JJM user manual

Mirian GERONIMO Criscely LUJAN
Instituto del Mar del Perú IMARPE

Contents

Abstract

This paper provides a detailed and comprehensive specification of the joint jack mackerel model (JJM), including the algebraic specifications of the assessment model, tables with the input data and key parameters for the assessment. In addition a case study has been used to illustrate the use of the JJM model. This paper aims to provide an illustrative description of the JJM which can serve as support and guidance to users.

1 Introduction

This paper gives a full algebraic description of the JJM model which is used for the Jack mackerel assessment in the South Pacific Regional Fisheries Management Organisation SPRFMO. For this work, we provide a set of data that is used as part of a case study (see Appendix A: Case study description). This information is used as data input to simulate an assessment (see results in Appendix B: Assessment results of case study). Part of the concepts of the JJM model presented here come from SPRFMO SC10 Report-Annex 10- Jack Mackerel Technical Annex.

2 JJM model

2.1 Model description

The Joint Jack Mackerel Model (JJM) is a statistical catch-at-age and age-structured model used to evaluate the Jack mackerel (*Trachurus murphyi*). This species is widespread throughout the South Pacific ocean, and there are at least five management units identified of Jack mackerel whose are associated to distinct fisheries: the Ecuadorian and Peruvian fishery, the northern and central-southern Chilean fisheries, and the purely high sea fishery.

The JJM model was adopted as the assessment method in 2010 and continues to be used in the SPRFMO. In this context, each year an update of the model data is carried out, and using updated data inputs and indicators the model is run. Model results are used to provide an recommendation of the Jack mackerel population status for its exploitation. On the other hand, the JJM model was been adopted for some SPRFMO delegations (e.g. in Peru) for its internal fishery assessment.

This JJM model, implemented in AD Molder Builder (ADMB), uses a forward projection approach and maximum likelihood estimation to solve for model parameters. The operational population dynamics model of the JJM is defined by the standard catch equation with various modifications such as those described by Fournier & Archibald (1982), Hilborn & Walters (1992) and Schnute & Richards (1995).

Algorithm sections

There are three obligatory and important sections in the JJM code:

- Data section: data reading from a document with init prefix
- Parameter section: model parameterisation
- Procedure section: current model calculations

2.2 Model history

Since the creation of the JJM model, this tool is in continuous development and has been improved by participant scientists mainly involved in the SPRFMO. As part of the most important changes since its creation, was to include length composition data (and specifying or estimating growth) and the capacity to estimate the natural mortality by age and time. Nowadays, the model allow the use of catch information either at age or size for any fleet, this is an important change that provides flexibility in terms of data usage. Besides, other important change is the explicit incorporation of regime shifts in population productivity by fleet.

The model consists of four main components: i) the dynamics of the stock, ii) the fishery dynamics, iii) the observation models for the data, and iv) the procedure used for parameter estimation (including uncertainties).

2.3 Main assumptions

A statistical catch-at-age model analyses data on the age of fish caught in scientific surveys and by fisheries to provide a management advice. Catch-at-age models typically require information on stock age, fishing effort and total catches for each fishery targeting a stock.

To apply a statistical catch-at-age models, specific data are needed for each age class, where an age class is a set of all fish born in a given year. Then, catch-at-age results provide the full suite of management advice estimating a stock's current size and its management reference points associated with the maximum sustainable yield (MSY). The main assumptions of such models and implemented in the JJM model are detailed in the following sections.

2.3.1 Stock dynamics

- The JJM model is not spatially-explicit, although the fisheries operate in geographically distinct areas.
- The model needs initial conditions which should preferably be set at equilibrium conditions.
- The population's age composition considers individuals of diverse years (from 1 to more). But in all cases a stochastic Beverton-Holt relationship between stock and recruitment is included.
- The recruitment and the spawning season should be assumed to occur in specific month or period of time.
- Each cohort survives an age-specific mortality composed of fishing mortalities at age by fleet and natural mortality.
- Natural mortality is assumed to be constant over time and age.

2.3.2 Fishery dynamics

- The JJM model assumes that the interaction of the population with the fisheries occurs through the fishing mortality.
- The fishing mortality is assumed to be a composite of several processes: selectivity (by fleet), catchability and effort deviations.
- The selectivity report the age-specific pattern of fishing mortality and its pattern is non-parametric assuming to be fishery-specific and time-variant.
- The catchability describes the scales of fishing effort to fishing mortality and it is specific to each of abundance indices.

- The effort deviations describes a random effect in the fishing effort.
- The JJM model includes temporal variation in both fishery and index selectivity patterns at the annual and regime scales, depending on the index and the stock structure hypothesis.

2.3.3 Observation models for data

- There are four data components that contribute to the log-likelihood function: the total catch data, the age-frequency data, the length-frequency data and the abundance indices.
- Probability distributions for the age and length-frequency proportions are assumed to be approximated by multinomial distributions.
- Sample size is specified to be gear-specific but mostly constant over years.
- For the total catch by fishery and the abundance indices, a log-normal assumption has been assumed with constant coefficient of variation (CV).

2.3.4 Parameter estimation

- The most numerous parameters estimated involve estimates of annual and age-specific components of fishing mortality for each year and for each of the four fisheries identified in the model.
- Model parameters are estimated by maximising the log-likelihoods of the data plus the log of the probability density functions of the priors and smoothing penalties specified in the model.
- Parameter estimation is conducted in a series of phases, the first of which used arbitrary starting values for most parameters.

2.4 Mathematical Model details

This catch-at-age model is used as the underlying assessment model able to fit to CPUE indices as well as catch-at-age and length data. The assessment process involves developing a model of the resource dynamics and conditioning its output to the available data by minimizing a log-likelihood function.

2.4.1 Population dynamics

a. Numbers at age

The population dynamics are modelled by the following set of equations:

$$N^s_{y,a=1} = e^{\mu_R+\epsilon_y} \quad , y_1 \leq y \leq y_N \tag{1}$$

where:

- s is the fish stock, a the age and y the year;
- the simulation period $y \in \{y_0, y_N\}$;
- $N^s_{y,a=1}$ is the numbers at age a = 1 for the stock s in year y;
- μ_R is the mean recruitment;
- ϵ_y is the annual deviation of recruitment.

The JJM uses the Pope approximation, a variant of the statistical catch-at-age. This fixes the predicted catches to the observed catches using Pope's approximation to calculate the annual exploitation rate in the midpoint of the year. In this case:

$$N^s_{y+1,a+1} = N^s_{y,a} e^{-M^s_y} - C^s_{y,a} e^{-M^s_y 0.5}, \quad 1 \leq a \leq m-2 \tag{2}$$

$$N^s_{y+1,m} = N^s_{y,m-1} e^{-M^s_y} - C^s_{y,m-1} e^{-M^s_y 0.5} + N^s_{y,m} e^{-M^s_y} - C^s_{y,m} e^{-M^s_y 0.5} \tag{3}$$

where:

- m is the maximum age considered;
- $N^s_{y+1,a+1}$ is the number of fish at age a + 1 for the stock s in the year y + 1;
- $N^s_{y+1,m}$ is the number of fish at age m for the stock s in the year y + 1;
- M^s_y denotes the natural mortality rate on fish of stock s in the year y;
- $C^s_{y,a}$ and $C^s_{y,m}$ denotes the total catch of stock s in the year y at age a and m respectively.

In addition, the fishing mortalities and survival rate are calculated:

$$F^s_{y,a} = log\left(\frac{N^s_{y,a}}{N^s_{y+1,a+1}}\right) - M^s_y, \quad 1 \leq a \leq m-1 \tag{4}$$

$$F^s_{y,m} = log\left(\frac{N^s_{y,m-1} + N^s_{y,m}}{N^s_{y+1,m}}\right) - M^s_y \tag{5}$$

where:

- $F^s_{y,a}$ is the fishing mortality for the stock s at the age a in the year y;
- $F^s_{y,m}$ is the fishing mortality for the stock s at the maximum age m considered in the year y.

Also, the fishing mortality for each fishery and the survival rate are calculated as follows:

$$F^k_{y,a} = F^s_{y,a} \frac{\sum_{a=1}^{m} Cat^k_{y,a}}{\sum_{a=1}^{m} C^s_{y,a}}, \quad 1 \leq a \leq m. \tag{6}$$

$$S^s_{y,a} = e^{-(F^s_{y,a} + M^s_y)} \tag{7}$$

where:

- k is the fishery number and s is the corresponding stock due to the fishery;
- $1 \leq k \leq n_{fsh}$ where n_{fsh} is the total number of fisheries;
- $F^k_{y,a}$ is the fishing mortality for fishery k at age a in the year y;
- $Cat^k_{y,a}$ is the catch at age a for fishery k in the year y (see bellow);
- $S^s_{y,a}$ is survival rate for the stock s at age a in the year y.

When the Pope approximation is not used the number at age and survival rate are calculated as follows:

$$N^s_{y+1,a+1} = N^s_{y,a} S^s_{y,a}, \quad 1 \le a \le m-2 \tag{8}$$

$$N^s_{y+1,m} = N^s_{y,m-1} S^s_{y,m-1} + N^s_{y,m} S^s_{y,m} \tag{9}$$

Defining the fishing mortality for the stock, survival rate, and fishing mortality for the fishery as:

$$F^s_{y,a} = \sum_{k_s} F^{k_s}_{y,a}, \tag{10}$$

where the sum is over all fisheries k_s belonging to stock s.

$$S^s_{y,a} = e^{-(F^s_{y,a} + M^s_y)}, \tag{11}$$

$$F^k_{y,a} = e^{Fmort^k_y} Se^k_{y,a}, \quad y_0 \le y \le y_N \quad and \quad 1 \le a \le m \tag{12}$$

where:

- $Fmort^k_y$ is the annual mortality for the fishery k in the year y;
- $Se^k_{y,a}$ is the fishing selectivity of the fishery k in the year y at the age a.

The numbers at age when y_0 for the stock s at the age a is calculated as following:

$$N^s_{y_0,a=1} = e^{\mu^s_{R,y_0} + \epsilon^s_{y_0}} \tag{13}$$

If $r_0 = y_0 - m + a_R$, where r_0 is the first year of recruitment and a_R is the age at recruitment. For this case $a_R = 1$:

$$N^s_{y_0,a} = e^{\mu^s_{R,y_0-a+1} + \epsilon^s_{y_0-a+1}} \prod_{j=1}^{a-1} e^{-M^s_{y_0,j}}, \ 1 < a < m \tag{14}$$

If $r_0 = y_0 - m + a_R$, where $a_R > 1$:

$$N^s_{y_0,a} = e^{\mu^s_{R,y_0-a+1} + \epsilon^s_{y_0-a+1}} \prod_{j=1}^{a-1} e^{-M^s_{y_0,j}}, \ 1 < a \le m - a_R + 1 \tag{15}$$

$$N^s_{y_0,a} = R^s_0 \prod_{j=1}^{a-1} e^{-M^s_{y_0,j}}, \ m - a_R + 1 < a \le m-1 \tag{16}$$

where R^s_0 is the recruitment to the first regime of stock s.

Finally, the number at age when the age es the maximum age considered in the population:

$$N^s_{y_0,m} = N^s_{y_0-1,m-1} e^{-M^s_{y_0,m-1}} + N^s_{y_0-1,m} e^{-M^s_{y_0,m}} \tag{17}$$

b. Spawning stock biomass

The spawning stock biomass (SSB) is the total biomass of fish of reproductive age during the breeding season of a stock. SSB is calculated from the first year of spawning (styr_sp) until $y_N + 1$ as follows:

$$SSB_y^s = wt\_mat_1^s e^{-(M_{y_0,1}^s)(s_f)} R_0^s + \sum_{a=2}^{m-1} wt\_mat_a^s e^{-(M_{y_0,a}^s)(s_f)} R_0^s \prod_{l=1}^{a-1} e^{-M_{y_0,l}^s} + wt\_mat_m^s e^{-(M_{y_0,m}^s)(s_f)} \frac{R_0^s}{1 - e^{-(M_{y_0,m}^s)}} \prod_{l=1}^{m-1} e^{-M_{y_0,l}^s} \tag{18}$$

where:

- SSB_y^s is the spawning stock biomass for stock s in year y, when styr_sp $\leq y \leq r_0$;
- r_0 is the first year of recruitment;
- $wt\_mat_a^s$ is the proportion of mature females (in weight) at each age a in each stock s that is calculated as a product of the population weight at age ($wt\_pop_a^s$) and the maturity ($maturity_a^s$) as follows:

$$wt\_mat_a^s = wt\_pop_a^s maturity_a^s, \quad 1 \leq a \leq m \tag{19}$$

- $M_{y_0,m}^s$ is the natural mortality for stock s at age m in the year y_0;
- R_0^s is the is the recruitment to the first regime of stock s;
- s_f is computed as $s_f = \dfrac{\text{spawnmo} - 1}{12}$.

