Gadget for 9a South (WKPELA 2018)

Margarita María Rincón[a,*], Fernando Ramos[b], Andrés Uriarte[c], Susana Garrido[d], Alexandra Silva[e]

[a]*Department of Coastal Ecology and Management, Instituto de Ciencias Marinas de Andalucía, Consejo Superior de Investigaciones Científicas, Avda República Saharaui 2, 11519 Puerto Real, Cádiz, Spain*
[b]*Instituto Español de Oceanografía, Centro Oceanográfico de Cádiz, Puerto pesquero, Muelle de Levante s/n, Apdo. 2609, 11006 Cádiz, Spain*
[c]*AZTI, Spain*
[d]*IPMA, Portugal*
[e]*IPMA, Portugal*

1. Model Description

Gadget is an age-length-structured model that integrates different sources of information in order to produce a diagnose of the stock dynamics. It works making forward simulations and minimizing an objective (negative log-likelihood) function that measures the difference between the model and data, the discrepancy is presented as a likelihood score for each time period and model component.

The general Gadget model description and all the options available can be found in Gadget manual (Begley, 2004) and some specific examples can be found in Taylor et al. (2007), Elvarsson et al. (2014) and WKICEMSE assessment for Ling (Elvarsson, 2017). The latest was used as a guide for this document.

The Gadget model implementation consists in three parts, a simulation of biological dynamics of the population (simulation model), a fitting of the model to observed data using a weighted log-likelihood function (observation model) and the optimization of the parameters using different iterative algorithms.

A list of the symbols used and a graph with the Gadget model structure are presented in Table 1 and a prezi canvas available at `http://prezi.com/j8rinhq5kstg/?utm_campaign=share&utm_medium=copy`, respectively.

1.1. Simulation model

The model consists of one stock component of anchovy (*Engraulis encrasicolus*) in the ICES subdivision, 9.a South-Atlantic Iberian waters, Gulf of Cádiz. Gadget works by keeping track of the number of individuals, $N_{a,l,y,t}$, at age $a = 0, \dots, 3$, at length $l = 3, 3.5, 4, 4.5, \dots, 22$, at year $y = 1989, \dots, 2016$, and each year divided into quarters $t = 1, \dots, 4$.. The last time step of a year involves increasing the age by one year, except for the last age group, which its age remains unchanged and the age group next to is added to it, like a 'plus group' including all ages from the oldest age onwards (Taylor et al., 2007).

*Corresponding author
Email addresses: `margarita.rincon@icman.csic.es` (Margarita María Rincón), `fernando.ramos@cd.ieo.es` (Fernando Ramos)

Growth

The growth function is a simplified version of the Von Bertalanffy growth equation, defined in Begley (2004) as the LengthVBSimple Growth Function (*lengthvbsimple*). Length increase for each length group of the stock is given by the equation below:

$$\Delta l = (l_\infty - l)(1 - e^{k\Delta t}), \tag{1}$$

where Δt is the length of the timestep, $l_\infty = 19\ cm$ (fixed) is the terminal length and k is the growth rate parameter.

The corresponding increase in weight (in Kg) of the stock is given by:

$$\Delta w = a((l + \Delta l)^b - l^b), \tag{2}$$

with $a = 3.128958e^{-6}$ and $b = 3.277667619$ set as fixed and extracted from all the samples available in third and fourth quarters from 2003 to 2017. The growth functions described above calculate the mean growth for the stock within the model. In a second step the growth is translated into a beta-binomial distribution of actual growths around that mean with parameters β and n. The first is fitted by the model as described in Taylor et al. (2007) and the second represents the number of length classes that an individual is allowed to grow in a quarter and it is fixed and equal to 5.

Initial abundance and recruitment

Stock population in numbers at the starting point of the simulation is defined as:

$$N_{a,l,1,1} = 10000\nu_a q_{a,l}, \quad a = 0, \dots, 3, l = 3, \dots, 20$$

Where ν_a is an age factor to be calculated by the model and $q_{a,l}$ is the proportion at lengthgroup l that is determined by a normal density with a specified mean length and standard deviation for each age group. Mean length at age (μ_a) and its standard deviation (σ_a) were extracted from all the data available from 1989 to 2016 including three surveys that are not included in the model: ARSA, ECOCADIZ-RECLUTAS and SAR survey (See table 1). The mean weight at age for this initial population is calculated by multiplying a reference weight corresponding to the length by a relative condition factor assumed as 1. This reference weight at length was calculated using the formula $w = al^b$, with a and b as defined before. In Gadget files this was specified as a normal condition distribution (*Normalcondfile*).

Similarly to the process of calculate the initial abundance described above, the recruitment specifies how the stock will be renewed. Recruits enter to the age 0 population at quarters 2, 3, 4 (because of the Gadget order of calculations for each time step this is equivalent to have recruitment one quarter later, i.e. in quarters 3,4 and 1 of the next year) of all years, respectively, as follows:

$$N_{0,l,y,t} = p_{l,t} R_{y,t}, \quad t = 2, 3, 4, l = 3, \dots, 15,$$

where $R_{y,t}$ represents recruitment at year y and quarter t, and $p_{l,t}$ the proportion in lengthgroup l that is recruited at quarter t which is sampled from a normal density with mean (μ) and standard deviation (σ_t) calculated by the model. The mean weight for these recruits is calculated by multiplying the reference weight corresponding to the length by a relative condition factor assumed as 1. Reference weight at age was the same used to calculate the initial population mean weight at age explained above. In Gadget files this was specified also as a normal condition distribution (*Normalcondfile*).

Fleet operations

In the model the fleets act as predators. There are three fleets inside the model: two for surveys (ECOCADIZ acoustic survey and PELAGO acoustic survey) and one for commercial landings including all fleets: Spanish purse-seine, trawlers, Portuguese purse-seine, and others. The main fleet is Spanish purse-seine representing more than a 90 % of all the catches from 2001 to 2016 and more than a 80 % from 1989 to 2000. It is also the only fleet with a lenght distribution available, then we decide to include all commercial reported data in the same fleet which is mostly the Spanish purse-seine.

Surveys fleets are assumed to remove 1 Kg in each of the quarters when the surveys take place while the commercial fleet is assumed to remove the reported number of individuals each quarter. This total amount of biomass (for the surveys) or numbers (for the commercial fleet) landed is then split between the length groups according to the equations 3 and 4 respectively, as follows:

$$C_{l,y,t} = \frac{E_{y,t} S_{l,T} N_{l,y,t} W_l}{\sum\limits_{l} S_{l,T} N_{l,y,t} W_l}, \tag{3}$$

and

$$C_{l,y,t} = \frac{E_{y,t} S_{l,T} N_{l,y,t}}{\sum\limits_{l} S_{l,T} N_{l,y,t}}, \tag{4}$$

where $E_{y,t}$ represents biomass landed (in Kg) at year y and quarter t in equation 3 and numbers landed in equation 4, W_l corresponds to weight at length and $S_{l,T}$ represents the suitability function that determines the proportion of prey of length l that the fleet is willing to consume during period $T, T = 1, 2, 3$ where $T = 1$ corresponds to the period 1989-2000, $T = 2$ to 2001-2016 and $T = 3$ to 1989-2016.

For this model the suitability function chosen for the fleet and surveys is specified in Gadget manual as an ExponentialL50 function (*expsuitfuncl50*), and it is defined as follows:

$$S_{l,T} = \frac{1}{1 + e^{\alpha_T (l - l_{50,T})}} \tag{5}$$

where $l_{50,T}$ is the length of the prey with a 50% probability of predation during period T and α_T a parameter related to the shape of the function, both parameters are estimated from the data within the Gadget model. The whole model time period (1989-2016) has been splited into two different periods for suitability parameters of the commercial fleet because of changes in size regulation for the fishery around 1995 that become effective around 2001.

1.2. Observation model

Data are assimilated by Gadget using a weighted log-likelihood function. The model uses as likelihood components three biomass survey indices: ECOCADIZ acoustic survey, PELAGO acoustic survey and BOCADEVA daily-egg-production-survey (DEPM); age - length keys from the commercial fleet (Spanish purse-seine), PELAGO survey and the ECOCADIZ survey; and length distributions for the commercial fleet, PELAGO and ECOCADIZ surveys (see Table 1.2 for a detailed description of the likelihood data used in the model).

