The following supplements accompany the article

Challenges of management strategy evaluation for small pelagic fish: the Bay of Biscay anchovy case study

Sonia Sánchez*, Leire Ibaibarriaga, Andrés Uriarte, Raul Prellezo, Marga Andrés, Pablo Abaunza, Ernesto Jardim, Sigrid Lehuta, Lionel Pawlowski, Beatriz Roel

*Corresponding author: ssanchez@azti.es

Marine Ecology Progress Series 617-618: 245–263 (2019)

Supplement 1. Two-stage biomass model

The basic structure of the management strategy evaluation and the economic model is detailed in Figure 2 in the main text of the paper.

Operating Model

The system was modelled considering one unique anchovy stock and one fleet operating in several seasons along the year (Figure S1).

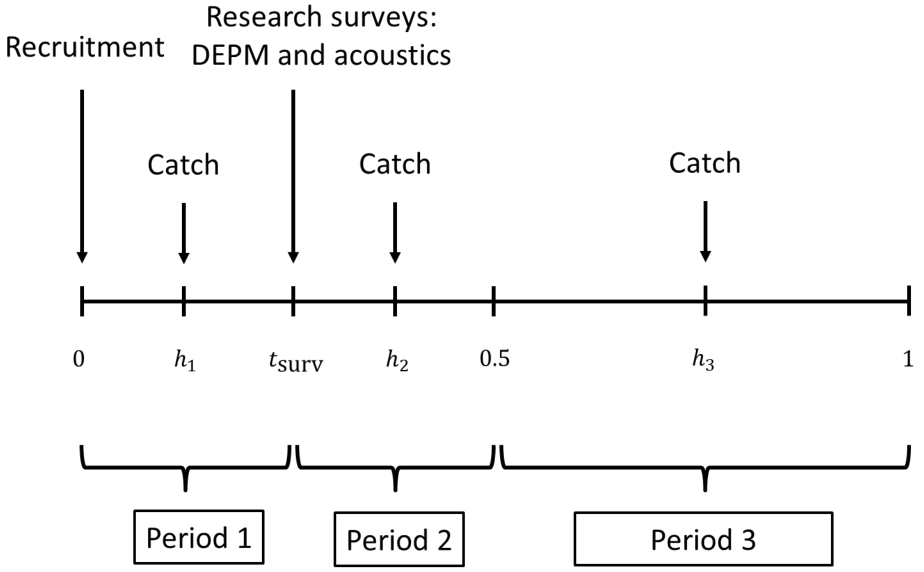

Figure S1. Timing of events taking place throughout the year for the Bay of Biscay anchovy population. Adapted from Ibaibarriaga (2012).

Population dynamics are described in terms of biomass with two age classes: the recruits (individuals at age 1) and the adults (age 2+). State equations of the two-stage biomass dynamic model developed for this anchovy population by Ibaibarriaga et al. (2008), known as the Bayesian biomass-based model (BBM), are used to describe the dynamics of the resource from one year to the next. Three periods were considered within each year: (i) per_1: January 1st (when recruits enter the exploitable population) – May 15th (when spring research surveys occur); (ii) per_2: May 16th –June 31st; and (ii) per_3: July 1st –December 31st. Recruitment and catch are assumed to occur instantaneously as pulses, whereas growth and natural mortality operate continuously in time, as described by the following equations:

$$B(t_{\text{surv}}, y, 1) = R_y \cdot e^{-g\, t_{\text{surv}}} - C(\text{per}_1, y, 1) \cdot e^{-g\,(t_{\text{surv}} - h_1(y))} \tag{S1}$$

$$\begin{aligned} B(t_{\text{surv}}, y, 1^{+}) = B_0 \cdot e^{-gy} &+ \sum_{j=1}^{y} R_j \cdot e^{-g(t_{\text{surv}} + y - j)} \\ &- \sum_{j=1}^{y} C(\text{per}_2, j-1, 1^{+}) \cdot e^{-g(t_{\text{surv}} + 1 - h_2(j-1) + y - j)} \\ &- \sum_{j=1}^{y} C(\text{per}_3, j-1, 1^{+}) \cdot e^{-g(t_{\text{surv}} + 1 - h_3(j-1) + y - j)} \\ &- \sum_{j=1}^{y} C(\text{per}_1, j, 1^{+}) \cdot e^{-g(t_{\text{surv}} - h_1(j) + y - j)} \end{aligned} \tag{S2}$$