Also, the SSB is calculated for the years $r_0 + 1 \leq y \leq y_0 - 1$ and when $1 \leq i \leq y_0 - r_0$. First, the natagetmp is calculated as follows:

$$natagetmp_{y=r_0+i,a}^s = e^{\epsilon_{r_0+i+1-a}^s + \mu_{R,r_0+i+1-a}^s} \prod_{t=1}^{a-1} e^{-M_{y_0,t}^s}, \quad and \;\; 2 \leq a \leq i+1 \tag{20}$$

$$natagetmp_{y=r_0+i,a}^s = R_0^s \prod_{t=1}^{a-1} e^{-M_{y_0,t}^s}, \quad i+2 \leq a \leq m-1 \tag{21}$$

$$natagetmp_{y=r_0+i,m}^s = natagetmp_{r_0+i-1,m-1}^s + natagetmp_{r_0+i-1,m}^s e^{-M_m^s}, \quad a = m \tag{22}$$

With these previous calculations, the SSB is obtained:

$$SSB_y^s = \sum_{a=2}^{m} natagetmp_{y,a}^s e^{-M_{y_0}^s s_f} . wt\_mat_a^s, \tag{23}$$

After having calculated the numbers at age for each year and the survival rate (both depending on the choice of popes, if true or false), the SSB is calculated for the stock s in the year y:

$$SSB_y^s = \sum_{a=1}^{m} N_{y,a}^s (S_{y,a}^s)^{s_f} wt\_mat_a^s, \quad y_0 \leq y \leq y_N \tag{24}$$

Now for the year $y = y_N + 1$:

$$SSB^s_{y_N+1} = e^{\mu^s_{R,y_N+1}}(S^s_{y_N,1})^{s_f}\, wt\_mat^s_1 + \sum_{a=2}^{m-1}(N^s_{y_N,a-1}S^s_{y_N,a-1})(S^s_{y_N,a})^{s_f}\, wt\_mat^s_a \tag{25}$$
$$+(N^s_{y_N,m-1}S^s_{y_N,m-1} + N^s_{y_N,m}S^s_{y_N,m})(S^s_{y_N,m})^{s_f}\, wt\_mat^s_m$$

The SSB ($SSB^s_{y_N+1}$) is also projected over the time when the number of projected years is nproj_yrs > 0 as function of futures numbers at age (N^s_{fut}) and survival rate (S^s_{fut}):

$$SSB^s_{y_N+1} = \sum_{a=1}^{m} wt\_mat^s_a {N_{fut}}^s_{y_N+1,a}({S_{fut}}^s_{y_N+1,a})^{s_f} \tag{26}$$

where:

- ${S_{fut}}^s_{y_N+1,a} = e^{-M^s_{y_N}}$
- ${N_{fut}}^s_{y_N+1,a} = N^s_{y_N,a-1}S^s_{y_N,a-1}, \quad 2 \le a \le m-1$
- ${N_{fut}}^s_{y_N+1,m} = N^s_{y_N,m-1}S^s_{y_N,m-1} + N^s_{y_N,m}S^s_{y_N,m}, \quad a = m$
- ${N_{fut}}^s_{y_N,1} = \mathrm{SRecruit}(SSB^s_{y_N-\mathrm{rec\_age}}, \mathrm{cum\_reg}(s) + \mathrm{yy\_sr}(s, y_N))e^{\epsilon^s_{y_N}}$, where SRecruit is a function of spawning biomass and the number of regimen (see section Recruitment).

c. Catches

When the model is using the Popes's approximation, the total catch of stock ($C^s_{y,a}$) is calculated as a function of ${C_{tmp}}^{k_s}_{y,a}$ for each stock s ($1 \le s \le n_{stk}$) at age a in the year y ($y_0 \le y \le y_N$):

$${C_{tmp}}^{k_s}_{y,a} = N^s_{y,a}e^{-0.5M^s_{y,a}}Se^{k_s}_{y,a}\frac{c_{tmp}}{v_{bio}}, \quad 1 \le a \le m, \quad where \tag{27}$$

$$v_{bio} = \sum_{a=1}^{m} N^s_{y,a}e^{-0.5M^s_{y,a}}Se^{k_s}_{y,a}w^{k_s}_{y,a}, \quad and \tag{28}$$

$$c_{tmp} = v_{bio} - posfun\left(\frac{v_{bio} - {C_{obs}}_{k_s,y}}{v_{bio}}, 0.1, pen_{tmp} = 0\right).v_{bio} \tag{29}$$

Following this, the catch of the stock (C), catch-at-age (Cat) and the predicted catch (C_{pred}) are calculated as follows:

$$C^s_{y,a} = \sum_{k_s} {C_{tmp}}^{k_s}_{y,a} \tag{30}$$

$$Cat^{k_s}_{y,a} = {C_{tmp}}^{k_s}_{y,a}, \quad 1 \le a \le m \tag{31}$$

$${C_{pred}}^{k_s}_{y} = \sum_{a=1}^{m} {C_{tmp}}^{k_s}_{y,a}w^{k_s}_{y,a} \tag{32}$$

where:

- $Se^{k_s}_{y,a}$ is the fishing selectivity of the fishery k at the age a in the year y;
- $w^{k}_{y,a}$ is the weight at age a for the fishery k in the year y of observation;
- C_{obs} is the observed catch.

However, when the Pope's approximation is not used, the catch-at-age and predicted catch are estimated as follows:

$$Cat^{k_s}_{y,a} = \frac{F^{k_s}_{y,a}}{F^{s}_{y,a} + M^{s}_{y}} \left(1 - S^{s}_{y,a}\right) N^{s}_{y,a} \tag{33}$$

$$C_{pred}{}^{k}_{y} = \sum_{a=1}^{m} Cat^{k}_{y,a} w^{k}_{y,a}. \tag{34}$$

d. Calculation of zero biomass

The zero biomass (also called virgin biomass) is calculated for each regime $1 \leq r \leq n_{regs}$. This estimation is needed to calculate recruitment and is calculated as follows:

$$B_0^{s,1} = wt\_mat^s_1 e^{(-M^s_{y_0,1})(s_f)} R^s_0 + \sum_{a=2}^{m-1} wt\_mat^s_a e^{(-M^s_{y_0,a})(s_f)} R^s_0 \prod_{l=1}^{a-1} e^{-M^s_{y_0,l}} + wt\_mat^s_m e^{(-M^s_{y_0,m})(s_f)} \frac{R^s_0}{1 - e^{-M^s_{y_0,m}}} \prod_{l=1}^{m-1} e^{-M^s_{y_0,l}} \tag{35}$$

$$B_0^{s,r} = SSB^s_{reg\_shift(s,r-1)-a_R}, \quad 2 \leq r \leq n_{regs} \tag{36}$$

where:

- n_{regs} is the number of regimes of stock number s;
- $B_0^{s,1}$ is the virgin biomass for the first regime belonging to the stock s;
- $B_0^{s,r}$ is the virgin biomass for regime r belonging to stock s with $2 \leq r \leq n_{regs}$;
- reg_shift(s,r-1) is input, line 41 of .ctl file, for each stock s and regime number r.

e. Stock-Recruitment Parameters

The parameters of the recruitment curve (α, β) are calculated according to the specified stock-recruitment relationship type (sr_type). Also, they are parameterized in terms of the steepness of the stock-recruitment relationship (h), the recruitment to the first regime of stock (R_0), and the virgin biomass (B_0).

Using the Ricker stock-recruitment relationship (sr_type = 1):

$$\alpha = log\left(\frac{-4h}{h-1}\right). \tag{37}$$

Using the Beverton-Holt stock-recruitment relationship (sr_type = 2):

$$\alpha = \frac{B_0^{s,r}}{R_0^{s,r}} \left(\frac{1-h}{4h} \right), \tag{38}$$

$$\beta = \frac{5h-1}{4hR_0^{s,r}} \tag{39}$$

When sr_type = 4:

$$\alpha = log \left(\frac{R_0^{s,r}}{B_0^{s,r}} \right) + \beta B_0^{s,r}, \tag{40}$$

$$\beta = log \left(\frac{5h}{0.8B_0^{s,r}} \right) \tag{41}$$

where:

- $R_0^{s,r}$ is the recruitment to the first regime r of stock s, where $1 \leq r \leq n_{regs}$;
- $B_0^{s,r}$ is the virgin biomass for regime r belonging to the stock s.

e. Recruitment

The number of recruits is calculated for each year y, where $y_0 \leq y \leq y_N$:

$$recruits_y^s = N_{y,a=1}^s, \text{ and} \tag{42}$$

$$recruits_{y_{N+1}}^s = e^{\mu_{R,y_{N+1}}^s}, \text{ } when\ y = y_{N+1} \tag{43}$$

Besides, the number of recruits is calculated according to the specified curve type of the stock-recruitment relationship. Besides, the recruits will depend on the virgin biomass of the stock ($stock_i^r$), as follows:

$$stock_i^r = \frac{iB_0^{s,r}}{250}, \quad 1 \leq i \leq 300 \tag{44}$$

- When sr_{type} = 1 (Ricker form from Dorn):

$$recruits^{s,r} = \frac{R_0^{s,r} stock_i^r}{B_0^{s,r}} e^{\alpha \left(1 - \frac{stock_i^r}{B_0^{s,r}} \right)} \tag{45}$$

- When sr_{type} = 2 (Beverton-Holt form):

$$recruits^{s,r} = \frac{stock_i^r}{\alpha + \beta stock_i^r} \tag{46}$$

- When sr_{type} = 3 (mean recruitment):

$$recruits^{s,r} = e^{\mu_{R,r}}, \tag{47}$$

where $\mu_{R,r}$ is the average recruitment in the regime r ($1 \leq r \leq n_{regs}$).

- When sr_{type} = 4 (old Ricker form):

$$recruits^{s,r} = stock_i^r e^{\alpha - stock_i^r \beta} \tag{48}$$

g. von Bertalanffy growth model

For the fish growth the JJM uses the von Bertalanffy growth model.

$$\mu_{age}(r,1) = L_0(r) \tag{49}$$

$$\mu_{age}(r,i) = Linf(r)(1 - e^{-k\_coeff(r)}) + \mu_{age}(r, i-1)(e^{-k\_coeff(r)}). \tag{50}$$

- $\mu_{age}(r, i)$ is the mean lenght for each age i.
- r is a entire number between $1 \leq r \leq$ ngrowth(maximum of the Growth map matrix values).
- Linf(r) is the maximum lenght.
- k_coeff(r) is the parameter curvature.
- $L_0(r)$ is the lenght initial.

h. Equation weight at lenght

$$wt\_age\_vb(r) = lw\_a.\left(\mu_{age}(r)\right)^{lw\_b} \tag{51}$$

- wt_age_vb(r) is the weight vector at lenght vector $\mu_{age}(r)$.
- lw_a, lw_b are growth parameters given by lw_a = $0.007778994e-3$ and lw_b = 3.089248476 in the model.

i. Maturity equation

$$maturity\_vb(r) = \frac{1}{1 + e^{32.93 - 1.45.\mu_{age}(r)}} \tag{52}$$

- maturity_vb(r) is the proportion of mature species at lenght $\mu_{age}(r)$.

j. Age composition to length composition

It uses normal Distribution to model the probability of the random variable X_a,

$$P(l - 0.5 \leq X_a \leq l + 0.5) = P\left(\frac{(l-0.5) - \mu_a}{\sigma_a} \leq Z \leq \frac{(l+0.5) - \mu_a}{\sigma_a}\right) \tag{53}$$

$P(l-0.5 \leq X_a \leq l+0.5)$, is the probability that the number of fish at age "a" varies in lenght between $l-0.5$ and $l+0.5$.
The right expression is the normalization for X_a because X_a is a random variable with normal distribution, mean μ_a and standard deviation σ_a where it is calculated from σ_a = sdage(r).μ_{age}(r)).
Let P_age2len(r) the matrix such that Cl(1, nyears, 1, nlenght) = C(1, nyears, 1, nages).P_age2lenght where Cl is the matrix composition for lenghts that we want to obtein and C is the matrix composition for ages.

$$P\_age2len(a,j) = \frac{P(l_j - 0.5 \leq X_a \leq l_j + 0.5)}{\sum_a P(l_j - 0.5 \leq X_a \leq l_j + 0.5)}. \tag{54}$$

- P_age2len is a array with dimensions (1, ngrowth, 1, nages, 1, nlength).
- l_j is the lenght jth considered from the vector len_bins (lengthbin is in the .dat file in line 10).

Survey Predictions
Prediction from the index number k in year y, with y between $1 \leq y \leq$ nyrs_ind(k), where nyrs_ind(k) is the number of years of observation for survey number k (is located on line 138 of the .dat file).
Let us first calculate q_ind(k, y) for each survey $1 \leq k \leq$ nind and each year of observation $1 \leq y \leq$ nyrs_ind(k).

$$q\_ind(k,y) = e^{log\_q\_ind(k,y)} \tag{55}$$

for $1 \leq y <$ yrs_rw_q(k, 1) $-$ yrs_ind(k, 1) + 1.