Biomass Survey indices

The survey indices are defined as the total biomass of fish caught in a survey. The survey index is compared to the modelled abundance using a log linear regression with slope equal to 1 (*fixedslopeloglinearfit*), as follows:

$$\ell = \sum_t (\log(I_{y,t}) - (\alpha + \log(N_{y,t}))^2 \tag{6}$$

where $I_{y,t}$ is the observed survey index at year y and quarter t and $N_{y,t}$ is the corresponding population abundance calculated within the model. Note that the intercept of the log-linear regression, $\alpha = \log(q)$, with q as the catchability of the fleet (i.e $I_{y,t} = qN_{y,t}$).

Catch distribution

Age-length distributions are compared using l lengthgroup at age a and time-step y, t for both, commercial and survey fleets with a sum of squares likelihood function (*sumofsquares*):

$$\ell = \sum_y \sum_t \sum_l (P_{a,l,y,t} - \pi_{a,l,y,t})^2 \tag{7}$$

where $P_{a,l,t,y}$ is the proportion of the data sample for that time/age/length combination, while $\pi_{a,l,t,y}$ is the proportion of the model sample for the same combination, as follows:

$$P_{a,l,t,y} = \frac{O_{a,l,y,t}}{\sum\limits_a \sum\limits_l O_{a,l,y,t}} \tag{8}$$

and

$$\pi_{a,l,t,y} = \frac{N_{a,l,y,t}}{\sum\limits_a \sum\limits_l N_{a,l,y,t}}, \tag{9}$$

where $O_{a,l,y,t}$ corresponds to observed data.

When only length or age distribution is available. It is compared using equation 7 described above but considering all ages or all lengths, respectively.

Understocking

If the total consumption of fish by all the predators (fleets in this case) amounts to more than the biomass of prey available, then the model runs into "understocking". In this case, the consumption by the predators is adjusted so that no more than 95% of the available prey biomass is consumed, and a penalty, given by the equation 10 below, is applied to the likelihood score obtained from the simulation (Stefansson 2005, sec 4.1.)

$$\ell = \sum_t U_t^2 \tag{10}$$

where U_t is the understocking that has occurred in the model for that timestep.

Penalties

The BoundLikelihood likelihood component is used to give a penalty weight to parameters that have moved beyond the bounds in the optimisation process. This component does specify the penalty that is to be applied when these bounds are exceeded.

$$\ell_i = \begin{cases} lw_i(val_i - lb_i)^2 & \text{if } val_i < lb_i \\ uw_i(val_i - ub_i)^2 & \text{if } val_i > ub_i \\ 0 & otherwise \end{cases}$$

Where $lw_i = 10000$ and $uw_i = 10000$ are the weights applied when the parameter exceeds the lower and upper bounds, respectively, val_i is the value of the parameter and, lb_i and ub_i are the lower and upper bounds defined for the parameter.

1.3. Order of calculations

The order of calulations is as follows:

1. **Printing**: model output at the beginning of the time-step
2. **Consumption**: by the fleets
3. **Natural mortality**
4. **Growth**
5. **Recruitment**: new individuals enter to the population
6. **Likelihood comparison**: Comparison of estimated and observed data, a likelihood score is calculated
7. **Printing**: model output at the end of the time-step
8. **Ageing**: if this is the end of year the age is increased

Because of this order of calculations the time step of indexes, age-length keys and length distributions of the surveys are defined in Gadget a quarter before.

1.4. Implementation, weighting procedure

Input data (Likelihood files) were prepared for Gadget format using the *mfdb* R package (**?**), running and weighting procedures were implemented in R with the gadget.iterative function from *Rgadget* package. This function follows the approach presented in Taylor et al. (2007) and in the appendix of Elvarsson et al. (2014)

based on the iterative reweighting scheme of Stefánsson (1998) and Stefansson (2003), which is summarized as follows:

Let $\mathbf{w_r}$ be a vector of length L with the weights of the likelihood components (excluding understocking and penalties) for the run r, and $SS_{i,r}, i = 1, \ldots, L$, the likelihood score of component i after run r. First, a Gadget optimization run is performed to get a likelihood score ($SS_{i,1}$) for each likelihood component assuming that all components have a weight equal to one, i.e., $\mathbf{w_1} = (1, 1, \ldots, 1)$. Then, a separated optimization run for each of the components (L optimization runs) is performed using the following weight vectors:

$$\mathbf{w_{i+1}} = (1/SS_{1,1}, \ldots, (1/SS_{i,1}) * 10000, 1/SS_{i+1,1}, \ldots, 1/SS_{L,1}), i = 1, \ldots, L.$$

Resulting likelihood scores $SS_{i,i+1}$ are then used to calculate the residual variance, $\hat{\sigma}_i^2 = SS_{i,i+1}/df^*$ for each component, that is used to define the final weight vector as

$$\mathbf{w} = (1/\hat{\sigma}_1^2, \ldots, 1/\hat{\sigma}_L^2).$$

Where degrees of freedom df^* are approximated by the number of non-zero data points in the observed data for each component. Finally, the total objective function is the sum of all likelihoods components multiplied by their respective weights according to the vector $\mathbf{w}$.

In order to assign weights to the individual likelihood components (See table 1.2) in the procedure described above, all the survey indices were grouped together.

1.5. Initial parameters and optimization

Initial parameter values with their boundaries and settings for the optimising algorithms can be found in `https://github.com/mmrinconh/gadgetanchovy/blob/master/Anchovybenchmark_allnumbers_59/params.in` and `https://github.com/mmrinconh/gadgetanchovy/blob/master/Anchovybenchmark_allnumbers_59/optfile`. The optimization algorithms converged in individual and weighted runs.

2. Remarkable Model Assumptions

- The model was implemented quarterly from 1989 to 2016
- All commercial fleets where grouped into only one: The Spanish purse-seine which represents more than a 90 % of all the catches from 2001 to 2016 and more than a 80 % from 1989 to 2000. It is also the only fleet with a lenght distribution available.
- The parameters for weight-length relationship equation ($w = al^b$,) were assumed fixed and defined as $a = 3.128958e^{-6}$ and $b = 3.277667619$. Those values were calculated from all the samples available in third and fourth quarters from 2003 to 2017.
- Natural mortality at age was also considered fixed with $M_0 = 2.21$ and $M_1, M_2, M_3 = 1.3$,.

- There was a size restriction from 1995, that were only effective until 2001. As a consequence it was neccesary to define different parameters for two different periods. One from 1989 to 2000, and the other from 2001 to 2016.

3. Natural mortality selection

Natural mortality selection is justified by the following arguments:

- Natural mortality was preferred to be selected from classical indirect formulations based on life history parameters. For it we used the R package *FSA* to obtain empirical estimates of natural mortality.
- For the estimation of the a constant natural mortality natural mortality rate, the Von Bertalanffy growth parameters and the maximum age that the species can live were used. Growth parameters of the Von Bertalanffy function were taken from Bellido et al., (2000) (Linf =18.95; K = 0.89, t0 = -0.02), and the maximum observed age (It was explored from age 3 to 5, but finally age 4 was considered adequate). In total 13 estimators were produced using the R package *FSA* and the a value of $M = 1.3$ was undertaken (midway between the median and the mean of the available estimates for Agemax=4). See the table below.
- Currently is generally accepted that Natural mortality may decrease with age, as far as it presumed to be particularly greater at the juvenile phase. The group agreed to adopt for the adult ages of anchovy (ages 1 to 4) the constant natural mortality estimated before (1.3), but for the juveniles (age 0) a greater one in proportion to the ratio of natural mortality at ages 0 and 1 (M0/M1) resulting from the application of the Gislanson et al.(2010) Modelling of Natural mortality as a function of the growth parameters. For it we used four vectors of length-at-age: derived from the Von Bertalanffy growth function in Bellido et al. (2000) for ages 1-5, from the Ecocadiz survey for ages 0-3, the average of the length-at-age in the catches from 1987 to 2016 and the average of the length-at-age in the catches from 2007 to 2016 (i.e., last 10 years) (see the figure below). There was no major basis to select one or the other, we directly choosed the pattern shown by the Ecocadiz data just because it seemed to be smoothest one (particularly for age 1 onwards as presumed here). The ratio M0/M1 is 2.722670/ 1.595922 = 1.7. Therefore M0=1.3*1.7= 2.21
- In summary for anchovy 9a South, the adopted Natural mortality by ages are M0=2.21, M1=1.3 and M2+=1.3 (similar at any older age).

	method	M.age3	M.age4	M.age5
	AlversonCarney:1	Min. :1.335	Min. :0.9309	Min. :0.6034
	HewittHoenig :1	1st Qu.:1.433	1st Qu.:1.0818	1st Qu.:0.8690
	HoenigLM :1	Median :1.506	Median :1.3350	Median :1.0958
	HoenigNLS :1	Mean :1.543	Mean :1.2815	Mean :1.1264
	HoenigO :1	3rd Qu.:1.685	3rd Qu.:1.4326	3rd Qu.:1.4326

```
|   |HoenigO2      :1   |Max.   :1.836 |Max.   :1.5183 |Max.   :1.5183 |
|   |(Other)       :7   |NA            |NA             |NA             |
```

4. Fit to data

A summary of likelihood scores is presented in Figure 1 while a comparison of estimated versus observed data is summarized in the following Figures:

Length distributions

- Figure 2: Length distribution of the commercial fleet.
- Figure 3: Length distribution of the ECOCADIZ acoustic survey.
- Figure 4: Length distribution of the PELAGO acoustic survey.
- Figure 5: Summary of residuals for length distributions.

