixed at 0.8 for the base case, but we also used some other values such as 0.7 and 0.9. We did not try to estimate the steepness parameter within the model. Deviation of recruitment was allowed; the extent of recruitment deviation (sigma_R) was not able to estimate and therefore we fixed it at 0.2 for the base case and changed it for the sensitivity. Deviations before 1970 and those after 2005 were assumed to be respectively preceded and proceeded.

2) **Recruitment assignment:** Actually, we are not very sure if this is a right decision, but the recruitments are assigned only to Season 4 (October to December) in the base case.

3) **Initial population**: we assumed to be in unfished equilibrium state in 1950 because the fishery started in that year and full catch information is available since then.

4) **Selectivity:** A flexible double-normal size-selectivity function (#24) was assumed.

3.3 Statistical procedures

3.3.1 Fitting to CPUE series

Initial results based on the three independent incompatible CPUE series produced unreasonable results. Therefore, a CPUE series for Taiwanese longline fishery, in which fishing operation and fishing ground have been stable and its catch accounts for a large extent of total catch in the Indian Ocean, was employed in the base case scenario.

Also, the weighted average of Japanese and Taiwanese CPUEs was also used in sensitivity tests. (see Matsumoto et al. 2012 and Nishida et al. 2012).

3.3.2 Sample size for length composition

Weighting to length compositions is much more uneasy sort of issue. If the sampling is randomly conducted, the nominal sample sizes can be indicators of relative weight. However, fish measured may not be randomly selected but rather very correlated because those fish may be caught by a same shot or in a same fish patch. For example, the range of length composition in Taiwanese fishery is from 179 to 80002 except for cases of 0 sample size and in that case the sample size of 80002 might be too over-representative compared to other data set. Therefore, the nominal sample size for length frequencies may not provide the suitable relative information among seasons/years/fisheries. In this regard, it is *ad hoc*, but all the sample sizes for length frequency data greater than 1000 were set to 1000.

The estimated effective sample sizes in this initial SS3 run were then used in the final run as sample sizes.

As mentioned earlier, frequency data for Fishery 3 was inferred by the secretariat from data existing from other fleets or strata, so to reduce the weight, we assume a fixed sample size, 100, for this fishery. It should also be noted that those for Fishery 5 were available only a few seasons, and therefore these were less contributed to likelihood calculation in the assessment.

3.3.3 Optimization

No prior distribution was used for any optimization. Whether multiple minima occurred or not was tested in the base case by changing some initial values of some important parameters. A total of five phases are used for sequential optimization.

3.3.4 Uncertainty

Any standard deviations were assessed by the inverse of hessian matrix evaluated at the estimates. (if convergence is attained). No MCMC and bootstrapping computations were made at this stage due to computational burden and so on.

3.3.5 Forecasting

A primary objective of this paper is to provide information on the stock status for comparison to the other methods, and we have not tried forecasting yet, but we have recognized that it is highly important to give future projections to meet the requirement of the agreed KOBE process, so we will prioritize it for the next intercessional period.

3.4 Sensitivity runs

The following several sensitivity runs were planned to implement.

1) Use averaged CPUE series
2) Steepness: Base case 0.8 | sensitivity = 0.6, 0.7, 0.9.
3) Recruitment deviation: Sigma_R=0.2 => 0, 0.4
4) Natural mortality M=0.2207 => 0.4

Table 1. Specification for our "base case scenario" for SS3 assessment

Biological and ecological structures	
#Gender Group	1 (Sex ratio 1:1)
Age classes	0 - 10
Natural mortality	M=0.2207 (/year) constant over ages
Growth formula	L=147.5(1-exp(-0.126(t+1.89))) common to sex
Weight-length allometry	$W = aL^b$ with $a = 5.691 \times 10^{-5}$, $b = 2.7514$. common to sex.
Maturity	Age-specific (0 for Age <=3, 0.25 for Age=4, 0.5 for Age=5, 0.75 for Age=6 and 1 for Age>=7)
Fecundity	Proportional to the spawning biomass
Spawner-recruitment	B-H (fixed steepness at 0.8) and sigma_R=0.2
Fisheries and other structures	
Selectivity pattern	Fishery-specific dome-shaped double-normal (#24). Among the six parameters, only the first four parameters are estimated.
Discard	None
Abundance index and length composition	
STD CPUE	Taiwanese (1980-2010)
Weight for CPUE series	SEs of log(CPUE)
Length composition	Length bin=2cm.
Effective sample size for length composition	The maximum initial sample size is 1000 for Fisheries other than Fishery 3, where the max is set at 100, and sample sizes were replaced with the effective sample sizes estimated in the initial run
Variance adjustment	No at this stage

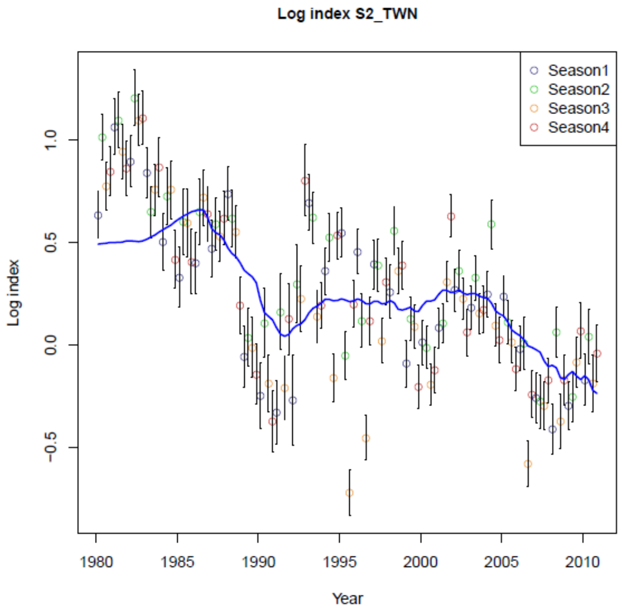
4. Results and Discussion

4.1 Fitting to the CPUE data

Fitting to the standardized CPUE series was not so very well at this stage (see Figure 5). In the Japanese series, the level of index in Season 2 is larger than the rest of seasons, but the current calculation assumed a same catchability. In this regard, further investigation by treating the CPUE series as separate fishery should be considered.

Also, a lack of fit to the later Japanese and earlier Taiwanese indices might be 1) due to relatively less weights to the CPUE series compared to those to the length frequencies; 2) due to changes in catchability over years, and therefore some change to weights (for point 1 above) and time blocking (for point 2 above) would be worth considering.