where $B(\text{t}, \text{y}, \text{a})$ and $C(\text{t}, \text{y}, \text{a})$ denote the biomass and catches (in tonnes) of age class a at time instant t of year y, respectively; B_0 the total initial biomass; R_y the recruitment in year y (which corresponds to age 1 biomass at the beginning of the year); g is an instantaneous rate of biomass decrease accounting for intrinsic rates of growth (G) and natural mortality (M), where $g = M - G$; t_{surv} fraction of the year corresponding to the first period; per_1 and per_2 corresponds to the two periods defined previously; and h_1 and h_2 are the time instants when catches occur, with $0 < h_1(y) < t_{\text{surv}} < h_2(y) < h_3(y) < 1$.

Recruitment was modelled following a Ricker stock-recruitment model (the best model in terms of the Akaike's Information Criterion, AIC), fitted by least squares from the time series of median spawning stock biomass and recruitment estimates from 1987 to 2007 (ICES 2007).

Management Procedure

Due to computational limitations the management was not model-based. That is, assessment was not simulated within the Management Procedure. Alternatively, a short-cut approach was taken. That is, observation and assessment errors were considered jointly based on the assumption that both processes generate a spawning stock biomass (SSB) estimate subject to an error, upon which decisions are taken. In this case, the SSB estimates were considered log-normally distributed, with median equal to the true population SSB and a coefficient of variation ($CV_{B.obs} = 0.25$). This value was higher than the CV of the biomass estimates from the assessment and was considered sufficiently large to account for both the observation and assessment errors.

Implementation model

The management advice was generated using a harvest control rule (HCR) which sets the TAC from July of year y to June of year $y{+}1$. The implementation of the advice was considered perfect (i.e. without error). Therefore, the total catch taken from the population in this period was equal to the TAC set. Catches by season were estimated based on fixed percentages (0.348, 0.252, and 0.4, respectively for periods 1-3). These percentages by season were calculated given the historical catches by semester (1992-2004). Then, 60% of the total catches were allocated to the first semester, assuming that 58% of the catches allocated to the first semester were taken in the first season, that is before May 15th. No selectivity at ages was modelled, so that age composition of catches was equal to those of the population, which is equivalent to assuming a flat selectivity pattern at age of the fishery (Ibaibarriaga et al. 2008). In cases when the population was not large enough to support the expected catch in a season, a TAC undertake was forced, setting final catch in this season equal to 95% of population biomass in the OM.

Economic model

The economic model had the following components: (i) a price function to model the prices for the anchovy stock, and fixed price for the rest of the species; (ii) a Schaefer type production function (Schaefer 1954) with effort and biomass elasticities equal to 1:

$$Y_{i,t} = q_i \cdot SSB_t \cdot NB_{i,t} + u_t \Leftrightarrow \frac{Y_{i,t}}{SSB_t} = q_i \cdot NB_{i,t} + u_t \qquad \text{(S3)}$$

where $Y_{i,t}$ is the yield of fleet i at time t, q_i is the catchability parameter for fleet i, NB is the number of vessels, and u_t the error term. Three fleets were considered, and their estimated catchability parameters are listed in Table S1. Equation (S3) was used to estimate the effort required to catch the anchovy quotas and to estimate the catches of the rest of the species given the remaining effort available. Costs parameters (fixed and variable ones) were assumed constant and different for each fleet. Profits were computed given the total costs, but excluding capital costs, given the following equation: $Profits_{i,t} = \left(P_{i,t} - AVC_{i,t}\right) \cdot Y_{i,t} - FC_i$, where P is the price, AVC are the average variable costs, and FC are the fixed costs, for fleet i and year t.

Table S1. Catchability coefficients for the different fleets with their standard errors and their coefficient of determination (R^2).

Country	**Fleet**	**Catchability**	**Std. error**	**R^2**
Spain	purse seine	0.99 e-03	0.96 e-04	0.86
France	purse seine	1.51 e-03	1.31 e-04	0.89
	pelagic trawler	2.75 e-03	3.32 e-04	0.81

For calculating the anchovy price by semester, a price model was estimated given the data on landings in the Atlantic ports and prices from the corresponding auction market for the period 2000-2006. These landings represented 85% to 99% of the total landings, as French boats sell anchovy in the Spanish ports (Pita et al. 2014). Deflated prices (in €, corrected relative to year 2006) per semester and total landings were used in the estimations. The deflated price (PD), relative to the reference year ($ref.yr$), was calculated as follows:

$$PD = P_y \cdot \frac{1}{(1+DR)^{(y-ref.yr)}} \qquad \text{(S4)}$$

where P_y represents the original price (in year y) and $DR = 0.05$ is the discount rate.