Age distributions

- Figure 6: Age distribution of the commercial fleet.
- Figure 7: Age distribution of the ECOCADIZ acoustic survey.
- Figure 8: Age distribution of the PELAGO acoustic survey.
- Figure 12: Summary of residuals for age distributions.

Age-length distributions

- Figure 9: Fitted length at age by quarter compared to observed values from the spanish purse-seine samples
- Figure 10: Fitted length at age by quarter compared to observed values from the ECOCADIZ acoustic survey samples
- Figure 11: Fitted length at age by quarter compared to observed values from the PELAGO acoustic survey samples

Biomass survey indices fit

- Figure 13: Summary of biomass survey indices fit.

The following shows the likelihood component scores from the different stages of the iterative reweighting run normalised with the minimum score for each component

```
> fit$nesTable
```

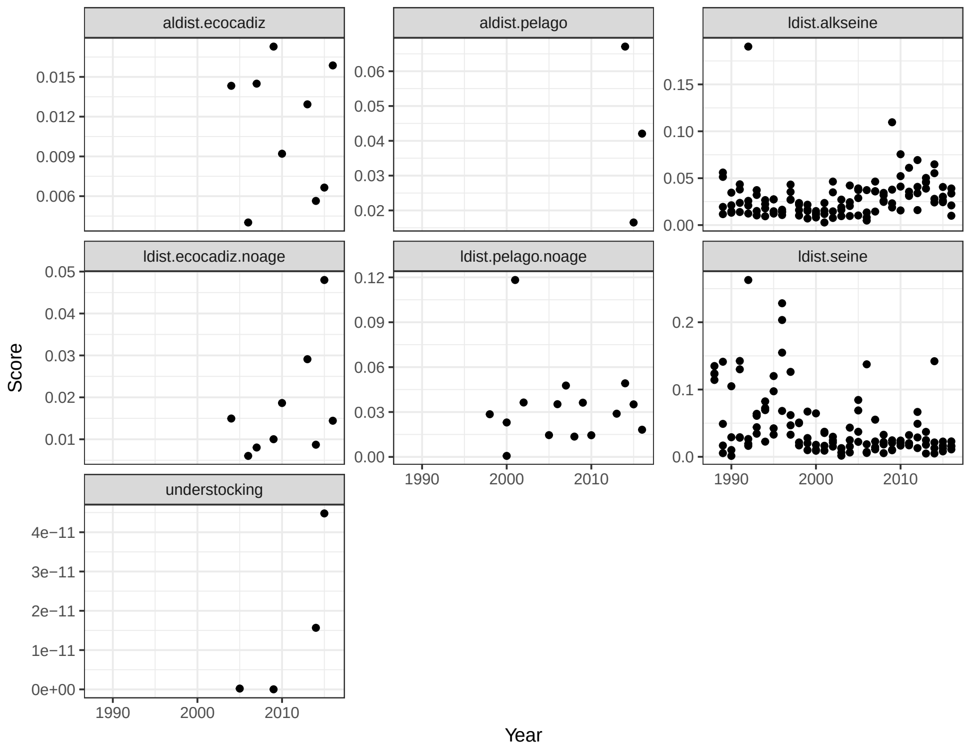

Figure 1: Likelihood scores for age-length key of ECOCADIZ survey, PELAGO survey and commercial landings (Upper panel) and length distribution of ECOCADIZ survey, PELAGO survey and landings. Dots represent the score for each quarter.

`.id`

`aldist.ecocadiz` `aldist.ecocadiz`

```
aldist.pelago                                                aldist.pelago
ldist.ecocadiz.noage                                  ldist.ecocadiz.noage
ldist.pelago.noage                                      ldist.pelago.noage
ldist.seine.ldist.alkseine                      ldist.seine.ldist.alkseine
pelagonumber.survey.ecocadiz.survey pelagonumber.survey.ecocadiz.survey
final                                                                final
                                    aldist.ecocadiz aldist.pelago
aldist.ecocadiz                            1.000000      9.249823
aldist.pelago                              9.781997      1.000000
ldist.ecocadiz.noage                      52.566807     11.415428
ldist.pelago.noage                        12.454290     21.924982
ldist.seine.ldist.alkseine                 5.675105      9.087049
pelagonumber.survey.ecocadiz.survey       10.193390      9.391366
final                                      3.530239      8.895966
                                    ldist.alkseine ldist.ecocadiz.noage
aldist.ecocadiz                           1.866235            63.903282
aldist.pelago                             1.312500            82.009211
ldist.ecocadiz.noage                      5.087652             1.000000
ldist.pelago.noage                        3.657774            15.359816
ldist.seine.ldist.alkseine                1.000000            10.708117
pelagonumber.survey.ecocadiz.survey       2.502287             8.644214
final                                     1.233613             4.545193
                                    ldist.pelago.noage ldist.seine
aldist.ecocadiz                              15.104217    3.743252
aldist.pelago                                18.182259    4.119433
ldist.ecocadiz.noage                          5.758604    2.376856
ldist.pelago.noage                            1.000000    2.270580
ldist.seine.ldist.alkseine                    3.735337    1.000000
pelagonumber.survey.ecocadiz.survey           3.891905    1.534244
final                                         2.423170    0.877193
                                    ecocadiz.survey pelagonumber.survey
aldist.ecocadiz                            64.17668            28.40055
aldist.pelago                             145.24196            37.02763
ldist.ecocadiz.noage                      185.06008           130.30592
ldist.pelago.noage                        435.53102           206.41473
ldist.seine.ldist.alkseine                206.30075            55.45676
```

pelagonumber.survey.ecocadiz.survey	1.00000	1.00000
final	89.76941	47.69768

	understocking	bounds
aldist.ecocadiz	0.000e+00	0
aldist.pelago	2.234e-12	0
ldist.ecocadiz.noage	1.251e-12	0
ldist.pelago.noage	4.655e-09	0
ldist.seine.ldist.alkseine	9.752e-11	0
pelagonumber.survey.ecocadiz.survey	5.926e-11	0
final	6.067e-11	0

Figure 2: Comparison between observed and estimated catches length distribution. Black lines represent estimated data while gray lines represent observed data

Index	
a	Age, $a = 0,\ldots,3$
l	Length, $l = 3,3.5,4,4.5,\ldots,22$
y	Years, $y = 1989,\ldots,2016$
t	Quartely timestep, $t = 1,\ldots,4$
T	$T = 1$ for period 1989-2000, $T = 2$ for period 2001-2016
Parameters	
Fixed	
a	Parameter of weight-length relationship $w = al^b$, $a = 3.128958 \times 10^{-6}$
b	Parameter of weight-length relationship $w = al^b$, $b = 3.277667619$
μ_a	Initial population mean length at age
	$\mu_0 = 9.99, \mu_1 = 12.1, \mu_2 = 15.2, \mu_3 = 16.1$
σ_a	Initial population standard deviation for length at age
	$\sigma_0 = 0.836, \sigma_1 = 0.5, \sigma_2 = 1, \sigma_3 = 1.2$
M_a	Natural mortality, $M_0 = 2.21, M_1 = 1.3, M_2 = 1.3, M_3 = 1.3$
n	Maximum number of length classes that an individual is supposed to grow $n = 5$
Estimated	
l_∞	Asympthotic length, l_∞=30
k	Annual growth rate, $k = 0.0770501$
β	Beta-binomial parameter, $\beta = 5000$
ν_a	Age factor, $\nu_0 = 120000, \nu_1 = 81000$,
	$\nu_2 = 0.125, \nu_3 = 3.3e-07$
μ	Recruitment mean length, $\mu = 9.91079$
σ_t	Recruitment length standard deviation by quarter, $\sigma_2 = 3.05845$, $\sigma_3 = 1.64798$, $\sigma_4 = 4$
$l_{50,T}$	Length with a 50% probability of predation during period T,
	$l_{50,1}^{seine} = 10.6$, $l_{50,2}^{seine} = 11$, $l_{50,3}^{ECO} = 13.7$, $l_{50,3}^{PEL} = 13.1$
α_T	Shape of function, $\alpha_1^{seine} = 0.385$, $\alpha_2^{seine} = 0.86$, $\alpha_3^{ECO} = 1.03$, $\alpha_3^{PEL} = 0.596$
Observed Data	
$E_{y,t}$	Number or biomass landed at year y and quarter t
W_l	Weight at length
$I_{y,t}$	Observed survey index at year y and quarter t
$P_{a,l,y,t}$	Proportion of the data sample over all ages and lengths for timestep/age/length combination
$O_{a,l,y,t}$	Observed data sample for time/age/length combination
$x_{a,y,t}$	Sample mean weight from the data for the timestep/age combination
Others	
Δl	Length increase
Δw	Weight increase
Δt	Length of timestep
$N_{a,l,y,t}$	Number of individuals of age a, length l in the stock at year and quarter y and t, respectively.
$q_{a,l}$	Proportion in lengthgroup l for each age group
$R_{y,t}$	Recruitment at year y and quarter t
$p_{l,t}$	Proportion in lengthgroup l that is recruited at quarter t
$C_{l,y,t}$	Total amount in biomass landed by surveys and in number landed by commercial fleet
$S_{l,T}$	Proportion of prey of length l that the fleet/predator is willing to consume during period T
$\pi_{a,l,y,t}$	Proportion of the model sample over all ages and lengths for that timestep/age/length combination
$\mu_{a,y,t}$	Mean length at age for the timestep/age combination
U_t	Understocking for timestep t
lw_i and uw_i	Weights applied when the parameter exceeds the lower or upper bound
lb_i and ub_i	Lower and upper bound defined for the parameter
val_i	Value of the parameter

