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LONG-TERM MANAGEMENT STRATEGY FOR SOUTHERN HORSE MACKEREL (hom27.9a) – MANAGEMENT STRATEGY EVALUATION (MSE)

Manuela Azevedo, Hugo Mendes, Gersom Costas, Ernesto Jardim, Iago Mosqueira, Finlay Scott

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Long-Term Management Strategy for Southern Horse Mackerel (hom27.9a) Management Strategy Evaluation

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ABSTRACT

The development of the long term management strategy (LTMS) for southern horse mackerel (*Trachurus trachurus*) started in October 2014 through a dialogue process between scientists and stakeholders. The process involved the definition of management objectives, a Harvest Control Rule and several TAC setting options, the F_{MSY} target year, and catch stability levels proposed by the stakeholders of Pelagic Advisory Council (PelAC) and the South West Waters Advisory Council (SWWAC). The PelAC in October 2017 sent a proposal for a LTMS for southern horse mackerel to the European Commission with a request that this be scientifically assessed. The Commission requested ICES to evaluate whether the proposed plan is seen as precautionary and to assess if the plan ensures that the stock is fished and maintained, also in the future, at levels which can produce Maximum Sustainable Yield (MSY). This report presents the Management Strategy Evaluation (MSE) on the performance of the LTMS. The conditioning of the operating model is based on the latest stock assessment, following the stock benchmark in early 2017, and with recruitment stochasticity. To implement a full-feedback MSE the management procedure component includes a stock assessment and advice cycle. The stock assessment cycle, with observation error, is performed using a statistical catch-at-age model that mimics the current assessment method. Two hundred populations are simulated from 2017 to 2080. Performance statistics for catch, spawning stock biomass and fishing mortality are computed for the short (2017-2027) and long-term (2070-2080). The proposed LTMS, with a Harvest Control Rule defined by F_{MSY} at 0.11, $F_{by\text{-}catch}$ at 0.01, MSY $B_{trigger}$ at 181 kt and B_{lim} at 103 kt and with a ±15% catch constraint is precautionary as the probability of SSB being below B_{lim} is less than 5% over the entire simulated period. The long-term equilibrium catches of the LTMS are very close to MSY. Sensitivity analyses indicate that the LTMS is also precautionary in a low productivity scenario.

Keywords: Long-term management plan, management strategy evaluation, southern horse mackerel

Resumo

Título: Plano de Gestão a longo prazo para o carapau-branco do sul (hom27.9a)-Avaliação da Estratégia de Gestão

O desenvolvimento de um plano de gestão a longo prazo para o carapau-branco (*Trachurus trachurus*) do sul teve início em Outubro de 2014 num processo interactivo entre cientistas e os principais intervenientes na pesca deste recurso. Foram definidos pelos representantes dos Conselhos Consultivos Pelágico (PelAC) e das Águas Ocidentais Sul (SWWAC) objectivos de gestão, uma regra de controlo das capturas, várias opções de estabelecimentos de TAC, o ano alvo para o F_{MSY} e limites para a variação anual da captura. Em Outubro de 2017, o PelAC solicitou à Comissão uma avaliação científica da sua proposta de plano de gestão para o stock sul de carapau-branco. A Comissão Europeia solicitou ao CIEM a avaliação do plano proposto no que respeita ao critério de precaução e de captura máxima sustentável (MSY) a longo prazo. A avaliação destes critérios foi realizada com simulações usando a abordagem designada 'Avaliação de Estratégias de Gestão' (MSE – 'Management Strategy Evaluation'). A componente MSE que representa a dinâmica populacional do recurso é condicionada com base nas estimativas dos parâmetros populacionais resultantes da mais recente avaliação de stock e incluindo estocasticidade no recrutamento. A componente MSE que simula a implementação do aconselhamento inclui, em cada ciclo anual, uma avaliação de stock com erro de observação, projecções a curto prazo e a aplicação da regra de controlo. A avaliação de stock é realizada com um modelo estatístico estruturado por idades, replicando o actual método de avaliação. Indicadores de captura, biomassa reprodutora e mortalidade por pesca são calculados no curto prazo (2017-2027) e no longo prazo (2070-2080) com base na dinâmica de 200 populações simuladas. O plano de gestão proposto tem uma regra de controlo definida por F_{MSY} = 0.11, $F_{by\text{-}catch}$ = 0.01 (F 'capturas acessórias'), MSY $B_{trigger}$ = 181 mil toneladas (biomassa 'gatilho') e B_{lim} = 103 mil toneladas (biomassa limite) e ainda considerando um limite de variação anual da captura de ±15%. Os resultados indicam que o plano é precaucionário dado que a probabilidade da biomassa reprodutora estar abaixo de B_{lim} é inferior a 5% ao longo do período simulado e que a captura de equilíbrio a longo prazo é semelhante à captura máxima sustentável. Análises de sensibilidade indicam que o plano de gestão também é precaucionário num cenário de baixa produtividade do stock.

Palavras-chave: Avaliação de estratégias de gestão, carapau-branco do sul, plano de gestão a longo prazo.

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1. Introduction

This report presents the analysis carried out to evaluate the performance of the long-term management strategy (LTMS) for southern horse mackerel (hom27.9.a) proposed by the Pelagic Advisory Council (PelAC).

The request to the long-term management strategy was as follows:

Background
A long-term management strategy (LTMS) was developed for this stock by initiative of the Pelagic Advisory Council (PELAC) in a collaborative work between scientists from IPMA and IEO and stakeholders from Portugal and Spain, with collaboration/knowledge of the South Western Waters Advisory Council (SWWAC).

Objectives
The Parties agree to propose a LTMS for the fisheries on the southern horse mackerel stock, which is consistent with the precautionary approach and the MSY objective (article 2.2) of the Common Fisheries Policy[1].

Criteria and definitions
Article 1 - Subject matter
This management strategy pertains to the southern horse mackerel stock.

Article 2 - Geographical definitions of stocks
ICES Division 9.a (The Iberian coast from the Strait of Gibraltar to Cape Finisterre in Galician waters).

Article 3 - Definitions
For the purpose of this management strategy, in addition to the definitions laid down in Article 4 of Regulation (EC) No 1380/2013, the following definitions shall apply:

> *i) "$F_{by\text{-}catch}$" refers to the level of fishing mortality which shall be applied when the Spawning Stock Biomass (SSB) is equal to or below B_{lim} to account for horse mackerel by-catches.*

Article 4 - Reference points

> *i) The minimum spawning biomass level and the precautionary spawning biomass level for the combined shall be as follows: B_{lim} = 103 000 tonnes, B_{pa} or MSY $B_{trigger}$ = 181 000 tonnes (ICES, 2017a,b).*
>
> *ii) The maximum fishing mortality associated with Maximum Sustainable Yield (F_{msy}) for the southern horse mackerel stock shall be as follows: F_{msy}= 0.11 (ICES, 2017a,b).*

[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:354:0022:0061:EN:PDF

Article 5 - TAC setting procedures

i) In the case that the spawning stock biomass is forecast to be above or equal to MSY $B_{trigger}$ (equivalent to B_{pa}) at mid-January of the year for which the TAC is to be set, the TAC shall be fixed to a catch estimated based on an gradual increase of fishing mortality towards F_{msy} in 2025.*

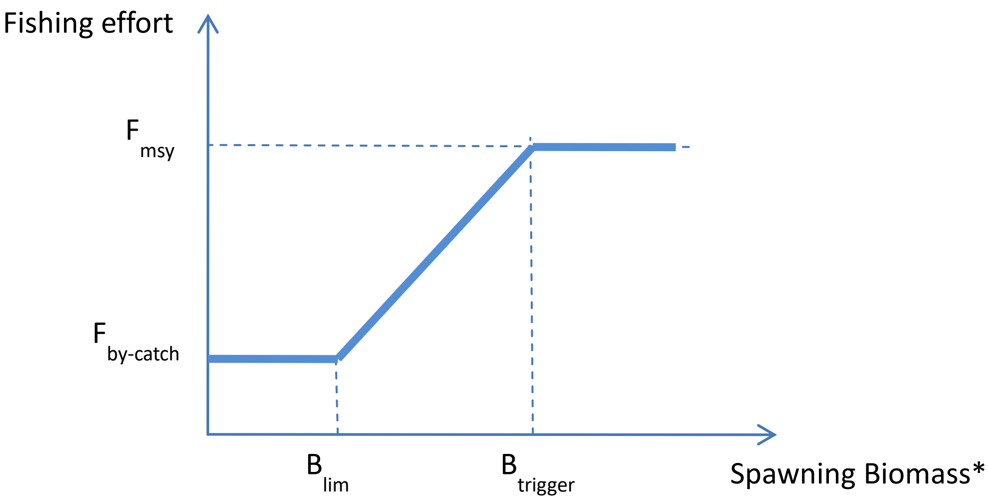
ii) In the case that the spawning stock biomass of the stock is forecast to be less than MSY $B_{trigger}$ and larger than B_{lim} at mid-January of the year for which the TAC is to be set, the TAC shall be fixed that is consistent with a fishing mortality (F) given by the harvest control rule:

$F = F_{by\text{-}catch} + [(F_{MSY} - F_{by\text{-}catch}) / (B_{trigger} - B_{lim}) / (SSB - B_{lim})]$

iii) In accordance with the objectives of the plan detailed above, where the rules in paragraph i and ii would lead to a fishing mortality higher than F_{MSY}, this fishing mortality shall be set in line with article 2.2 of the CFP.

iv) Where the rules in paragraph i, ii and iii would lead to a TAC which deviates by more than 15%from the TAC of the preceding year a TAC shall be set that is no more than 15% greater or 15% less than the TAC of the preceding year.

v) In the case that the spawning biomass is forecast to be equal to or less than B_{lim} in mid-January of the year for which the TAC is to be set, the TAC will be fixed corresponding to a fishing mortality $F_{by\text{-}catch}$=0.01.



**For this stock, the spawning stock biomass is determined at spawning time (assumed to be mid-January)*

Article 6 - Conditions of the monitoring fishery

Vessels participating in the fishery, if requested, shall take on-board scientific fisheries observers under the Data Collection Framework (DFC) to improve knowledge of the state of the stock. Those vessels upon request shall provide samples for the same scientific purpose.