Base scenario (Run 3: only Taiwanese CPUE, M=0.2207, h=0.8, sigmaR=0.2)



A Sensitivity (Run 9: average CPUE of Japan and Taiwan, M=0.2207, h=0.8, sigmaR=0.2)

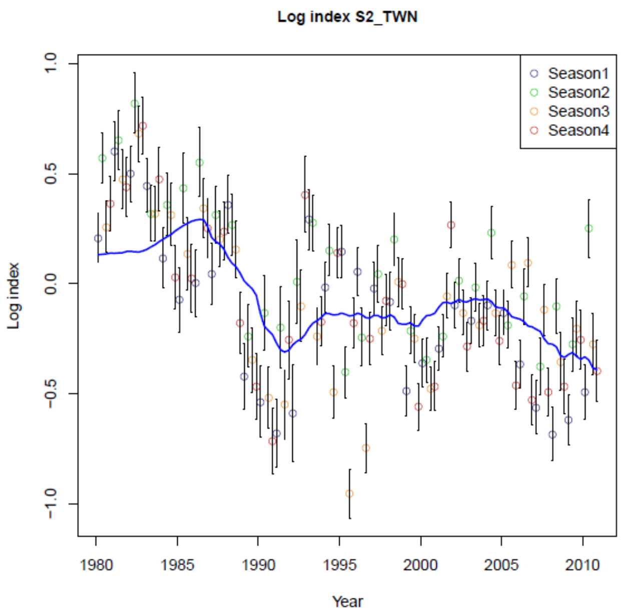


Figure 5. Observed CPUE series (circles) and predicted ones (solid line) for the base case scenario (top) and a sensitivity test Run 9 (bottom).

4.2 Fitting to the length composition data

Estimated selectivity patters for the base case are shown in Figure 6. These are not so different from those estimated in Sensitivity 1.

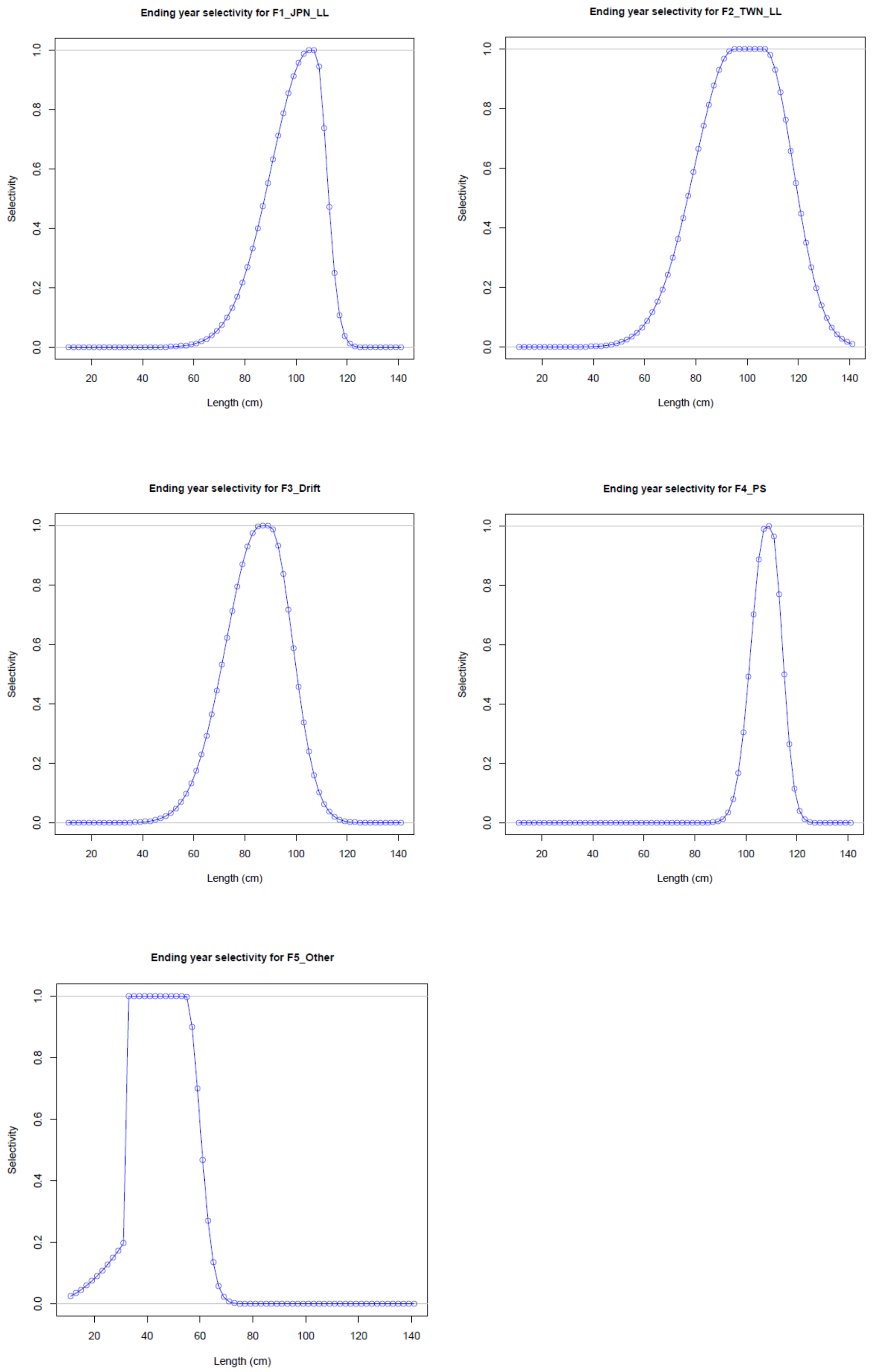


Figure 6. Estimated selectivity patters for Fisheries 1-5 for the base case. The results for sensitivity tests are similar.

Observed and estimated length compositions by fishery and season are given in Figure 7. Some further figures for the base case scenario are shown in Appendix 2. Fortunately, fits to the length composition data were generally not so bad. This is the case for Sensitivity 1 (omitted to show here).

