NPFC-2020-SSC PS06-WP09

A trial study of stock assessment for North Pacific Ocean Pacific Saury (*Cololabis saira*) using Age-Structured Assessment Program

Member: China

1 Introduction

Pacific saury (*Cololabis saira* Brevoort, 1856) is a commercially important fish species in the North Pacific Ocean. The saury is widely distributed from the subarctic to the subtropical regions of the North Pacific Ocean, while their fishing grounds are limited to the west of 180°E. The majority of catch for Pacific saury has been harvest by stick-held dip net vessels from China, Japan, Korea, Russia, Chinese Taipei and Vanuatu (NPFC-2019-SSC PS04-Final Report). During the past few years, the stock assessments of Pacific saury were conducted by the Technical Working Group on Pacific Saury Stock Assessment (TWG PSSA) and Small Scientific Committee on Pacific Saury (SSC PS) established under the Scientific Committee (SC) of the North Pacific Fisheries Commission (NPFC).

The stock assessments of Pacific saury have been conducted by employing the Bayesian state-space biomass dynamic models (BSSPM) which could explicitly account for process and model errors in addition to observation errors in the biomass indices (NPFC-2017-TWG PSSA01-Final Report). At the SSC PS05 meeting, the participants were encouraged to propose new population dynamic models that are capable of taking into account the data availability and biology of Pacific saury (NPFC-2019-SSC PS05-Final Report).

This working paper presented a trial study of stock assessment for North Pacific Ocean Pacific Saury with Age Structured Assessment Program (ASAP, Version 3; NOAA Fisheries Toolbox, 2013). ASAP is a formal stock assessment model and has been used for assessing many commercially exploited stocks worldwide (see https://nmfs-fish-tools.github.io/ASAP/).

2 Biological parameters and assumptions

2.1 Stock structure

Genetic evidence suggests there are no distinct stocks in the Pacific saury population based on 141 individuals collected from five distant locales (East China Sea, Sea of Okhotsk, northwest Pacific, central North Pacific, and northeast Pacific) (Chow et al. 2009). Thus, a single stock was assumed for the present assessment.

2.2 Growth and maturity

Pacific saury is 2-year lived fish which grows up to 320 mm in knob length and 200 g body weight (Suyama et al., 2006). Previous studies showed that there is some variation in growth rate depending on the hatching month and geographical differences (Suyama et al., 2012). For the present assessment, Gompertz growth function was used to describe the growth trajectory of Pacific saury, and the relationship between knob length and body weight was derived from Suyama et al. (2015) (**Table 1**).

Since all age-1 Pacific saury would get matured in the last spawning season and only a part of age-0 fish would get matured in the first year (NPFC-2019-SSC PS05-WP13), the maturity probability for age-0 and age-1 Pacific saury in this assessment was assumed to be 0.6 and 1.0, respectively.

2.3 Natural mortality

Nakayama et al. (2019) used several natural mortality estimators and recommended "Gislason 2" to calculate age-specific natural mortality for Pacific saury. For this assessment, the natural mortality for age-0 and age-1 Pacific saury was specified as 1.6 and 1.5, respectively (Nakayama et al., 2019).

3 Fisheries data

3.1 Total catch and catch-at-age data

The total catch and monthly catch-at-age data from 2007 to 2018, estimated and provided by Japan (Fleet 1), Chinese Taipei (Fleet 2), Russia (Fleet 3) and Korea (Fleet 4), were used as basic fishery data for conducting the present stock assessment of Pacific saury in the North Pacific Ocean (**Figure 1 and 2**).

3.2 Abundance indices

The standardized catch per unit effort (CPUE) for each member/fleet and Japanese fishery-independent survey biomass were used as abundance indices for fitting the model **(Figure 3)**. The CPUE and biomass indices and their coefficient of variation (CV) were derived from previous working papers (NPFC-2019-SSC PS05-WP02; NPFC-2019-SSC PS05-WP05; NPFC-2019-SSC PS05-WP06; NPFC-2019-SSC PS05-WP07; NPFC-2019-SSC PS05-WP08).

4 Stock assessment

4.1 Model configurations

The ASAP uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and abundance indices. Technical details of the ASAP model can be found in NOAA Fisheries Toolbox (2013).

The objective function in ASAP is the sum of a number of model fits and two penalties. There are two types of error distributions in the calculation of the objective function: lognormal and multinomial. Multinomial distribution is assumed for catch-at-age data, with effective sample size iteratively adjusted based on initial model runs. The lognormal error distribution is assumed for total catch, abundance indices and stock-recruitment relationship.

The CV for annual catch in initial model run was assumed to be 0.1 for each of four members and constant throughout the time. Adjustment was made according to the diagnostic results for the residual pattern and root mean square error (RMSE).

We assumed all abundance indices have equal weights and the CV=0.1 was assumed for initial runs and then adjusted based on diagnostics.

Beverton-Holt stock recruitment (S-R) model was used in the present assessment. The steepness (h) was assumed to be 0.3 based on Hoshino et al. (2014).

4.2 Parameter estimate

The following parameters are assumed to be known for the present Pacific saury stock assessment in the North Pacific Ocean:

(1) Length-at-age and weight-at-age;

(2) Age-specific maturity;

(3) Age-specific natural mortality;

(4) The deviation for abundance indices;

(5) The steepness of the stock-recruitment relationship.

The following parameters are to be estimated in the present stock assessment:

(1) Recruitment in each year from 2007-2018 (CV=0.6 for log-transformed recruitment deviations);

(2) Catchability coefficients (q, constant over time) for the abundance indices;

(3) Selectivity curves for the 4 fleets. All selectivity curves were assumed to be age-dependent and constant throughout the time. The initial guess of selectivity for age-0 and age-1 Pacific saury was assumed to be 0.9 and 1, respectively. The initial guess of selectivity was based on that the smallest length at full selection for Pacific saury was 10 cm (NPFC01-2016-SSC-PS01-WP04).

(4) Effective sample size (ESS) for catch-at-age for each fleet;

(5) Initial population size and age structure;

(6) Fully recruited fishing mortality (*F*mult) for each fleet for the first year, and deviations for *F*mult for the remaining years.

4.3 Management quantities

The ASAP program computes a number of biological reference points (BRPs) based on the estimated selectivity pattern, weights at age, natural mortality, and relative fishing intensity among fleets in the terminal year of the assessment (i.e. 2018). The reference points computed are MSY, $C_{current}$/MSY, F_{MSY}, $F_{current}/F_{MSY}$, SSB_{MSY}, $SSB_{current}/SSB_{MSY}$, and $SSB_{current}/SSB_0$. The term “current” means the terminal year in the model.

4.4 Stock assessment results

4.4.1 Model fit diagnostics

The present ASAP model has been converged. The model was then diagnosed by looking at the residual pattern in fitting abundance indices, catch, and age composition data. The diagnostics is also made by checking the root mean square error (RMSE) computed for each set of residuals. The input CV can be adjusted based on the RMSE values. The effective sample size (ESS) for the age composition data can be adjusted based on the iteration results. A five-year (2018-2014) retrospective analysis was also conducted to diagnose the model misspecification.

The model fits to the catch and abundance indices data were shown in **Figure 4 and 5**, respectively. In general, the model fits the all catch and abundance indices observations very well. The input and estimated effective sample size for the age composition of catch were shown in **Figure 6**. The initial ESS for each fleet was set at 200, and the estimated ESS was used to re-run the model. However, the model cannot be converged after using estimated ESS. Finally, we still input 200 as ESS for all fleets over time. The model fits to the age composition data are shown in **Figure 7**. For each fleet, the model estimates follow the main pattern of the variation in the observations.

Figure 8 showed likelihood components of the model fit, indicating that the most majority of the likelihood was contributed by age composition and catch data. Retrospective analysis showed that there was no strong retrospective pattern associated with the biomass and fishing mortality estimates (**Figure 9**).

4.4.2 Fishery and population dynamics

The selectivity-at-age for each fleet was shown in **Figure 10**. It was indicated that age-1 fish were fully selected while age-0 fish had low probability to be selected. The catchability coefficients for the five abundance indices were shown in **Figure 11**.

The fully recruited fishing mortality for 2007-2018 was shown in **Figure 12**. The fishing mortality decreased gradually from 2007 to 2010, followed by an increase from 2010 to 2014. From 2014 to 2018, the fishing mortality showed a declining trend. In contrast to fishing mortality, the spawning stock biomass (SSB) has been declining since 2010. From 2016 to 2018, the SSB showed an increasing trend (**Figure 12**).

The estimated stock abundance has been declining since 2007, although there was a short increase in 2009. After 2016, there was an increasing trend in estimated stock abundance (**Figure 13**). The recruitment variation and the estimated stock-recruitment relationship were shown in **Figure 14**.

4.4.3 Biological reference points and Kobe plot

The biological reference points (BRPs) derived from ASAP model were listed in **Table 2**. The MSY for Pacific saury in the North Pacific Ocean was 511,278 metric tons. The SSB_{MSY} was 1,283,740 metric tons. **Figure 15** showed the time trajectory of SSB/SSB_{MSY} and F/F_{MSY} from 2007 to 2018. The SSBratio and Fratio for the initial year (i.e. 2007) and terminal year (i.e. 2018) fell in the green quadrant of the Kobe plot.