Article 7 - End of the management strategy

The Parties, on the basis of ICES advice, shall review the biological reference points and this long-term management strategy at intervals not exceeding five years.

In the LTMS simulation testing, and following Article 5, paragraph (i), it was assumed a linear increase of fishing mortality from 2016 towards F_{MSY} in 2025. The expression of the harvest control rule in Article 5, paragraph (ii), used to compute F when $B_{lim} < SSB < B_{trigger}$ should be presented as:

$$F = F_{by\text{-}catch} + (F_{MSY} - F_{by\text{-}catch}) / [(B_{trigger} - B_{lim}) / (SSB - B_{lim})]$$

This expression can be also presented as:

$$F = F_{by\text{-}catch} + (F_{MSY} - F_{by\text{-}catch}) \times (SSB - B_{lim})/(B_{trigger} - B_{lim})$$

2. Background Information

2.1. Process

The development of the LTMS for southern horse mackerel started in October 2014 through an interactive process between scientists and stakeholders. The process involved the definition of management objectives, a Harvest Control Rule (HCR) and several TAC setting options, F_{MSY} target year and catch stability levels proposed by the stakeholders of PelAC/SWWAC. A preliminary analysis of the management strategies was performed using an MSE short-cut approach based on the 2015 stock assessment and preliminary Biological Reference Points (BRP). The results from these preliminary set of stochastic simulations were discussed with stakeholders and were proven useful to decide on the preferred range of management options.

A summary of the main meetings and relevant milestones and also on the range of tested options are available in Annex 1. The description of the MSE short-cut approach is available in Annex 2.

Following the stock benchmark in 2017 (ICES, 2017a) and the adoption of BRP's (ICES, 2016a) a full-feedback MSE approach is used to assess the performance of the proposed LTMS.

2.2. Biological Reference Points

Biological Reference Points were estimated in the 2016 Assessment Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA, ICES 2016a). The methodology to estimate Biological Reference Points (BRP) for southern horse mackerel stock followed the framework proposed in ICES guidelines for fisheries management reference points for category 1 stocks (ICES, 2017c). Stochastic equilibrium reference points were estimated based on the equilibrium distribution of stochastic long-term projections and based on the most recent period to reflect the stock current biological, productivity and fishery regimes. Simulations analyses were conducted using the *Eqsim* routines in the *msy* package (version downloaded 02/06/2016). The estimated BRPs were adopted by ICES for scientific advice on catch opportunities (ICES, 2016a,b). The BRPs were re-analysed during the Benchmark Workshop on Pelagic Stocks (WKPELA) and the estimates were very consistent with the adopted ones and did not require to be changed (ICES, 2017a).

Table 1 presents the adopted BRPs for southern horse mackerel. The long term yield at F_{MSY}=0.11 was estimated at 43516 t (median) and 45880 t (mean).

Table 1. Summary table of Biological Reference Points and predicted MSY for southern horse mackerel.

BRP	Value	Technical basis
B_{lim}	103 kt	$B_{lim} = B_{pa} * \exp(-1.645\ \sigma)$ $\sigma = 0.34$
$B_{trigger}$	181 kt	Lower bound (average) of 90%CI of $SSB_{1992-2015}$
B_{pa}	181 kt	$B_{pa} = B_{trigger}$
F_{lim}	0.19	Stochastic long-term simulations (50% probability SSB > B_{lim})
F_{pa}	0.11	$F_{pa} = F_{lim} * \exp(-1.645\ \sigma)$ $\sigma = 0.32$
F_{MSY}	0.11	Stochastic long-term simulations; constrained by F_{pa} (F_{MSY}=F_{pa})
MSY[(1)]	43.5 kt (45.9 kt)	Stochastic long-term yield at F_{MSY}

[(1)] **median (mean)**

2.3. Stock benchmark and assessment model

The stock was benchmarked in February 2017 (ICES, 2017a), following the Data Compilation Workshop in November 2016 (Uriarte *et al.*, 2017). During the benchmark, decisions on Stock ID, biological parameters, BRP's and assessment method were undertaken after technical discussions and agreement among the ICES members and invited external experts.

The AMISH (Assessment Method for the Ibero-Atlantic Southern Horse mackerel, Lowe *et al.*, 2012), an age-based model similar to Stock Synthesis (Methot and Wetzel, 2013) and implemented in ADMB, is the adopted assessment model. Data used in the assessment is the time series (data back to 1992) of total catch (Portugal and Spain), catch-at-age (ages 0-11+), a biomass index and an abundance-at-age from the International Bottom Trawl Survey (IBTS) autumn survey (ages 1-11+), and the mean weight-at-age in the catch and stock. Natural mortality-at-age and maturity-at-age are time invariant. The proportion of F and M before spawning is set fixed at 0.04 which corresponds to mid January, when it is assumed that most of the spawning takes place. The model begins in the first year of available data with an estimate of the population abundance-at-age with starting values for recruitment (age 0) generated from a Beverton-Holt stock recruitment relationship with steepness of 0.8. In subsequent ages and years the abundance-at-age is reduced by the total mortality rate. This projection continues until the terminal year is specified. The fishing mortality is assumed to be separable into an age component and a year component. Selectivity-at-age (constant for ages 7+) is allowed to change over time. Following the benchmark assessment, one selectivity block for the survey abundance index and three selectivity blocks for the catch-at-age (1992-1997, 1998-2011, and 2012 onwards) were adopted. Catch data by year is fitted assuming a CV of 5%, and the survey index data is fitted assuming a CV of 30%. For the fishery proportions-at-age an "effective sample size" of 100 is assumed, and for the survey estimates of age composition an "effective sample size" of 10 is applied. Lognormal priors are included for some parameters. Further details are provided in the hom27.9.a Stock Annex (ICES, 2017b). Figure 1 presents a summary of the last stock assessment with data from 1992-2016, used as basis for the simulation testing of the LTMS.

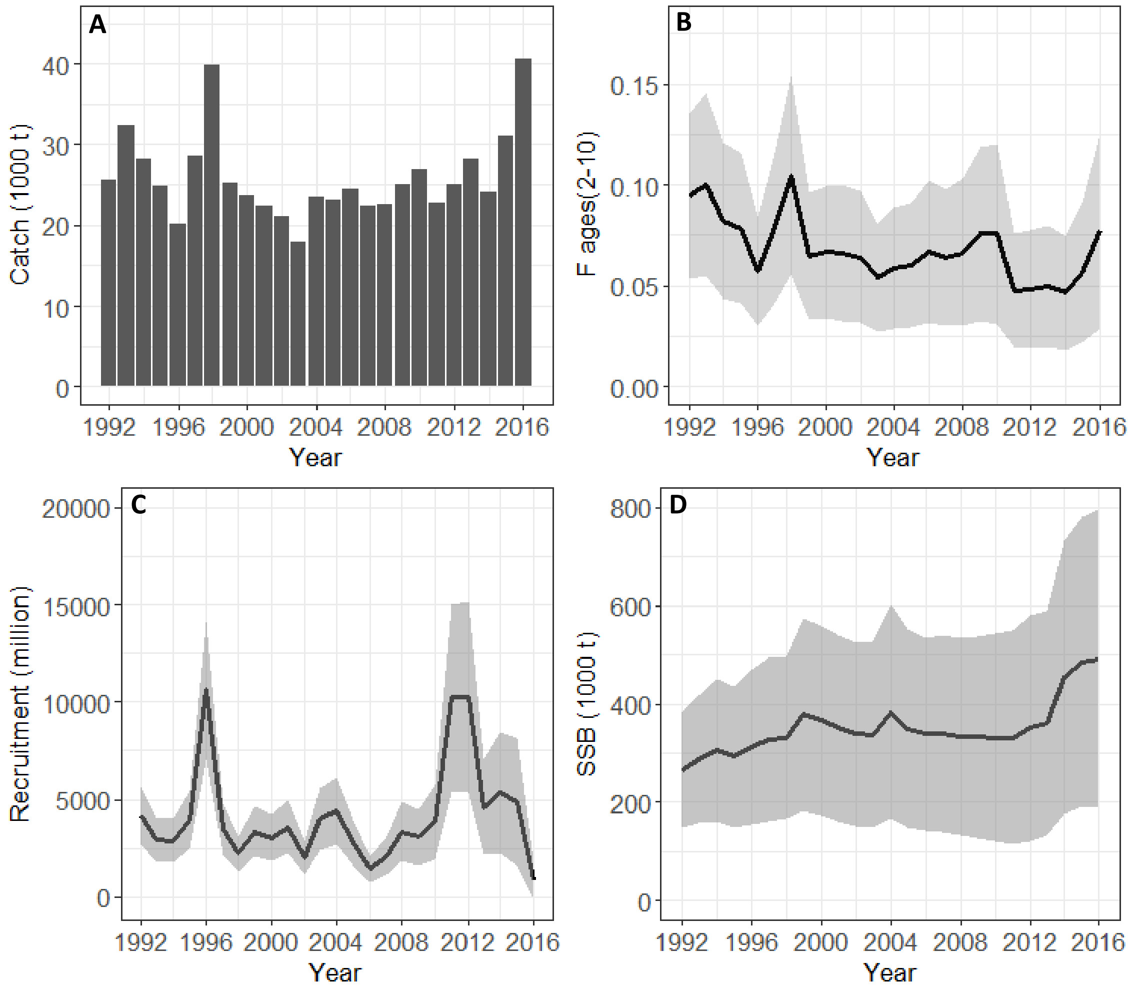


Figure 1. Horse mackerel stock assessment summary from 1992-2016. Panel A – Yield. Panel B – Fishing Mortality. Panel C – Recruitment. Panel D – Spawning Stock Biomass.