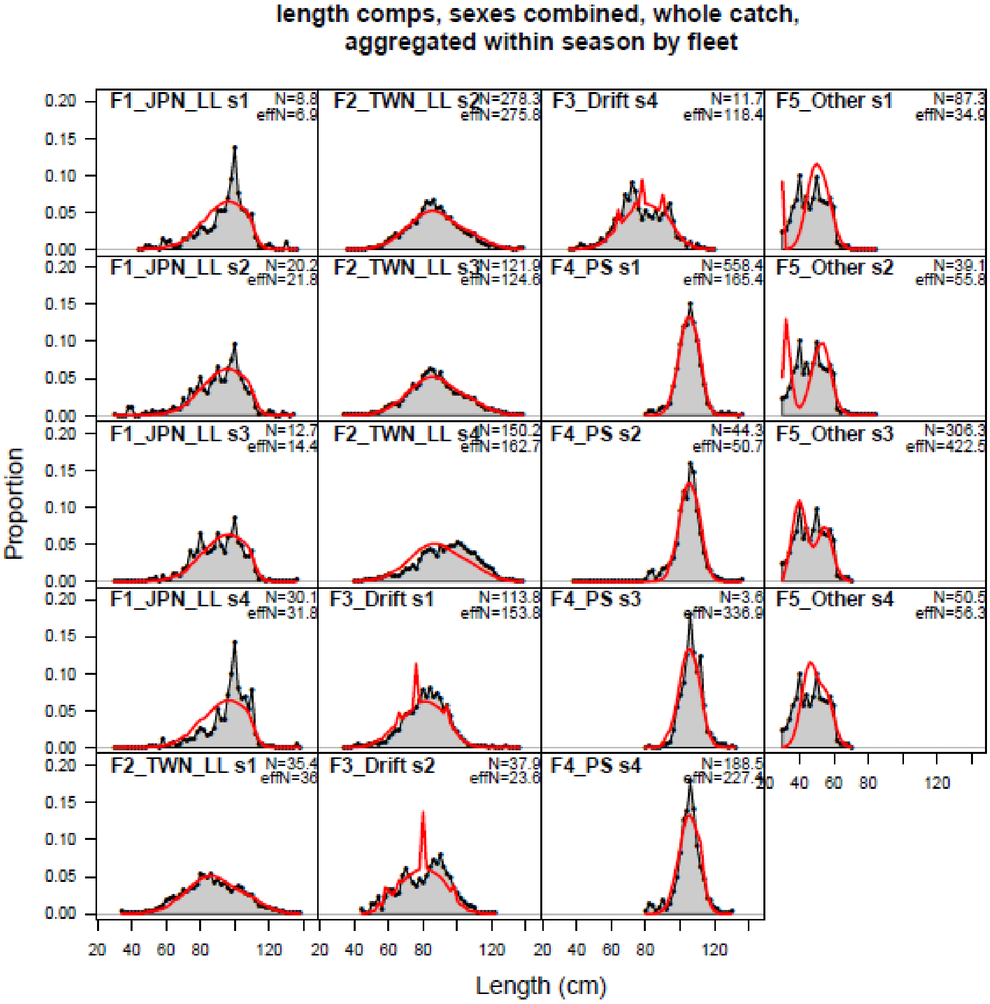


Figure 7. Observed and estimated length compositions by fishery and season for the base case.

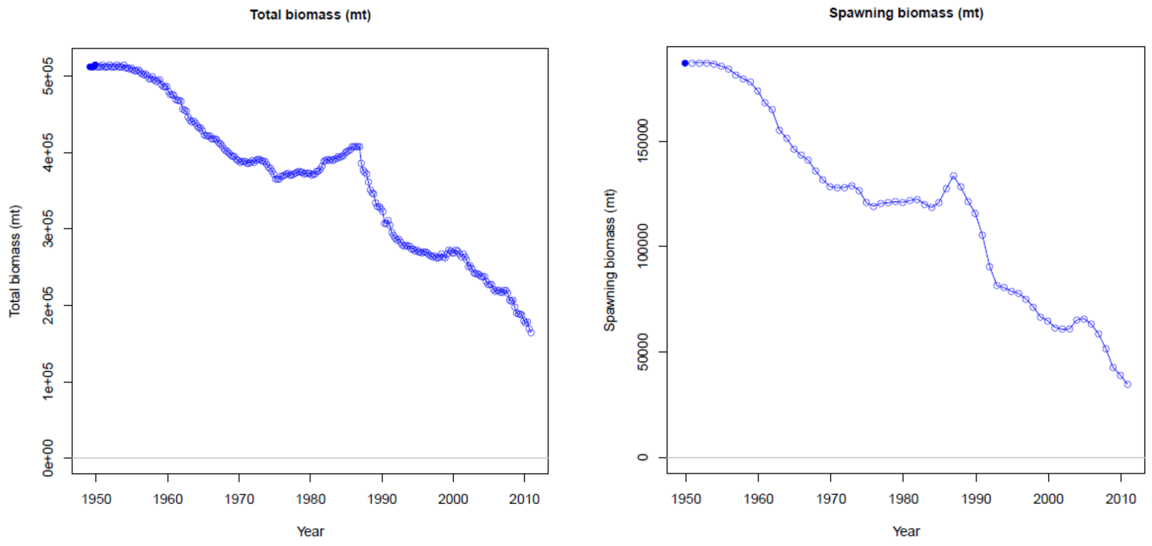
4.3 Population trend and stock status indicators

Estimated total and spawning biomass trends for the base case scenario are shown in Figure 8, and estimated spawner/recruitement trend (SPR) and B-H stock-recruitment curve are shown in Figure 9.

Table 2 summarizes stock status indicators under both the base case assessment and Sensitivity test 1. In the base case, a SSB2010/SSB0 ratio was 0.784 while SSB1980/SSB0 was 0.257. The current SSB/SSB_{MSY} and F/F_{MSY} were estimated as 3.156 and 0.908, respectively. However, the population behavior seemed unreasonable. In an alternative scenario (Sensitivity 1: use only Taiwanese CPUE series), SSB/SSB0 was 0.449 and the level of MSY was assessed as 40,234 (t). The current SSB/SSB_{MSY} and F/F_{MSY} were 2.008 and 0.749, respectively. This result might be optimistic.

However, as shown in Table 3, these results were very sensitive to changes in the value of steepness, the extent of recruitment deviation and the natural mortality parameter. We have not assessed yet, but such difference driven by "model and parameter uncertainty" might be greater than the extent of estimation uncertainty.

Base scenario (Run 3)



A Sensitivity (Run 9)