Let $2 \leq i \leq 1$ + npars_rw_q(k) and p_i = yrs_rw_q(k, i $-$ 1) $-$ yrs_ind(k, 1) + 1:

$$q\_ind(k,p_i) = q\_ind(k,p_i - 1) * e^{log\_rw\_q\_ind(k,1)}, \tag{56}$$

$$q\_ind(k,iyr) = q\_ind(k,p_i), \tag{57}$$

for $p_i + 1 \leq$ iyr $\leq$ nyrs_ind(k).

- log_q_ind is a parameter to be estimated. It is initialized.
- yrs_rw_q(k, i $-$ 1) is input, line 95 of .ctl file.
- yrs_ind(k, 1) is the first year of observation for the survey number k.
- yrs_rw_q is input, line 95 of .ctl file.
- yrs_ind(k) is the set of years of observation of survey number k.
- log_rw_q_ind is a parameter to be estimated.

Now we calculate the prediction for the survey number k in the year $1 \leq i \leq$ nyrs_ind(k):

$$pred\_ind(k,i) = q\_ind(k,i). \tag{58}$$

$$\left(\left(\sum_{j=1}^{m} N^{istk}_{iyr,j}.{S^{istk}_{iyr,j}}^{ind\_month\_frac(k)} sel\_ind_j(k,iyr).wt\_ind_j(k,iyr)\right)\right)^{q\_power\_ind(k)}, \tag{59}$$

with iyr = yrs_ind(k, i).

- nind is the number of surveys (or indexes).
- ind_month_frac is calculated as ind_month_frac(k) = $\frac{\text{mo\_ind(k)} - 1}{12}$, where mo_ind(k) (for each fishery number k) is on line 144 of the .dat file.
- istk = sel_map(1, k + nfsh) i.e., it is the stock number corresponding to the survey number k.

- $sel\_ind_j(k, iyr)$ is the selectivity index of survey number k in year iyr at age j.
- $wt\_ind_j(k, iyr)$ weight composition at age j in year iyr of survey number k. It is input, line 171 of the .dat file.

We calculate the expected age composition from the index (eac_ind).
Let i be the index of the year for which age data are available for survey k, that is, $1 \leq i \leq$ nyrs_ind_age(k):

i. If use_age_err=TRUE then:

$$eac\_ind(k, i)_j = age\_err * \frac{tmp\_n_j}{\sum_{j=1}^{m} tmp\_n_j} \tag{60}$$

ii. If use_age_err=FALSE :

$$eac\_ind(k, i)_j = \frac{tmp\_n_j}{\sum_{j=1}^{m} tmp\_n_j} \tag{61}$$

where

$$tmp\_n_j = {S^{istk}_{iyr,j}}^{ind\_month\_frac(k)} sel\_ind(k, iyr)_j . N^{istk}_{iyr,j}, \tag{62}$$

iyr = yrs_ind_age(k, i) y $1 \leq j \leq m$.

Now, the expected size composition (elc_ind) is calculated from the index. Let i be the index of the year for which size data are available for survey k, i.e. $1 \leq i \leq$ nyrs_ind_length(k):

$$elc\_ind(k, i)_l = \sum_{j=1}^{m} \frac{tmp\_n_j}{\sum_{j=1}^{m} tmp\_n_j} * P\_age2len(igrowth, j, l). \tag{63}$$

donde

$$tmp\_n_j = {S^{istk}_{iyr,j}}^{ind\_month\_frac(k)} sel\_ind(k, iyr)_j . N^{istk}_{iyr,j}, \tag{64}$$

y

$$igrowth = growth\_map(istk, yy\_sr(istk, iyr)). \tag{65}$$

- growth_map growth matrix, is input. Line 43 of file .ctl.
- P_age2len(igrowth,j,l)is the element of the respective matrix at age j and size l.
- iyr=yrs_ind_lenght(k, i), year of index i for which survey k length data are available.

Index predicted for the next year of the survey k is calculated from:

$$pred\_ind\_nextyr(k) = q\_ind(k, nyrs\_ind(k)) * \tag{66}$$

$$\Big(SRecruit . {S^{istk}_{y_N,i}}^{ind\_month\_frac(k)} sel\_ind_i(k, y_N) wt\_ind_i(k, y_N).$$

$$+ \sum_{i=2}^{m-1} S^{istk}_{y_N,i-1} N^{istk}_{y_N,i-1} {S^{istk}_{y_N,i}}^{ind\_month\_frac(k)} sel\_ind_i(k, y_N) wt\_ind_i(k, y_N) + \tag{67}$$

$$(S^{istk}_{y_N,m-1} . N^{istk}_{y_N,m-1} + N^{istk}_{y_N,m} S^{istk}_{y_N,m}) {S^{istk}_{y_N,i}}^{ind\_month\_frac(k)} sel\_ind_i(k, y_N) wt\_ind_i(k, y_N)\Big)^{q\_power\_ind(k)} .$$

Fishery Predictions
Calculate the expected age composition (eac_fsh) from fisheries. Let y a positive integer with $1 \leq y \leq$ nyrs_fsh_length(k):

i. If use_age_err = TRUE:

$$eac\_fsh_a(k,y) = age\_err.\frac{Cat_a(k, yrs\_fsh\_age(k,y))}{\sum_{a=1}^{m} Cat_a(k, yrs\_fsh\_age(k,y))} \tag{68}$$

ii. If use_age_err = FALSE:

$$eac\_fsh_a(k,y) = \frac{Cat_a(k, yrs\_fsh\_age(k,y))}{\sum_{a=1}^{m} Cat_a(k, yrs\_fsh\_age(k,y)))}, \tag{69}$$

for $1 \leq a \leq m$. After calculate eac_fsh:

$$eac\_fsh_a(k,y) = \frac{eac\_fsh_a(k,y)}{\sum_{a=1}^{m} eac\_fsh_a(k,y)},\ 1 \leq a \leq m. \tag{70}$$

Now for the lenghts. Calculate the expected length composition (elc_fsh) for fisheries from:

$$elc\_fsh_a(k,y) = Cat_a(k, yrs\_fsh\_length(k,y)).P\_age2len(igrowth_{iyr}^{istk}), \tag{71}$$

finally

$$elc\_fsh_a(k,y) = \frac{elc\_fsh_a(k,y)}{\sum_{l=1}^{m} elc\_fsh_l(k,y)}, \tag{72}$$

for $1 \leq y \leq$ nyrs_fsh_length(k).

- $igrowth_{iyr}^{istk}$ = growth_map(istk, yy_sr(istk, iyr)), where istk is the stock number corresponding to fishery number k, iyr is the index year i for which fishery k has data available and growth_map is input on line 43 of .ctl file.

Selectivity
- The treatment of selectivity patterns and how they are shared among fisheries and indices need to be specified. Also the selectivity for each fleet, and depending on the model configuration, some growth functions were employed inside the model to convert model-predicted age compositions to length compositions, in order to fit the model to the length composition data.

Let k the number of fishery and y is the year between y_0 and y_N. Depending on which values fsh_sel_opt takes in order to calculate the logarithm of fishery selectivity log_sel_fsh:

- fsh_sel_opt = 1 :
  Se asume y_0 como el primer año de cambio de selectividad, es decir yrs_sel_ch_fsh(k, 1) = y_0, luego se toman en cuenta el resto de años de cambio de selectividad yrs_sel_ch_fsh(k, y), para $2 \leq y \leq$ n_sel_ch_fsh(k), introducidos en el archivo .ctl en la línea 116.
  - yrs_sel_ch_fsh(k) contiene los años de cambio de selectividad para cada pesquería número k.
  - n_sel_ch_fsh(k) es el número de cambios de selectividad para la pesquería k.

Calculamos la selectividad de la pesquería k en el año y. Sea A el conjunto de años de cambio de selectividad (i.e A = yrs_sel_ch_fsh(k), además se incluye y_0) y $p_k \in A$ (p_{k+1} vendría ser el siguiente año de cambio de selectividad), algún elemento de A:

$$log\_sel\_fsh(k,y)_a = log\_selcoffs\_fsh(k,jj_{p_k})_a - log\left(\frac{1}{m}.\left(\sum_{i=1}^{nselages\_fsh(k)} e^{log\_selcoffs\_fsh(k,jj_{p_k})_i} + \sum_{i=nselages\_fsh(k)+1}^{m} e^{log\_selcoffs\_fsh(k,jj_{p_k})_{nselages\_fsh(k)}}\right)\right), \tag{73}$$

for $1 \leq a \leq$ nselages_fsh(k).

Now for the remaining ages:

$$log\_sel\_fsh(k,y)_a = log\_selcoffs\_fsh(k,jj_{p_k})_{nselages\_fsh(k)} - log\left(\frac{1}{nages}.\left(\sum_{i=1}^{nselages\_fsh(k)} e^{log\_selcoffs\_fsh(k,jj_{p_k})_i} + \sum_{i=nselages\_fsh(k)+1}^{m} e^{log\_selcoffs\_fsh(k,jj_{p_k})_{nselages\_fsh(k)}}\right)\right), \tag{74}$$

for nselages_fsh(k) $\leq a \leq m$ where $p_k \leq y < p_{k+1}$.

- jj_{p_k} es el número de cambio que le corresponde al año de cambio $p_k \in A$.
- log_selcoffs_fsh es parámetro a estimar.

• fsh_sel_opt = 2 : Sea p_k como antes,

$$log\_sel\_fsh(k,y)_a = -log(1.0 + e^{(-1.sel\_slope\_fsh(k,jj_{p_k}).(age\_vector_a - sel50\_fsh(k,jj_{p_k})))}) \tag{75}$$

for $1 \leq a \leq$ nselages_fsh(k).

$$log\_sel\_fsh(k,y)_a = log\_sel\_fsh(k,y)_{nselages\_fsh(k))}, \tag{76}$$

for nselages_fsh(k) $\leq a \leq m$ where $p_k \leq y < p_{k+1}$.

- sel_slope_fsh$(k, jj_{p_k}) = e^{logsel_slope_fsh(k,jj_{p_k})}$.
- logsel_slope_fsh and sel50_fsh are parameters to be estimated.

• fsh_sel_opt = 3 : Sea p_k como antes,

$$log\_sel\_fsh(k,y)_a = \left(-log(1.0 + e^{(\frac{-2.9444389792}{du}.(age\_vector_a - bu))})\right. \tag{77}$$

$$\left.+log\left(1 - \frac{1}{1 + e^{(\frac{-2.9444389792}{dd}(age\_vector_a - bd))}}\right)\right) + 0.102586589$$

for $1 \leq a \leq$ nselages_fsh(k).
Now for the remaining ages:

$$log\_sel\_fsh(k,y)_a = log\_sel\_fsh(k,y)_{nselages\_fsh(k)}, \tag{78}$$

for nselages_fsh(k) $\leq a \leq m$.

- $bu = e^{logsel\_p1\_fsh(k, jj_{p_k})}$
- $du = e^{logsel\_p2\_fsh(k, jj_{p_k})}$
- $dd = e^{logsel\_p3\_fsh(k, jj_{p_k})}$
- bd = bu + du + dd.
- logsel_p1_fsh, logsel_p2_fsh and logsel_p3_fsh are parameters to be estimated.

For the surveys:

- ind_sel_opt = 1 : Calculamos la selectividad del crucero k en el año y. Sea B el conjunto de años de cambio de selectividad (i.e B = yrs_sel_ch_ind(k), además se incluye y_0) y $p_k \in A$, algún elemento de B:

$$sel\_tmp_{y,a} = log\_selcoffs\_ind(k, jj_{p_k})_a \tag{79}$$

for $1 \le a \le$ nselages_ind(k). Now for remaining ages

$$sel\_tmp_{y,a} = log\_selcoffs\_ind(k, jj_{p_k})_{nselages\_ind(k)}, \tag{80}$$

for nselages_ind(k) $\le a \le m$.

Now we calculate log_sel_ind

$$log\_sel\_ind(k, y)_a = sel\_tmp_{y,a} - log\left(\frac{1}{q\_age\_max(k) - q\_age\_min(k) + 1}\sum_{i=q\_age\_min(k)}^{q\_age\_max(k)} sel\_tmp_{y,i}\right) \tag{81}$$

for $1 \le a \le m$ and $p_k \le y < p_{k+1}$.

  - jj_{p_k} es el número de cambio que le corresponde al año de cambio $p_k \in B$.
  - log_selcoffs_ind es parámetro a estimar.

- ind_sel_opt = 2 : Sea p_k como antes,

$$log\_sel\_ind(k, y)_a = -log(1.0 + e^{(-sel\_slope\_ind(k, jj_{p_k}).(age\_vector_a - sel50\_ind(k, jj_{p_k})))}). \tag{82}$$

for $1 \le a \le m$ where $p_k \le y < p_{k+1}$.