Table 1: List of Symbols used in model specification

Data source	type	Timespan	Likelihood function
Commercial landings	Length distribution	All quarters, 1989-2016	See eq. 7
	Age-length key	All quarters, 1989-2016	See eq. 7
ECOCADIZ acoustic survey	Biomass survey indexes	Second quarter 2004, 2006	see eq. 6
		third quarter 2007, 2009, 2010, 2013-2016	
	Length distribution	Second quarter 2004, 2006	see eq. 7
		third quarter 2007, 2009, 2010, 2013-2016	
	Age-length key	Second quarter 2004, 2006	see eq. 7
		third quarter 2007, 2009, 2010, 2013-2016	
PELAGO acoustic survey	Biomass survey indexes	First quarter 1999, 2001-2003	see eq. 6
		second quarter 2005-2010 and 2013-2016	
	length distribution	First quarter 1999, 2001-2003	see eq. 7
		second quarter 2000, 2005-2010, 2013-2016	
	Age-length key	second quarter 2014-2016	see eq. 7
BOCADEVA DEPM survey	Biomass survey indexes	Second quarter 2005,2008	see eq. 6
		third quarter 2011,2014	

Table 2: Overview of the likelihood data used in the model

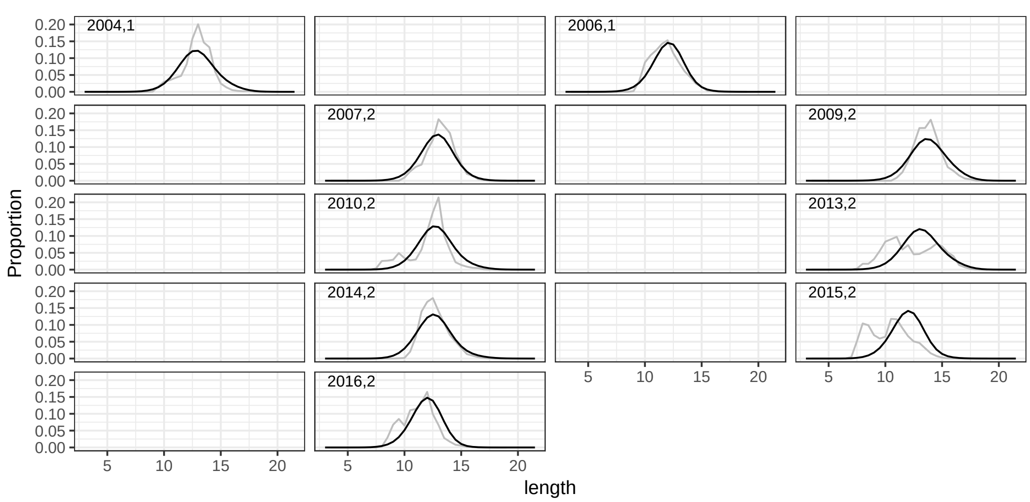

Figure 3: Comparison between observed and estimated catches length distribution for ECOCADIZ survey. Black lines represent estimated data while gray lines represent observed data

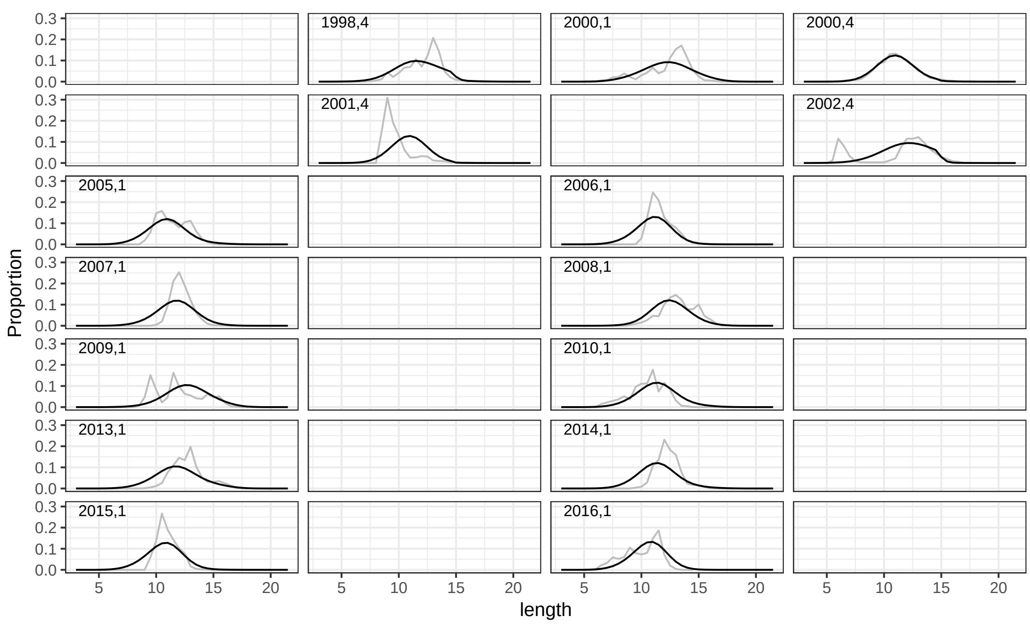

Figure 4: Comparison between observed and estimated catches length distribution for PELAGO survey. Black lines represent estimated data while gray lines represent observed data

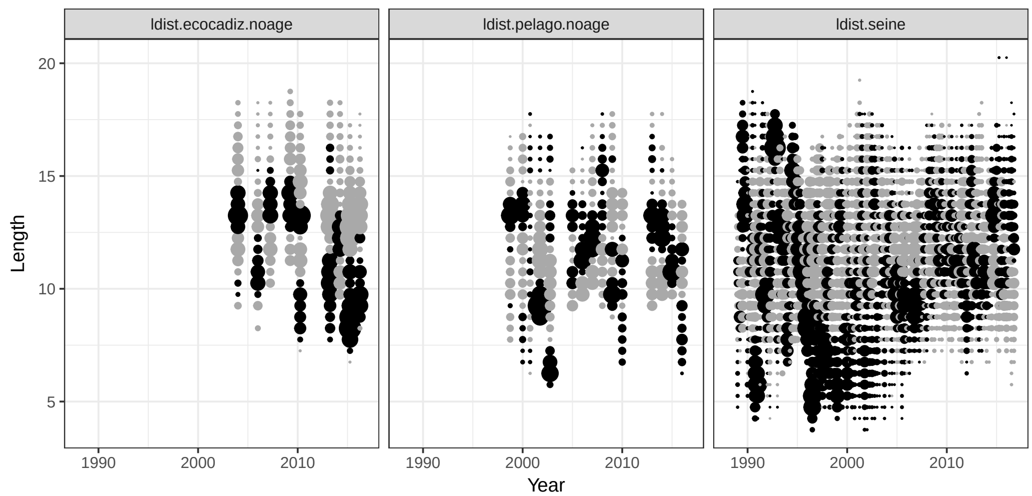

Figure 5: Standardised residual plots for the fitted length distribution from the ECOCADIZ survey, PELAGO survey and commercial landings. Black points denote a model underestimate and gray points an overestimated. The size of the points denote the scale of the standardised residual.