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Table and figures

Table 1 Growth function and length-weight relationship of Pacific saury used in the present assessment

	Equation	Reference
Gompertz growth function	$\mathrm{KnL} = 305.8e^{(-e^{-0.01196(t-112.1)})}$	Suyama et al. (2015)
Length-weight relationship	$\mathrm{BW} = 0.0022KnL^{3.2315}$	Suyama et al. (2015)

Table 2 Management related quantities from ASAP model

Management quantity	Estimates
MSY (t)	511,278
C_{curr}/MSY	0.67
F_{MSY}	1.60
F_{curr}/F_{MSY}	0.42
SSB_{MSY} (t)	1,283,740
SSB_{curr}/SSB_{MSY}	1.02
SSB_0 (t)	1,783,500
SSB_{curr}/SSB_0	0.73

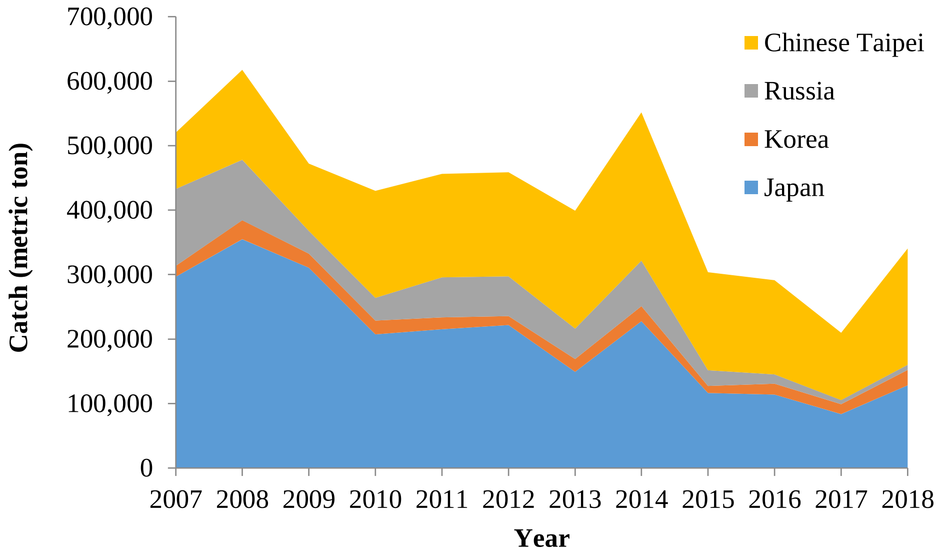


Figure 1 Fleet-specific historical catch of Pacific saury in the North Pacific Ocean

Figure 2 Fleet-specific age composition data of Pacific saury in the North Pacific Ocean

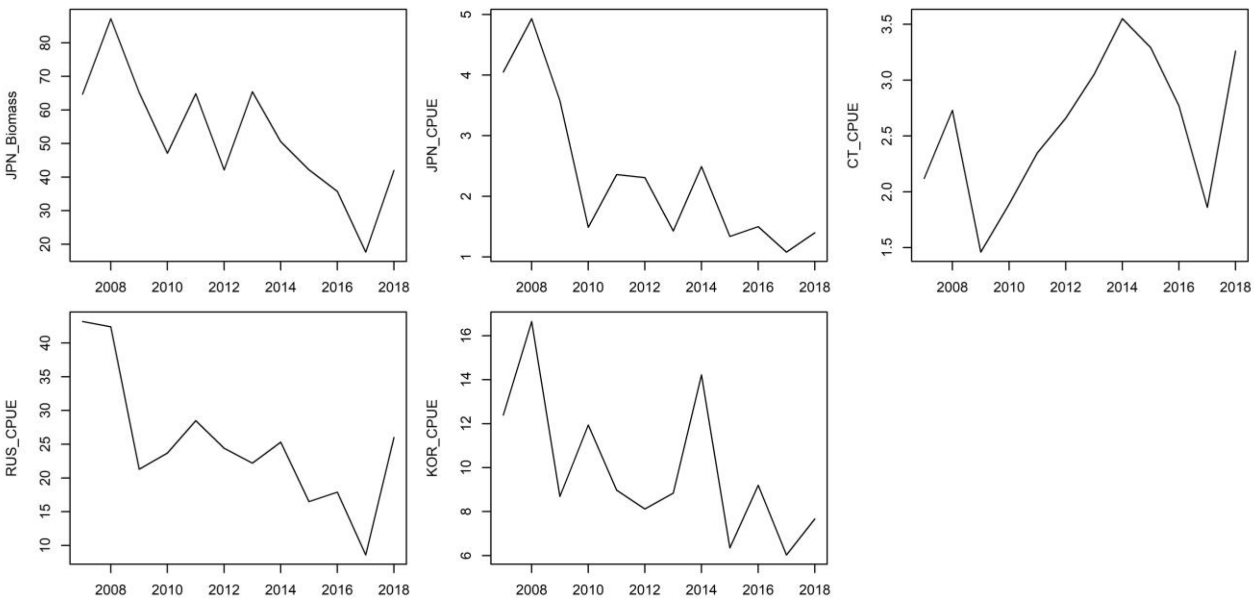
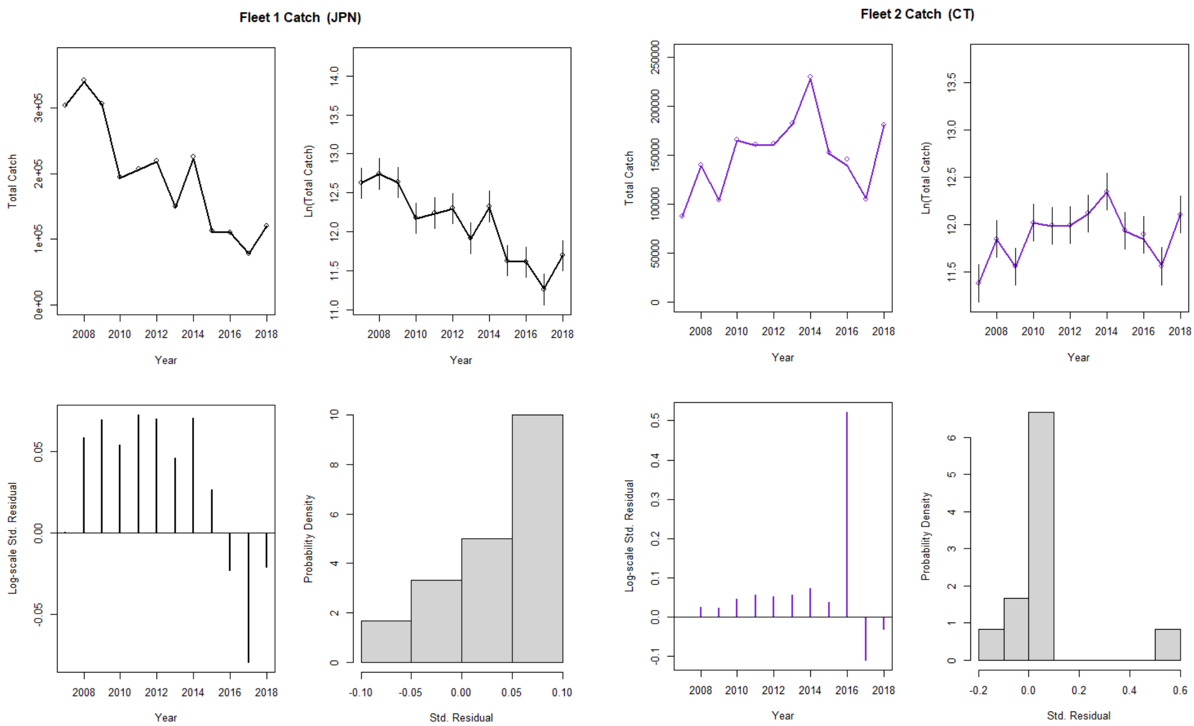


Figure 3 Standardized CPUE indices for four fleets (Japan, Chinese Taipei, Russia, and Korea) and Japanese fishery-independent survey biomass index



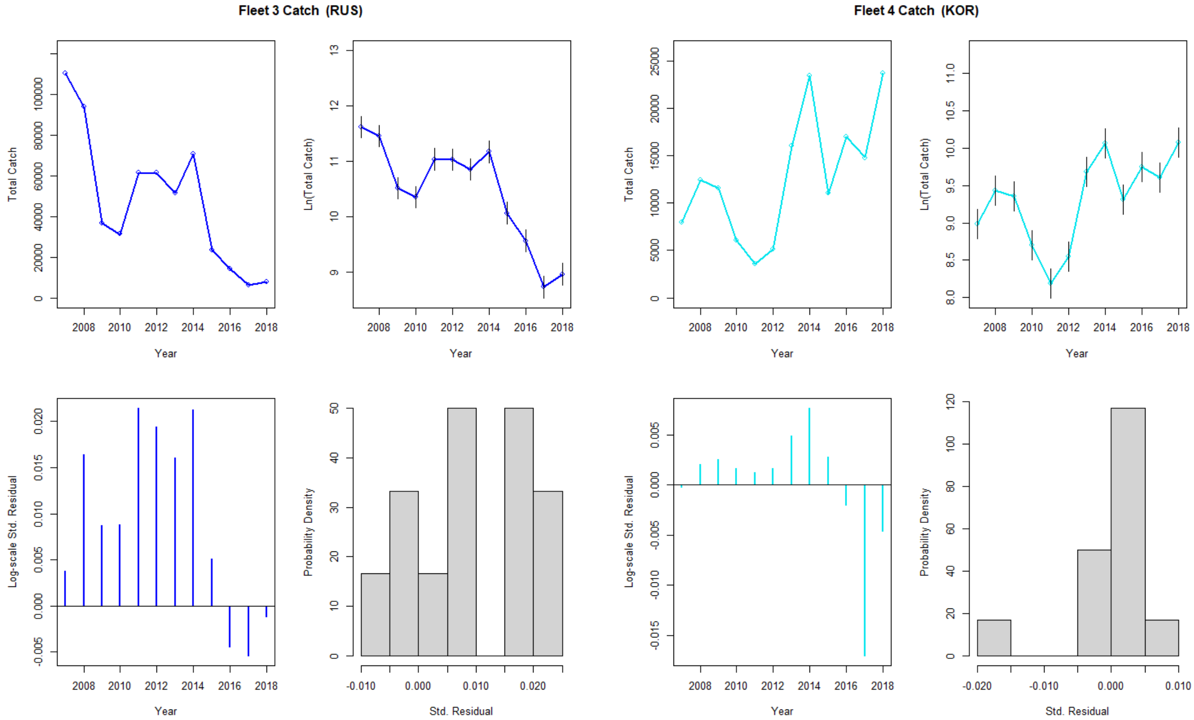
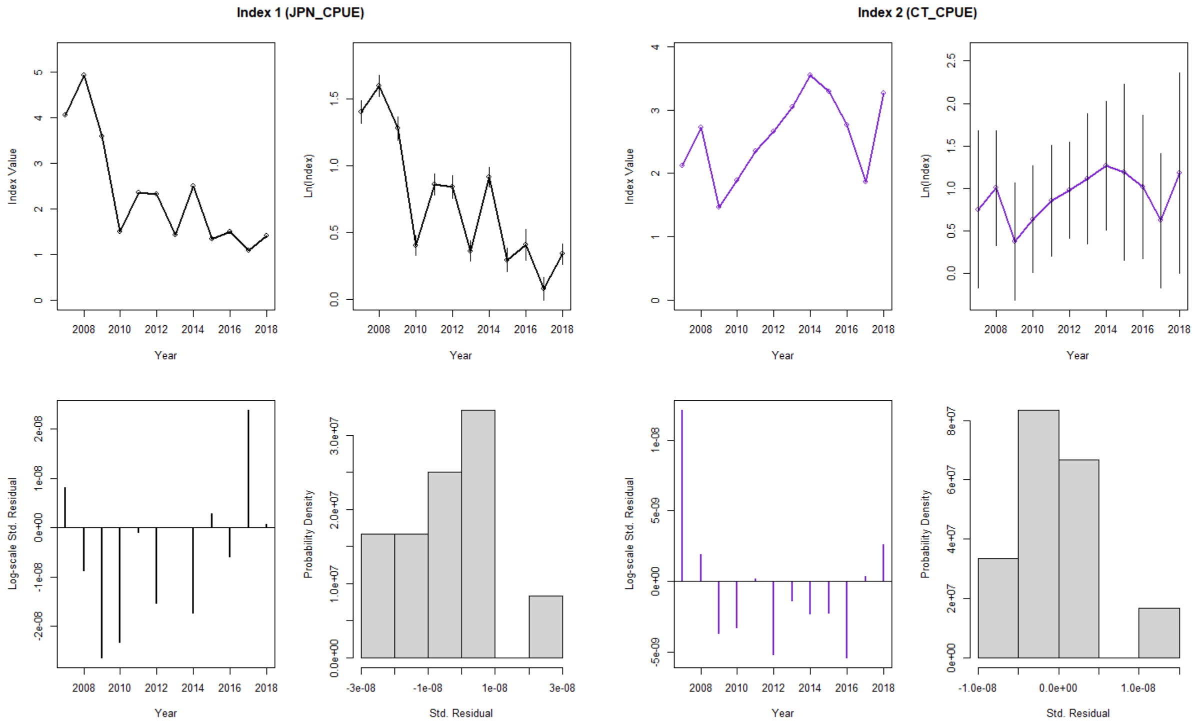