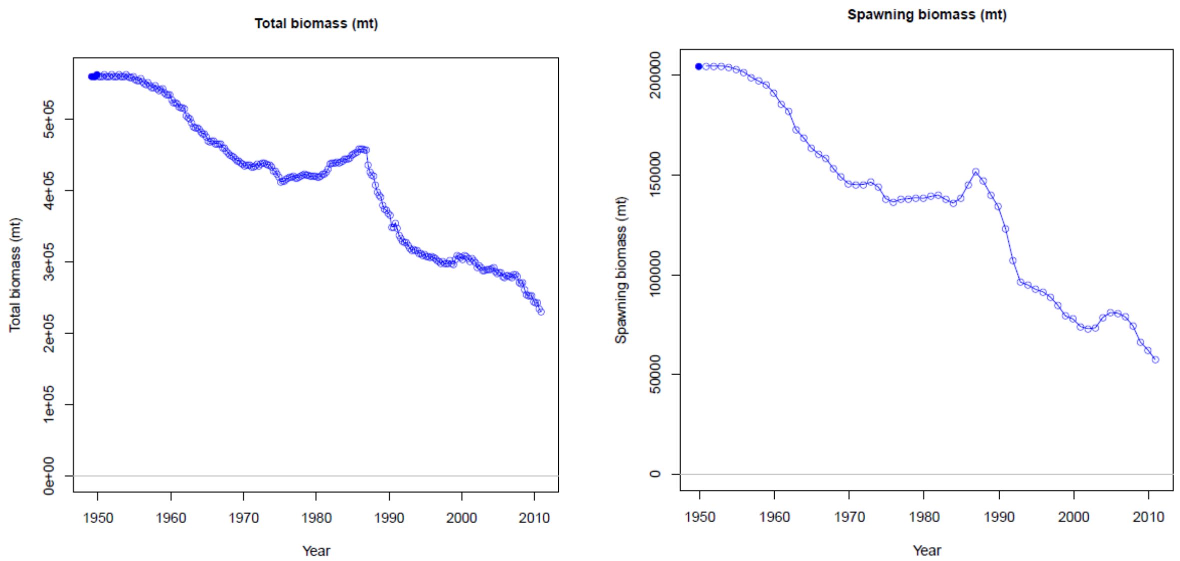
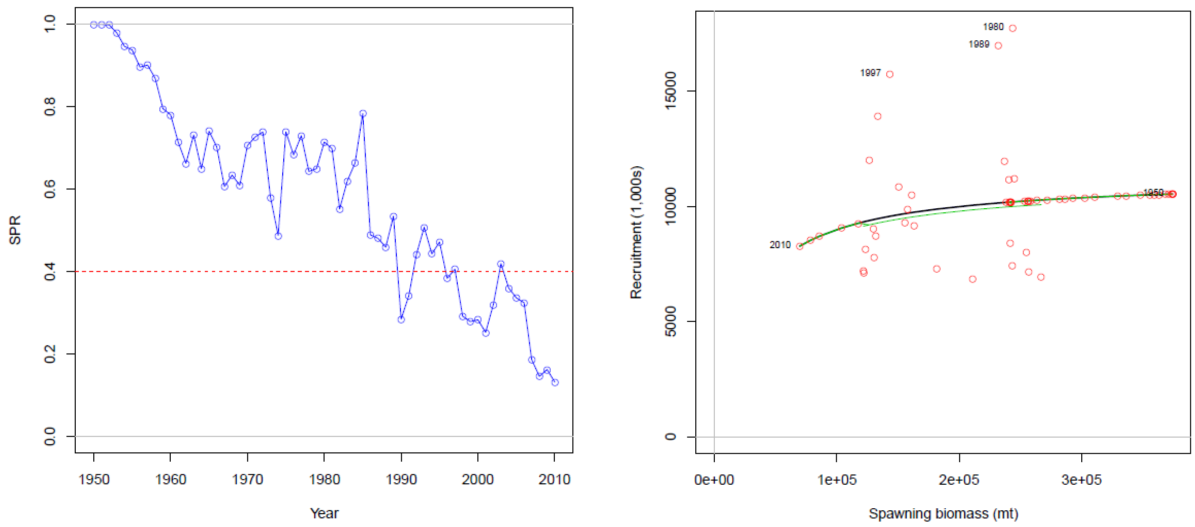


Figure 8. Estimated total (left) and spawning (right) biomass trends for the base case scenario (top) and sensitivity 1 (bottom).

Base scenario (Run 3)



A Sensitivity (Run 9)

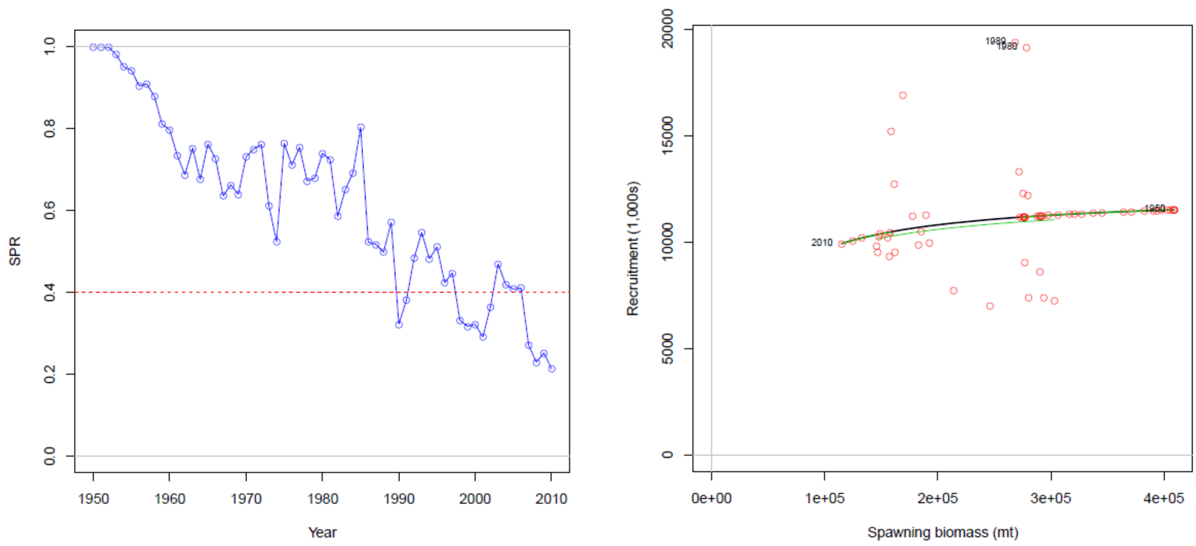


Figure 9. Estimated spawner/recruitement trend (SPR) and B-H stock-recruitment curve for the base case scenario. Top and bottom panels are for the base case and sensitivity 1).

Table 2. Summary of stock status under the base case assessment and Sensitivity test 1 for the Indian Ocean albacore. Note that $B_{Initial}$ is 1980 and 1950 for result in 2011 and 2012, respectively.

Management quantity	ASPIC	ASPM	SS3 base case (Run 3)	SS3 sensitivity (Run 8)	SS3 sensitivity (Run 9)
Catch estimate in year y	42,968 t	42,968 t	42,968 t	42,968 t	42,968 t
Mean catch for past 5 years	39,833 t	39,833 t	39,833 t	39,833 t	39,833 t
MSY	35,900 t (31,300-39,100)	33,300 t (31,100-35,600)	28,093 t (NA)	27,162 t (NA)	30,296 t (NA)
Data period used (catch/CPUE)	1950-/1980-	1950-/1980-	1950-/1980-	1950-/1980-	1950-/1980-
F_{2010}/F_{MSY}	1.00 (0.75-1.24)	1.33 (0.90-1.76)	1.657 (NA)	1.546 (NA)	1.242 (NA)
B_{2010}/B_{MSY}	1.16 (0.96-1.49)				
SSB_{2010}/SSB_{MSY}		1.06 (0.54-1.56)	0.844 (NA)	1.011 (NA)	1.268 (NA)
B_{2010}/B_{1950}	0.44 (NA)				
SSB_{2010}/SSB_{1950}		0.32 (NA)	0.186 (NA)	0.267 (NA)	0.281 (NA)
CPUE	Weighted Ave	Weighted Ave	Taiwan	Weighted Ave	Weighted Ave
B1950/K	0.9 (fixed)	1	1	1	1
Natural mortality	NA	0.2207	0.2207	0.2207	0.2207
Steepness	NA	0.7	0.8	0.7	0.8
Recruitment deviation or process error	NA	Rec dev (but surprisingly small deviation)	Rec dev	Rec dev	Rec dev
Remark	1) Uncertainty underestimated 2) Convergence problem in some scenarios 3) Only Fox model	1) Unreasonable selectivity 2) Only two fishery categories 3) Convergence problem in some scenarios	1) Only Taiwanese CPUEs were used 2) No projections and precisions	No projections and precisions	No projections and precisions