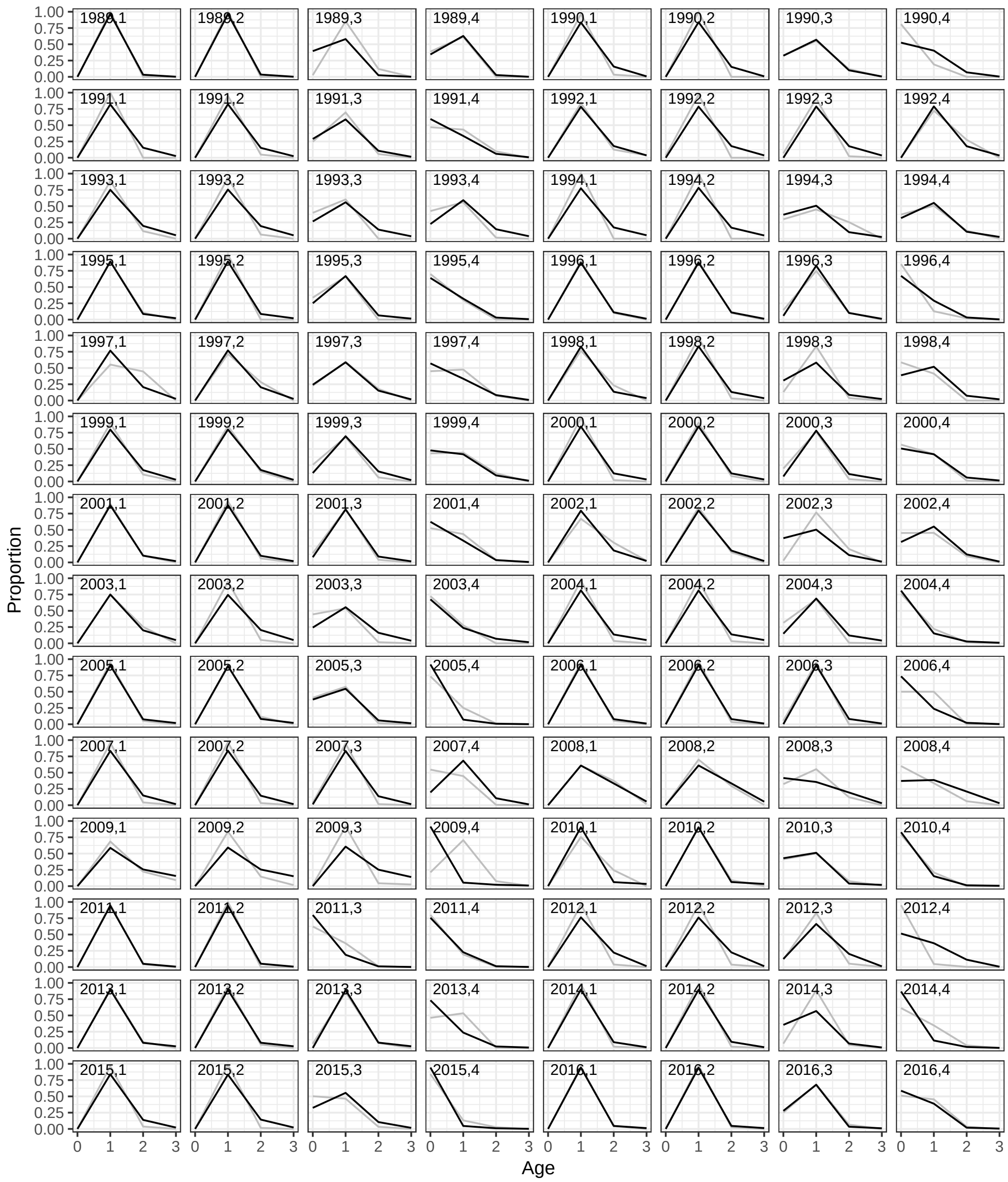

Figure 6: Comparison between observed and estimated catches age distribution. Black lines represent estimated data while gray lines represent observed data.

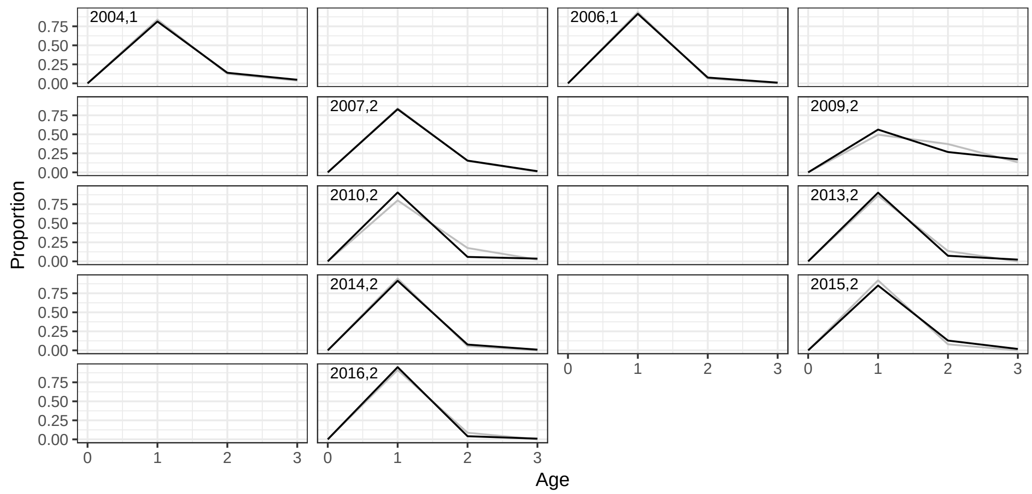

Figure 7: Comparison between observed and estimated ECOCADIZ survey age distribution. Black lines represent estimated data while gray lines represent observed data.

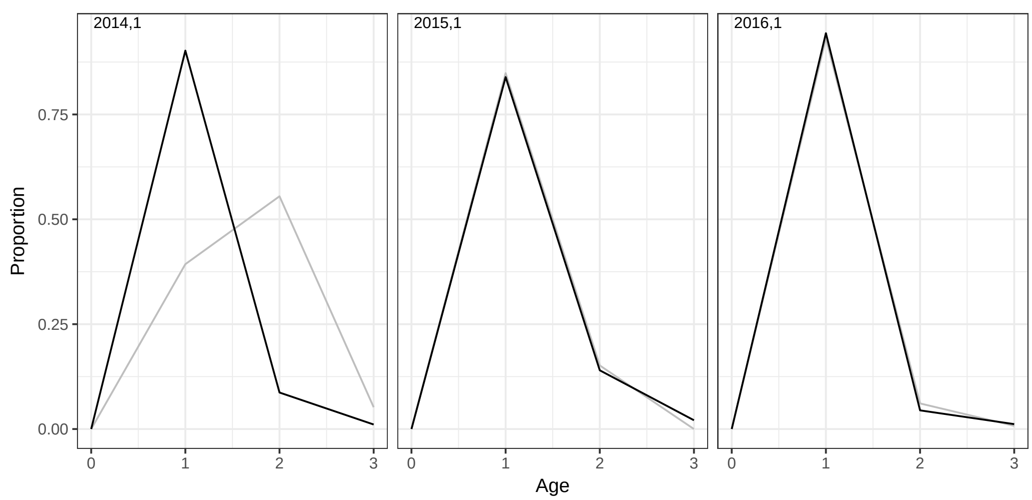

Figure 8: Comparison between observed and estimated PELAGO survey age distribution. Black lines represent estimated data while gray lines represent observed data.