3. Methodology

3.1. Management Strategy Evaluation

The analysis of the proposed LTMS is undertaken with the components of the MSE shown in Figure 2. The fleet behavior and the biological dynamics of the stock were simulated in an Operating Model (OM), which is the mathematical representation of the best knowledge of the natural and fishery systems (‘true’ stock). The management procedure (MP) includes the stock assessment (‘perceived’ stock) and advice for fisheries management following the application of the management strategy (HCR defined in Article 5 of the LTMS proposal, specifying future catch with a ±15% constraint), and the management process to implement the scientific advice. Two other important components are the observation error, which represents the process of collecting information for stock assessment, and the implementation error which incorporates the way the actors implement regulations and perceive the management objectives. The current MSE is run without implementation error assuming full implementation of the TAC advice.

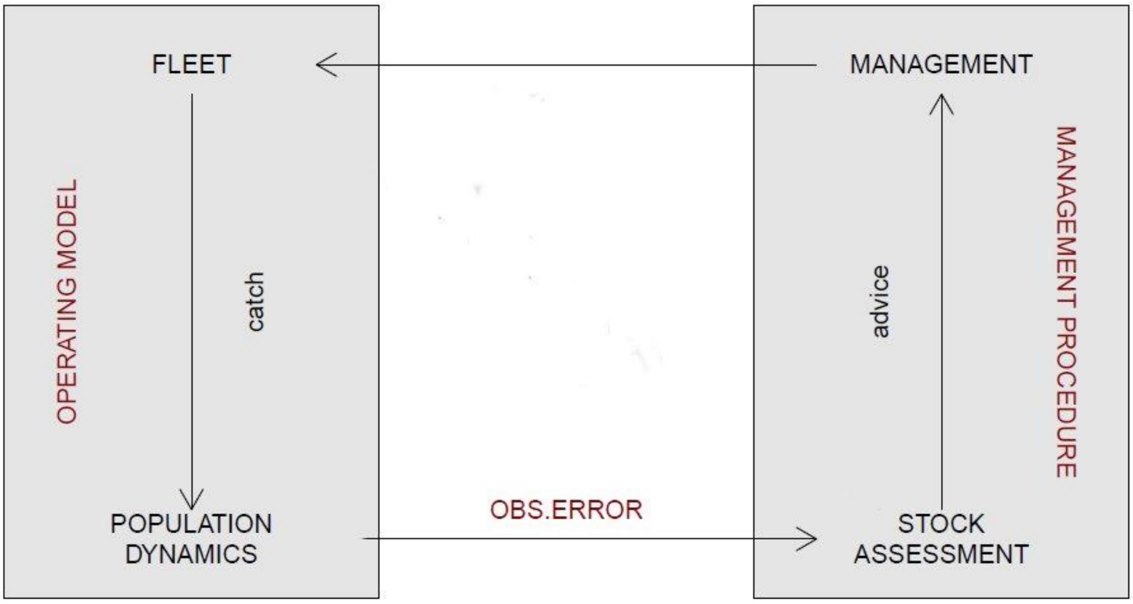


Figure 2. Diagram of the implemented full-feedback Management Strategy Evaluation (adapted from Jardim *et al.*, 2017).

3.2. Operating model

The fleet and the stock are represented in an OM that characterizes the dynamics of the natural and fishery systems with the best available scientific knowledge. The operating model described in Figure 2 includes the population dynamics of stock numbers (*N*) at age (*a*) and time (*t*):

$$N_{a+1,t+1} = N_{a,t}e^{-F_{a,t}-M_{a,t}}$$

while age 0 is estimated from the spawning stock biomass (SSB) following a stock-recruitment relationship (see section 3.2.2). The SSB is dependent on the proportion of mature individual at age (*P*) and the mean weight at age (*W*) in the stock:

$$SSB_t = \sum_{a=1}^{11+} N_{a,t} e^{-0.04F_{a,t} - 0.04M_{a,t}} W_{a,t} P_{a,t}$$

with M being Natural mortality and F being Fishing mortality, calculation of catch at age in numbers follows the standard Baranov equation:

$$C_{a,t} = \frac{F_{a,t}}{F_{a,t}+M_{a,t}} N_{a,t}(1 - e^{-F_{a,t}-M_{a,t}})$$

In southern horse mackerel discarding is known to be negligible and catches and landings are considered equal (ICES, 2017b). Total yield in weight is calculated as:

$$Y_t = \sum_{a=1}^{11+} W_{a,t} C_{a,t}$$

Fishing mortality at age is a separable model with selectivity-at-age (S_a), and annual fishing mortality (F_t):

$$F_{a,t} = S_a F_t$$

The parameters used in the LTMS will be described in the following sections. Selectivity and catchability at age (Q_a) are described in section 3.2.3. The proportion of mature individual at age (P_a), the mean weight at age in the stock (W_a) and the natural mortality (M_a) are detailed in Table 3, section 3.3.4.

3.2.1. Starting population

A statistical catch-at-age stock assessment model (hereinafter referred as *sca*) was used to mimic the current stock assessment model AMISH. The *sca* model was run in FLa4a, an R package (http://www.r-project.org/) which implements the a4a stock assessment framework (Jardim *et al.*, 2017) using the FLR routines (Kell *et al.*, 2007). The *sca* model can be applied rapidly to a wide range of situations using pre-built R estimation routines and using maximum likelihood estimation methods, which allowed running full-feedback MSE simulations on the several management scenarios proposed by the stakeholders (Annex 1), drastically reducing the computation time and complexity.

The *sca* model was conditioned to the same settings as the AMISH model, following the "effective sample size" of 100 for the fishery proportions-at-age and of 10 for the survey estimates of age composition and was proven successful in emulating the selectivity blocks for both catch at age and the survey abundance index (details in section 3.2.3). The *sca* model structure is defined by three submodels, a model for fishing mortality (*fmodel*), survey catchability (*qmodel*) and stock-recruitment relationship (*srmodel*) and defined in R code as:

sca(stk, idx, fmodel, qmodel, srmodel)

with *stk* as the FLStock with all input data and parameters for stock assessment and *idx* as the FLIndex with survey data for stock assessment.

The different submodels required structural assumptions and further details on each will be presented in the next sections. The assessment with *sca* is considered appropriate for the purpose of this MSE given comparable fits to catch-at-age, to index-at-age and retrospective pattern (Annex 3). Moreover, the historical estimates of key metrics, including spawning biomass, fishing mortality and catch (Figure 3) showed correlations between assessments of 0.71-0.95. The estimates in the terminal year, which are the initial conditions for the MSE simulations, were overall very similar between the two assessments (Table 2, Figure 4).

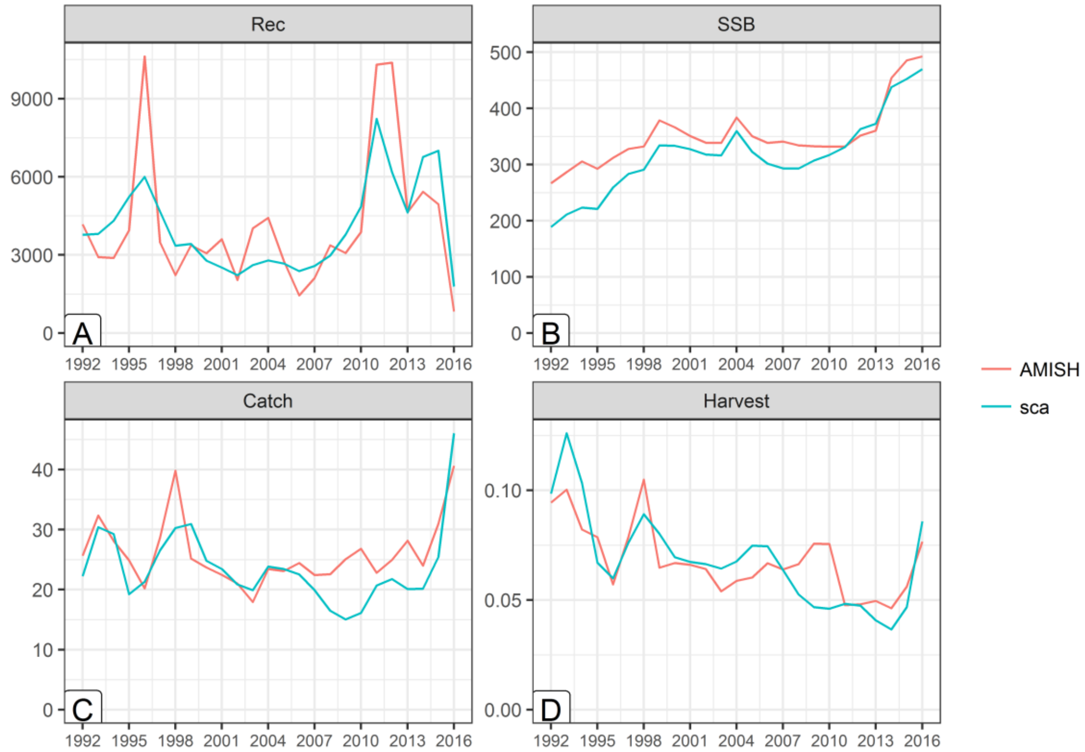


Figure 3. Comparison of the outputs of key parameters between the AMISH model (red) currently used in the assessment and the *sca* model (blue) used to perform the full-feedback MSE. Panel A- Recruitment (millions). Panel B – Spawning Stock Biomass (kt). Panel C – Yield (kt). Panel D – Fishing Mortality (year^{-1}).

The starting population number at ages 1-11+ were taken from the terminal year of the *sca* assessment. As in the stock assessment procedure, population at age 0 (recruits) estimated in the final year is replaced by the geometric mean of the recruitment time series (Table 2, Figure 4).

Table 2. Numbers-at-ages 0-11+ (in millions) estimated by *sca* and the AMISH model in last year of assessment.