Figure 4 Model fits for annual catch data



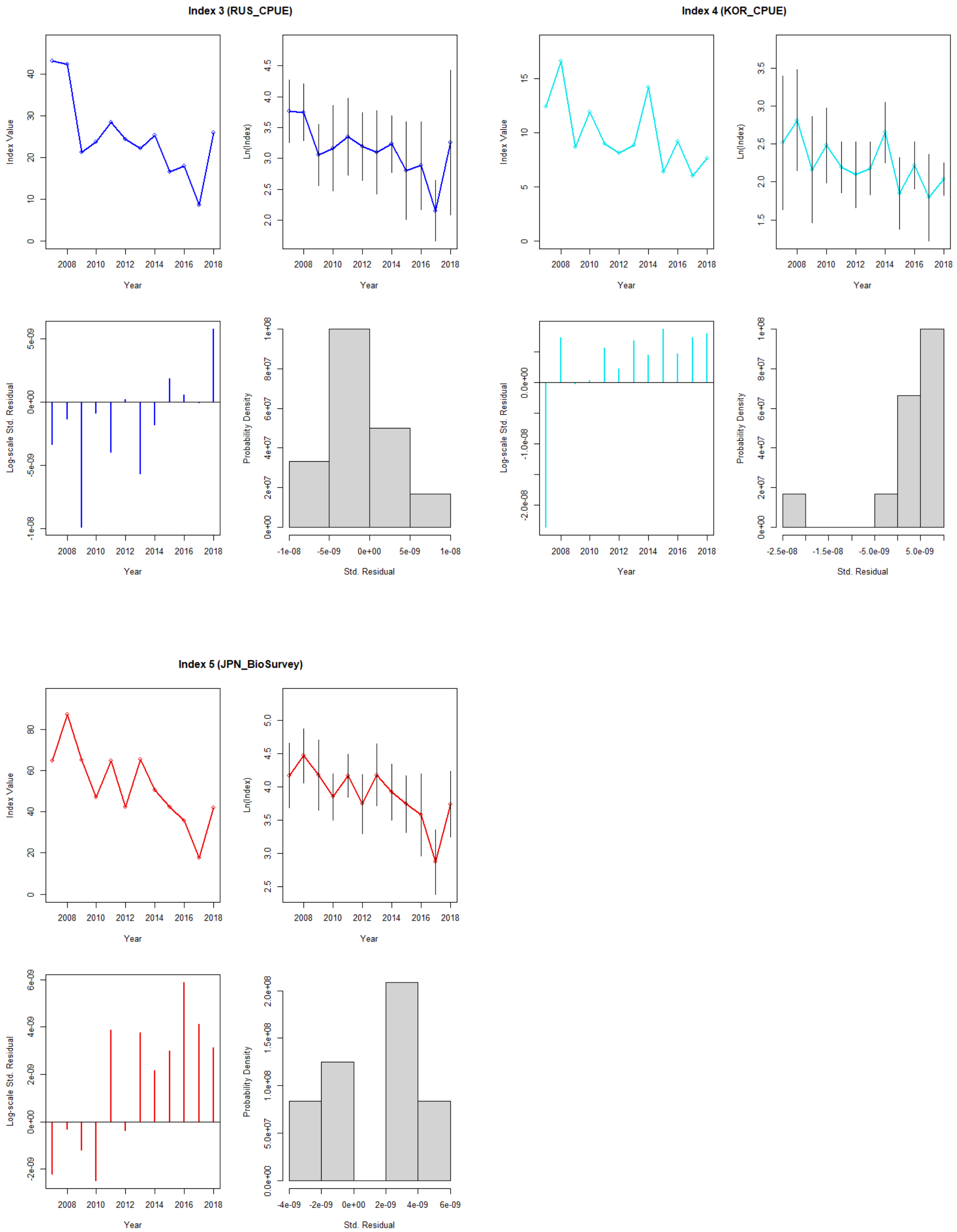


Figure 5 Model fits for the abundance indices

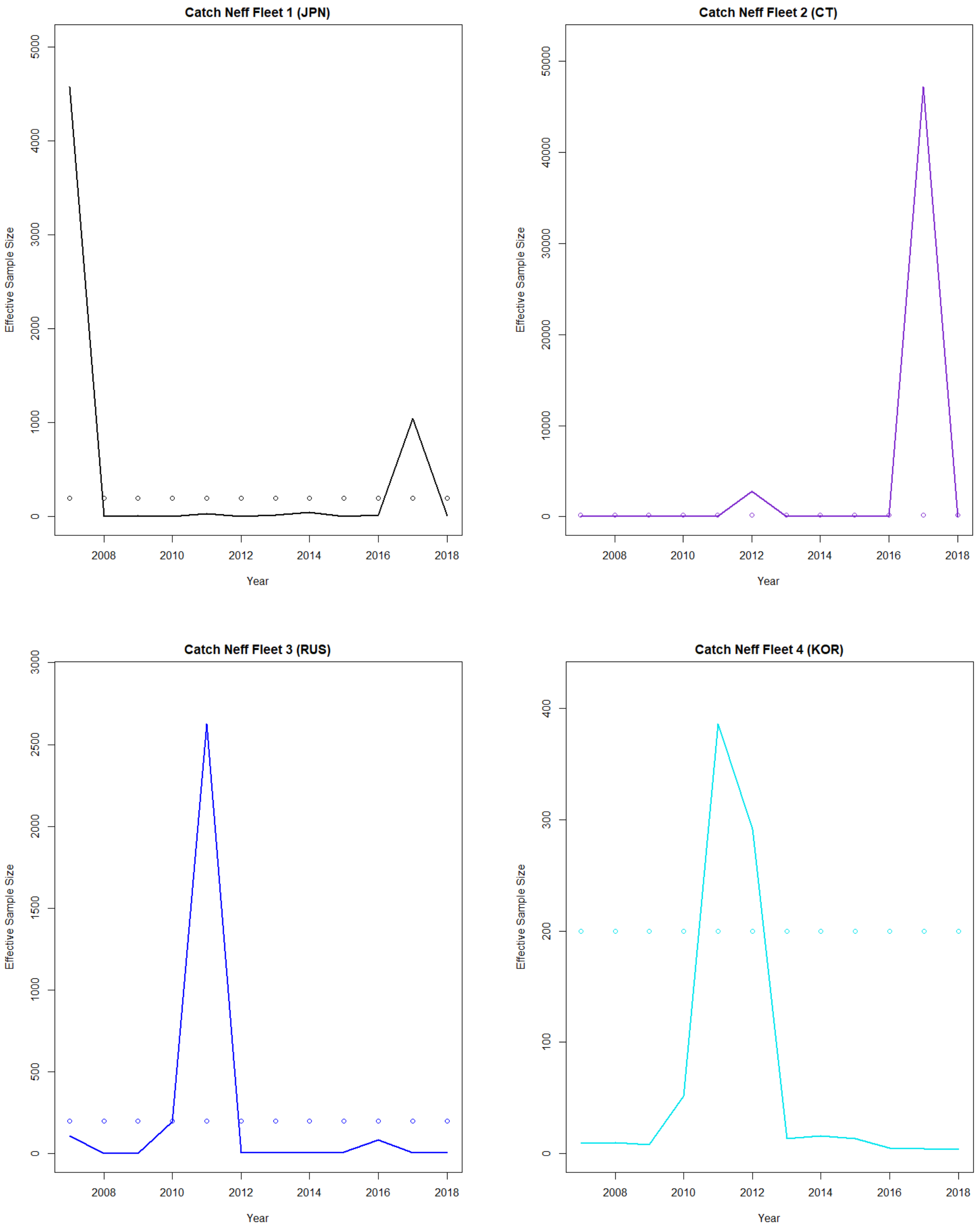


Figure 6 Model fits to the effective sample size for the age composition data of catch