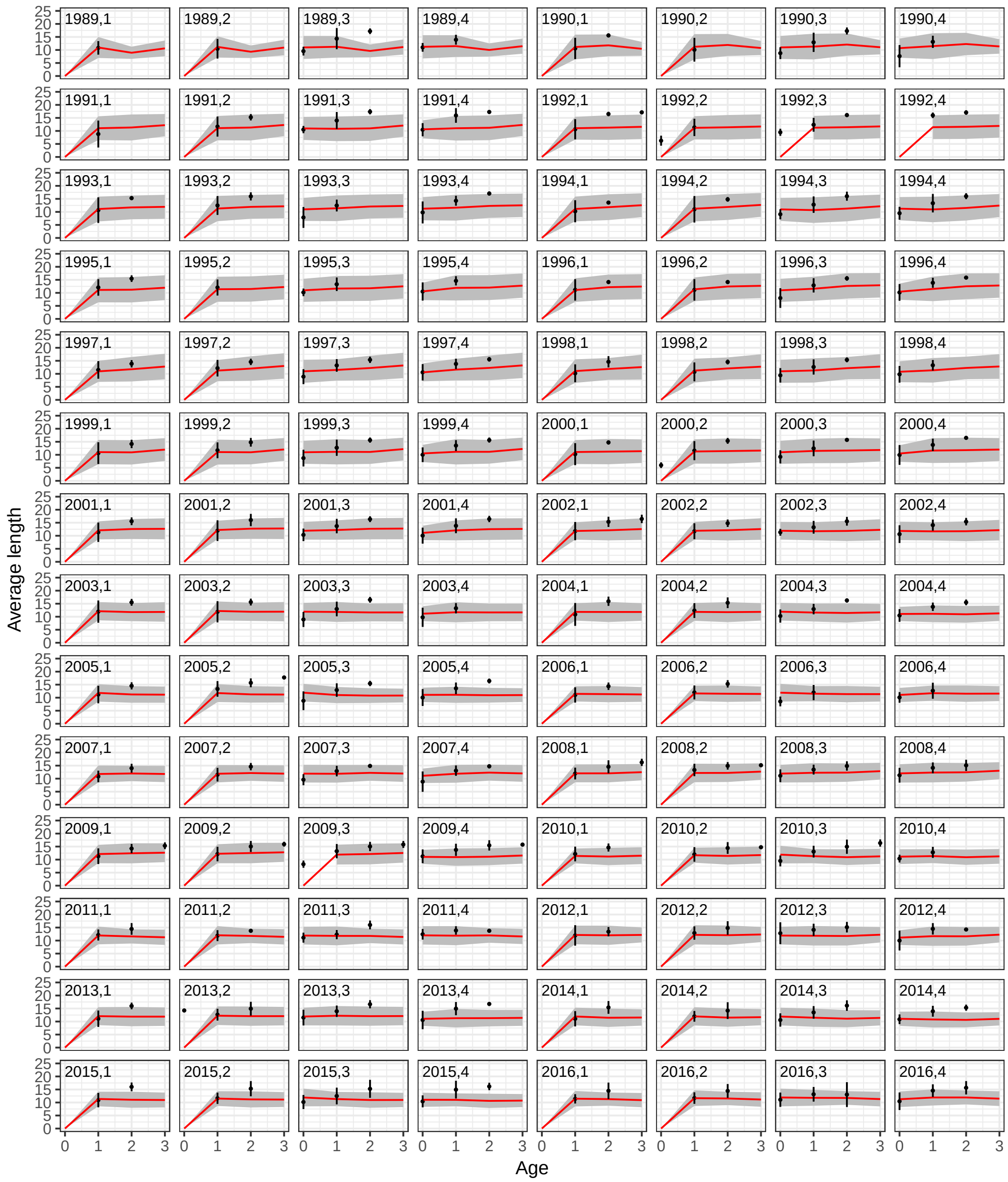

Figure 9: Fitted length at age by quarter compared to observed values from the spanish purse-seine samples. The black point and vertical bar denotes the observed mean and 95% confidence intervals of length at age, while the grey ribbon and red line indicates the model estimates.

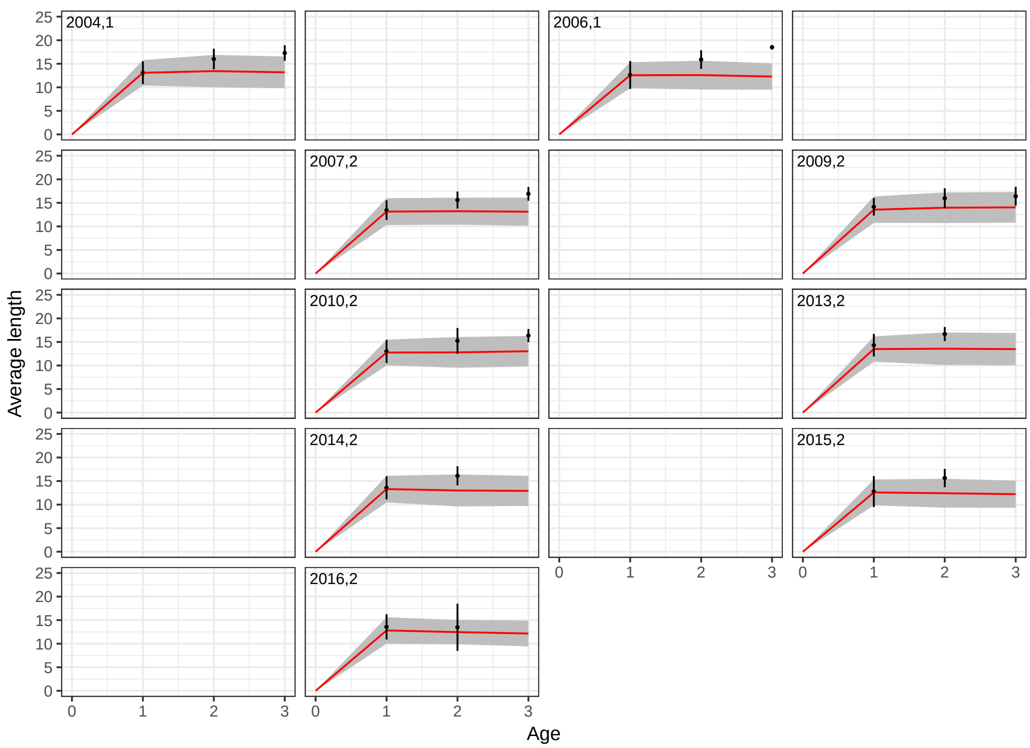

Figure 10: Fitted length at age by quarter compared to observed values from the ECOCADIZ survey samples. The black point and vertical bar denotes the observed mean and 95% confidence intervals of length at age, while the grey ribbon and red line indicates the model estimates.

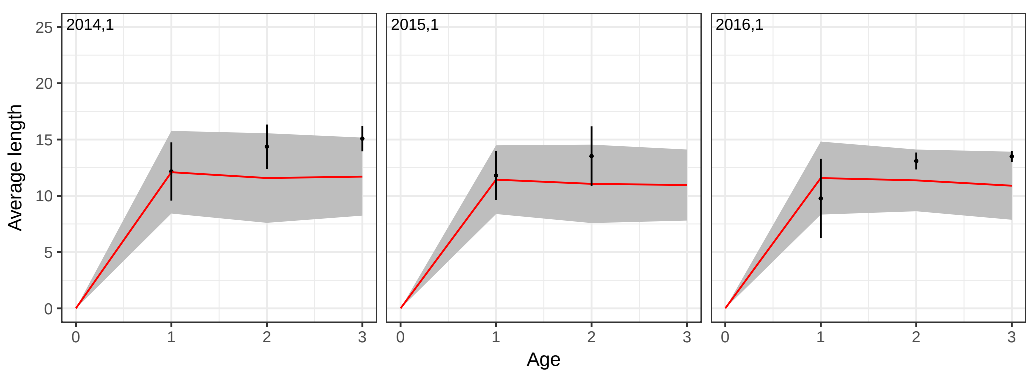

Figure 11: Fitted length at age by quarter compared to observed values from the PELAGO survey samples. The black point and vertical bar denotes the observed mean and 95% confidence intervals of length at age, while the grey ribbon and red line indicates the model estimates.

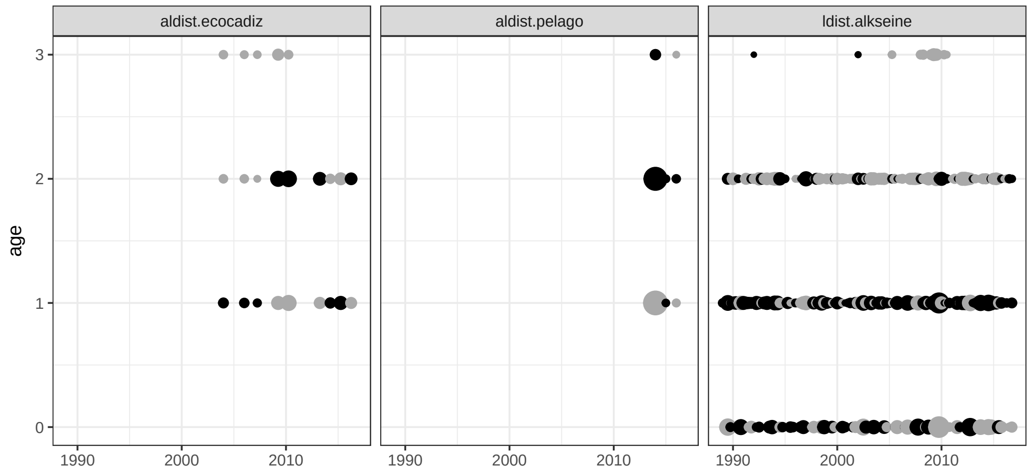

Figure 12: Standardised residual plots for the fitted age distribution from the ECOCADIZ survey, PELAGO survey and commercial fleet. Black points denote a model underestimate and gray points an overestimated. The size of the points denote the scale of the standardised residual.