	0	1	2	3	4	5	6	7	8	9	10	11+
sca	3857	2827	1448	626	589	610	296	191	124	88	66	339
AMISH	3774	1967	1129	603	954	747	229	144	123	61	34	365

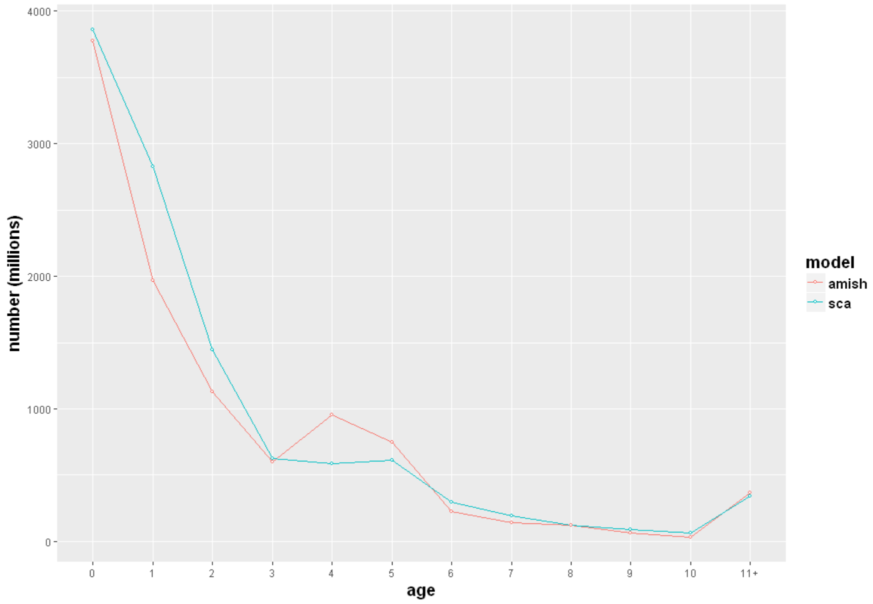


Figure 4. Numbers at age 0-11+ estimated in the final year of the assessments by the AMISH model (red) and the *sca* model (blue). Population number at age 0 is replaced by the geometric mean of the recruitment time series.

3.2.2. Stock recruitment relationship

Recruits (numbers at age 0) are estimated from the spawning stock biomass following a functional relationship:

$$N_{0,t} = f(SSB_t)\exp(\varepsilon_t)$$

The hockey-stick relationship, also adopted for the estimation of BRP´s, was used in the simulations to generate future recruitments. Recruitment variability (ε_t) was based on the *sca* recruitment estimates, introduced by generating random draws from a lognormal distribution with μ=0 and σ=0.6 and modelled as a 1st order AR model with ϕ_1=0.8. The adopted value for ϕ_1 was based on the upper limit of the observed autocorrelation in R. These parameters simulated the behaviour of AMISH recruitment time-series estimates with occasional spikes.

3.2.3. Selectivity and catchability

The *sca* model was conditioned to the same settings as the AMISH model with the fishing mortality model assumed to be separable into an age component and a year component. The *sca* uses the smoothing spline method provided by package mgcv (Wood, 2017) to model the changes in F through time and age. The fishing mortality model (*fmod*) required several structural assumptions to allow for gradual changes over age (constant for ages 7+) and time. The *fmod* that successfuly emulated the AMISH catch at age selectivity blocks (1992-1997, 1998-2011, 2012 onwards) was defined with the following code:

fmod <- ~s(replace(age, age>7, 7), k=6) + s(year, k=14)

Moreover, the estimates of the current exploitation pattern of higher selectivity for young ages (0-2) and lower selectivity to older ages, adopted for the simulations, was very similar between assessment methods (Figure 5).

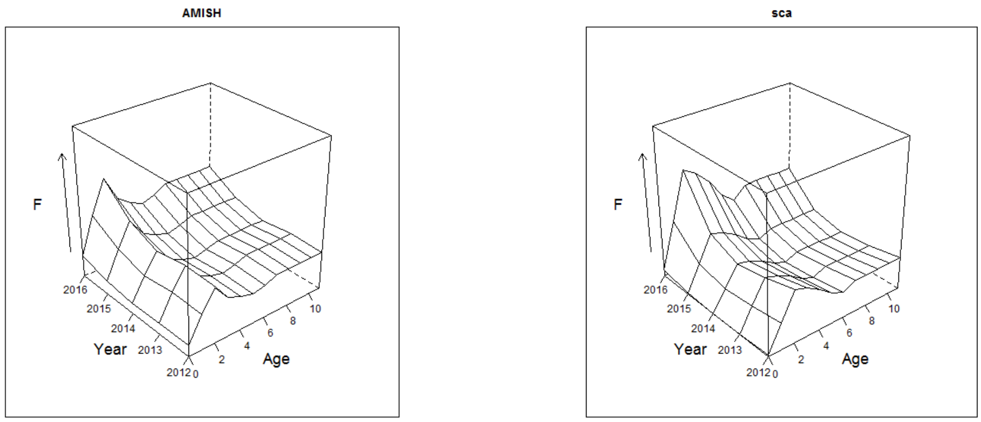


Figure 5. Current selectivity-at-age from 2012-2016 for ages 0-11+ as estimated by AMISH (left) and from *sca* (right), used to condition the OM.

The catchability submodel (*qmod*) was set up the same way as the fishing submodel with the smoothing splines fitted to the IBTS autumn survey index. The selectivity block for the survey abundance index, defined in the last stock benchmark, was quicker to emulate resulting in a more parsimonious catchability model:

qmod <- list(~s(replace(age, age>7, 7), k=6))

Again, the catchability submodel was successful in replicating the AMISH catchability block from 1992 to 2016 as show in Figure 6.

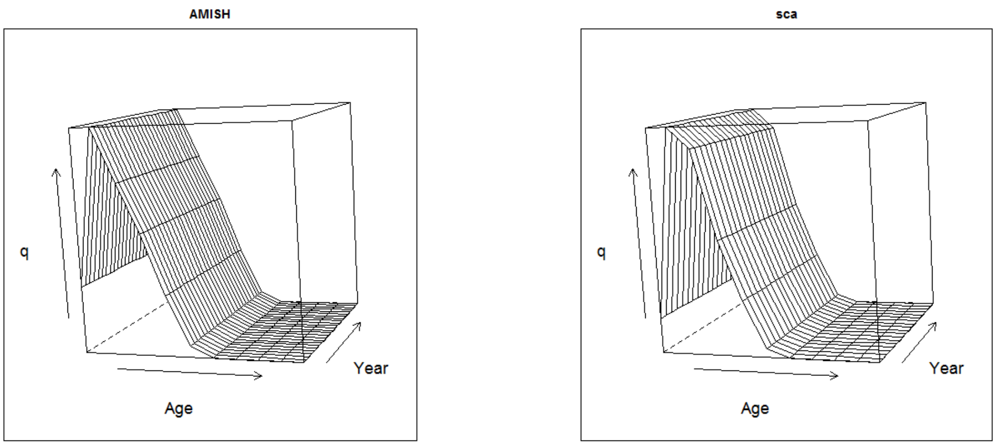


Figure 6. Age dependent catchability for 1992-2016 as estimated by AMISH (left) and from *sca* (right) and used to condition the OM.

3.2.4. Biological parameters

In the simulations, assumptions about the future natural mortalities and proportion of mature individual at age of horse mackerel were based on the last stock benchmark review. The proportion of mature individual at age and the natural mortality used in the operating model are detailed in Table 3.

The natural mortality adopted for the southern horse mackerel stock is age dependent, being higher for younger ages and time invariant. The adopted values are based in the estimates for other similar pelagic species, a strong decrease of predation with age from observed diet composition of fish predators in the area and taking into account the observed mean life span and growth rate (Jennings *et al.*, 2001, Cabral and Murta, 2002).

The proportion mature is age dependent, based on a logistic model fit to the histological analysis of female gonads from the combined data of three Daily Egg Production Method (DEPM) surveys, and time invariant (ICES, 2017b).

Assumptions about future weights of southern horse mackerel were based on the terminal year estimations. There are no indication of density-dependent growth for this stock and no significant trends in historical weight-at-age (ICES, 2017b). Additionally, taking in consideration that the spawning season is very long, from September to June, that the whole length range of the species has commercial interest in the Iberian Peninsula and that discards are negligible, there is no evidence to consider that the mean weight in the catch is significantly different from the mean weight in the stock.

Table 3. Natural mortality (M), mean weight at age in the stock and catch (Weight) and proportion of mature individuals (Maturity) at age 0-11+ used in the simulations.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**
M (1/year)	0.9	0.6	0.4	0.3	0.2	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Weight (catch & stock;kg)	0.02	0.03	0.04	0.07	0.12	0.15	0.17	0.18	0.22	0.24	0.25	0.3
Maturity	0	0	0.36	0.82	0.95	0.97	0.99	1	1	1	1	1

3.3. Management Procedure

3.3.1. Assessment uncertainty

Because we are running a full-feedback MSE with an independent assessment for each population in each simulation loop, there is an added variability generated from the assessment cycle based on the differences between the ‘true’ and ‘perceived’ stock. Survey indices used as input to each assessment cycle were generated from the “true” population using the estimated catchability-at-age (from the *sca* model) with log-normally distributed errors from the *qmodel* to include observation error. Catch-at-age from the perceived stock is assumed known since there is evidence that catch-at-age for this stock is accurate with good sampling coverage, negligible discards and good agreement in age reading. Although the uncertainty observed in the AMISH assessment was not directly included in the MSE the range of the CVs of the SSB and F from the *sca* estimates were in the range 24-27%, close to those from AMISH (27-28%).

3.3.2. Short-term forecasts

The short-term forecasts in each assessment loop are carried out adopting for the interim year (t) the estimates of F-at-age and the input values for the biological parameters in the final year of the assessment (i.e. considering 1 year as the *status quo* period) as agreed in the last benchmark and described in stock annex (ICES, 2017a,b). The forecast SSB at spawning time (mid-January) of year t+1 (advice year) is used to apply the TAC setting procedures according to the LTMS. It is noted that this forecast SSB is very close to the SSB estimated at the end of the interim year since the fraction of total fishing mortality before spawning is 0.04.

3.3.3. Simulations

The FLR MSE simulation carried out to analyse the performance of the proposed LTMS is based on 200 populations (*npop*), each projected from 2017 to 2080. Therefore, the full-feedback MSE performed simulations for *nt* = 64 future years resulting in 12800 assessment cycles. Simulations were carried out using the FLR packages FLCore (version 2.6.0.20170228), FLa4a (version 1.0.0; used to run *sca*) and FLash (version 2.5.7; used for OM projections). Code specifically developed for the specificities of this stock assessment procedures allowed for a wide range of settings, in scenario testing and supported the robustness of the results.