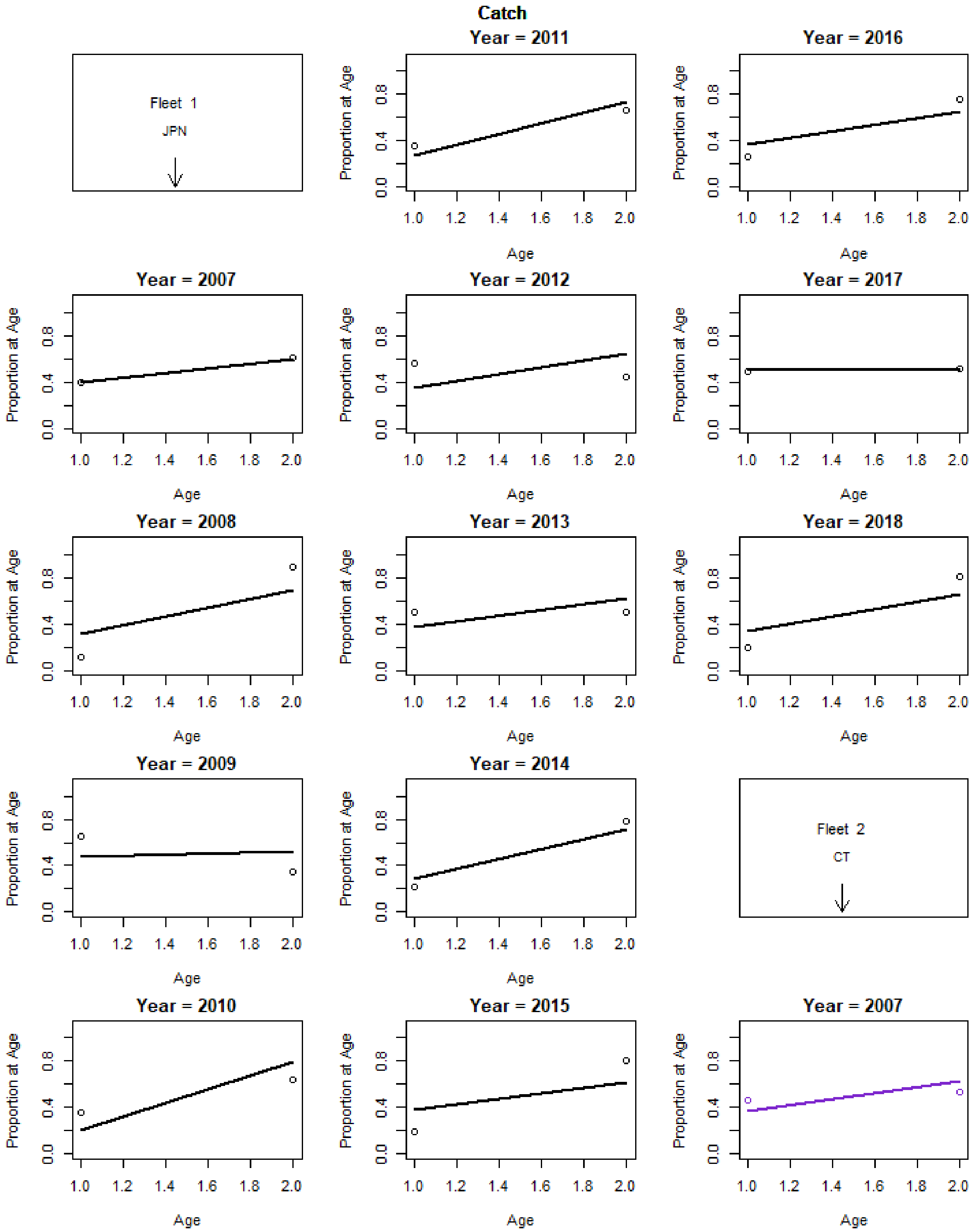


Figure 7 Model fits to the age composition data for each fleet

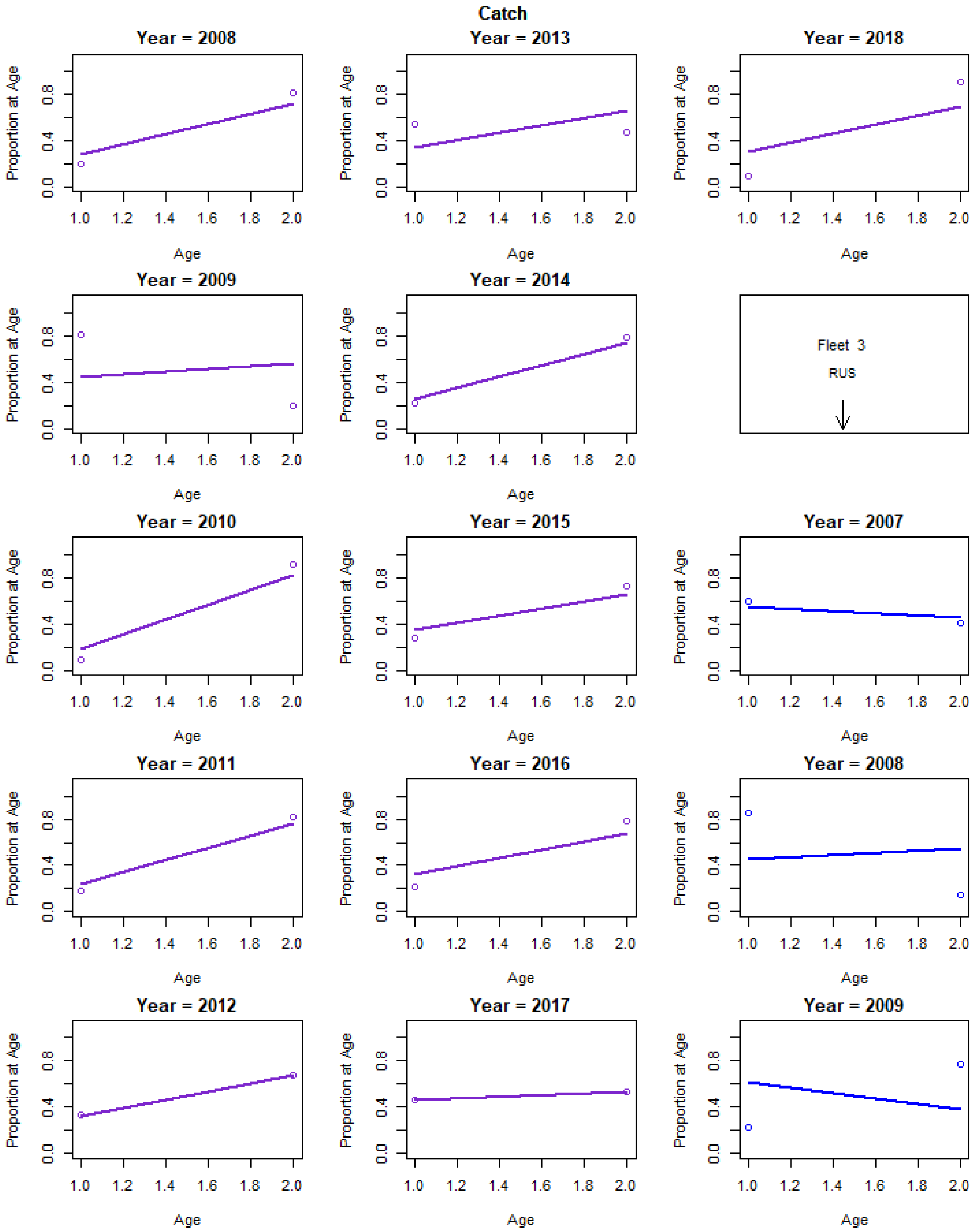
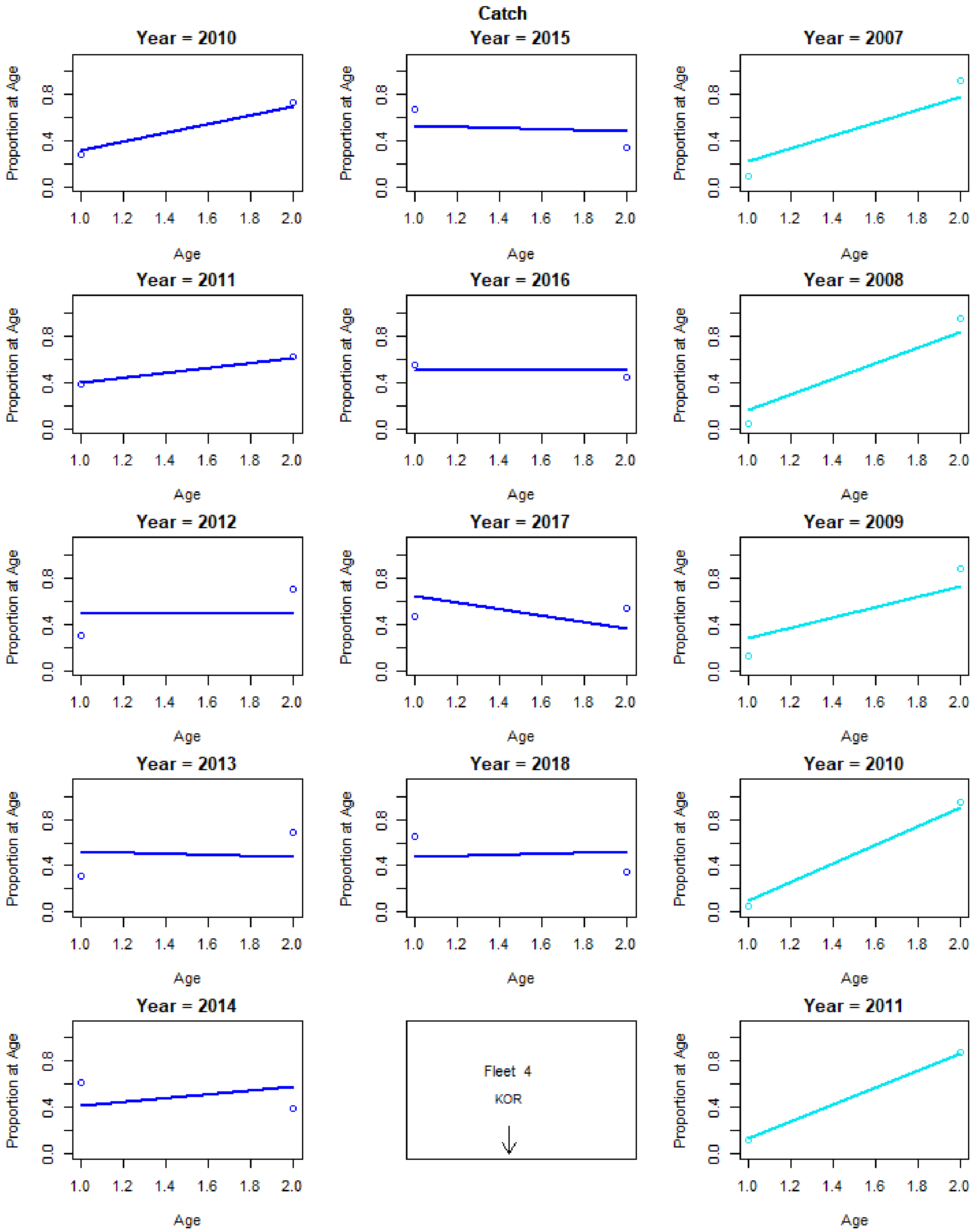