  - $sel\_slope\_ind(k, jj_{p_k}) = e^{logsel\_slope\_ind(k, jj_{p_k})}$.
  - logsel_slope_ind and sel50_ind are parameters to be estimated.

- ind_sel_opt = 3 :

$$log\_sel\_ind(k, y)_a = (-log(1.0 + e^{(\frac{-2.9444389792}{p1}.(age\_vector_a - i1))}) \tag{83}$$

$$+log\left(1 - \frac{1}{(1 + e^{(\frac{-2.9444389792}{p3}.(age\_vector_a - i2))})}\right)\right) + 0.102586589 \tag{84}$$

for $1 \le a \le$ nselages_ind(k).

Now for remaining ages

$$log\_sel\_ind(k, y)_a = log\_sel\_ind(k, y)_{nselages\_ind(k)}, \tag{85}$$

for nselages_ind(k) $\le a \le m$ where $p_k \le y < p_{k+1}$.

- $p1 = e^{logsel\_p1\_ind(k,jj_{p_k})}$
- $p2 = sel\_p2\_ind(k, jj_{p_k})$
- $p3 = e^{logsel\_p3\_ind(k,jj_{p_k})}$
- $i1 = p1 + p2$
- $i2 = p1 + i1 + p3$
- logsel_p1_ind, sel_p2_ind y logsel_p3_ind are parameters to be estimated.

(falta pequeño cálculo)

Finally we get the selectivites from:

$$sel\_fsh = e^{log\_sel\_fsh} \tag{86}$$

$$sel\_ind = e^{log\_sel\_ind}. \tag{87}$$

- The equilibrium-based reference points are calculated within the JJM model. The model estimates values of Maximum Sustainable Yield (MSY) and the Fishing mortality expected to produce maximum sustainable yield (F_{MSY}) using a Newton-Raphson minimization routine that finds the value of fishing mortality, given the terminal year relative catches (and selectivities-at-age) by fleet, and the terminal year weights-at-ages for each fleet, that maximizes catch. Since weights-at-age and effective selectivity change each year, these values can vary. MSY is thus defined as the maximum amount of catch that allows the remaining stock to generate sufficient recruitment to maintain the population at the same level. Besides (B_{MSY}) is taken as the long-term average of biomass fished under MSY.

Between 2013 and 2021, a provisional B_{MSY} level of 5.5 millions tons was applied. An interim management reference point for B_{MSY} was revised to a ten-year average of the model-estimated (B_{MSY}). A limit reference point B_{LIM} (where B refers to spawning biomass) was defined as the spawning biomass level below which recruitment would likely be impaired. As such, there should be no fishing when the current spawning biomass is estimated to be below B_{LIM}. For the jack mackerel, B_{LIM} was computed from the lowest ratio of historical spawning biomass relative to the most recently estimated unfished spawning biomass (e.g. as the 8% of the unfished spawning biomass).

In the last phase, the model calculate the Replacement Yield.

Replacement Yield

It is the volume by weight that can be removed from a fish stock without increasing or decreasing the biomass of the stock. For calculate the Replacement Yield for each stock number s use Newton method for 4 iterations to find the root of

$$dssb = \frac{ssb2 - ssb3}{df}, \text{ with } df = 1.e - 3. \tag{88}$$

The iteration is on

$$F_1^s \leftarrow F_1^s - \frac{dssb}{dssbp}, \text{ with initial } F_1^s = 0.1. \tag{89}$$

Other variables are

$$F_2^s \leftarrow F_1^s + df * 0.5, \tag{90}$$

$$F_3^s \leftarrow F_2^s - df. \tag{91}$$

Here dssp is the second derivative of dssb:

$$dssbp = \frac{(ssb2 + ssb3 - 2. * ssb1)}{(.25 * df * df)}, \tag{92}$$

where

$$ssb1 = -1000.\left(log\left(\frac{repl\_ssb(F_1^s, s)}{SB_{y_N}^s}\right)\right)^2, \tag{93}$$

$$ssb2 = -1000.\left(log\left(\frac{repl\_ssb(F_2^s, s)}{SB_{y_N}^s}\right)\right)^2, \tag{94}$$

and

$$ssb3 = -1000.\left(log\left(\frac{repl\_ssb(F_3^s, s)}{SB_{y_N}^s}\right)\right)^2, \tag{95}$$

The numerical solution (F_1^s) is the FMSY for each stock s.
Finally:

$$repl\_F(s) = F1^s, \tag{96}$$

$$repl\_SSB(s) = repl\_ssb(F1^s, s). \tag{97}$$

- repl_ssb(F, s) is a function calculated for each F and each stock s. (See the next section).
- repl_F(s) is the FMSY for each stock s.
- repl_SSB(s) is the yield for each stock s.

In addition, this section also calculates:

$$sumF(s) = \sum_{k_s}\sum_{l=1}^{m} F_{y_N,l}^{k_s}, \text{ with } 1 \leq s \leq nstk, \tag{98}$$

where the k_s are the numbers of fisheries belonging to stock number s, and

$$Fratio(k) = \frac{\sum_{l=1}^{m} F_{y_N,l}^{k}}{sumF(s_k)}, \text{ with } 1 \leq k \leq nfsh, \tag{99}$$

where s_k is the stock number where fishery number k belongs to.

Function repl_ssb(F, s):
It is calculated from:

$$repl\_ssb(F, s) = \sum_{a=1}^{m} ntmp_a.Stmp_a^{spmo\_frac}.wt\_mature_a^s, \tag{100}$$

where (ver)

$$Ztmp_a = M_{y_N}^s + \sum_{k_s} F.Fratio(k_s), \text{ Fratio as defined in eq. 108}, \tag{101}$$

$$Stmp_a = e^{-Ztmp_a}, \text{ with } 1 \leq a \leq m, \tag{102}$$

and

$$ntmp_1 = \frac{\displaystyle\sum_{i=styr\_rec}^{y_N} mod\_rec(s, i)}{y_N - r_0 + 1}, \tag{103}$$

$$ntmp_a = Stmp_{a-1}.N_{y_N+1,a-1}^s, \; 2 \leq a \leq m-1, \tag{104}$$

$$ntmp_m = Stmp_{m-1}.N_{y_N+1,m-1}^s + N_{y_N+1,m}^s.Stmp_m. \tag{105}$$

- mod_rec(s, i) is the recruitment as estimated by model. It is calculated, from year styr_rec to year y_N, for each stock s as

$$mod\_rec(s,i) = e^{\epsilon_i^s + \mu_{R,i}^s},\ r_0 \le i \le y_0 - 1, \tag{106}$$

$$mod\_rec(s,y_0) = N^s_{y_0,1}, \tag{107}$$

$$mod\_rec(s,i+1) = N^s_{i+1,1},\ y_0 \le i \le y_N - 1. \tag{108}$$

In this section is also calculated

$$repl\_yld(s) = \sum_{a=1}^{m} Ctmp, \tag{109}$$

where

$$Ctmp_a = \sum_{k_s} wt\_fsh^{k_s}_{y_N,a} \frac{F.Fratio(k_s)}{Ztmp_a}(1 - Stmp_a).ntmp_a,\ 1 \le a \le m. \tag{110}$$

Function yld (Fratio, Ftmp, s)

This function returns msy_stuff(i) for i positive integer with $1 \le i \le 5$.
The msy_stuff(5) (BmsyTot) is calculated from

$$msy\_stuff(5) = \left(\sum_{a=1}^{m} Ntmp_a.wt\_pop^s_a\right).msy\_stuff(3), \tag{111}$$

where

$$Ztmp_a = M^s_{y_0} + \sum_{k_s} Fratio(k) * Ftmp * sel\_fsh_a(k_s, y_N),\ 1 \le a \le m, \tag{112}$$

where k_s are the indexes of the fisheries belonging to the stock s, then let

$$survtmp_a = e^{-Ztmp_a},\ 1 \le a \le m, \tag{113}$$

finally we obtain

$$Ntmp_1 = 1, \tag{114}$$

$$Ntmp_{j+1} = Ntmp_j.survtmp_j,\ 1 \le j \le m-2, \tag{115}$$

$$Ntmp_m = \frac{Ntmp_{m-1}.survtmp_{m-1}}{1 - survtmp_m}. \tag{116}$$

The msy_stuff(4) (SPR) is calculated from

$$msy\_stuff(4) = \frac{phi}{phizero^s_{y_N}} \tag{117}$$

where

$$phi = \sum_{a=1}^{m} Ntmp_a(survtmp_a)^{spmo\_frac}.wt\_mature^s_a, \tag{118}$$

and

$$phizero(r) = \frac{Bzero(r)}{Rzero(r)},\ 1 \le r \le nregs. \tag{119}$$

The msy_stuff(3) (Eq Recruitment) is calculated from

$$msy\_stuff(3) = Requil(phi, y_N, s), \tag{120}$$

where Requil(phi, y_N, s) is a function that depends on the choice of SrType, that is, let ireg = cum_regs(s) + yy_sr(s, y_N):
If SrType = 1

$$Requil(phi, y_N, s) = Bzero(ireg) * \frac{(alpha(ireg) + log(phi) - log(phizero(ireg)))}{(alpha(ireg) * phi)}. \tag{121}$$

If SrType = 2

$$Requil(phi, y_N, s) = \frac{(phi - alpha(ireg))}{(beta(ireg) * phi)}. \tag{122}$$

If SrType = 3

$$Requil(phi, y_N, s) = e^{\mu^s_{R,y_N}}. \tag{123}$$

If SrType = 4

$$Requil(phi, y_N, s) = \frac{(log(phi) + alpha(ireg))}{(beta(ireg) * phi)}. \tag{124}$$

The msy_stuff(2) (MSY) is calculated from

$$msy\_stuff(2) = \left(\sum_{k_s} \sum_{a=1}^{m} wt\_fsh^{k_s}_{y_N,a} Ntmp_a.Fratio(k_s).Ftmp.sel\_fsh_a(k_s, y_N) \frac{1 - survtmp_a}{Ztmp_a} \right).msy\_stuff(3). \tag{125}$$

Note that the first sum of equation 130 is about the indexes of fisheries belonging to stock s.
Finally, the msy_stuff(1) (Bmsy) is calculated from

$$msy\_stuff(1) = phi.(msy\_stuff(3)). \tag{126}$$

Get MSY

Calculate MSY, FMSY, MSY, Bmsy for the last year of observation (y_N). Use Newton Raphson method with 4 iterations to find the root of

$$dyld = \frac{yld2 - yld3}{df} \tag{127}$$

for each stock. Let

$$F^s_2 \leftarrow F^s_1 + df * 0.5, \text{ with } df = 1.e - 05, \tag{128}$$

$$F^s_3 \leftarrow F^s_2 - df. \tag{129}$$

Iteration on

$$F^s_1 \leftarrow F^s_1 - \frac{dyld}{dyldp}, \text{ with initial } F^s_1 = 0.8 * natmortprior(mort\_map(s, 1)) \tag{130}$$

here dyldp is the derivative expression of dyld, that is

$$dyldp = \frac{yld2 + yld3 - 2.yld1}{0.25 * df * df} \tag{131}$$

where

$$yld1 = yield(Fratio, F^s_1, s), \tag{132}$$

$$yld2 = yield(Fratio, F2^s, s), \tag{133}$$

$$yld3 = yield(Fratio.F3^s, s). \tag{134}$$

The function yield(Fratio, F^s, s) is calculated in the next section.