3.3.4. Performance Statistics

During each simulation a series of metrics were recorded for the evaluation of the LTMS. Table 4 summarizes the performance statistics used during the LTMS development and decision analysis. They include the median average and 5^{th} - 95^{th} percentiles in total catch (short as well as long terms), fishing mortality ('true' and 'perceived') and SSB. The probability of SSB falling below B_{lim} and MSY $B_{trigger}$ was also computed throughout the entire time series (2017-2080). According to the precautionary approach the LTMS should ensure with high probability that the SSB is maintained above B_{lim}. ICES (2013) defines the probability of SSB going below B_{lim}, $P(SSB<B_{lim})$, as the maximum probability that SSB is below B_{lim}, where the maximum (of the annual probabilities) is taken over *nt* (Risk type 3). A 'high probability' of the LTMS maintaining the stock above B_{lim} is achieved if $P(SSB<B_{lim})$ is less than 5% (ICES precautionary criterion). The LTMS also has to ensure that the stock is fished and maintained, in the future, at levels which can produce MSY.

From a stakeholder´s request, two statistics for the catch interannual variation ($IAV^{1,2}$), were estimated for the short and long-term and also for the simulations initial 5-years period (Table 4). These indicators were proven very useful for their decision on the preferred management option.

Table 4. Performance statistics used to summarize the performance of the LTMS.

	Indicator	Time period
Yield	Median catch (5^{th} and 95^{th}percentiles) IAV^1: $[(\sum\|(catch_t / catch_{t-1}) - 1\|) / nt] *100$ IAV^2: $\sum\|catch_t - catch_{t-1}\|$	i) Short-term 2017-2027; ii) Long-term 2070-2080; iii) Initial years 2016-2020
Fishing Mortality	Median F (5^{th} and 95^{th}percentiles)	i) Short-term 2017-2027; ii) Long-term 2070-2080
Spawning Stock Biomass	Median SSB (5^{th} and 95^{th}percentiles) $P(SSB < B_{lim})^*$ $P(SSB < MSY\ B_{trigger})^*$	i) Short-term 2017-2027; ii) Long-term 2070-2080; iii) All years 2017-2080

*Maximum probability that SSB is below B_{lim} or MSY $B_{trigger}$, where the maximum is taken over *nt*

A summary of the methodology used in the evaluation of the Long-Term Management Strategy for southern horse mackerel stock is presented in Table 5.

Table 5. Summary of the methodology used in the evaluation of the Long-Term Management Strategy for southern horse mackerel stock (hom27.9a).		
Background		
Motive/initiative/background	The LTMS was proposed for this stock by initiative of the Pelagic Advisory Council (PelAC) in a collaborative work between scientists from IPMA and IEO and Portuguese and Spanish stakeholders from the South Western Waters Advisory Council (SWWAC). The stock has no management plan and is currently above MSY $B_{trigger}$ and exploited below F_{MSY}.	
Main objectives	Evaluate whether the plan is in accordance with the precautionary approach and MSY approach.	
Formal framework	Request from PELAC to European Commission.	
Who did the simulations work	Scientists from IPMA, IEO, JRC.	
Method		
Software	Stock assessment model (*sca*) and MSE framework implemented in R using the FLR packages (FLCore, FLa4a, FLash).	
Name, brief outline	Age-structured operating model and assessment with catches-at-age and one survey (IBTS) included in the loop. Survey indices used as input to the assessments in the simulations were generated from the "true" population on the basis of estimated catchability-at-age (from the *sca* model) with error coefficients log-normally distributed to simulate observation error. Catch-at-age from the perceived stock is assumed known and without implementation error.	
Reference or documentation	Documentation for the stock assessment model and MSE framework in Jardim, *et al.* (2017). Code available upon request.	
Type of stock	Medium life span (11+), pelagic/demersal, medium value, regionally important.	
Knowledge base	ICES category 1 stock.	
Type of regulation	TAC based on F in the TAC year.	
Operating model conditioning	**Function, source of data**	**Stochastic? – how (distribution, source of variability)**
Recruitment	Hockey-stick model (Azevedo *et al.*, 2016)	Log-normal (μ=0, σ=0.6), autocorrelated in time (ϕ_1=0.8).
Growth & maturity	As in last assessment (WGHANSA,2017)	No significant trends in historical weight-at-age. No indications of density-dependent growth.
Natural mortality	As in last assessment (WGHANSA,2017)	No. Natural mortality is age dependent and time invariant.
Selectivity	F-at-age as in latest 2012-2016 selectivity block reviewed in 2017 assessment/benchmark	No. The recent exploitation pattern of increased selectivity of young ages and decreased selectivity of older ages reflected in simulations.

Initial stock numbers	Population vector from *sca* model mimicking AMISH assessment	Similar to AMISH model.
Decision basis	SSB at spawning time in the TAC advice year	
Number of populations	200	
Projection time	2017-2080; 64 years	
Observation and implementation models		
With assessment		
Input data	Catches and one survey	Survey: error coefficients log-normally distributed to simulate observation error.
Comparison with ordinary assessment?	Yes	*sca* model is used to condition the simulation framework using the same setting as the AMISH model. Comparisons in several parameters including CV´s, retrospective patterns.
Deviations from WG practice?	No	Changes from WG practice were only applied in a range of robustness/sensitivity tests.
Harvest rule		
Harvest rule design	i) If SSB ≥ $B_{trigger}$, F = F_{MSY} ii) If B_{lim} < SSB < $B_{trigger}$, F = $F_{by\text{-}catch} + (F_{MSY} - F_{by\text{-}catch}) \times (SSB - B_{lim})/(B_{trigger} - B_{lim})$ iii) If SSB ≤ B_{lim} , F = $F_{by\text{-}catch}$	
Stabilizers	TAC shall not deviate more than 15% from the TAC the year before.	
Duration of decisions	Annual.	
Revision clause	After 5 years.	
Presentation of results		
Interest parameters	SSB risk analysis (B_{lim} and $B_{trigger}$), median catch, median fishing mortality.	
Risk type and time interval	Type 3, over entire simulated period (2017-2080).	
Precautionary risk level	5%	

4. Results and discussion

4.1. Proposed LTMS

The trajectories of the key parameters recruitment, SSB, Yield and fishing mortality of the LTMS are shown in Figure 7. The stock has been exploited below F_{MSY} and the SSB at the start of the simulation period is at an historical high. The short-term median SSB is at 424669 t and after a small decrease in the initial period stabilizes, reaching a long-term median of 352148 t. This very healthy state of the stock at start of the simulated period, results in short-term median catches around 51468 t above the long-term average catch estimated around 40877 t.

Figure 7. Simulation summary results for 2017-2080. Panel A – Recruitment (millions). Panel B – SSB (kt). Panel C – Yield (catch, kt). Panel D – Fishing Mortality (harvest, year^{-1}). The red line indicates the median value from the 200 populations and the shaded area the 10th and 90th percentiles. The green and blue lines show the results from two simulated populations selected randomly.

The SSB trajectory in the simulated period with 90% confidence intervals shows that in the proposed LTMS the size of the stock is maintained above B_{lim} with high probability (Figure 8). The maximum P(SSB < B_{lim}) was at 0% both in the short and long-term.

The preliminary F_{MSY} estimated for this stock (0.15) was higher than F_{pa} (0.11) and to ensure consistency between the precautionary and the MSY frameworks F_{MSY} was reduced to F_{pa} (ICES, 2017c). This restricted F_{MSY} reinforced the high probability of the stock being above B_{lim} and also not falling below the MSY $B_{trigger}$ level. Therefore, the HCR was never “triggered” in the simulated period.

Figure 8 shows the long-term average catch distribution to evaluate whether the LTMS also ensures that the stock is fished and maintained, in the future, at levels which can produce MSY. The long-term median catch was estimated at 40877 t, with 90% confidence interval encompassing the median maximum sustainable yield of 43516 t (Table 1).