Table 3. Comparison of some stock status indicators among different runs

Run	CPUE	Natural Mortality (M)	Steepness (h)	Recruitment deviation (σR)	F_{2010}/F_{MSY}	SSB_{2010}/SSB_{MSY}	SSB_{2010}/SSB_{1950}	MSY
1	Taiwanese CPUE only	0.2207	0.6	0.2	2.614	0.563	0.171	23,135 t
2	Taiwanese CPUE only	0.2207	0.7	0.2	2.113	0.667	0.176	25,291 t
3 (base)	Taiwanese CPUE only	0.2207	0.8	0.2	1.657	0.844	0.186	28,093 t
4	Taiwanese CPUE only	0.2207	0.9	0.2	0.997	1.349	0.264	36,444 t
5	Taiwanese CPUE only	0.4	0.8	0.2	1.657	0.844	0.186	28,093 t
6	Taiwanese CPUE only	0.2207	0.8	0	0.469	2.994	0.612	59,074 t
7	Taiwanese CPUE only	0.2207	0.8	0.4	1.477	0.913	0.201	30,533 t
8	Weighted average of JPN and TWN CPUEs	0.2207	0.7	0.2	1.546	1.011	0.267	27,162 t
9	Weighted average of JPN and TWN CPUEs	0.2207	0.8	0.2	1.242	1.268	0.281	30,296 t

Run	Parameters	F_{2010}/F_{MSY}	B_{2010}/B_{MSY}	SB_{2010}/SB_{1950}	MSY (t)
3 (base)	Growth Lee and Yeh (2007)	1.657	0.844	0.186	28,093
3'	Growth Huang et al. (1990)	1.387	1.023	0.243	29,791

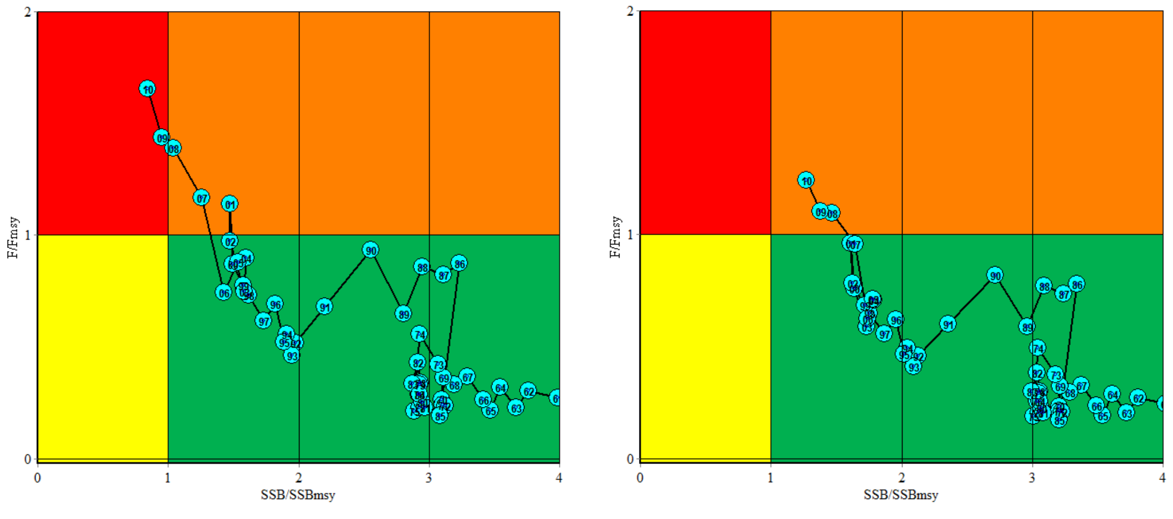


Figure 10. KOBE I plot for the base case assessment (Run 3: left) and a Sensitivity test (Run 9: right).

5. Concluding remarks and future works (self-recommendations to ourselves)

Given this preliminary nature of our assessments, the results presented in this paper may not be useful for giving management advice, but we do believe that this first attempt could give an opportunity to compare with results by other stock assessment methods and also to discuss possible and reasonable sets of parameters and scenarios used in our future assessment. In addition, the work would be a possible kick-off for future improvement toward management advice and also a basis of developing operating models (OMs) in the management strategy evaluations (MSEs).

We will conduct further analyses at least according to the list blew in due time (e.g. when some updated information on recent catch including length composition data and CPUE series), but we welcome any constructive comments for our future works.

- We have now assumed no area separation although this may not sound good. Instead of the use of area separation, however, we will consider to confine a portion of core fishery ground because of unavailability of tagging data for this species (see Section 1).

- Further sensitivity runs are required (see Section 3.4).

- Due to the large extent of the model and parameter uncertainty, we have not spent out time for assessing the estimation uncertainty, but these will be done, of course. This is also be the case for the work on forecasting (see Section 3.3.4 and 3.3.5),

- We did not consider any difference in catchability among seasons and over years, but these are worth trying in the next assessment (see Section 4.1).

- Relevant to the above, but to overcome the lack of fit to CPUE indices (see Section 4.1),
  1) greater weighting to CPUEs
  2) use time blocking
  3) separate the each country's survey into four seasons

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Appendix 1:

Underlying abundance indices (standardized CPUEs) and standard errors of logCPUEs for the three fisheries