After obtaining the numerical solution $F1^s$ (FMSY) for each stock s, this uses the function yld(Fratio, F1, s) (from previous section) in the last year (y_N):

$$Fmsy(s) = F_1, \tag{135}$$

$$Rtmp(s) = msy\_stuff(3), \tag{136}$$

$$MSY(s) = msy\_stuff(2), \tag{137}$$

$$Bmsy(s) = msy\_stuff(1), \tag{138}$$

$$MSYL(s) = \frac{msy\_stuff(1)}{Bzero^s_{y_N}}, \tag{139}$$

exploitation fraction relative to total biomass:

$$lnFmsy(s) = log\left(\frac{MSY(s)}{msy\_stuff(5)}\right), \tag{140}$$

and

$$Bcur\_Bmsy(s) = \frac{SB^s_{y_N}}{Bmsy(s)}. \tag{141}$$

It is also calculated

$$FFtmp_s = \sum_{k_s}\left(\frac{1}{m}\sum_{a=1}^{m} F^{k_s}_{y_N,a}\right), \tag{142}$$

$$Fcur\_Fmsy(s) = \frac{FFtmp}{Fmsy(s)}, \tag{143}$$

and finally

$$Rmsy(s) = Rtmp(s). \tag{144}$$

Function yield(Fratio, F^s**,s)**

Let

$$Ztmp_a = M^s_{y_0} + \sum_{k_s} Fratio(k) * Ftmp * sel\_fsh_a(k_s, y_N),\ 1 \le a \le m, \tag{145}$$

where k_s are the indexes of the fisheries belonging to the stock s, then let

$$survtmp_a = e^{-Ztmp_a},\ 1 \le a \le m, \tag{146}$$

and

$$Ntmp_1 = 1, \tag{147}$$

$$Ntmp_{j+1} = Ntmp_j.survtmp_j,\ 1 \le j \le m-2, \tag{148}$$

$$Ntmp_m = \frac{Ntmp_{m-1}.survtmp_{m-1}}{1 - survtmp_m}. \tag{149}$$

We also need

$$phi = \sum_{a=1}^{m} Ntmp_a(sruvtmp_a)^{spmo\_frac}.wt\_mature^s_a \tag{150}$$

and

$$Req = Requil(phi, y_N, s) \text{ (as eq.130 to eq. 133)} \tag{151}$$

and finally we obtein

$$yield(Fratio, F^s, s) = \left(\sum_{k_s} \sum_{a=1}^{m} wt\_fsh^{k_s}_{y_N,a} Ntmp_a.Fratio(k_s).Ftmp.sel\_fsh_a(k_s, y_N) \frac{1 - survtmp_a}{Ztmp_a} \right) .Req. \quad (152)$$

N_NoFsh
Let s the number stock, that is $1 \leq s \leq nstk$.

$$N\_NoFsh_j(s, styr) = N^s_{y_0,j},\ 1 \leq j \leq m, \quad (153)$$

and for $styr\_sp \leq i \leq styr$

$$Sp\_Biom\_NoFish_j(s, i) = SB^s_{i,j},\ 1 \leq j \leq m. \quad (154)$$

- N_NoFsh
- Sp_Biom_NoFish

Now for $styr \leq i \leq endyr$, the number of recruits from stock s in year i is equal to the number of individuals of stock s in year i at age 1 i.e recruits(s, i) = $N^s_{i,1}$.
Let $y_0 \leq i \leq y_N$. Si $i > y_0$:

$$N\_NoFsh(s, i, 1) = recruits(s, i) * \frac{SRecruit(Sp\_Biom\_NoFish(s, i - rec\_age), cum\_regs(s) + yy\_sr(s, i))}{SRecruit(SB^s_{i-a_R}, cum\_regs(s) + yy\_sr(s, i))} \quad (155)$$

- recruits:
- SRecruit:
- rec_age
- cum_regs
- yy_sr

$$N\_NoFsh(s, i)_j = N\_NoFsh(s, i - 1)_{j-1}.e^{-M(s,i-1)_{j-1}} \quad (156)$$

for $2 \leq j \leq m$. Updating for m:

$$N\_NoFsh(s, i, m) = N\_NoFsh(s, i - 1)_{m-1}.e^{-M^s_{i-1,m-1}} + N\_NoFsh(s, i - 1, m).e^{-M^s_{i-1,m}} \quad (157)$$

Now for $y_0 \leq i \leq y_N$:

$$totbiom\_NoFish(s, i) = \sum_{j=1}^{m} N\_NoFsh(s, i)_j.wt\_pop^s_j. \quad (158)$$

$$totbiom(s, i) = \sum_{j=1}^{m} N^s_{i,j}.wt\_pop^s_j. \quad (159)$$

$$Sp\_Biom\_NoFish(s, i) = \sum_{j=1}^{m} N\_NoFsh(s, i)_j.e^{-M^s_{i,j}.spmo\_frac} wt\_mature^s_j \quad (160)$$

$$Sp\_Biom\_NoFishRatio(s, i) = \frac{SB^s_i}{Sp\_Biom\_NoFish(s, i)} \quad (161)$$

$$depletion(s) = \frac{totbiom(s, y_N)}{totbiom(s, y_0)} \quad (162)$$

$$depletion\_dyn(s) = \frac{totbiom(s, y_N)}{totbiom\_NoFish(s, y_N)} \quad (163)$$

- totbim_NoFish
- totbiom
- Sp_Biom_NoFish
- Sp_Biom_NoFishRatio
- depletion_dyn

$$Nnext(s)_j = N^s_{y_N,j-1}.S^s_{y_N,j-1},\ for\ 2 \leq j \leq m-1, \tag{164}$$

$$Nnext(s)_m = N^s_{y_N,m-1}.S^s_{y_N,m-1} + N^s_{y_N,m}.S^s_{y_N,m}, \tag{165}$$

$$Nnext(s,1) = e^{\mu^s_{R,y_N+1}}, \tag{166}$$

and then

$$recruits(s, endyr+1) = Nnext(s,1), \tag{167}$$

$$totbiom(s, endyr+1) = \sum_{j=1}^{m} Nnext(s)_j.wt\_pop(s)_j. \tag{168}$$

- Nnext

Now OFL for the next year:

$$OFL(s) = \sum_{k_s} \sum_{j=1}^{m} wt\_fsh^{k_s}_{y_N,j}.Nnext(s)_j * Fatmp(k_s, j) * \frac{(1 - e^{-Ztmp^s_j})}{Ztmp^s_j},\ 1 \leq s \leq nstk, \tag{169}$$

where

$$seltmp_j(k) = sel\_fsh_j(k, endyr), \tag{170}$$

for $1 \leq k \leq$ nfsh and

$$Fatmp_j(k) = Fratio(k).Fmsy(s_k).seltmp_j(k),\ 1 \leq j \leq m, \tag{171}$$

$$Ztmp_j(s) = M^s_{y_0,j} + \sum_{k_s} Fatmp(k_s). \tag{172}$$

Get Future Fs:
Let stock s, a positive integer i and some iscenario.
Depending the value of iscenario:

- Caso iscenario=1.

$$F\_fut\_tmp_a(k) = F^k_{y_N,a}, \tag{173}$$

- Caso iscenario=2.

$$F\_fut\_tmp_a(k) = F^k_{y_N,a} * 0.75, \tag{174}$$

- Caso iscenario=3.

$$F\_fut\_tmp_a(k) = F^k_{y_N,a} * 1.25, \tag{175}$$

- Caso iscenario=4.

$$F\_fut\_tmp_a(k) = seltmp_a(k) * Fratio(k) * Fmsy(s), \tag{176}$$

  where $\mathrm{seltmp_a(k) = sel\_fsh_a(k, y_N)}$,

- Caso iscenario=5.

$$F\_fut\_tmp = 0.0 \tag{177}$$

for $1 \leq a \leq m$ and $1 \leq k \leq nfsh$.
It also calculates

$$F_{fut}{}^{k}_{i,a} = F\_fut\_tmp_a(k) \tag{178}$$

$$Z_{fut}{}^{s}_{i,a} = M^s_{y_N,a} + \sum_{k_s} F\_fut\_tmp_a(k_s) \tag{179}$$

and

$$S_{fut}{}^{s}_{i,a} = e^{-Z_{fut}{}^{s}_{i,a}}. \tag{180}$$

Future Projections
Here we calculate the future biomass $Sp\_Biom\_future^s_y$ for each stock s with $1 \leq s \leq nstk$ and $styr\_fut - a_R \leq y \leq endyr\_fut$, and different scenarios iscen with $1 \leq iscen \leq 5$, where $styr\_fut = y_N + 1$ if $nproj\_yrs > 0$ and else $styr\_fut = y_N$, and $endyr\_fut = y_N + nproj\_yrs$

$$Sp\_Biom\_future^s_y = \sum_{a=1}^{m} wt\_mat^s_a N^s_{y,a} (S^s_{y,a})^{s_f}, \tag{181}$$

$styr\_fut - a_R \leq y \leq styr\_fut - 1$.

Now for $y = styr\_fut$

$$Sp\_Biom\_future^s_{styr\_fut} = \sum_{a=1}^{m} wt\_mat^s_a . N_{fut}{}^{s}_{y,a} . (S_{fut}{}^{s}_{y,a})^{s\_f} \tag{182}$$

where

$$N_{fut}{}^{s}_{y,a} = N^s_{y_N,a-1} . S^s_{y_N,a-1},\ 2 \leq a \leq m-1, \tag{183}$$

$$N_{fut}{}^{s}_{y,m} = N^s_{y_N,m-1} . S^s_{y_N,m-1} + N^s_{y_N,m} . S^s_{y_N,m}, \tag{184}$$

and

$$N_{fut}{}^{s}_{y_N,1} = SRecruit(SB^s_{y_N-rec\_age}, cum\_reg(s) + yy\_sr(s, y_N)) . e^{\epsilon^s_{y_N}}. \tag{185}$$

Then for $styr\_fut + 1 \leq y \leq endyr\_fut$

$$Sp\_Biom\_future^s_y = \sum_{a=1}^{m} wt\_mat^s_a . N_{fut}{}^{s}_{y,a} . (S_{fut}{}^{s}_{y,a})^{s_f} \tag{186}$$

where

$$N_{fut}{}^{s}_{y,a} = N_{fut}{}^{s}_{y-1,a-1} . S_{fut}{}^{s}_{y-1,a-1},\ 2 \leq a \leq m-1, \tag{187}$$

$$N_{fut}{}^{s}_{y,m} = N_{fut}{}^{s}_{y-1,m-1} . s_{fut}{}^{s}_{y-1,a-1} + N_{fut}{}^{s}_{y,m} . S_{fut}{}^{s}_{y,m}, \tag{188}$$

and

$$N_{fut}{}^{s}_{y,1} = SRecruit(SB^s_{y-rec\_age}, cum\_reg(s) + yy\_sr(s, y_N)) . e^{\epsilon^s_y}. \tag{189}$$

On the other hand if iscen = 1, $N\_NoFsh^s_{y,a}$ and $Sp\_Biom\_NoFish^s_y$ are calculated for $y_N + 1 \leq y \leq endyr\_fut$, $1 \leq a \leq m$ and each stock s, as follows

$$N\_NoFsh^s_{y,1} = N_{fut}{}^{s}_{y,1} . \frac{SRecruit(Sp\_Biom\_NoFish(s, y - a_R), cum\_regs(s) + yy\_sr(s, y_N))}{SRecruit(Sp\_Biom\_future(s, y - a_R), cum\_regs(s) + yy\_sr(s, y_N))}, \tag{190}$$

$$N\_NoFsh^s_{y,a} = N\_NoFsh^s_{y-1,a-1} . e^{-mean(natmort(s))},\ 2 \leq a \leq m-1, \tag{191}$$

$$N\_NoFsh^s_{y,m} = N\_NoFsh^s_{y-1,m-1} . e^{-mean(natmort(s))} + N\_NoFsh^s_{y-1,m} . e^{-mean(natmort(s))}, \tag{192}$$

and

$$Sp\_Biom\_NoFish^s_y = \sum_{a=1}^{m} N\_NoFsh^s_{y,a}.(e^{-mean(natmort(s))})^{s_f}\, wt\_mat_a(s). \tag{193}$$

Now get catch at future ages i.e when styr_fut $\leq$ y $\leq$ endyr_fut. If iscen $\neq$ 5

$$catage\_future^s_{y,a} = \sum_{k_s} N_{fut}{}^{s}_{y,a}.F_{fut}{}^{k_s}_{y,a}.\frac{1 - S_{fut}{}^{s}_{y,a}}{Z_{fut}{}^{s}_{y,a}}, \tag{194}$$

$$catch\_future(s, iscen, y) = \sum_{k_s}\sum_{a=1}^{m} N_{fut}{}^{s}_{y,a}.F_{fut}{}^{k_s}_{y,a}.\frac{1 - S_{fut}{}^{s}_{y,a}}{Z_{fut}{}^{s}_{y,a}}.wt\_fsh^s_{y_N,a} \tag{195}$$

where $\sum_{k_s}$ represents the sum is over all fisheries k_s belonging to stock s.

The objective function obj_fun

The parameters of the model are chosen so that this value obj_comp is minimized. That is, it should be the negative of the log-likelihood.

$$\begin{gathered} obj\_fun = obj\_fun + sum(catch\_like) + sum(age\_like\_fsh) + sum(lenght\_like\_fsh) + sum(sel\_like\_fsh) + \\ sum(ind\_like) + sum(age\_like\_ind) + sum(lenght\_like\_ind) + \\ sum(sel\_like\_ind) + sum(rec\_like) + sum(fpen) + sum(post\_priors\_indp) + sum(post\_priors). \end{gathered} \tag{196}$$

Cat_Like

Cat_Like depends on the optimization phase.

- If current_phase() $>$ 3 (i.e if if the current optimization phase is greater than 3):

$$catch\_like(k) = \sum_{y=y_0}^{y_N} \frac{1}{2}\frac{(log(catch\_bio(k, y) + .0001) - log(pred\_catch(k, y) + .0001))^2}{catch\_bio\_lva(k, y)} \tag{197}$$

  for each fishery number k with 1 $\leq$ k $\leq$ nfsh.