Figure 7 Continued



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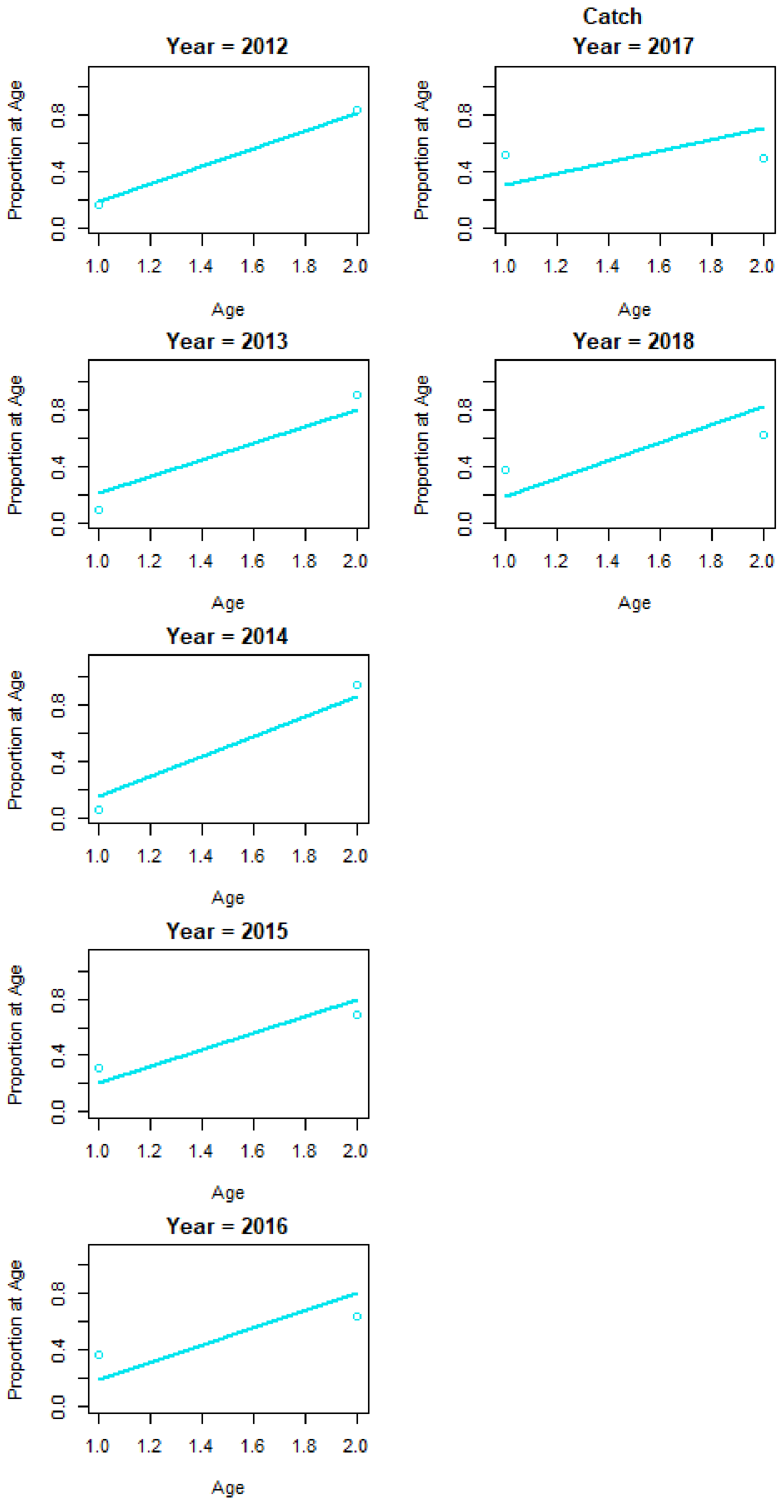

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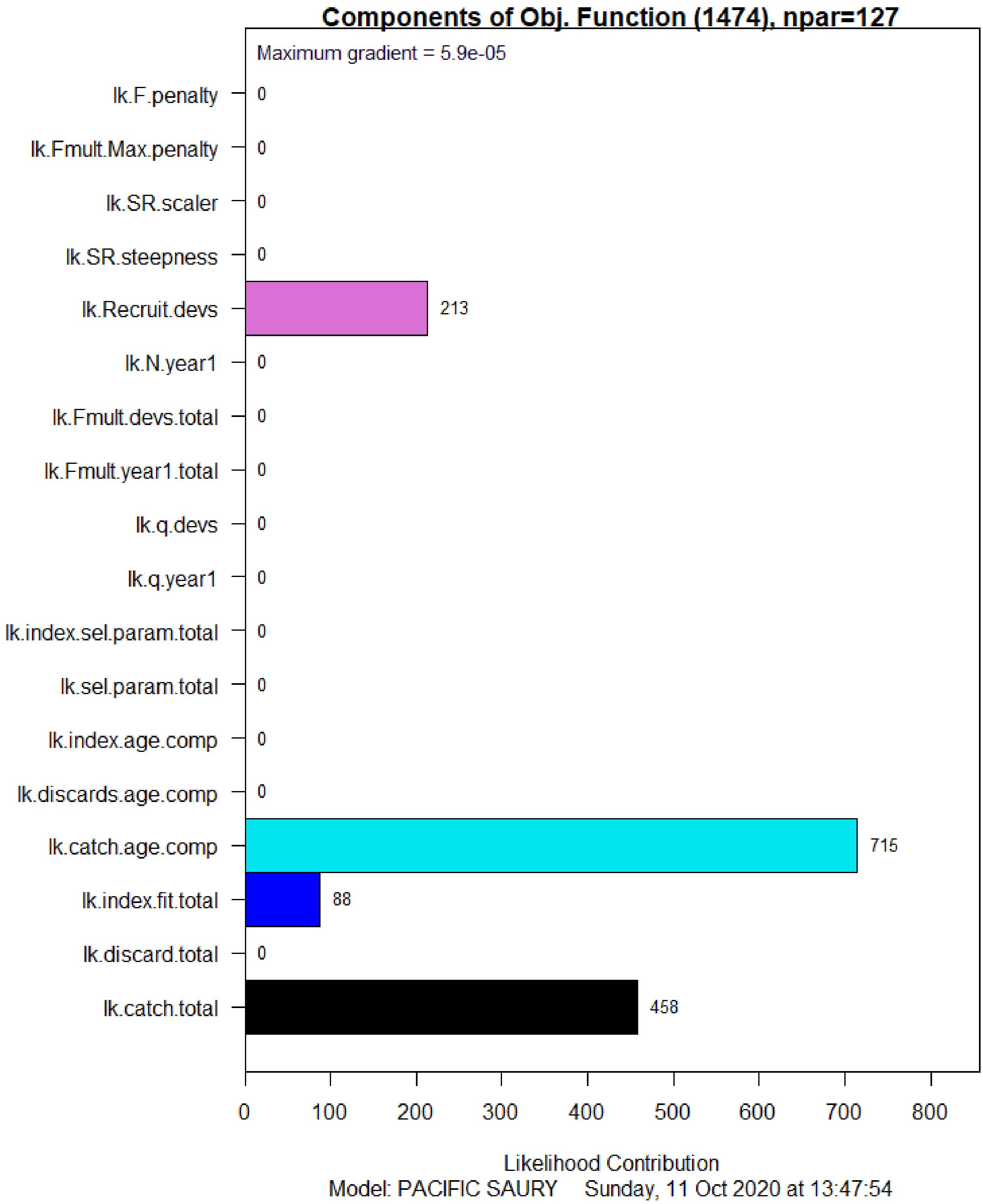
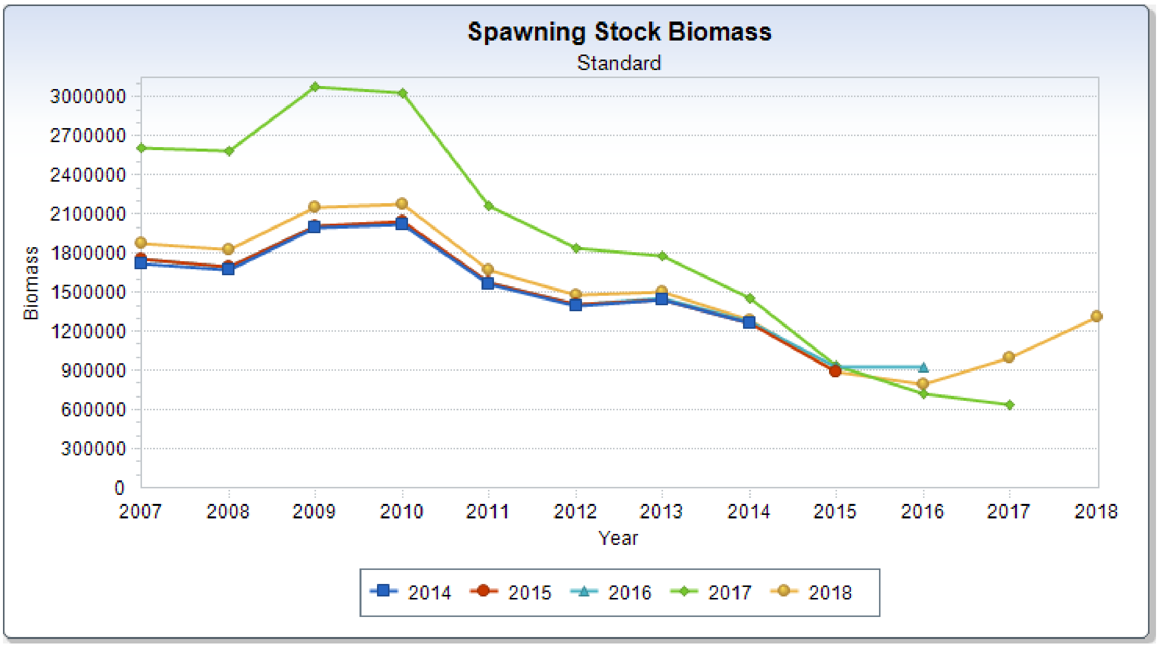
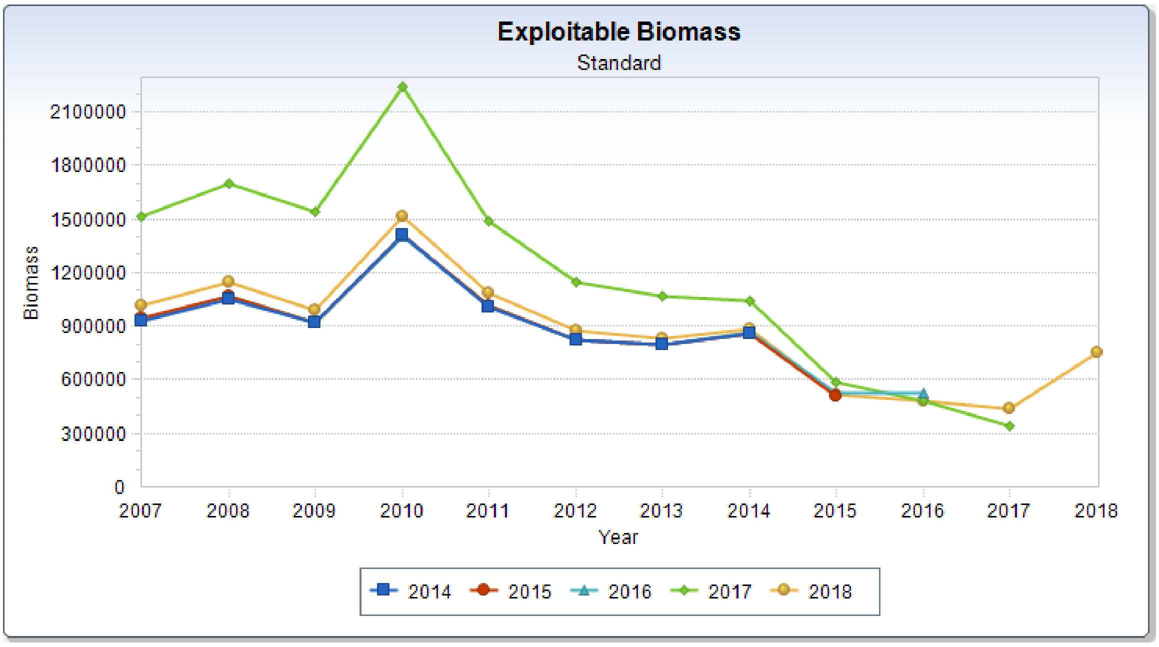