(1) Japanese longline

Year	Quarter	Std CPUE	Std Err
1966	1	2.472	0.0167
1966	2	7.289	0.0206
1966	3	6.735	0.0190
1966	4	2.368	0.0144
1967	1	2.624	0.0135
1967	2	6.468	0.0167
1967	3	4.215	0.0150
1967	4	1.769	0.0142
1968	1	2.731	0.0165
1968	2	4.851	0.0171
1968	3	2.354	0.0136
1968	4	1.197	0.0147
1969	1	2.162	0.0194
1969	2	3.286	0.0166
1969	3	2.642	0.0131
1969	4	1.713	0.0154
1970	1	1.310	0.0359
1970	2	2.014	0.0176
1970	3	2.512	0.0131
1970	4	1.413	0.0159
1971	1	2.501	0.0197
1971	2	2.491	0.0182
1971	3	2.094	0.0141
1971	4	1.347	0.0182
1972	1	1.223	0.0327
1972	2	2.328	0.0182
1972	3	2.020	0.0152
1972	4	1.318	0.0227
1973	1	0.769	0.0330
1973	2	2.273	0.0154
1973	3	1.768	0.0147
1973	4	1.451	0.0176
1974	1	1.281	0.0261
1974	2	2.068	0.0158
1974	3	1.560	0.0137
1974	4	1.005	0.0169
1975	1	0.639	0.0216
1975	2	0.953	0.0151
1975	3	1.196	0.0134
1975	4	0.896	0.0186
1976	1	1.191	0.0280
1976	2	2.285	0.0176
1976	3	1.396	0.0134
1976	4	1.101	0.0179
1977	1	1.386	0.0268
1977	2	0.875	0.0205
1977	3	1.158	0.0134
1977	4	1.101	0.0195
1978	1	0.572	0.0205
1978	2	1.056	0.0168
1978	3	0.623	0.0141
1978	4	0.933	0.0187
1979	1	0.664	0.0266
1979	2	0.638	0.0183
1979	3	0.630	0.0134
1979	4	1.012	0.0178
1980	1	0.833	0.0218
1980	2	0.917	0.0156
1980	3	0.735	0.0128
1980	4	1.003	0.0148
1981	1	0.911	0.0187
1981	2	1.090	0.0142
1981	3	0.761	0.0128
1981	4	0.919	0.0157
1982	1	0.911	0.0193
1982	2	1.954	0.0149
1982	3	0.915	0.0127
1982	4	1.042	0.0147
1983	1	0.801	0.0174
1983	2	2.249	0.0140
1983	3	1.088	0.0119
1983	4	1.046	0.0145
1984	1	0.870	0.0167
1984	2	1.811	0.0138
1984	3	1.202	0.0116
1984	4	1.011	0.0130
1985	1	0.911	0.0157
1985	2	2.614	0.0134
1985	3	1.323	0.0109
1985	4	0.906	0.0141
1986	1	1.202	0.0152
1986	2	4.026	0.0142
1986	3	1.796	0.0119
1986	4	1.046	0.0130
1987	1	0.947	0.0161
1987	2	2.558	0.0155
1987	3	1.883	0.0122
1987	4	1.137	0.0142
1988	1	1.152	0.0183
1988	2	1.863	0.0150
1988	3	1.228	0.0128
1988	4	0.930	0.0169
1989	1	0.768	0.0227
1989	2	1.655	0.0154
1989	3	1.129	0.0131
1989	4	0.997	0.0167
1990	1	1.055	0.0223
1990	2	2.269	0.0164
1990	3	0.969	0.0152
1990	4	0.722	0.0283
1991	1	0.718	0.0251
1991	2	0.891	0.0176
1991	3	0.882	0.0141
1991	4	0.791	0.0200
1992	1	0.884	0.0257
1992	2	2.200	0.0149
1992	3	1.469	0.0147
1992	4	0.930	0.0245
1993	1	0.834	0.0284
1993	2	1.986	0.0178
1993	3	0.873	0.0156
1993	4	0.799	0.0200
1994	1	0.740	0.0144
1994	2	1.165	0.0101
1994	3	0.973	0.0098
1994	4	0.734	0.0117
1995	1	0.931	0.0120
1995	2	0.933	0.0099
1995	3	0.918	0.0093
1995	4	0.805	0.0101
1996	1	0.732	0.0112
1996	2	0.961	0.0093
1996	3	0.978	0.0089
1996	4	0.872	0.0091
1997	1	0.692	0.0112
1997	2	1.565	0.0096
1997	3	1.688	0.0085
1997	4	1.036	0.0087
1998	1	1.338	0.0100
1998	2	1.604	0.0102
1998	3	1.398	0.0094
1998	4	0.838	0.0103
1999	1	0.616	0.0129
1999	2	1.319	0.0115
1999	3	1.321	0.0105
1999	4	0.727	0.0110
2000	1	0.829	0.0158
2000	2	1.266	0.0160
2000	3	1.442	0.0127
2000	4	1.039	0.0129
2001	1	0.873	0.0146
2001	2	1.250	0.0126
2001	3	1.197	0.0108
2001	4	0.948	0.0122
2002	1	1.243	0.0146
2002	2	1.507	0.0148
2002	3	1.148	0.0121
2002	4	1.109	0.0128
2003	1	1.209	0.0148
2003	2	1.592	0.0165
2003	3	1.271	0.0154
2003	4	1.264	0.0151
2004	1	1.310	0.0163
2004	2	1.664	0.0139
2004	3	1.889	0.0124
2004	4	1.319	0.0134
2005	1	1.057	0.0144
2005	2	1.938	0.0132
2005	3	3.202	0.0127
2005	4	0.917	0.0126
2006	1	0.985	0.0135
2006	2	2.816	0.0133
2006	3	3.564	0.0123
2006	4	1.049	0.0125
2007	1	1.105	0.0132
2007	2	2.403	0.0147
2007	3	3.804	0.0132
2007	4	1.235	0.0153
2008	1	1.015	0.0155
2008	2	3.117	0.0174
2008	3	3.099	0.0149
2008	4	1.264	0.0154
2009	1	0.906	0.0161
2009	2	2.479	0.0191
2009	3	3.632	0.0165
2009	4	1.501	0.0177
2010	1	1.125	0.0210
2010	2	5.968	0.0205
2010	3	3.339	0.0230
2010	4	0.789	0.0238
2011	1	1.376	0.0252
2011	2	5.541	0.0233
2011	3	4.841	0.0235
2011	4	0.866	0.0509

2) Taiwanese longline

Year	Quarter	Std CPUE	Std Err
1980	1	1.8912	0.05769
1980	2	2.7620	0.05781
1980	3	2.1733	0.05898
1980	4	2.3391	0.06215
1981	1	2.9072	0.06929
1981	2	3.0049	0.06840
1981	3	2.5760	0.06789
1981	4	2.3711	0.06839
1982	1	2.4540	0.06457
1982	2	3.3481	0.06951
1982	3	3.0050	0.06470
1982	4	3.0338	0.06637
1983	1	2.3183	0.06247
1983	2	1.9158	0.06379
1983	3	2.1329	0.06334
1983	4	2.3862	0.07320
1984	1	1.6543	0.07038
1984	2	2.0712	0.07162
1984	3	2.1337	0.07214
1984	4	1.5204	0.07293
1985	1	1.3945	0.07428
1985	2	1.8248	0.08126
1985	3	1.8154	0.08466
1985	4	1.5040	0.07955
1986	1	1.4895	0.07654
1986	2	1.9184	0.08094
1986	3	2.0541	0.06909
1986	4	1.8994	0.06817
1987	1	1.6040	0.07027
1987	2	1.8092	0.06539
1987	3	1.7010	0.06357
1987	4	1.8610	0.06642
1988	1	2.0932	0.06664
1988	2	1.8571	0.07089
1988	3	1.7384	0.06625
1988	4	1.2153	0.07080
1989	1	0.9449	0.07654
1989	2	1.0376	0.07204
1989	3	0.9892	0.07578
1989	4	0.8682	0.07625
1990	1	0.7809	0.08196
1990	2	1.1139	0.08549
1990	3	0.8292	0.07082
1990	4	0.6899	0.07678
1991	1	0.7200	0.07913
1991	2	1.1769	0.09447
1991	3	0.8117	0.07975
1991	4	1.1343	0.09007
1992	1	0.7635	0.11341
1992	2	1.3492	0.09781
1992	3	1.2542	0.08273
1992	4	2.2374	0.08868
1993	1	2.0071	0.06980
1993	2	1.8635	0.06387
1993	3	1.1496	0.06627
1993	4	1.2160	0.05663
1994	1	1.4355	0.05813
1994	2	1.6916	0.05951
1994	3	0.8538	0.05986
1994	4	1.7074	0.05838
1995	1	1.7310	0.06080
1995	2	0.9501	0.06014
1995	3	0.4865	0.05759
1995	4	1.2233	0.05793