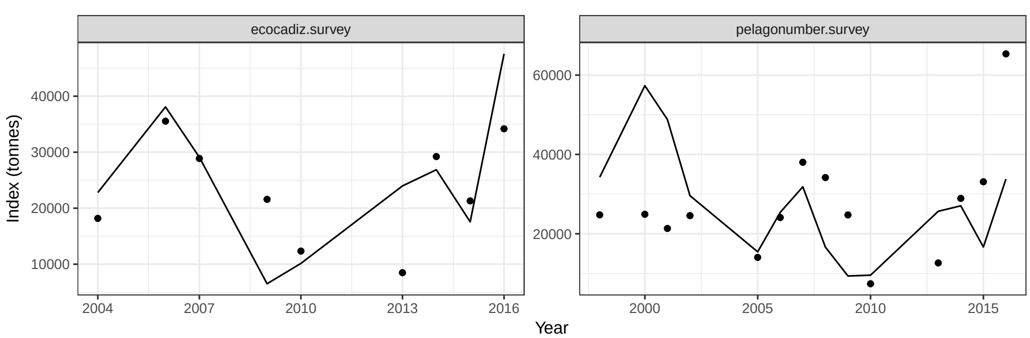

Figure 13: Comparison between observed and estimated survey indices. Black points represent observed data while black line represent estimated data

5. Model estimates

Parameter estimates after optimization are presented in Table 1.

5.1. Catchability

Figure 14 shows the catchability estimated by the model for the different surveys indices

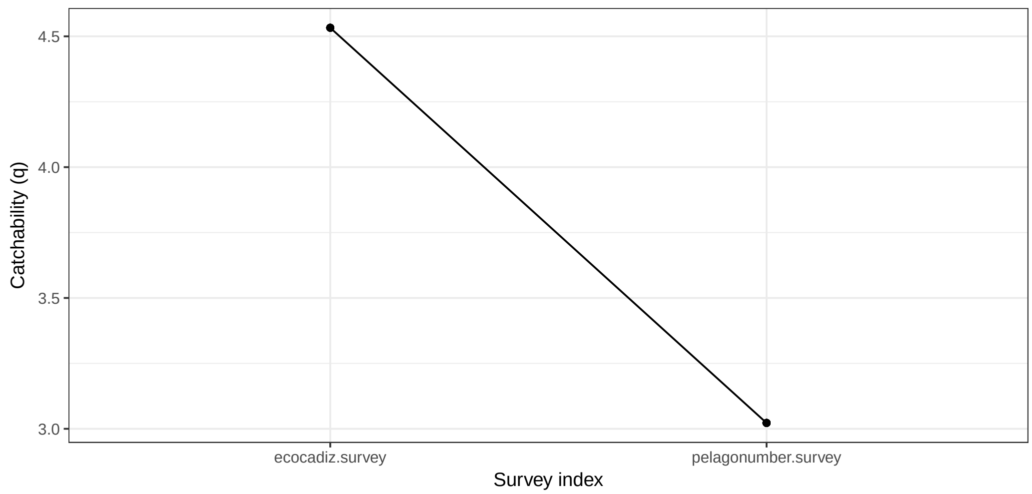

Figure 14: Estimated catchability parameters for the different survey indices

5.2. Suitability

Figure 15 shows the fleet suitability functions estimated by the model for the commercial fleet and different surveys

5.3. Abundance, recruitment and Fishing mortality

Figure 16 presents model annual estimates for abundance, recruitment, fishing mortality and catches. Figure 17 presents a comparison between SSB and recruitment

Total mortality Z was approximated using catch at age data with the following equation:

$$\log(\frac{C_1^{y-1}}{C_2^y}), y = 1990, \ldots, 2016,$$

where C_a^y denotes catches in numbers at age a during year y. The results are presented in Figure 18. Analogously, the same estimation was performed using the age data provided by the ECOCADIZ survey and the results are presented in Figure 19. Estimated F for age 1, mean estimated F for Ages 1 and 2 and estimated $Z_{1,2}$ are presented in figure 20.

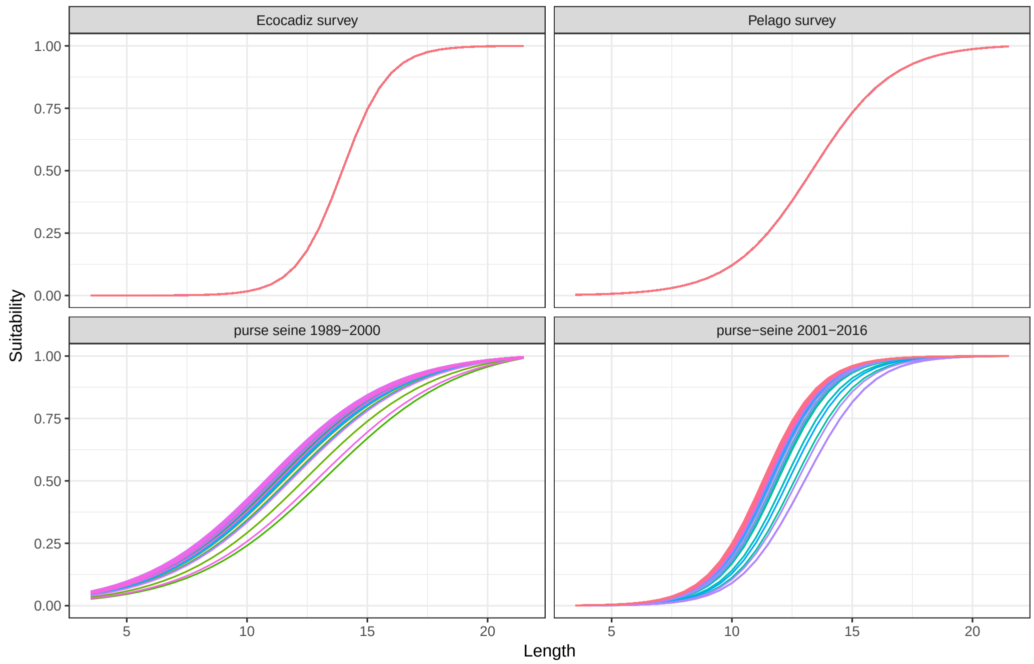

Figure 15: Estimated fleet suitability functions for the commercial fleet and different surveys.

6. Scenarios to explore

1. Natural mortality obtained by expert elicitation $M_0 = 1.5, M_1 = 1, M_2 = 1.5, M_3 = 1$: A bad fitting was obtained showing the sensitivity of the model results to this value. Some variations of this scenario should be explored.
2. Natural mortality at age estimated by the model
3. Forecast assuming that the advice is provided:
   – In June of year 'y' for year 'y+1' including the PELAGO survey performed in March/April.

7. Acknowledgements

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We gratefully thank CESGA (Galician Supercomputing Center) for computational time at the FTII Supercomputer and technical assistance.