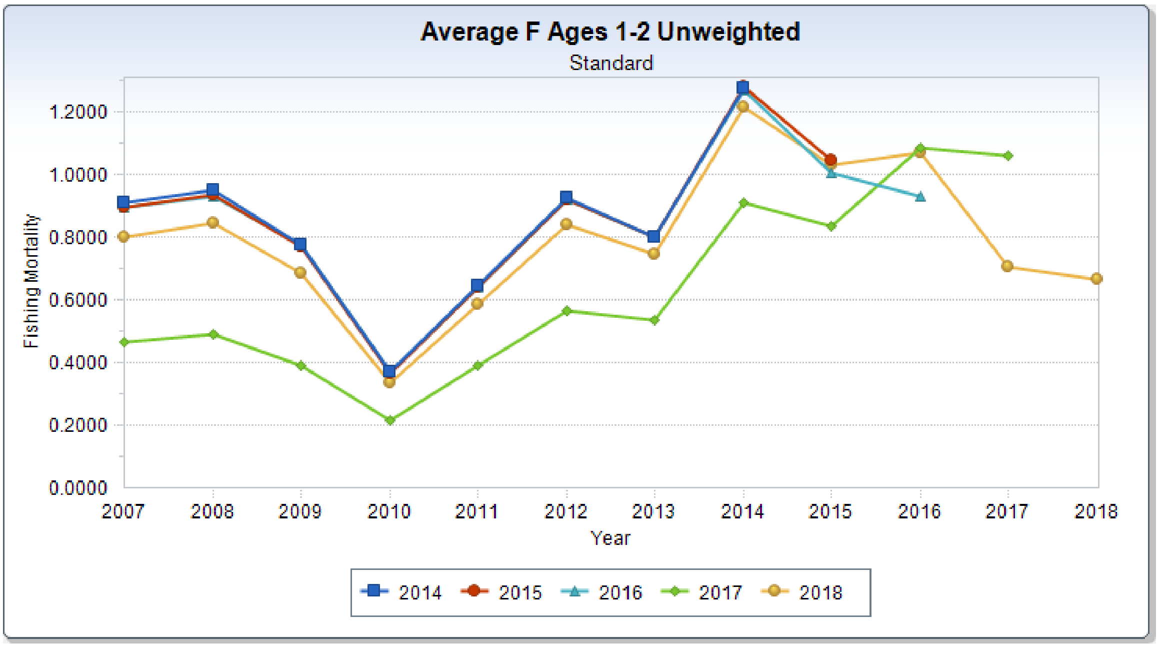
Figure 8 Likelihood components of the model fit for Pacific saury



Mohn's Rho=-0.052

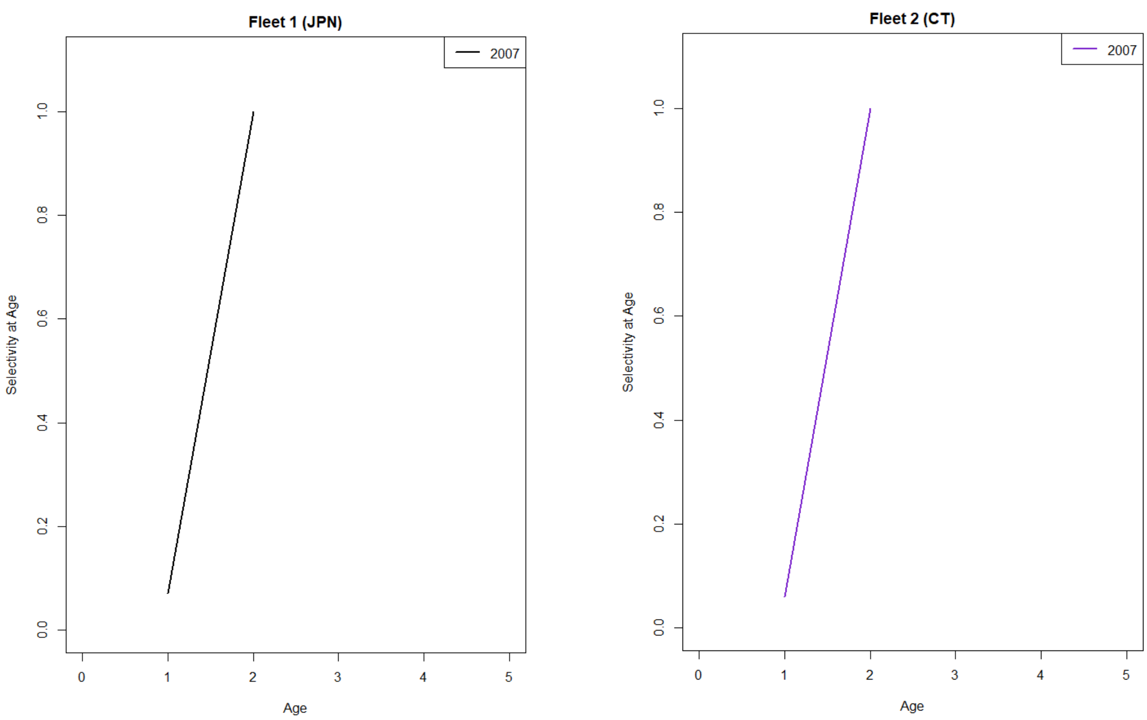


Mohn's Rho=-0.040



Mohn's Rho=0.110

Figure 9 Retrospective analysis results of the ASAP model for Pacific saury



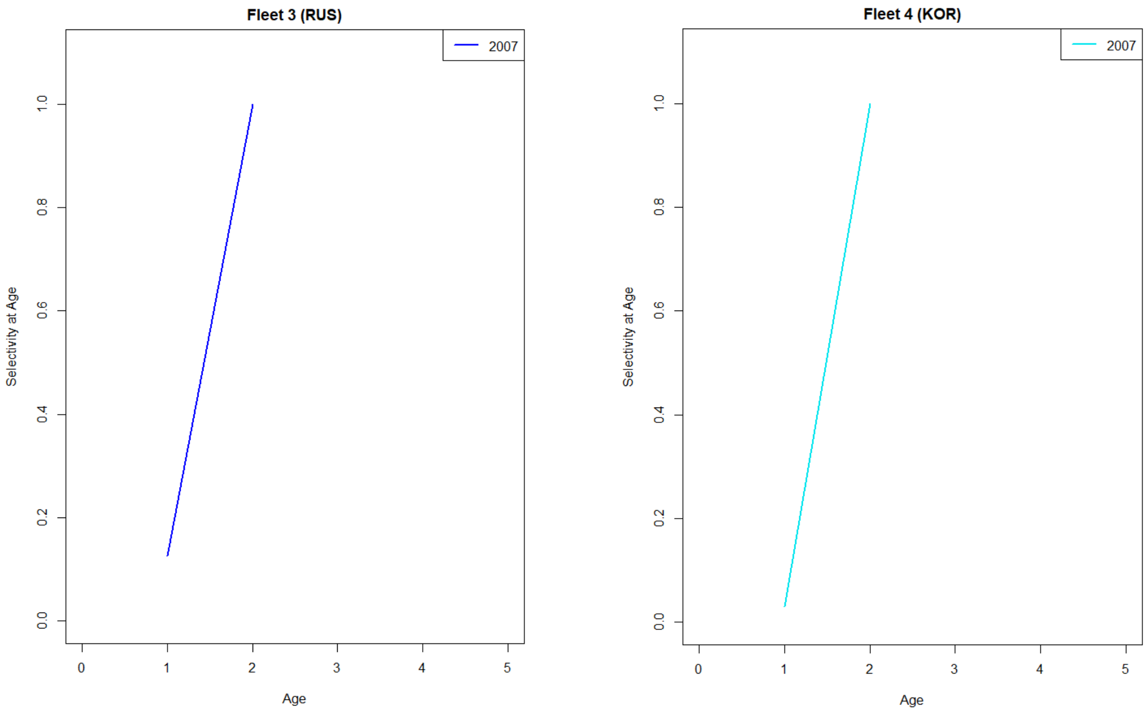


Figure 10 Age-dependent selectivity curves for each fleet for the first model year (constant during 2007-2018)