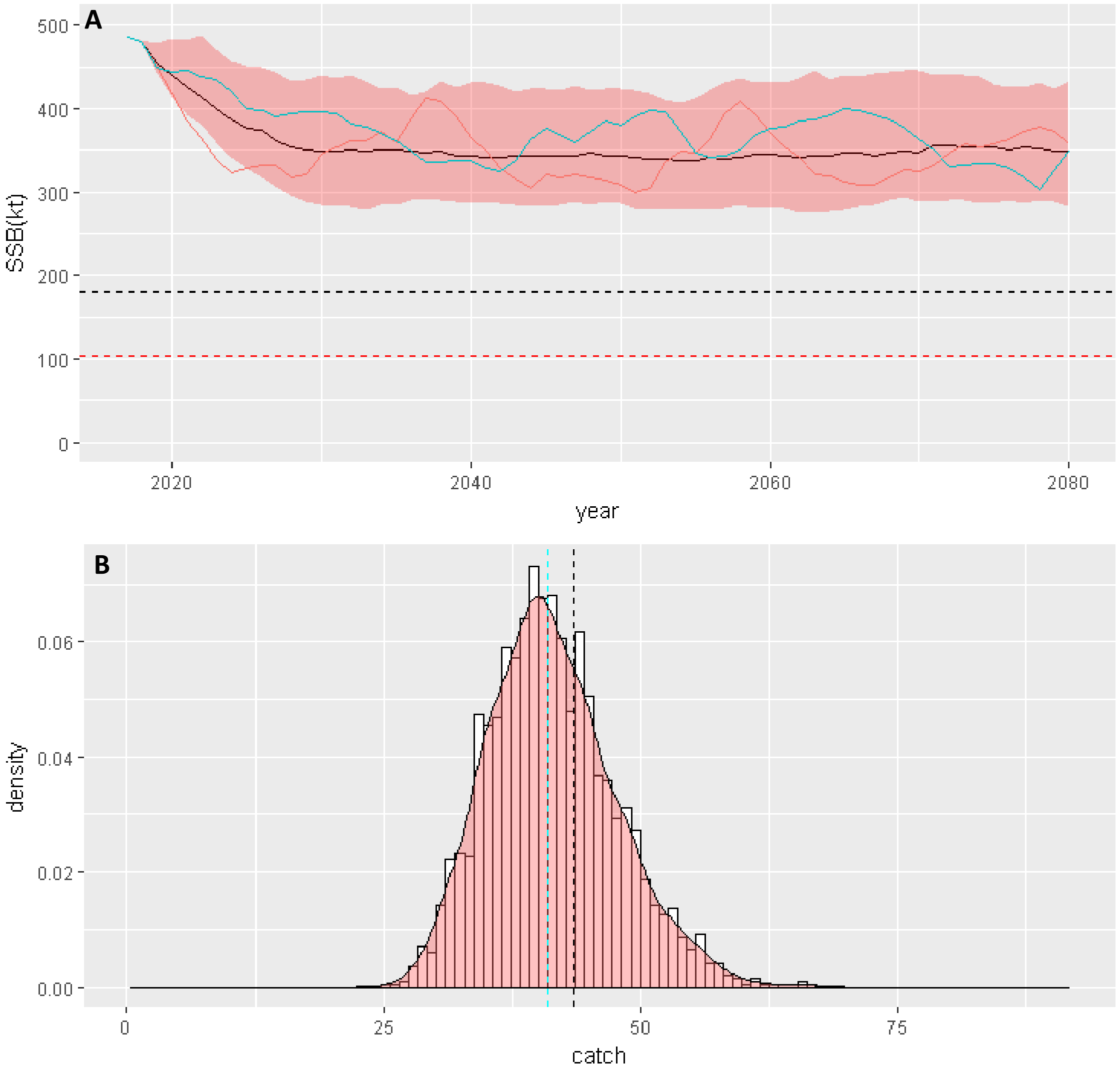


Figure 8. Panel A – SSB trajectory in the simulated period with 90% confidence intervals (shaded area) and B_{lim} (red line) and MSY $B_{trigger}$ (black line). Panel B – The long-term average catch distribution with the median of the distribution (40.88 kt, blue line) and the median MSY (43.52 kt, black line) as estimated in the BRP´s analysis.

The variability in F in the initial 10 to 15 years of the simulation period with median F´s (true and perceived) above F_{MSY} (Figure 9) is likely caused by the interim year short-term forecast in each assessment cycle, which tends to overestimate the ‘true’ SSB during the decreasing trajectory in this period (Figure 8). When the SSB stabilizes, the perception of the stock trajectory improves, decreasing the variability in F and increasing the agreement between $F_{perceived}$ and F_{true}. After the variability effects of the stock initial conditions, the median F at equilibrium is estimated around F=0.104, slightly below the established F_{MSY} (Figure 9, Table 6).

The retrospective pattern in the *sca* model between 2010 and 2016 (Annex 3) showed an overestimation of F, this is somehow reflected in the MSE simulations as the 'perceived' F is consistently higher than the 'true' F. This overestimation of F has the effect of underestimating the catch advice for year *y+1*, preventing the true F to reach F_{MSY} (Figure 9). Nevertheless, the median F at equilibrium, slightly below the established F_{MSY}, produces a long-term yield close to MSY.

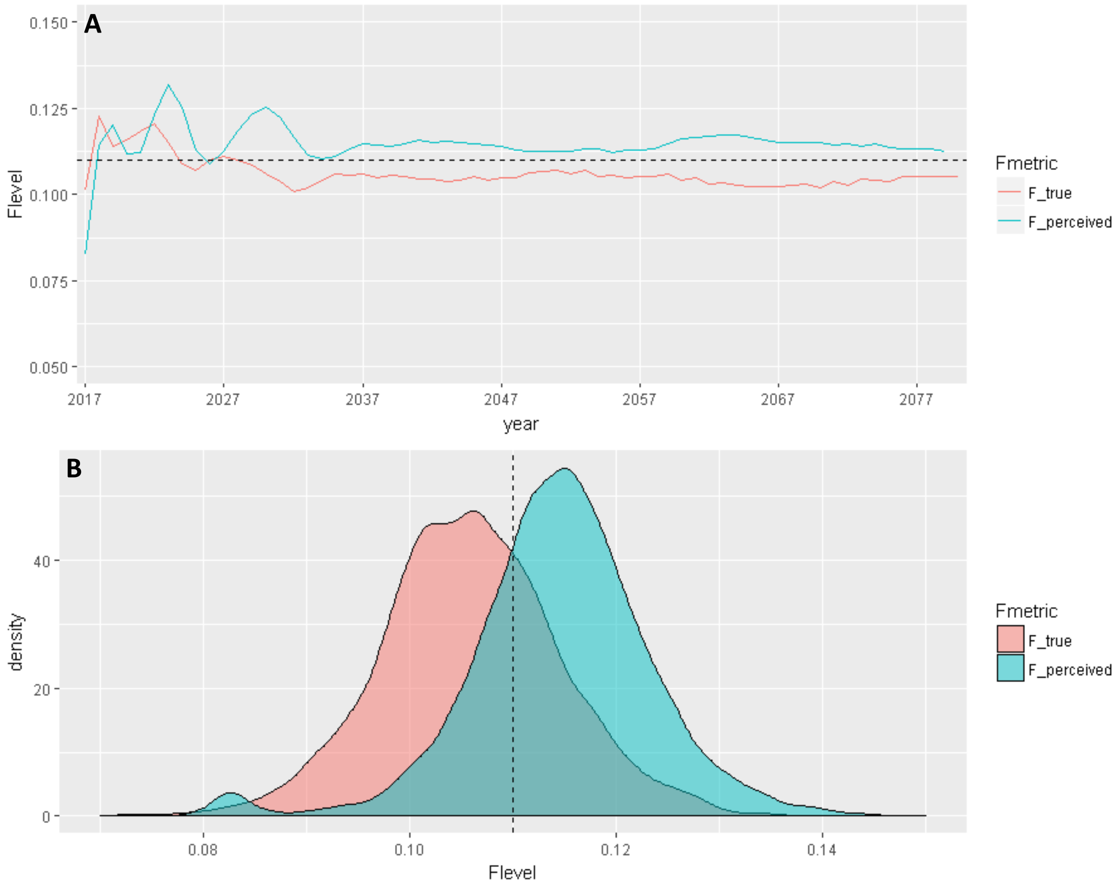


Figure 9. Panel A – Median F in the operating model (F_true) and median F in the terminal year of each assessment cycle (F_perceived) for the simulation period. Panel B – Density distribution of F_true and F_perceived for the simulation period. The dashed line in both graphs is the established F_{MSY} =0.11.

Table 6 summarizes the results of the LTMS performance metrics for yield, fishing mortality and SSB on the short term (2017-2027) and the long term (2070-2080). For precautionary considerations, P(SSB < B_{lim}) and P(SSB < MSY $B_{trigger}$) were computed as the maximum probability over the projection period (2017-2080).

Table 6. Performance statistics for yield, fishing mortality and SSB.

	Short Term 2017-2027	Long Term 2070-2080
Yield		
Median catch	51468 t	40877 t
5th perc.	38423 t	31979 t
95th perc.	60954 t	52425 t
Interannual variability IAV^1 (%) / IAV^2 (t)	6% / 35.97 t	<1% / 3.18 t
Fishing mortality		
Median F	0.113	0.104
5th perc.	0.099	0.090
95th perc.	0.127	0.117
SSB (Precautionary considerations)		
Median SSB	424669 t	352148 t
5th perc.	337165 t	286844 t
95th perc.	485520 t	436682 t
P (SSB < MSY $B_{trigger}$)	0%	0%*
P (SSB < B_{lim})	0%	0%*

* Maximum probability over all the simulation period (2017-2080).

4.2. Robustness/Sensitivity

The LTMS considers a re-evaluation of the BRP´s and the management strategy at intervals not exceeding five years to account for possible changes in the stock and fishery dynamics (Article 7). However, to improve our understanding on the robustness of the proposed LTMS we performed a sensitivity analysis with changing parameters in:

i) *Status quo* period, changed to a 3-yrs average in the estimates of F-at-age and for the input values for the biological parameters used in the short term projections in each management cycle.

ii) Selectivity at age, allowed to gradually change over time in the OM and MP using an updated smoother in the year component, with degrees of freedom conditioned to the increasing number of simulated years (*nt*):

*fmod<-substitute(~s(replace(age, age>7, 7), k=6) + s(year,k=KY),list(KY=floor(0.6*length(vy0))))*

iii) Stock productivity, considering low productivity based on the recruitment geometric mean.

iv) Target year for F_{MSY}: 2018.

The key performance statistics were analyzed (results available but not shown) for scenarios i) to iv). The minor changes observed further supported the robustness of the LTMS results.

As shown in the previous section, the stock is at very healthy state and currently being exploited below F_{MSY}. The good condition of the stock coupled with an F_{MSY} restricted by the F_{pa}, resulted in a very high probability of the stock being above B_{lim} and also not falling below MSY $B_{trigger}$ level. To further explore the robustness of the LTMS on the performance of the HCR with the catch constraint, we ran the simulations assuming a reduced productivity on the stock, to 40% of the observed geometric mean recruitment.

Figure 10 shows the recruitment, SSB and fishing mortality trajectories with 90% confidence intervals for the low productivity scenario. The HCR with the catch constraint also ensures that the stock is maintained above B_{lim} with very high probability (P(SSB < B_{lim}) = 0), fluctuating around MSY $B_{trigger}$ level, (P(SSB < MSY$B_{trigger}$) = 0.67). Fishing mortality is reduced according to the HCR and despite the ±15% catch constraint, the HCR successfully prevents the stock falling below B_{lim}.