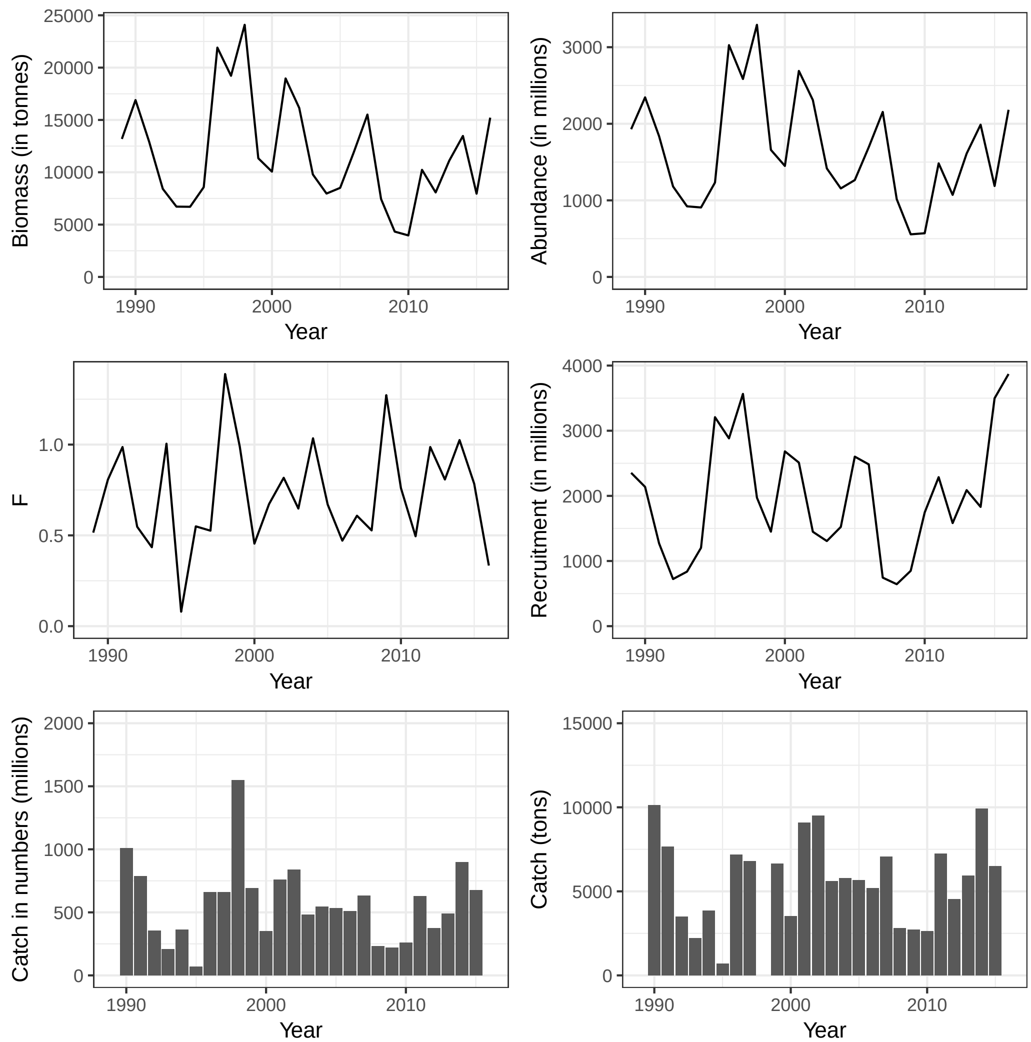


Figure 16: Annual catches time series (in numbers and biomass) compared with annual model estimates for abundance (in numbers and biomass), recruitment and fishing mortality.

Figure 17: Estimated Stock Spawning biomass (SSB_{t-1}) vs. Recruitment (R_t)

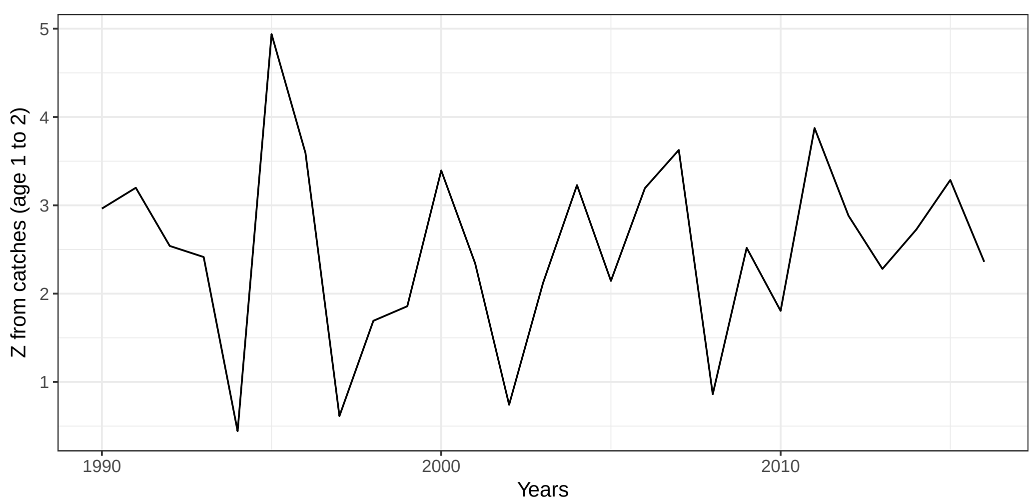
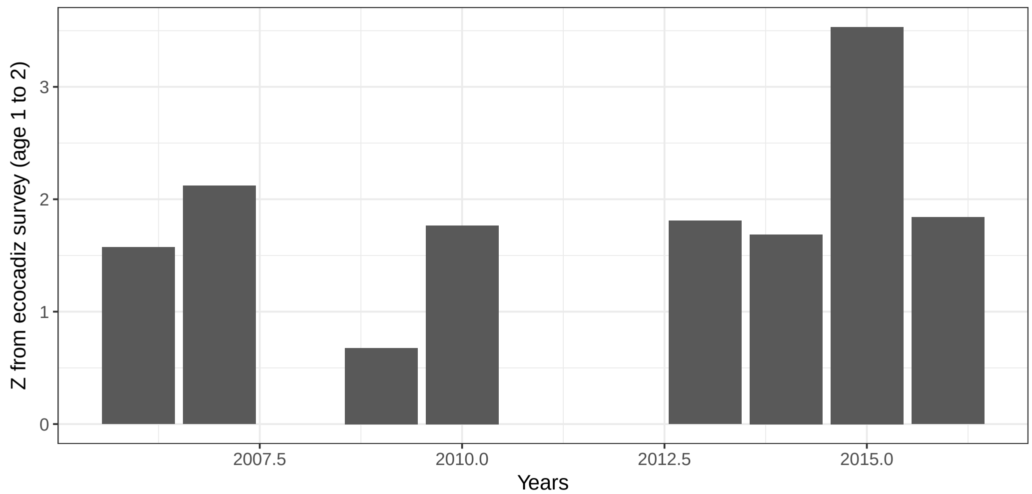


Figure 18: Estimation of Z using information from yearly catch in numbers from individuals of age 1 and 2.



Fi es from individuals of age 1 and 2.

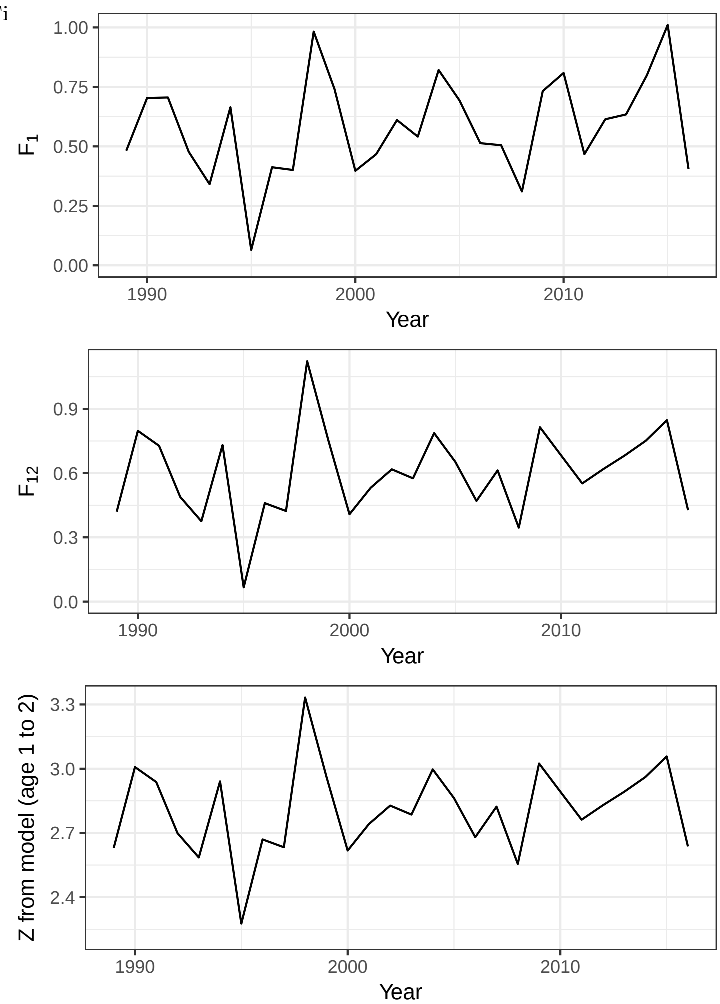


Figure 20: Estimated F for age 1, mean estimated F for Ages 1 and 2 and estimated $Z_{1,2}$

8. References

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