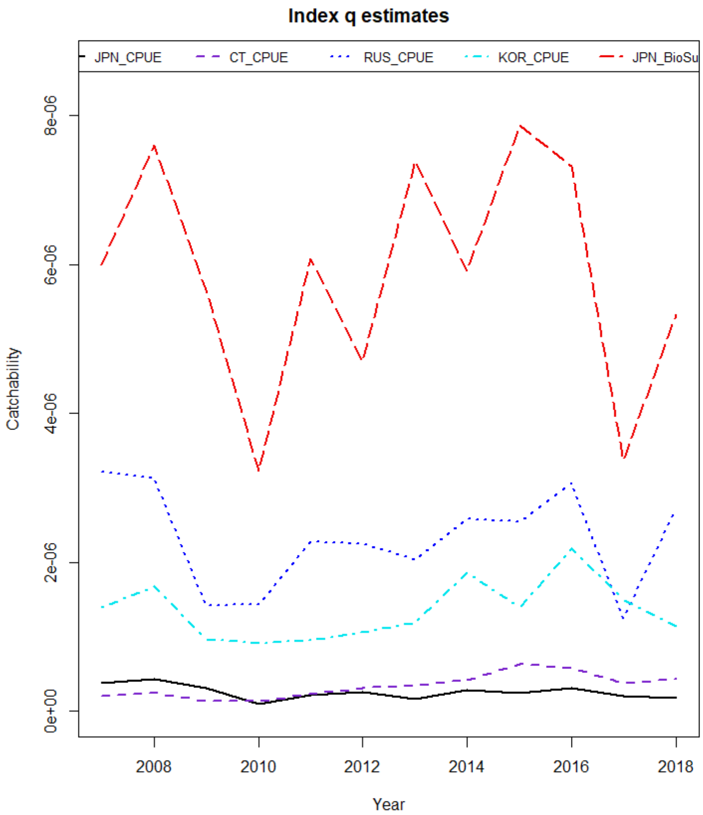


Figure 11 Catchability estimates of abundance indices

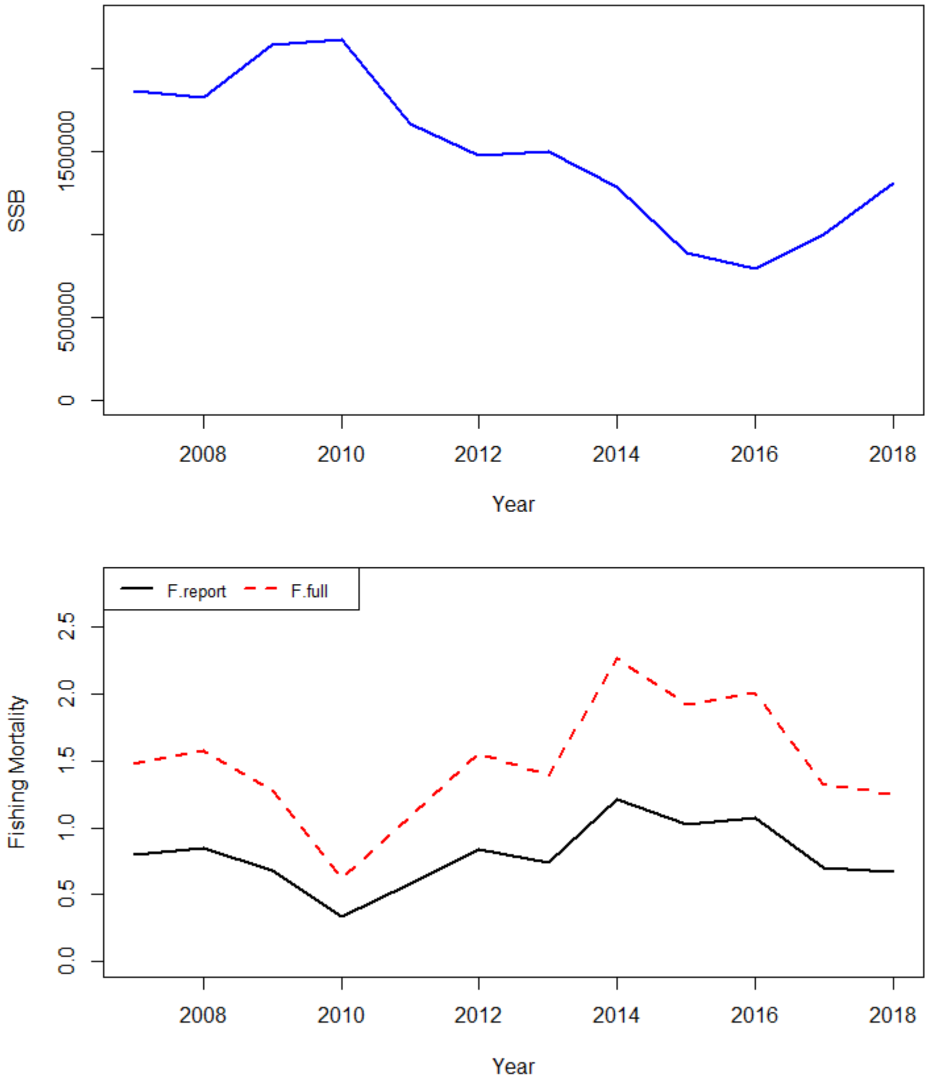


Figure 12 Time series of spawning biomass (metric ton) and fishing mortality for Pacific saury