- If current_phase() $\leq$ 3:

$$catch\_like(k) = catchbiomass\_pen.norm2(log(catch\_bio(k) + .000001) - log(pred\_catch(k) + .000001)). \tag{198}$$

  Finally, the Cat_Like is

$$Catch\_Like = catch\_like * catch\_pen. \tag{199}$$

  - catchbiomass_pen = 200, value given in the model.
  - catch_pen: catch_pen=0.1 if current_phase()=1, catch_pen=0.5 if current_phase()=2, catch_pen=0.8 if current_phase()=3, catch_pen=1 if current_phase()=4, catch_pen=5 if current_phase()=1, and in other cases catch_pen=1.
  - catch_bio_lva is the catch biomass variance (for lognormal).

– Cat_Like is the catch likelihood.

Rec_Like
This is calculated if rec_dev is active in the minimization phase.

$$sigmar = e^{log\_sigmar}, \tag{200}$$

$$sigmarsq(r) = (sigmar^{istk}_{ireg})^2, \;\; 1 \leq r \leq nregs, \tag{201}$$

where

- istk is the number of stock i.e $1 \leq$ istk $\leq$ nstk;
- ireg is the number of regime belonging at stock number istk.
- $\mathrm{sigmar}^{\mathrm{istk}}_{\mathrm{ireg}}$ es el valor de la posición rec_map(istk, ireg) del vector sigmar.
- log_sigmar is a parameter to be estimated. It is initialized with log_sigmarprior.

If the current optimization phase is more than 2 and in addition if it is the last phase, then

$$pred\_rec^s_i = SRecruit(Sp\_Biom^s_{i-rec\_age}, cum\_regs(s) + r) \tag{202}$$

where $1 \leq$ s $\leq$ nstk, $1 \leq$ r $\leq$ nreg(s) and yy_shift_st(s, r) $\leq$ i $\leq$ yy_shift_end(s, r).

- yy_shift_st is such that
$$yy\_shift\_st(s, 1) = styr\_rec$$
and
$$yy\_shift\_st(s, r) = reg\_shift(s, r-1), \; 2 \leq r \leq nreg(s)$$
where reg_shift is matrix input (line 41 of ctl file).
- yy_shift_end is such that
$$yy\_shift\_end(s, nreg(s)) = y_N$$
and
$$yy\_shift\_end(s, r-1) = reg\_shift(s, r-1) - 1, \; 2 \leq r \leq nreg(s).$$

On the other hand, if the current optimization phase is more than 2 but this is not the last phase, then

$$pred\_rec^s_i = 0.1 + SRecruit(Sp\_Biom^s_{i-rec\_age}, cum\_regs(s) + r), \tag{203}$$

where yy_shift_st(s, r) $\leq$ i $\leq$ yy_shift_end(s, r). Also we calculate

$$m\_sigmarsq(r) = \frac{norm2(chi(istk)(styr\_rec\_est(istk, ireg), endyr\_rec\_est(istk, ireg)))}{nrecs\_est\_shift(r)}, \tag{204}$$

$$m\_sigmar(r) = \sqrt{m\_sigmarsq(r)}. \tag{205}$$

where

$$chi(istk, yr\_rec\_est(r, j)) = log(mod\_rec(istk, yr\_rec\_est(r, j))) - log(pred\_rec(istk, yr\_rec\_est(r, j))), \tag{206}$$

with $1 \leq$ j $\leq$ nrecs_est_shift(r) and $1 \leq$ r $\leq$ nregs.

Now we calculate the rec_like. If the current phase is more than 4 or if it is the last phase then

$$rec\_like(istk,1) = \sum_{r=1}^{nregs} \left(\frac{\left(SSQRec(r) + \frac{m\_sigmarsq(r)}{2.} \right)}{(2 * sigmarsq(r))} + nrecs\_est\_shift(r) * log\_sigmar(rec\_map(istk, ireg)) \right). \tag{207}$$

Else

$$rec\_like(istk,1) = \sum_{r=1}^{nregs} 0.1* \left(\frac{\left(SSQRec(r) + \frac{m\_sigmarsq(r)}{2.} \right)}{(2 * sigmarsq(r))} + nrecs\_est\_shift(r) * log\_sigmar(rec\_map(istk, ireg)) \right). \tag{208}$$

If the current phase is the last then

- if $styr\_rec\_est(s,1) > styr\_rec$

$$rec\_like(s,4) = \sum_s \frac{1}{2} \frac{norm2(rec\_dev(s)(styr\_rec, styr\_rec\_est(s,1) - 1))}{sigmarsq(cum\_regs(s) + 1)} \tag{209}$$

$$+((styr\_rec\_est(s,1) - 1) - styr\_rec) * log(sigmar(rec\_map(s,1))).$$

  this sum is over all stocks number s such that $styr\_rec\_est(s,1) > styr\_rec$;

- if $endyr > endyr\_rec\_est(s, nreg(s))$

$$rec\_like(s,4) = \sum_s \frac{1}{2} \frac{norm2(rec\_dev(s)(endyr\_rec\_est(s, nreg(s)) + 1, endyr))}{sigmarsq(cum\_regs(s) + nreg(s))} + \tag{210}$$

$$(endyr - (endyr\_rec\_est(s, nreg(s)) + 1)) * log(sigmar(rec\_map(s, nreg(s)))).$$

  this sum is over the stocks number s such that $endyr > endyr\_rec\_est(s, nreg(s))$.

In addition, for $2 \leq r \leq nreg(s)$ and if $styr\_rec\_est(s,r) - 1) > endyr\_rec\_est(s, r - 1)$

$$rec\_like(s,4) = \sum_s \frac{1}{2} \frac{norm2(rec\_dev(s)(endyr\_rec\_est(s, r-1) + 1, styr\_rec\_est(s,r) - 1))}{sigmarsq(cum\_regs(s) + (r - 1))} \tag{211}$$

$$+((styr\_rec\_est(s,r) - 1) - (endyr\_rec\_est(s, r-1) + 1)) * log(sigmar(rec\_map(s, r-1))).$$

Else, i.e if the minimization phase is less than 2 and is not the last phase, then

$$rec\_like(istk,2) = \sum_{r_{istk}} \sum_{j=1}^{nrecs\_est\_shift(r)} (rec\_dev(istk, yr\_rec\_est(r,j)))^2, \tag{212}$$

where $\sum_{r_{istk}}$ is the sum over all the numbers of regimens that belong at stock istk.

With the last information we calculate the final value of Rec_Like(s,2):

$$Rec\_Like(s,2) = rec\_like(s,2) + norm2(rec\_dev(s)(styr\_rec\_est(s,1), y_N)). \tag{213}$$

And if the current phase is such that rec_dev_future is active then:

$$sigmar\_fut(s) = sigmar(rec\_map(s, nreg(s))), \tag{214}$$

$$rec\_like(s,3) = \sum_{stock\ s} \frac{norm2(rec\_dev\_future(s))}{(2*(sigmar\_fut(s))^2)} + size\_count(rec\_dev\_future(s)) * log(sigmar\_fut(s)). \quad (215)$$

Compute_priors

Let index number k ($1 \leq k \leq nind$),
(verificar suma y condicional if)

- if active(log_q_ind(k))

$$post\_priors\_indq_1(k) = \frac{\left(log\left(\frac{q\_ind(k,1)}{qprior(k)}\right)\right)^2}{(2.cvqprior^2(k))}, \quad (216)$$

  if not active then post_priors_indq$_1$(k)=0;

- if active(log_q_power_ind(k))

$$post\_priors\_indq_2(k) = \frac{\left(log\left(\frac{q\_power\_ind(k)}{q\_power\_prior(k)}\right)\right)^2}{(2.cvq\_power\_prior^2(k))}, \quad (217)$$

  if not active then post_priors_indq$_2$(k)=0;

- if active(log_rw_q_ind(k))

$$post\_priors\_indq_3(k) = \sum_{i=1}^{npars\_rw\_q(k)} \frac{(log\_rw\_q\_ind(k,i))^2}{(2.sigma\_rw\_q^2(k,i))} \quad (218)$$

  if not active then post_priors_indq$_1$(k)=0.

  Then

$$post\_priors\_indq(k) = post\_priors\_indq_1(k) + post\_priors\_indq_2(k) + post\_priors\_indq_3(k). \quad (219)$$

Let r such that $1 \leq r \leq nmort$,

- If active(Mest(r))

$$post\_priors_1(r,1) = \frac{\left(\frac{log(Mest(r)}{natmortprior(r)}\right)^2}{(2.cvnatmortprior^2(r))} \quad (220)$$

  else post_priors$_1$(r, 1) = 0.

- If active(Mage_offset(r))

$$post\_priors_2(r,1) = \frac{norm2(Mage\_offset(r))}{(2.cvnatmortprior^2(r))} \quad (221)$$

  else post_priors$_2$(r, 1) = 0, then

$$post\_priors(r,1) = post\_priors_1(r,1) + post\_priors_2(r,1). \quad (222)$$

Let the stock number s ($1 \leq s \leq nstk$)

- if active(M_rw(s))

$$post\_priors(s,1) = \sum_{i=1}^{npars\_rw\_M(s)} \frac{(M\_rw(s,i))^2}{(2.sigma\_rw\_M^2(s,i))}. \tag{223}$$

Let r such that $1 \leq$ r $\leq$ nrec

- if active(steepness(r))

$$post\_priors(r,2) = \frac{\left(log\left(\frac{steepness(r)}{steepnessprior(r)}\right)\right)^2}{(2.cvsteepnessprior^2(r))} \tag{224}$$

Let r such that $1 \leq$ r $\leq$ nrec

- if (active(log_sigmar(r)))

$$post\_priors(r,3) = \frac{\left(log\left(\frac{sigmar(r)}{sigmarprior(r)}\right)\right)^2}{(2.cvsigmarprior^2(r))}. \tag{225}$$

Let r such that $1 \leq$ r $\leq$ ngrowth:

- if (active(log_Linf(r)))

$$post\_priors(r,4) = \frac{(log\_Linf(r) - log\_Linfprior(r))^2}{(2.cvLinfprior^2(r))} \tag{226}$$

- if (active(log_k(r)))

$$post\_priors(r,5) = \frac{(log\_k(r) - log\_kprior(r))^2}{(2.cvkprior(r))} \tag{227}$$

- if (active(log_Lo(r)))

$$post\_priors(r,6) = \frac{(log\_Lo(r) - log\_Loprior(r))^2}{(2.cvLoprior^2(r))} \tag{228}$$

- if active(log_sdage(r))

$$post\_priors(r,7) = \frac{(log\_sdage(r) - log\_sdageprior(r))^2}{(2.cvsdageprior^2(r))}. \tag{229}$$

Fmort_Pen

- If (current_phase() < 3)

$$fpen(1) = norm2(F - 0.2) \tag{230}$$

- Else

$$fpen(1) = 0.0001.norm2(F - 0.2). \tag{231}$$

Sel_Like

Let the fishery number k.

- If logsel_p1_fsh(k) is active:

$$sel\_like\_fsh(k,3) = \frac{1}{2}(logsel\_p1\_fsh(k,1))^2 + \frac{1}{10}(logsel\_p2\_fsh(k,1))^2 + (logsel\_p3\_fsh(k,1))^2 \quad (232)$$
$$+ \sum_i \left(\frac{1}{10}(logsel\_p1\_fsh(k,i))^2 + \frac{1}{10}(logsel\_p2\_fsh(k,i))^2 + 5.0.(logsel\_p3\_fsh(k,i))^2 \right),$$

  where the last sum is over i such that $2 \leq i \leq$ n_sel_ch_fsh(k).

  On the other hand

$$sel\_like\_fsh(k,2) = \sum_i \frac{0.5 * norm2(log\_sel\_fsh(k,iyr-1) - log\_selfsh(k,iyr))}{(sel\_sigma\_fsh(k,i))^2},\ 2 \leq i \leq n\_sel\_ch\_fsh(k), \quad (233)$$

  where iyr = yrs_sel_ch_fsh(k, i).

- If log_selcoffs_fsh(k) is active:

$$sel\_like\_fsh(k,1) = \sum_{iyr} curv\_pen\_fsh(k).norm2(first\_difference(first\_difference(log\_sel\_fsh(k,iyr)))), \quad (234)$$

  where iyr = yrs_sel_ch_fsh(k, i) for each $1 \leq i \leq$ n_sel_ch_fsh(k).