Year	Quarter	Std CPUE	Std Err
1996	1	1.5786	0.05621
1996	2	1.1273	0.06772
1996	3	0.6363	0.05672
1996	4	1.1226	0.05980
1997	1	1.4817	0.06180
1997	2	1.4769	0.06619
1997	3	1.0215	0.05591
1997	4	1.3619	0.05829
1998	1	1.2991	0.06720
1998	2	1.7460	0.06019
1998	3	1.4349	0.05694
1998	4	1.4756	0.05917
1999	1	0.9134	0.05796
1999	2	1.1384	0.05404
1999	3	1.0948	0.05507
1999	4	0.8164	0.05405
2000	1	1.0122	0.05606
2000	2	0.9883	0.05216
2000	3	0.8246	0.05114
2000	4	0.8859	0.05633
2001	1	1.0861	0.05036
2001	2	1.1120	0.04878
2001	3	1.3637	0.05111
2001	4	1.8816	0.05380
2002	1	1.3073	0.05297
2002	2	1.4363	0.05130
2002	3	1.2540	0.05163
2002	4	1.0623	0.05711
2003	1	1.2006	0.05322
2003	2	1.3884	0.05514
2003	3	1.1660	0.04995
2003	4	1.1894	0.05804
2004	1	1.2826	0.05664
2004	2	1.8022	0.06034
2004	3	1.1010	0.05278
2004	4	1.0238	0.05724
2005	1	1.2684	0.05157
2005	2	1.1161	0.05434
2005	3	1.0154	0.05335
2005	4	0.8908	0.05498
2006	1	0.9839	0.05523
2006	2	1.0084	0.06459
2006	3	0.5595	0.05675
2006	4	0.7860	0.05811
2007	1	0.7718	0.06208
2007	2	0.7582	0.06572
2007	3	0.7432	0.05938
2007	4	0.8421	0.05587
2008	1	0.6646	0.06272
2008	2	1.0642	0.06323
2008	3	0.6882	0.06725
2008	4	0.8437	0.06271
2009	1	0.7428	0.05899
2009	2	0.7777	0.06196
2009	3	0.9185	0.06280
2009	4	1.0736	0.06895
2010	1	0.8450	0.06380
2010	2	1.0420	0.06716
2010	3	0.8288	0.07173
2010	4	0.9628	0.07082
2011	1	0.6878	0.07207
2011	2	1.2188	0.08544
2011	3	1.0535	0.09272
2011	4	0.7291	0.13096

3) Korean longline

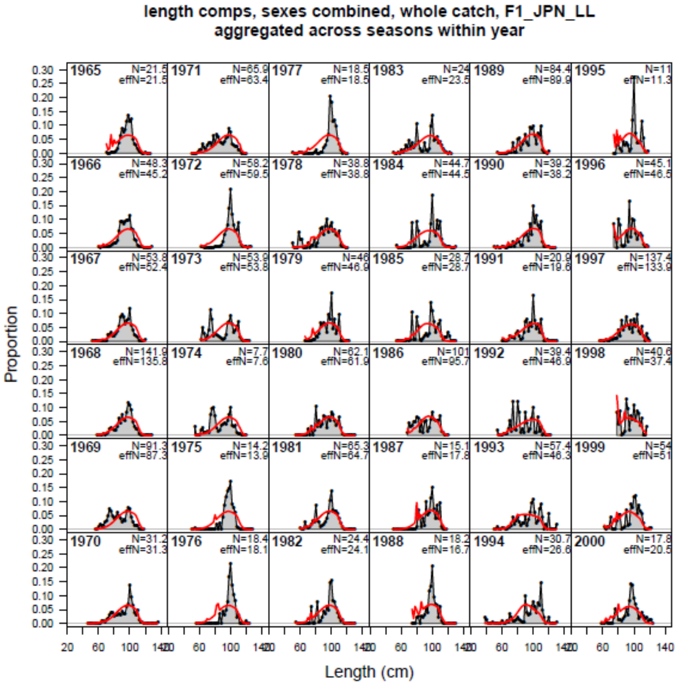
Year	Quarter	Std CPUE	Std Err
1986	1	0.5089	0.1901
1986	2	0.4748	0.2203
1986	3	0.7142	0.1922
1986	4	0.9854	0.1524
1987	1	0.4022	0.1815
1987	2	0.3879	0.2208
1987	3	0.5709	0.1764
1987	4	0.8597	0.1587
1990	1	0.3542	0.1571
1990	2	0.1507	0.2123
1990	3	0.4424	0.1758
1990	4	0.3675	0.1418
1991	1	0.2533	0.1780
1991	2	0.0342	0.2700
1991	3	0.2957	0.2367
1991	4	0.3971	0.1853
1992	1	0.4638	0.2314
1992	2	0.1269	0.2648
1992	3	0.7376	0.2079
1992	4	0.9687	0.1820
1993	1	0.5677	0.2115
1993	2	0.2879	0.2436
1993	3	0.6764	0.1795
1993	4	0.6437	0.1484
1994	1	0.3408	0.1582
1994	2	0.2516	0.2270
1994	3	0.3333	0.1757
1994	4	0.9662	0.1548
1995	1	0.4097	0.1696
1995	2	0.1195	0.2434
1995	3	0.4038	0.2024
1995	4	1.1020	0.1960
1996	1	0.4853	0.1774
1996	2	0.1342	0.2005
1996	3	0.1828	0.1792
1996	4	0.5724	0.1498
1997	1	0.6807	0.1687
1997	2	0.2785	0.2012
1997	3	0.2975	0.1752
1997	4	0.6140	0.1492
1998	1	0.8629	0.1676
1998	2	0.1890	0.2044
1998	3	0.3658	0.2067
1998	4	0.4381	0.2266
1999	1	0.1480	0.2064
1999	2	0.1467	0.2405
1999	3	0.0531	0.2465
1999	4	0.0979	0.1737
2000	1	0.3100	0.1816
2000	2	0.2594	0.2420
2000	3	0.5885	0.2134
2000	4	0.3011	0.1933