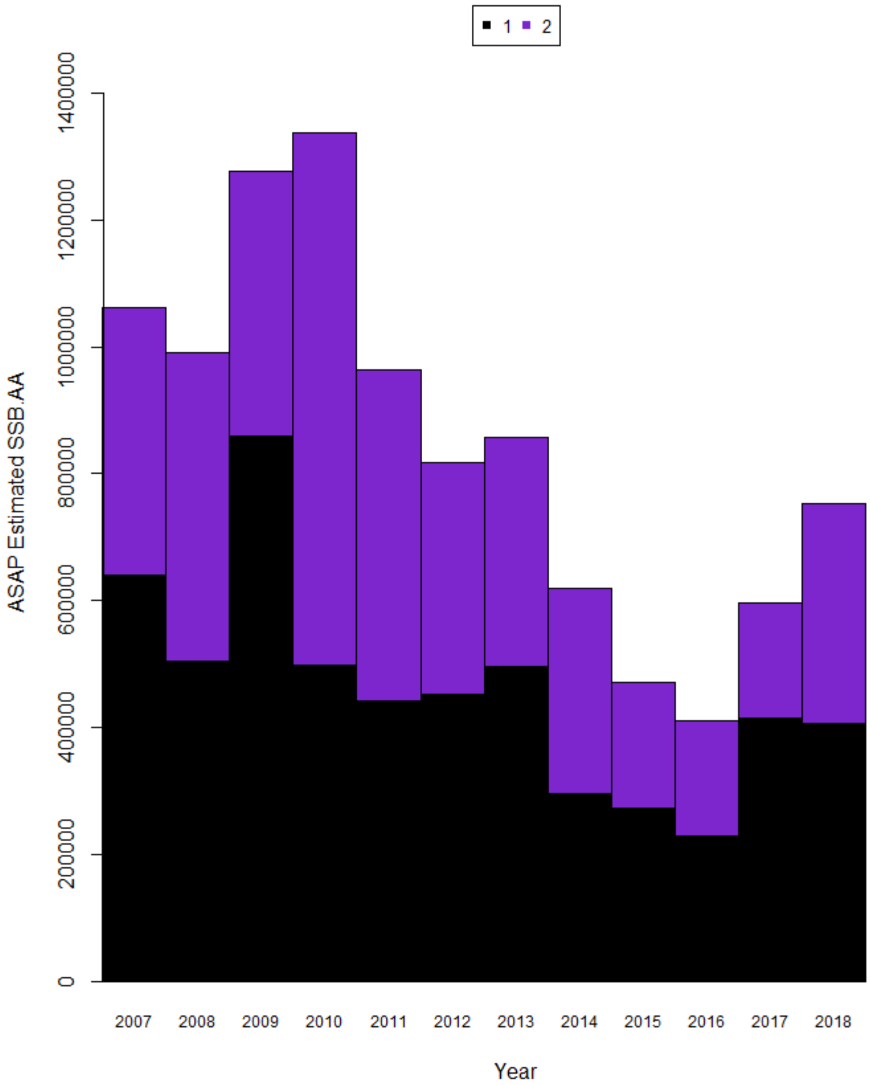


Figure 13 Estimated stock abundance (thousand fish) for Pacific saury

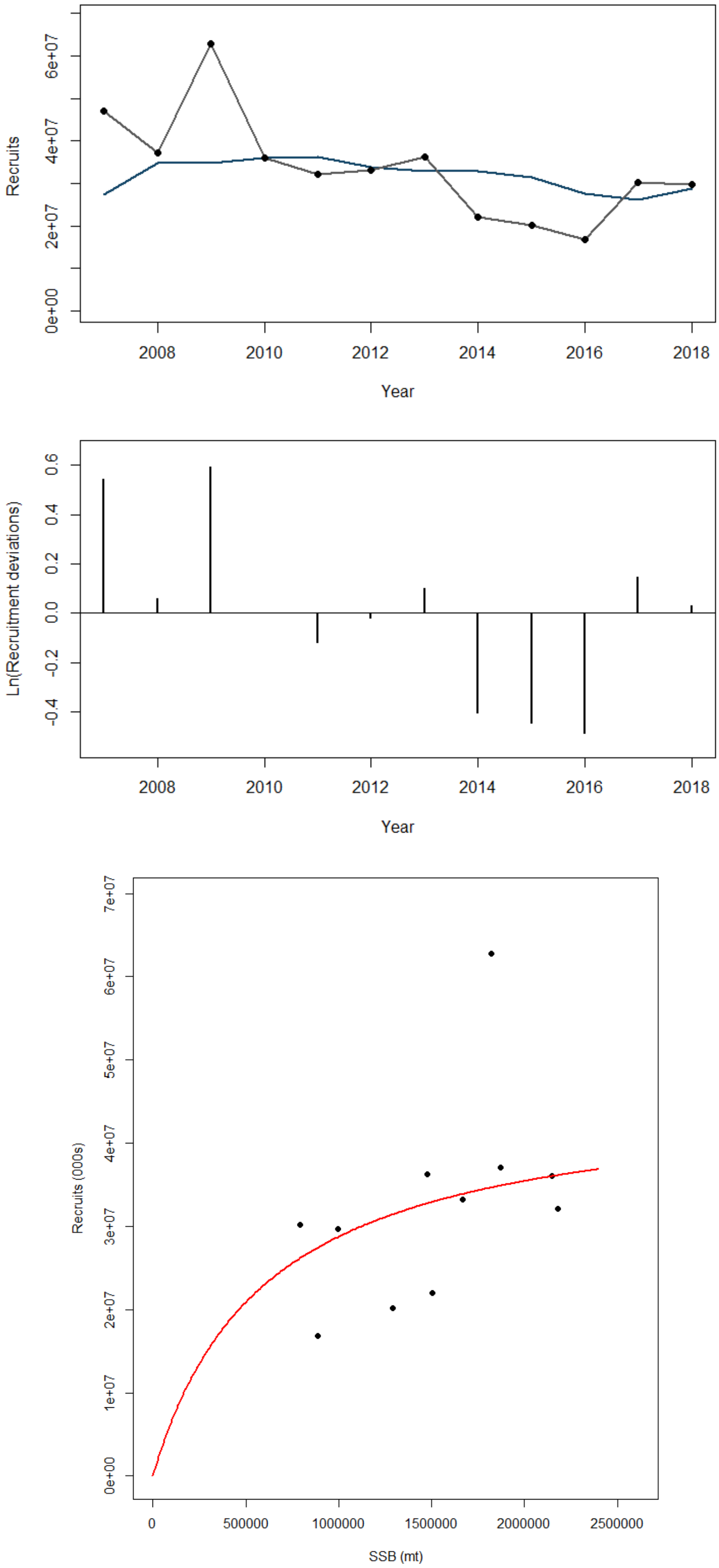


Figure 14 Estimated recruitments (thousand fish), recruitment variations and S-R relationship for the Pacific saury assessment

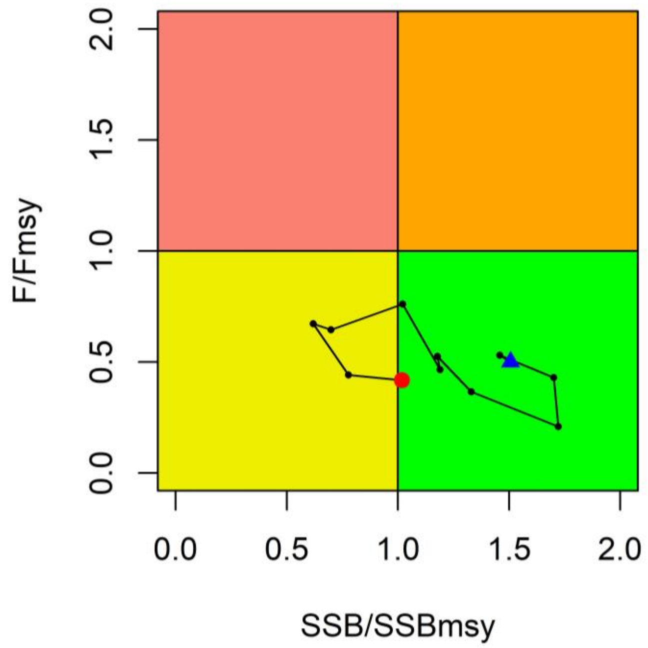


Figure 15 Kobe plot for the Pacific saury assessment in the North Pacific Ocean
The blue rectangle is the first year (i.e. 2007) and the red circle is the terminal year (i.e. 2018)

Appendix

Population dynamics model of ASAP

The spawning stock biomass is calculated based on the population abundance at age ($N_{t,a}$), the fecundity ($\phi_{t,a}$), and the proportion of the total mortality ($Z_{t,a}$) during the year prior to spawning (p_{SSB}) as

$$SSB_t = \sum_a N_{t,a}\phi_{t,a}e^{-p_{SSB}Z_{t,a}} \quad (1)$$

The Beverton and Holt stock recruitment relationship is used to calculate the expected recruitment in year *t*+1 from the spawning stock biomass in year *t* as

$$\hat{R}_{t+1} = \frac{\alpha SSB_t}{\beta + SSB_t} \quad (2)$$

The equation is reparametrized to use parameters unexploited spawning stock biomass (SSB_0) and steepness (h) and a constant of unexploited spawning stock biomass per recruit (SPR_0) so that

$$\alpha = \frac{4h(SSB_0/SPR_0)}{5h-1} \text{ and } \beta = \frac{SSB_0(1-h)}{5h-1} \quad (3)$$

SSB_0 is a parameter to be estimated. The recruitments, assumed to occur at age 1, are calculated as

$$N_{t,1} = R_t e^{\log(Dev(R_t))} \quad (4)$$

Selectivity at age for each fishery was modeled as separate blocks. Within each block, there are three selection model options:

(a) Estimate parameters for each age (one parameter for each age, and at least one age should be fixed at 1.0);

(b) Logistic function (2 parameters: α_1, β_1):

$$Sel_a = \frac{1}{1+e^{-(\alpha-\alpha_1)/\beta_1}} \quad (5)$$

(c) Double logistic function (4 parameters: $\alpha_1, \beta_1, \alpha_2, \beta_2$):

$$Sel_a = \left(\frac{1}{1+e^{-\frac{\alpha-\alpha_1}{\beta_1}}}\right)\left(1-\frac{1}{1+e^{-\frac{\alpha-\alpha_2}{\beta_2}}}\right) \quad (6)$$

Fishing mortality (*F*) at age is the product of a fully-recruited fishing mortality (*Fmult*) and selectivity at age. In ASAP, the *Fmult* for a fleet (*i*) is determined by two sets of parameters, $Fmult_{ifleet,1}$, the parameter for first year for that fleet, and $Dev(Fmult_{ifleet,i})$, where *t*=2 to the number of years, the deviation of the parameter from the value in the first year for that fleet. Both sets of parameters are estimated in log space and then exponentiated as

$$Fmult_{ifleet,1} = e^{\log(Fmult_{ifleet,1})}, t = 1 \quad (7)$$

$$Fmult_{ifleet,t} = Fmult_{ifleet,1}e^{\log(Dev(Fmult_{ifleet,t}))}, t \geq 2$$

The population abundance in the first year for ages 2 through the maximum age are derived from the initial guesses $Nini_{1,a}$ and the parameters $Dev(N_{1,a})$ as:

$$N_{1,a} = Nini_{1,a}e^{\log(Dev(N_{1,a}))} \quad (8)$$

Then, a partial spawning stock biomass for ages 2 through the maximum age is calculated and used in the stock recruitment relationship (Eq. 2) to estimate an expected recruitment in the first year. The recruitment deviation for the first year is applied to create the population abundance at age 1 in the first year (Eq. 4). The full spawning stock biomass is then computed for the first year using all ages (Eq. 1).

The population abundance for years 2 through the end year are filled by first computing the expected recruitment using stock-recruitment relationship (Eq. 2) and then applying the recruitment deviation to create the abundance at age 1 (Eq. 4). Ages 2 through the maximum age are filled using the following set of equations:

$$N_{t,a} = N_{t-1,a-1}e^{-Z_{t-1,a-1}}, 2 \leq a < A \qquad (9)$$
$$N_{t,A} = N_{t-1,A-1}e^{-Z_{t-1,A-1}} + N_{t-1,A}e^{-Z_{t-1}}, a = A$$

Each year the spawning stock biomass is computed (Eq. 1) and the cycle continued until the end year is reached.

The model predicted catch in units of numbers of fish for each fleet, year, and age are derived from the Baranov catch equation:

$$C_{ifleet,t,a} = N_{ifleet,t,a}F_{ifleet,t,a}(1 - e^{-Z_{t,a}})/Z_{t,a} \qquad (10)$$

The predicted total catch in weight is calculated by multiplying the catch in number by weight at age. The predicted catch proportions at age for each fleet and year are computed.

Catchability for each abundance index (*ind*) over time is computed similarly to the *Fmult*, with one parameter for the catchability in the first year ($q_{ind,1}$) and a number of deviation parameters for each additional year of index observations ($Dev(q_{ind,t})$). These parameters are combined and exponentiated to form the catchability value for the fleet and year as

$$q_{ind,t} = e^{\log(q_{ind,1}) + \log(Dev(q_{ind,t}))} \qquad (11)$$

Where the parameter for the deviation in the first year $Dev(q_{ind,1})$ is defined as one.

The estimated population numbers at age are modified to match the average population numbers, which are used for calculating the abundance index, according to

$$\bar{N}_{ind,t,a} = N_{t,a}\frac{1-e^{-Z_{t,a}}}{Z_{t,a}} \qquad (12)$$

The predicted abundance index (I_{pred}) is formed by summing the product of $\bar{N}$ and selectivity associated with each index over the appropriate ages and multiplying by the catchability for the index

$$Ipred_{ind,t} = q_{ind,t}\sum_{a=ind\_start}^{ind\_end}\bar{N}_{ind,t,a}Sel_{ind,t,a} \qquad (13)$$

After any index selectivity parameters are estimated, the proportions at age are computed in the same manner as the catch at age.