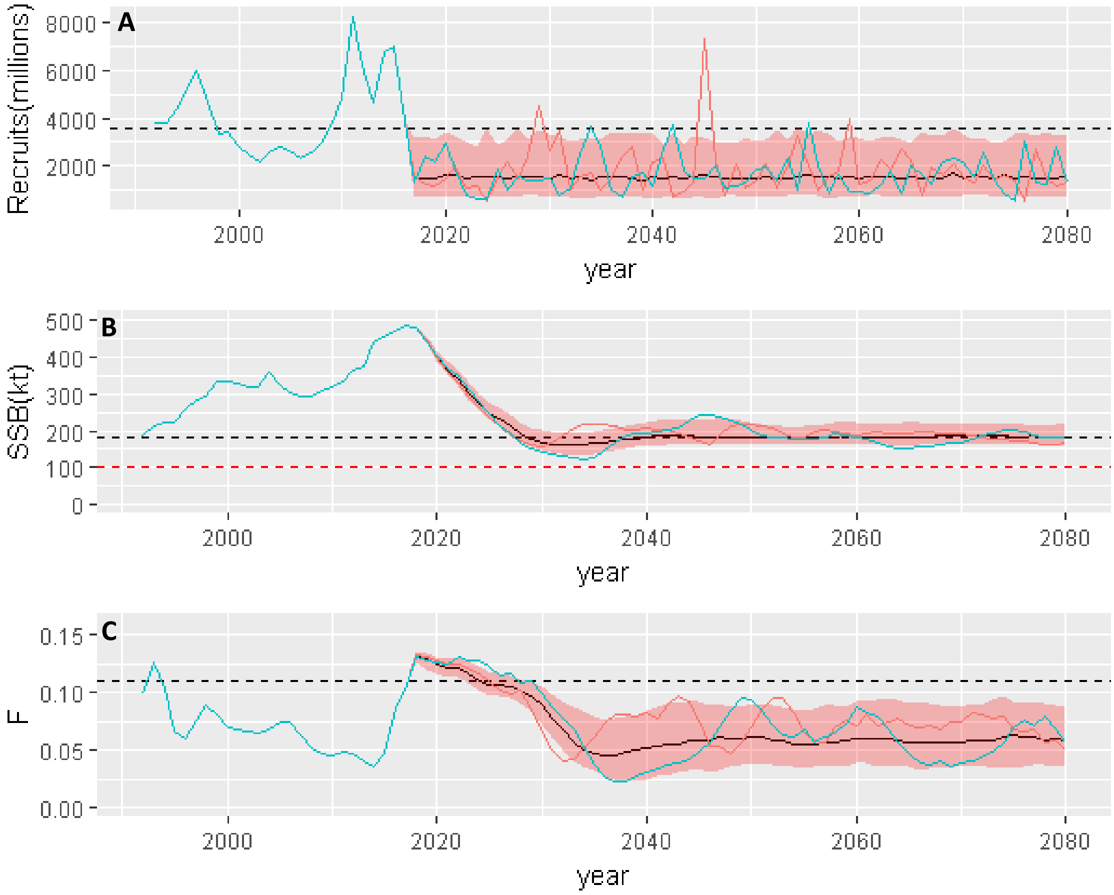


Figure 10. Simulation results on the low productivity scenario. Panel A – Median Recruitment with 90% confidence intervals and the geometric mean of 1992-2016 (black line). Panel B – Median SSB with 90% confidence intervals showing the B_{lim} (red line) and MSY $B_{trigger}$ (black line). Panel C – Median fishing mortality with 90% confidence intervals and the established F_{MSY} (black line). Two populations selected randomly are also shown in the simulation years.

The outputs and main results for all the MSE simulations carried out during the development of the LTMS are available upon request. The R code used to perform the full-feedback MSE is also available upon request.

5. Conclusions

The proposed LTMS, with a HCR defined by F_{MSY} at 0.11, $F_{by\text{-}catch}$=0.01, MSY $B_{trigger}$ at 181000 t and B_{lim} at 103000 t and with a ±15% catch constraint for SSB above B_{lim}, performs according to requirements. The probability of SSB being below B_{lim} is less than 5%, being considered precautionary under the ICES precautionary criterion. The proposed management plan also performed successfully (in terms of being precautionary) under changing parameters of stock productivity, selectivity and *status quo* period, showing that the proposal is robust to some of the major assumptions made in the initial conditions. The very healthy state of the stock and an F_{MSY} level restricted to a lower precautionary F_{pa} results in a very low probability of SSB also being below MSY $B_{trigger}$. The proposed long term management strategy also ensures that the stock is able to produce long-term equilibrium catches very close to MSY.

The results of the simulations assuming a very low productivity on the stock indicates that the HCR with the catch constraint is also able to prevent the stock to go below B_{lim}.

The Advisory Councils (ACs), and in particular the Pelagic Advisory Council with the collaboration of the South Western Waters Advisory Council, contributed from the very beginning of the LTMS development. Their involvement led to fruitful discussions with managers and scientists on different options for management objectives, HCR, TAC settings, F_{MSY} target year and catch stability levels. In fact, the interest and dedication showed by stakeholders during this process gives us hope that the fishery community will be strongly committed in the implementation of the proposed management strategy.

Acknowledgments

We thank José de Oliveira and Chris Legault for reviewing a first version of the report and providing constructive comments. The work was partly supported by IPMA National Sampling Programme for Biological Parameters (PNAB\EU Data Collection Framework) and the IEO Programme "Evaluación de recursos pesqueros en el área del ICES".

References

Azevedo, M., Mendes, H., Costas, G. 2016. Biological Reference Points for Horse mackerel (*Trachurus trachurus*) in Division IXa (southern stock). WD to the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA), 24-29 June 2016, Lorient, France. ICES CM 2016/ACOM:17.

Cabral, h. And Murta, A. 2002. The diet of blue whiting, hake, horse mackerel and mackerel off Portugal. Journal of Applied Ichthyology 18(1):14 – 23.

ICES. 2013. Report of the Working Group on Methods of Fish Stock Assessments (WGMG), 30 September - 4 October 2013, Reykjavik, Iceland. ICES CM 2013/SSGSUE:08.

ICES. 2016a. Report of the Working Group on the assessment of horse mackerel, sardine and anchovy (WGHANSA). ICES CM 2016/ACOM:17.

ICES. 2016b. Advice basis. In Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.2.

ICES. 2017a. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35.

ICES. 2017b. Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA), 24–29 June 2017, Bilbao, Spain. ICES CM 2017/ACOM:17.

ICES. 2017c. ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice, Book 12, Section 12.4.3.1.

Jardim, E., Scott, F., Mosqueira, I., Citores, L., Devine, J., Fischer, S., Ibaibarriaga, L., Mannini, A., Millar, C., Miller, D., Minto, C., De Oliveira, J., Chato-Osio, G., Urtizberea, A., Vasilakopoulos, P., Kell, L. 2017. Assessment for All initiative (a4a). Workshop on development of MSE algorithms with R/FLR/a4a. 30th January - 3rd February. Ispra, Italy.

Jennings, S., Kaiser, M.J., Reynolds, J.D. 2001. Marine Fisheries Ecology. Blackwell Science, Ltd. London.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M.A., Poos, J.J., Scott, F., Scott, R.D. 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science, 64(4), 640–646.

Lowe, S., Ianelli, J. and Palsson, W. 2012. Stock assessment of Atka mackerel stock in Bering Sea/Aleutian Islands. In Stock Assessment and Evaluation Report for the Groundfish Re-sources of the Bering Sea/Aleutian Islands. North Pacific Fisheries Management Council: 1561-1645.

Methot, R.D. and Wetzel, C. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142:86-99.

Uriarte, A., Azevedo, M., Costas, G., Mendes, H. 2017. Report of the Workshop on Data Evaluation for Southern Horse Mackerel (WKSHOM) *in* Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35. 142-225 p.

Wood, S.N. 2017. Generalized Additive Models: An Introduction with R (2nd edition). Chapman and Hall/CRC.

Annexes

Annex 1

Summary of the main meetings and relevant milestones (Table I) and range of options tested during the development of the LTMS, including TAC settings, target year for F_{MSY} and catch stability levels (Table II)

Table I – Main meetings and relevant milestones throughout the development of the LTMS.

Meeting date and Forum	Subject and milestones
1. October 2014, SWWAC/PELAC meeting, Madrid	First debate on Management plan
2. November 2014, SWWAC/PELAC webex meeting	Type of harvest control rule (TAC, F or Harvest Rate)
3.February 2015, SWWAC meeting, Lisbon	Refinement of HCR type and relevant Biological Reference Points - BRPs
4.February 2016, PELAC meeting, Denn Haag	BRP estimates (2015 assessment data); Rationale accepted by PELAC
5.March 2016, SWWAC stakeholders meeting, Matosinhos	Stakeholders feedback on options for catch stability; Level of catch for $F_{by\text{-}catch}$
6. June 2016, ICES WGHANSA, Lorient	BRP estimates, used by ICES for advice (Azevedo *et al.*, 2016; ICES 2016a)
7.October 2016, PELAC meeting, Denn Haag	Presentation of BRPs and results from 1st set of stochastic simulations (MSE short-cut approach); questions to stakeholders on assumptions & Management options -> questionnaire sent to stakeholders
8.November 2016, SWWAC/PELAC meeting, Lisbon	Synthesis of stakeholders response to questionnaire; set roadmap for further analysis
9.February 2017, ICES WKPELA, Lisbon	Benchmark. Stock ID, biological and productivity parameters, BRP´s and assessment method reviewed (ICES, 2017a)
10..June 2017, SWWAC/PELAC meeting, Matosinhos	Preliminary results from stochastic simulations using full MSE; stakeholders feedback on HCR, management options and diagnostic metrics
11. June 2017, ICES WGHANSA,Bilbao	Scientific feedback on full MSE methodology and results
12.July 2017, PELAC meeting, Denn Haag	Results from full MSE for several management option; process follow-up
13.July 2017, SWWAC/PELAC meeting, Matosinhos	Stakeholders discussion and decision on the draft proposal for the LTMS
14.October 2017, PELAC meeting, Denn Haag	Proposal for LTMS accepted by PELAC; submission to DGMARE

Table II- Range of options tested during the development of the LTMS, including TAC settings, target year for F_{MSY} and catch stability levels.