  If $i > 1$, then:

$$sel\_like\_fsh(k,2) = 0.5 * \frac{norm2(log\_sel\_fsh(k,iyr-1) - log\_sel\_fsh(k,iyr))}{(sel\_sigma\_fsh(k,i))^2}. \quad (235)$$

  Now for seldecage $\leq j \leq$ nselages_fsh(k):

$$difftmp = log\_sel\_fsh(k,iyr,j-1) - log\_sel\_fsh(k,iyr,j), \quad (236)$$

  if difftmp > 0, then

$$sel\_like\_fsh(k,3) += 0.5 * \frac{(difftmp)^2}{seldec\_pen\_fsh(k)}. \quad (237)$$

  and

$$obj\_fun += 20.(avgsel\_fsh(k,i))^2. \quad (238)$$

Now, let index number k (i.e $1 \leq k \leq$ nind):

- If log_selcoffs_ind(k) is active

$$sel\_like\_ind(k,1) += curv\_pen\_ind(k) * norm2(first\_difference(first\_difference(log\_sel\_ind(k,iyr)))); \quad (239)$$

  where iyr = yrs_sel_ch_ind(k, i) for each $1 \leq i \leq$ n_sel_ch_ind(k), and nagestmp = nselages_ind(k).
  If $i > 1$:

$$sel\_like\_ind(k,2) += .5 * norm2(log\_sel\_ind(k,iyr-1) - log\_sel\_ind(k,iyr))/(sel\_sigma\_ind(k,i))^2. \quad (240)$$

  Let

$$difftmp = log\_sel\_ind(k,iyr,j-1) - log\_sel_ind(k,iyr,j), \quad (241)$$

if difftmp > 0 then

$$sel\_like\_ind(k,3) += 0.5 * \frac{(difftmp)^2}{seldec\_pen\_ind(k)} \tag{242}$$

and

$$obj\_fun += 20.0 * (avgsel\_ind(k,i))^2. \tag{243}$$

Srv_Like

$$ind\_like(k) = \sum_{i=1}^{nyrs\_ind(k)} \frac{(log(obs\_ind(k,i)) - log(pred\_ind(k,i)))^2}{(2.obs\_lse\_ind^2(k,i))} \tag{244}$$

Age_Like

$$age\_Like\_fsh(k) = \left(\sum_{i=1}^{nyrs\_fsh\_age(k)} -n\_sample\_fsh\_age(k,i).(oac\_fsh(k,i)+0.001).log(eac\_fsh(k,i)+0.001)\right) - offset\_fsh(k). \tag{245}$$

$$lenght\_like\_fsh(k) = \left(\sum_{i=1}^{nyrs\_fsh\_lenght(k)} -n\_sample\_fsh\_lenght(k,i).(olc\_fsh(k,i)+0.001).log(elc\_fsh(k,i)+0.001)\right) - offset\_lfsh(k). \tag{246}$$

$$length\_like\_ind(k) = \left(\sum_{i=1}^{nyrs\_ind\_lenght(k)} -n\_sample\_ind\_lenght(k,i).(olc\_ind(k,i)+0.001).log(elc\_ind(k,i)+0.001)\right) - offset\_lind(k). \tag{247}$$

$$age\_like\_ind(k) = \left(\sum_{i=1}^{nyrs\_ind\_age(k)} -n\_sample\_ind\_age(k,i).(oac\_ind(k,i)+0.001).log(eac\_ind(k,i)+0.001)\right) - offset\_ind(k). \tag{248}$$

Function dvariable get_spr_rates(double spr_percent,int istk)

Let $\mathrm{sel\_tmp}_j^k$ for each fishery k and age j:

$$sel\_tmp_j^k = sel\_fsh_{y_N,j}^k \tag{249}$$

for each fishery k belonging at stock istk. Then let

$$Fratio(k) = \sum_{age\ j} F_{y_N,j}^k, \tag{250}$$

$$sumF(s) = \sum_{k_s} Fratio(k_s), 1 \leq s \leq nstk, \tag{251}$$

finally

$$Fratio(k) = \frac{\sum_{age\ j} F^k_{y_N,j}}{sumF(s_k)}, 1 \leq k \leq nfsh. \tag{252}$$

Use Newton Raphson method with 6 iterations to find the root of:

$$dyld = \frac{(yld2 - yld3)}{2 * df} \tag{253}$$

with second derivative:

$$dyldp = \frac{(yld3 - (2 * yld1) + yld2)}{df * df}, \tag{254}$$

iterations over

$$F1 = F1 - \frac{dyld}{dyldp},$$

where the initial value is F1 = 0.8 $*$ natmortprior(mort_map(istk, 1)) and

$$F2 = F1 + df,$$

$$F3 = F1 - df,$$

$$yld1 = -1000 * \left(log \left(\frac{spr\_percent}{spr\_ratio(F1, sel\_tmp, styr, istk)} \right) \right)^2,$$

$$yld2 = -1000 * \left(log \left(\frac{spr\_percent}{spr\_ratio(F2, sel\_tmp, styr, istk)} \right) \right)^2,$$

$$yld2 = -1000 * \left(log \left(\frac{spr\_percent}{spr\_ratio(F3, sel\_tmp, styr, istk)} \right) \right)^2.$$

This function returns F1 after the 6 iterations.

FUNCTION dvariable spr_ratio(dvariable trial_F,dvar_matrix sel_tmp,int iyr,int istk)

Let for each age j:

$$srvtmp(j) = e^{-(\sum_k sel_tmp^k_j * trial\_F * Fratio^k) - M^{istk}_{iyr,j}}. \tag{255}$$

Then let $Ntmp_1$ = 1,

$$Ntmp_j = Ntmp_{j-1} * srvtmp_{j-1},\ 2 \leq j < nages. \tag{256}$$

Now for j = nages:

$$Ntmp_{nages} = Ntmp_{nages-1} * \frac{srvtmp(nages - 1)}{(1. - srvtmp(nages))}. \tag{257}$$

$$SBtmp = wt\_mature(istk, j) * srvtmp(j)^{spmo\_frac} + \sum_{j=2}^{nages-1} Ntmp(j) * wt\_mature(istk, j) * srvtmp(j)^{spmo\_frac} \tag{258}$$

$$+Ntmp_{nages} * wt\_mature(istk, nages) * srvtmp(nages)^{spmo_frac}.$$

Finally this function returns

$$\frac{SBtmp}{phizero(cum\_regs(istk) + yy\_sr(istk, iyr))}. \tag{259}$$

FUNCTION dvariable spr_unfished(int istk,int i)

Let $Ntmp_1$ = 1 and then

$$Ntmp_j = Ntmp_{j-1} * e^{-M(istk,j)}.$$

Finally

$$Ntmp = \frac{Ntmp_{nages-1}}{(1. - exp(-M(istk, i, nages)))}, \tag{260}$$

and

$$SBtmp = \sum_j Ntmp_j * wt\_mature(istk, j) * e^{-spmo\_frac*M(istk,i,j)} \tag{261}$$

$$+Ntmp * wt\_mature(istk, nages) * exp(-spmo\_frac * M(istk, i, nages)).$$

This function returns SBtmp.

FUNCTION compute_spr_rates

FUNCTION void writerep(dvariable& tmp,adstring& tmpstring)
FUNCTION dvariable SolveF3(const int& iyr, const dvar_vector& N_tmp, const double& TACin, const int& istk)
FUNCTION dvariable SolveF2(const int& iyr, const dvar_vector& N_tmp, const double& TACin, const int& istk)
FUNCTION dvar_vector SolveF2(const int& iyr, const dvector& Catch, const int& istk)
FUNCTION Write_SimDatafile

FUNCTION double mn_age(const dvector& pobs)

$$mobs = (pobs * age\_vector) \tag{262}$$

This function returns mobs.

FUNCTION double mn_age(const dvar_vector& pobs)

$$mobs = value(pobs * age\_vector). \tag{263}$$

This function returns mobs.

FUNCTION double Sd_age(const dvector& pobs)

$$mobs = (pobs * age\_vector), \tag{264}$$

$$stmp = sqrt((elem\_prod(age\_vector, age\_vector) * pobs) - mobs * mobs). \tag{265}$$

This function returns stmp.
FUNCTION double mn_length(const dvector& pobs)

$$mobs = (pobs * len\_bins), \tag{266}$$

this function returns mobs.
FUNCTION double mn_length(const dvar_vector& pobs)

$$mobs = value(pobs * len\_bins), \tag{267}$$

this function returns mobs.

FUNCTION double Sd_length(const dvector& pobs)

$$mobs = (pobs * len\_bins), \tag{268}$$

$$stmp = sqrt((elem\_prod(len\_bins, len\_bins) * pobs) - mobs * mobs), \tag{269}$$

this function returns stmp.

FUNCTION double Eff_N_adj(const double, const dvar_vector& pobs, const dvar_vector& phat)

$$av = age\_vector(lb1, ub1), \tag{270}$$

$$mobs = value(pobs * av), \tag{271}$$

$$mhat = value(phat * av), \tag{272}$$

$$rtmp = mobs - mhat, \tag{273}$$

$$stmp = value(sqrt(elem\_prod(av, av) * pobs - mobs * mobs)), \tag{274}$$

this function returns $\frac{\text{stmp}^2}{\text{rtmp}^2}$.

FUNCTION double Eff_N2(const dvector& pobs, const dvar_vector& phat)

$$av = age\_vector(lb1, ub1), \tag{275}$$

$$mobs = (pobs * av), \tag{276}$$

$$mhat = value(phat * av), \tag{277}$$

$$rtmp = mobs - mhat, \tag{278}$$

$$stmp = (sqrt(elem\_prod(av, av) * pobs - mobs * mobs)), \tag{279}$$

this function returns $\frac{\text{stmp}^2}{\text{rtmp}^2}$.

FUNCTION double Eff_N(const dvector& pobs, const dvar_vector& phat)

$$rtmp = elem\_div((pobs - phat), sqrt(elem\_prod(phat, (1 - phat)))), \tag{280}$$

$$vtmp = value(norm2(rtmp)/size\_count(rtmp)), \tag{281}$$

this function returns $\frac{1}{\text{vtmp}}$.

FUNCTION double Eff_N2_L(const dvector& pobs, const dvar_vector& phat)

$$av = len\_bins, \tag{282}$$

$$mobs = (pobs * av), \tag{283}$$

$$mhat = value(phat * av), \tag{284}$$

$$rtmp = mobs - mhat, \tag{285}$$

$$stmp = (sqrt(elem\_prod(av, av) * pobs - mobs * mobs)), \tag{286}$$

this function returns $\frac{\text{stmp}^2}{\text{rtmp}^2}$.

FUNCTION double get_AC(const int& indind)

FUNCTION double sdnr(const dvar_vector& pred,const dvector& obs,double m)
FUNCTION double calc_Francis_weights(const dmatrix oac, const dvar_matrix eac, const ivector sam)

2.5 Models for stock structure hypothesis

The JJM model allows the exploration of two types of population structure. This allow the construction of models under the one-stock hypothesis "h1" and under the two-stock hypothesis "h2".

2.6 Description of Model Explorations

Model implementation could allow to analyse the effect of stock structure hypothesis, model updates and data revisions, changes in selectivity for a specific year, shift in the distribution of fishing effort, among others.

3 Model parameters

3.1 Estimable parameters

Para ajustar el modelo a los datos observados se estiman ciertos parámetros de manera que sus predicciones coincidan con las observaciones lo mejor posible. Los parámetros a estimar pueden tener predeterminado su fase de activación, luego si este es negativo quiere decir que el parámetro no es estimado en el modelo y por lo tanto toma un valor constante. Los parámetros estimables del JJM son los siguientes

3.1.1 Biological Parameters

- init_bounded_number_vector Mest(1,nmort,.02,4.8,phase_M)
- init_bounded_vector_vector Mage_offset(1,nmort,1,npars_Mage,-3,3,phase_Mage)
- init_bounded_vector_vector M_rw(1,nstk,1,npars_rw_M,-10,10,phase_rw_M)

3.1.2 Growth Parameters

- init_number_vector log_Linf(1,ngrowth,phase_Linf)
- init_number_vector log_k(1,ngrowth,phase_k)
- init_number_vector log_Lo(1,ngrowth,phase_Lo)
- init_number_vector log_sdage(1,ngrowth,phase_sdage)

3.1.3 Stock rectuitment params

- init_number_vector mean_log_rec(1,nregs,phase_mean_rec)
- init_bounded_number_vector steepness(1,nrec,0.21,Steepness_UB,phase_srec)

- init_number_vector log_Rzero(1,nregs,phase_Rzero)
- init_bounded_matrix rec_dev(1,nstk,styr_rec,endyr,-15,15,2)
- init_number_vector log_sigmar(1,nrec,phase_sigmar)
-

3.1.4 Fishing mortality parameters

- init_bounded_matrix fmort(1,nfsh,styr,endyr,-15,15.,phase_fmort)
- init_matrix_vector log_selcoffs_fsh(1,nfsh,1,n_sel_ch_fsh,1,nselages_fsh,phase_selcoff_fsh)
- init_matrix_vector log_sel_spl_fsh(1,nfsh,1,n_sel_ch_fsh,1,4,phase_sel_spl_fsh)
- init_vector_vector logsel_slope_fsh(1,nfsh,1,n_sel_ch_fsh,phase_logist_fsh)
- init_vector_vector sel50_fsh(1,nfsh,1,n_sel_ch_fsh,phase_logist_fsh)
- init_vector_vector logsel_p1_fsh(1,nfsh,1,n_sel_ch_fsh,phase_dlogist_fsh)
- init_vector_vector logsel_p2_fsh(1,nfsh,1,n_sel_ch_fsh,phase_dlogist_fsh)
- init_bounded_vector_vector logsel_p3_fsh(1,nfsh,1,n_sel_ch_fsh,-10,10,phase_dlogist_fsh)
- init_matrix rec_dev_future(1,nstk,styr_fut,endyr_fut,phase_proj)

3.1.5 Survey Observation parameters

- init_number_vector log_q_ind(1,nind,phase_q)
- init_number_vector log_q_power_ind(1,nind,phase_q_power)
- init_vector_vector log_rw_q_ind(1,nind,1,npars_rw_q,phase_rw_q)
- init_matrix_vector log_selcoffs_ind(1,nind,1,n_sel_ch_ind,1,nselages_ind,phase_selcoff_ind)
- init_vector_vector logsel_slope_ind(1,nind,1,n_sel_ch_ind,phase_logist_ind+1)
- init_bounded_vector_vector sel50_ind(1,nind,1,n_sel_ch_ind,0,nages,phase_logist_ind)
- init_vector_vector logsel_p1_ind(1,nind,1,n_sel_ch_ind,phase_dlogist_ind)
- init_vector_vector sel_p2_ind(1,nind,1,n_sel_ch_ind,phase_dlogist_ind)
- init_vector_vector logsel_p3_ind(1,nind,1,n_sel_ch_ind,phase_dlogist_ind)

3.2 Initialization Section

Here we give the values with which some parameters to be estimated are initialized in the model.