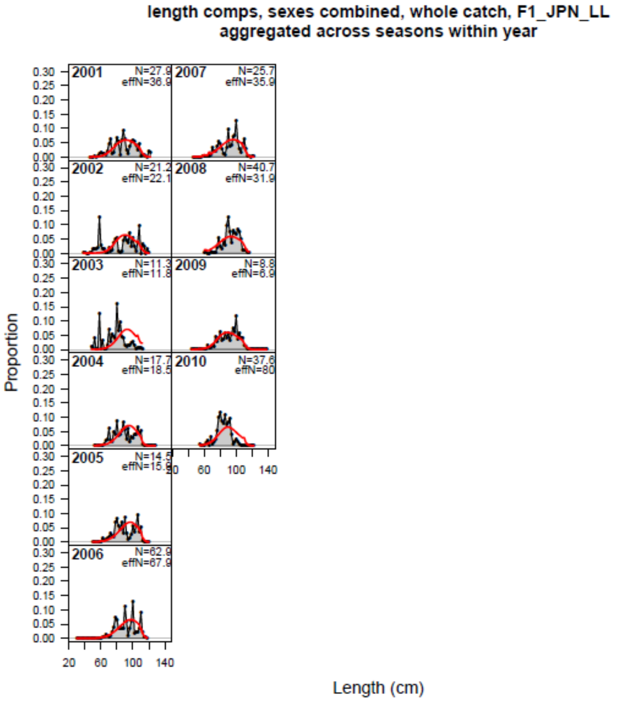
Year	Quarter	Std CPUE	Std Err
2001	1	0.4495	0.1737
2001	2	0.1208	0.2131
2001	3	0.0030	0.2712
2001	4	0.0977	0.2392
2002	1	0.1066	0.3693
2002	2	0.0066	0.3840
2002	3	0.3224	0.2417
2002	4	0.4040	0.2311
2003	1	1.5766	0.4807
2003	2	0.0974	0.5859
2003	3	1.2065	0.2145
2003	4	0.5147	0.1796
2004	1	0.8965	0.1988
2004	2	0.5186	0.2001
2004	3	0.6000	0.2789
2004	4	0.6692	0.2327
2005	1	0.1437	0.2373
2005	2	0.2126	0.2490
2005	3	1.0724	0.2421
2005	4	0.7370	0.2566
2006	1	0.3376	0.2177
2006	2	1.0598	0.2530
2006	3	0.9091	0.1738
2006	4	0.4224	0.1940
2007	1	0.4637	0.2014
2007	2	0.4546	0.2266
2007	3	1.8266	0.2486
2007	4	0.9048	0.2015
2008	1	0.5343	0.2487
2008	2	0.8604	0.2837
2008	3	1.7195	0.2208
2008	4	0.3870	0.2008
2009	1	0.5498	0.1780
2009	2	0.6553	0.2610
2009	3	0.9067	0.2086
2009	4	0.5776	0.1700
2010	1	1.2450	0.2339
2010	2	7.0906	0.2707
2010	3	0.9124	0.2798
2010	4	0.4604	0.2175

Appendix 2:

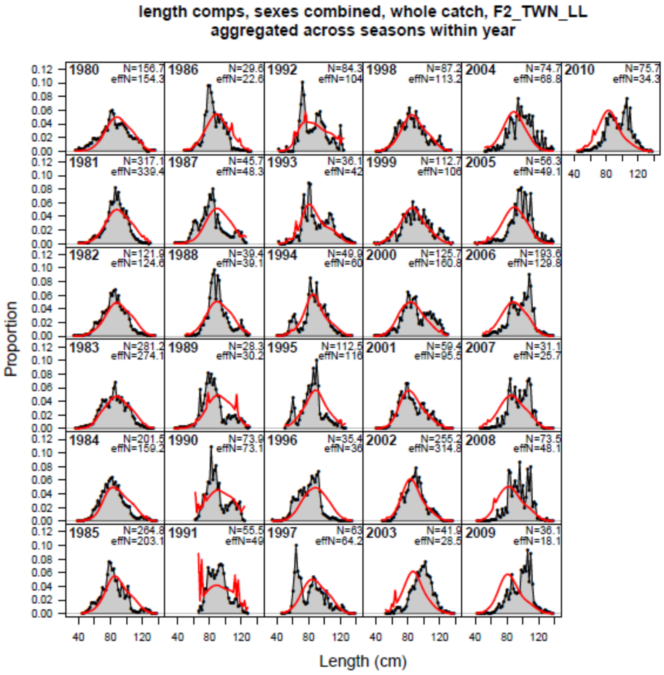
Fits to the length composition data in the base case scenario

1) Fishery 1 (JPN_LL)

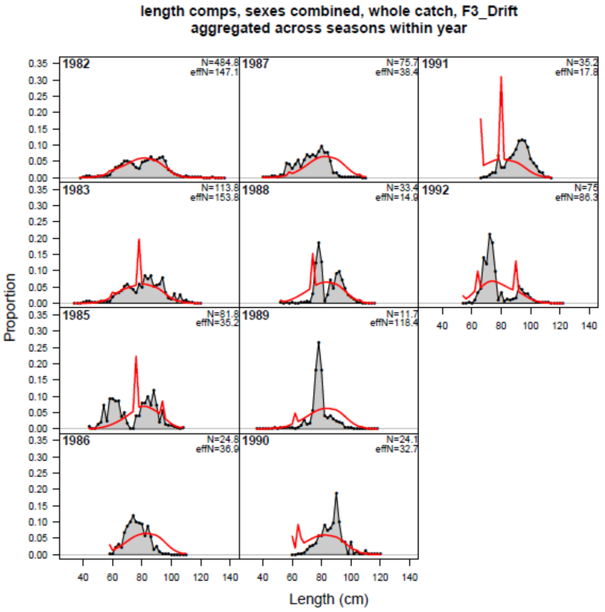




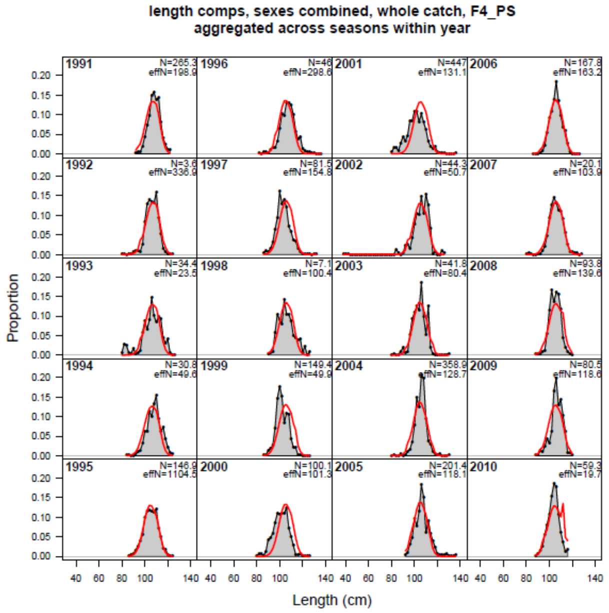
2) Fishery 2 (TWN_LL)



3) Fishery 3 (Drift)



4) Fishery 4 (Purse Seine)



5) Fishery 5 (Others)