Scenarios	Basis		Catch constraint
F management	Target: Management: Target year: HCR	F_{MSY} through F 2025 or 2018 on	Not applicable
TAC management	Target: Management: Target year: HCR	F_{MSY} TAC_{y+1}=$Catch_{y-1}$ 2025 or 2018 on	+/- 15% and +/- 20%
TAC management	Target: Management: Target year: HCR	F_{MSY} TAC_{y+1}=mean ($Catch_{y-3}$:$Catch_{y-1}$) 2025 or 2018 on	+/- 15% and +/- 20%
TAC management	Target: Management: Target year: HCR	F_{MSY} TAC_{y+1}=TAC_y 2025 or 2018 on	+/- 15% and +/- 20%

Annex 2

Description of the MSE short-cut approach

A preliminary analysis on the management strategies was performed using an MSE short-cut approach based on the 2015 stock assessment and the BRP's. The results from these preliminary set of stochastic simulations were discussed with stakeholders and were proven useful to decide on the preferred range of management options to evaluate under a full MSE. Code was developed in R and implemented with the use of the FLR packages (version 2.5.20160504), FLash and FLassess to implement the framework as described in Figure I. Simulations were run for 1000 iterations (populations) from 2017-2070, starting from the terminal year of the last assessment. Recruitment variability was generated assuming a multiplicative error using the residuals of the model fit to the historical stock-recruit pairs. Weight-at-age variability in the simulated period was generated from a log-normal error with standard deviation based on the observed time series (2005-2015). The main issue in this approach was to simulate the behaviour of the assessment model by generating from the operating model a population with similar statistical characteristics (e.g. CV) that reflect the behaviour of the AMISH model. To implement an observation error in the short-cut approach, a log normal distribution was applied directly on the stock numbers at age, with larger deviates for younger ages and scaled to give a CV on SSB similar to the CV of the assessment. Assessment error was applied directly to the F in the advice year adopting the CV of F in the last assessment year. Robustness of the HCR was also tested in a low productivity scenario without strong year classes and sensitivity of the simulations over a range of F values. Results available in: http://www.pelagic-ac.org/media/pdf/Presensation%20Azevedo%20SHom.pdf.

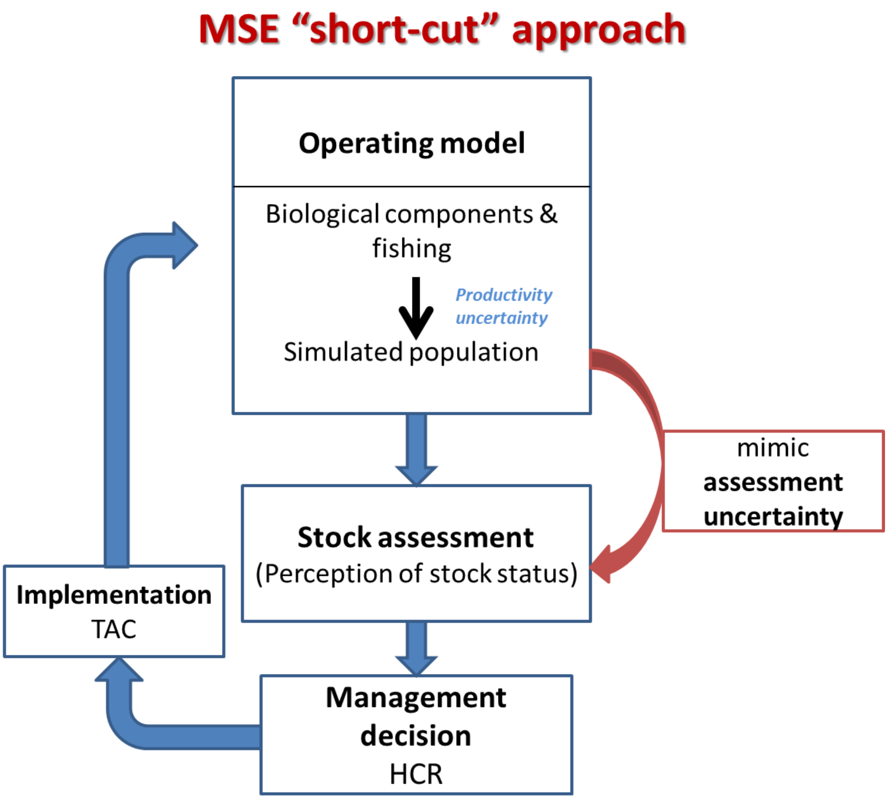


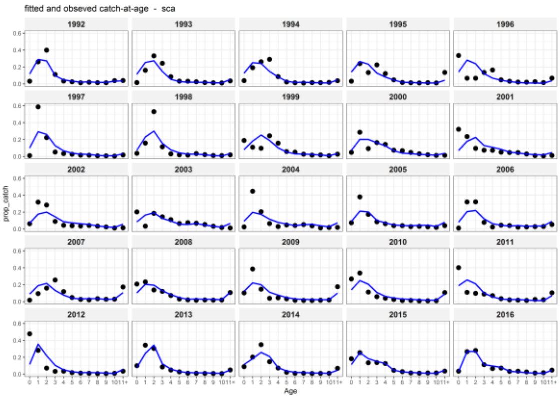
Figure I - Diagram of the MSE short-cut approach used in the development of the southern horse mackerel strategy proposal.

Annex 3

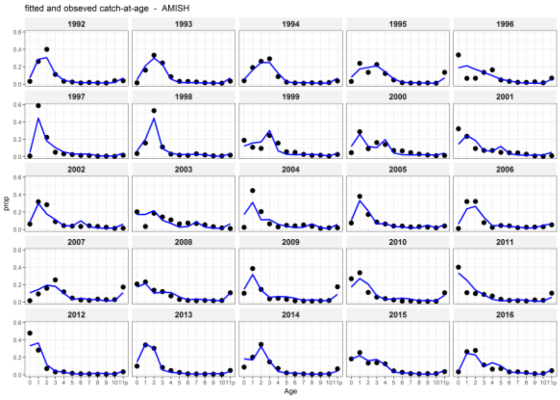
Diagnostics from model fit and retrospective analysis: **sca** (left) & **AMISH** (right)

MODEL FIT

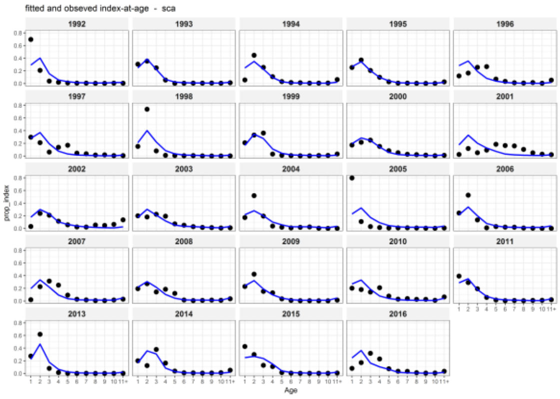
Observed (dots) & fitted (line) catch-at-age



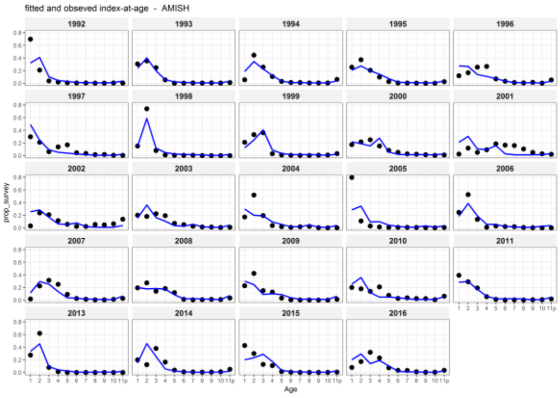
Observed (dots) & fitted (line) catch-at-age



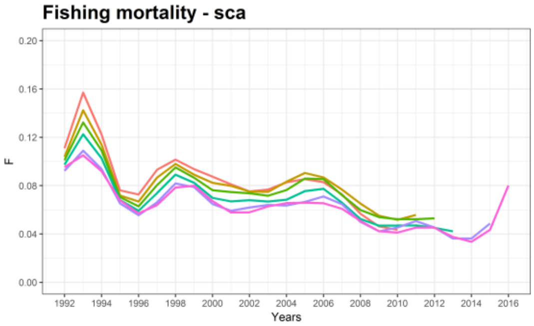
Observed (dots) & fitted (line) cpue-at-age

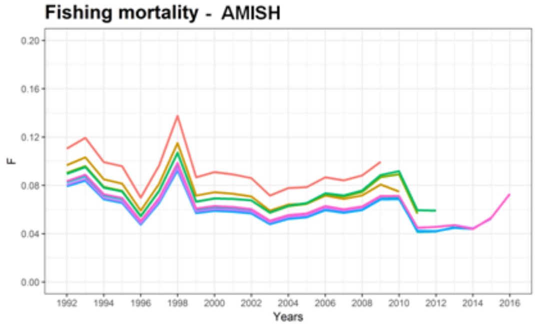


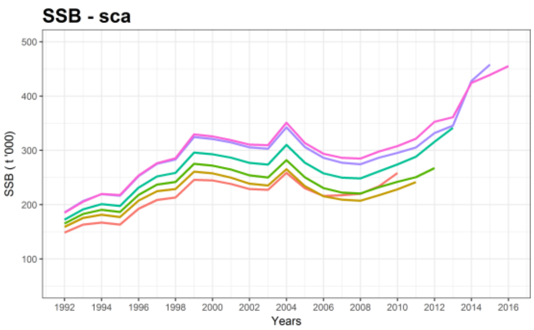
Observed (dots) & fitted (line) cpue-at-age

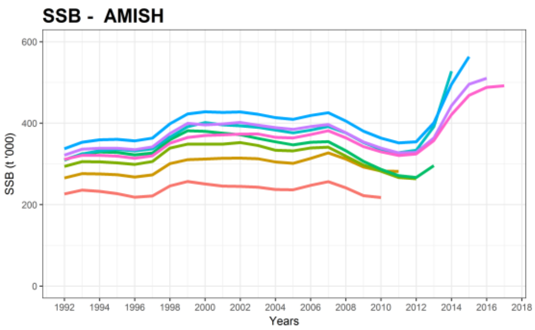


RETROSPECTIVE PATTERN









MINISTÉRIO DO MAR

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