Mest	natmortprior
steepness	steepnessprior
log_sigmar	log_sigmarprior
log_Rzero	R_guess
mean_log_rec	R_guess
log_Linf	log_Linfprior
log_k	log_kprior
log_Lo	log_Loprior
log_sdage	log_sdageprior
log_q_ind	log_qprior
log_q_power_ind	log_q_power_prior
sel50_fsh	sel_inf_in_fshv
logsel_p1_fsh	logsel_p1_in_fshv
logsel_p2_fsh	logsel_p2_in_fshv
logsel_p3_fsh	logsel_p3_in_fshv
logsel_p1_ind	logsel_p1_in_indv
sel_p2_ind	sel_p2_in_indv
logsel_p3_ind	logsel_p3_in_indv
logsel_slope_ind	logsel_slp_in_indv
sel50_ind	sel_inf_in_indv

Calculation of initialization values

$$log\_sigmarprior = log(sigmarprior) \tag{287}$$

$$R\_guess \tag{288}$$

$$log\_Linfprior = log(Linfprior) \tag{289}$$

$$log\_kprior = log(kprior) \tag{290}$$

$$log\_Loprior = log(Loprior) \tag{291}$$

$$log\_sdageprior = log(sdageprior) \tag{292}$$

$$log\_qprior = log(qprior) \tag{293}$$

$$log\_q\_power\_prior = log(q\_power\_prior) \tag{294}$$

$$sel\_inf\_in\_fshv \tag{295}$$

$$logsel\_p1\_in\_fshv \tag{296}$$

$$logsel\_p2\_in\_fshv \tag{297}$$

$$logsel\_p1\_in\_indv \tag{298}$$

$$sel\_p2\_in\_indv \tag{299}$$

$$logsel\_p3\_in\_indv \tag{300}$$

$$logsel\_slp\_in\_indv \tag{301}$$

$$sel\_inf\_in\_indv \tag{302}$$

4 Data files

Line in the .dat file	Name in .dat file	Name in the User Guide	Tpl name	Definition
3	years	y_0	styr	year of start of observation
4	years	y_N	endyr	end year of observation
6	ages	a_R	rec_age	recruitment age
7	ages		oldest_age	oldest age
9	nbins		n_lenght	number of sizes considered
10	lengthbin		len_bin	
12	Fnum		nfsh	
14	Fnames		fshnameread	
16	Fcaton		catch_bio_in	
19	Fcatonerr		catch_bio_sd_in	
21	FnumyearsA		nyrs_fsh_age	
23	FnumyearsL		nyrs_fsh_lenght	
25	Fageyears		yrs_fsh_age_in	
27	Flenghtyears		yrs_fsh_lenght_in	
29	Fagesample		n_sample_fsh_age_in	
31	Flenghtsample		n_sample_fsh_lenght_in	
33	Fagecomp		oac_fsh_in	
36	Flenghtcomp		olc_fsh_in	
80	Fwtatage		wt_fsh	
134	Inum		nind	
136	Inames		indnameread	
138	Inumyears		nyrs_ind	
141	Iyears		yrs_ind_in	
144	Imonths		mo_ind	
147	Index		obs_ind_in	
150	Indexerr		obs_se_ind_in	
153	Inumageyears		nyrs_ind_age	
156	Inumlenghtyears		nyrs_ind_lenght	
159	Iyearsage		yrs_ind_age_in	
161	Iagesample		s_sample_ind_age_in	
163	Ipropage		oac_ind_in	
165	Iyearslenght		syrs_ind_lenght_in	
167	Ilenghtsample		n_sample_ind_lenght_in	
169	Iproplenght		olc_ind_in	
171	Iwtatage		wt_ind	
278	Pspwn		spawnmo	
280	Pageerr		age_err	

4.1 Fishery data

- Catch data: This model uses the catch data for each of the fleet as part of the model representation.

- Length and age data: the age data is also an important input for the JJM model. But in the case any fleet is using length distribution data, this information in converted into age distributions by using age-length keys. The age-length keys is fleet dependent.

- CPUE (catch per unit effort) data series are used in the model, each fleet with a specific methodology for CPUE estimation. Besides, since 2022 the CPUE series include a factor that compensates for efficiency (also termed ”effort creep”) increases of fishing operations.

4.2 Fishery independent data

The model also allow the use of relative abundance indices such as for example acoustic biomass and numbers, spawning stock biomass, estimates of abundance and numbers-at-age, egg surveys results, among others. This information comes from hydro-acoustics, stock assessment and egg and larvae surveys. This information is also fleet-dependent.

4.3 Biological parameters

- The JJM model requires the maturity-at-age for the Jack mackerel. This parameter can be estimated by applying an ageing criteria to the otoliths and histological maturity data.

- On the other hand, for fleets that are using length data and age-length keys to convert length to age data, to fit the length composition data a growth curve is used to convert age composition predicted by the model to predicted lengths, with the conversion occurring withing the model.

- The model needs the growth parameters and in this case the JJM model uses the von Bertalanffy growth model. For the model under development is important to consistently use the same length metric for parameters and data, i.e. total length or fork length for model parameters and data.

- The mean weight-at-age will be calculated by year by taking the mean length-at-age in the catch and a length-weight relationship derived for the year. Mean weight-at-age is required for all fishing fleets and biomass indices in order to relate biomass quantities to the underlying model estimates of jack mackerel abundance (in numbers). In some cases, missing weight-at-age data could be replaced with data from the previous year. However, it is recommended that those missing data be replaced with appropriate mean values by fleet instead.

- The natural mortality is also required for the JJM model. For this, the (Natural Mortality Tool) could be used.

4.4 Data sets

A full description of data sets used to the assessment of Jack mackerel is in the Annex X. Summaries of all data available for the assessment are provided in Table X and Figure Y.

5 Getting started

6 File organization

7 Starting the JJM model

8 Configuration files

Line in the .ctl file	Name in .ctl file	Name in the User Guide	Tpl name	Definition
5	Number of stocks	nstk	nstk	number of stocks
6	Names of stocks		stknameread	
8	Selectivity sharing vector		sel_map	
15	Number of regimes		nreg	
17	Sr_type		SrType	
19	AgeError		use_age_err	
21	Retro		retro	
23	Recruitment sharing matrix		rec_map	
26	Steepness		steepnessprior	
27	Steepness		cvsteepnessprior	
28	Steepness		phase_srec	
30	SigmaR		sigmarprior	
31	SigmaR		cvsigmarprior	
32	SigmaR		phase_sigmar	
33	phase_Rzero		phase_Rzero	
35	Nyrs_sr		nrecs_est_shift	
38	yrs_sr		yr_rec_est	
41	reg_shifts		reg_shift	
43	Growth parameters sharing matrix		growth_map	
46	Linf		Linfprior	
47	Linf		cvLinfprior	
48	Linf		phase_Linf	
50	K		kprior	
51	K		cvkprior	
52	K		phase_k	
54	Lo_Len		Loprior	
55	Lo_Len		cvLoprior	
56	Lo_Len		phase_Lo	
58	Sigma_len		sdageprior	
59	Sigma_len		cvsdageprior	
60	Sigma_len		phase_sdage	
61	Mortality sharing matrix		mort_map	
64	Natural_Mortality		natmortprior	
65	Natural_Mortality		cvnatmortprior	
66	Natural_Mortality		phase_M	
67	NEW npars_mage		npars_Mage	
69	NEW ages_M_changes		ages_M_changes	
71	NEW Mage_in		Mage_in	
73	phase_Mage		phase_Mage	
75	Phase_Random_walk_M		phase_rw_M	
77	Nyrs_Random_walk_M		npars_rw_M	
79	Random_walk_M_yrs		yrs_rw_M	
81	Random_walk_M_sigmas		sigma_rw_M	

Line in the .ctl file	Name in .ctl file	Name in the User Guide	Tpl name	Definition
84	catchability		qprior	
85	catchability		cvqprior	
86	catchability		phase_q	
88	q_power		q_power_prior	
89	q_power		cvq_power_prior	
90	q_power		phase_q_power	
91	Random_walk_q_phases		phase_rw_q	
93	Nyrs_Random_walk_q		npars_rw_q	
95	Random_walk_q_yrs		yrs_rw_q	
97	Random_walk_q_sigmas		sigma_rw_q	
99	q_agemin		q_age_min	
102	q_agemax		q_age_max	
103	use vb wt age		use_vb_wt_age	
105	n_proj_yrs		nproj_yrs	
109	Fishery #		fsh_sel_opt	
110	Fishery #		nselages_in_fsh	
111	Fishery #		phase_sel_fsh	
112	Fishery #		curv_pen_fsh	
113	Fishery #		seldec_pen_fsh	
115	Years of selectivity		s_sel_ch_fsh	
116	Years of selectivity		yrs_sel_ch_fsh	
117	Years of selectivity		sel_sigma_fsh	
119	Initial values for coeff.		sel_fsh_tmp	
123	Index #		ind_sel_opt	
124	Index #		nselages_in_ind	
125	Index #		phase_sel_ind	
126	Index #		curv_pen_fsh	
127	Index #		seldec_pen_ind	
128	Index #			
129	Index #		sel_ind_tmp	
140	Population weight at age 1000		wt_pop	
143	Maturity at Age		maturity	
146	Test		test	

- Input Data File, model name, Number of stocks, Names of stocks, Selectivity sharing vector, (number_fisheries + number_surveys), Number of regimes (by stock), Sr_type, AgeError, Retro, Recruitment sharing matrix (number_stocks, number_regimes), Steepness, SigmaR, phase_Rzero, Nyrs_sr, yrs_sr, reg_shifts blank if nreg==1, Growth parameters sharing matrix (number_stocks, number_regimes), Linf, K, Lo_Len, Sigma_len, Mortality sharing matrix number_stocks, number_regimes), Natural_Mortality, npars_mage, ages_M_changes, Mage_in, phase_Mage, Phase_Random_walk_M, Nyrs_Random_walk_M, Random_walk_M_yrs blank if nyrs==0, Random_walk_M_sigmas blank if nyrs==0, catchability, q_power, Random_walk_q_phases, Nyrs_Random_walk_q, Random_walk_q_yrs blank if nyrs==0, Random_walk_q_sigmas blank if nyrs==0, q_agemin, q_agemax, use vb wt age, n_proj_yrs, Select type for fshry 1, n_sel_ages, phase sel, curvature penalty, Dome-shape penalty, Years of selectivity change Fishery 3 Peru, n_sel_ch_fsh, yrs_sel_ch_fsh, sel_sigma_fsh, Initial values for coefficitients at each change (one for every change plus 1), Initial values for parameters, Index number 5 Acoustic_Peru, SelOption, n_sel_ages, phase sel, curvature penalty, Dome-shape penalty, n_sel_ch_ind, yrs_sel_ch_ind, sel_sigma_ind, Initial values for parameters, Population Weight at Age 1000, Maturity at Age, Test.

9 Model outputs

To analyse the stock status the JJM model provides a big set of model outputs such as: the biomass of the population, the spawning stock biomass (SSB) and the recruitment over the time. Also, the management reference points such as: B_{MSY} and F_{MSY} over the time (years).

The fishery mean weights-at-age?, estimates of numbers-at-age?, fits to the composition data, fits of age composition data from the surveys, fit of the indices, relative abundance, estimates of fishery mean age compositions, survey mean age compositions.

Time series stock status: spawning biomass, fishing mortality, recruitment, total biomass, for each hypothesis.

10 Bibliography

11 Miscellaneous

12 Parameter index

13 Appendix A: Case study description

14 Appendix B: Assessment results of case study