Half-yearly prices were considered, as anchovy has historically shown differences, with higher prices in the first semester. The model used to estimate anchovy prices, both for Spain and France, was a semi-log price model (P_{ANE}), given by the formula:

$$P_{ANE,t} = a + b \cdot Log\left(Y_{ANE,t}\right) + c \cdot SEM_t + u_t, \qquad \text{(S5)}$$

where $Y_{ANE,t}$ represents total anchovy landings at time t, SEM is a dummy variable, equal to 1 when landings correspond to the first semester of the year and 0 otherwise, and u_t is the error term. Table S2 shows the estimates obtained. Regarding the sign of the parameters, the estimated effect for the volume of landings was negative and anchovies landed in the first semester reached higher prices. In the second semester, the fishery was mainly exploited by pelagic trawlers and according to the species characteristics, anchovies were smaller and they had more fat content, which is less valued by the canning industry.

Table S2. Estimated parameters for the demand function for both semesters, conditioned to 2000-2006 data.

Parameter	Value	Std. error	R^2
a	22.3717	2.7417	0.85
b	-2.1538	0.2963	
c	1.0556	0.0041	

The price of other species (P_{OTH}) was assumed fixed, although different for each fleet involved in the fishery. It was calculated as an average for the period 2000-2004 (deflated price in €, corrected relative to year 2006) as follows:

$$P_{OTH,i} = mean\left(\frac{ROL_{i,t} - RAL_{i,t}}{Y_{i,t} - Y_{ANE,i,t}}\right) \tag{S6}$$

where $P_{OTH,i}$ is the price of other species captured by fleet i, ROL is the revenue related to overall landings, RAL is the specific revenue from anchovy, Y is the overall landings, and Y_{ANE} represents anchovy landings. Subscripts i and t stand for fleet and time, respectively. Table S3 shows the estimated prices for the other species.

Table S3. Estimated prices for the other species (annual, for the Spanish fleet and by semester for the French fleets), conditioned to 2000-2004 data.

Country	Fleet	Price	
		Semester 1	Semester 2
Spain	purse seine	2.5	
France	purse seine	2	2.18
	pelagic trawler	0.98	0.61

The biological results were translated into financial identities of the fishing firms, using the identities described below.

The fleet gross revenue ($GR_{i,t}$), Equation (S7), was defined as the sum of the anchovy (*ANE*) revenues and other fisheries (*OTH*) gross revenues.

$$GR_{i,t} = GR_{ANE,i,t,1} + GR_{ANE,i,t,2} + GR_{OTH,i,t,1} + GR_{OTH,i,t,2}, \tag{S7}$$

where $GR_{ANE,i,t,s} = P_{ANE,i,t} \cdot Y_{ANE,i,t,s}$, $GR_{OTH,i,t,s} = P_{OTH,i} \cdot Y_{OTH,i,t,s}$.and subscripts i, t, s stand for fleet, year, and semester, respectively.

The net revenue related to anchovy ($NR_{ANE,i,t}$) and other species ($NR_{OTH,i,t}$) was defined as:

$$NR_{sp,i,t} = \left(1 - Landing\ fee_{i,t}\right) \cdot GR_{sp,i,t}, \text{ with } sp \in \{ANE, OTH\} \qquad \text{(S8)}$$

where the landing fee is a percentage of the gross revenue (GR) imputed to anchovy and other species. Subscripts sp, i, t stand for species, fleet, and year, respectively.

The revenue to be shared ($RTBS$) was defined as the difference between the net revenue and the so-called “shared cost” (SC)[*]:

$$RTBS_{sp,i,t} = NR_{sp,i,t} - SC_{sp,i,t}, \text{ with } sp \in \{ANE, OTH\} \qquad \text{(S9)}$$

The shared cost ($SC_{i,t}$) for the French and Spanish fleets[†] were respectively: $SC_{ANE,i,t} = (Fuelc_i + Baitc_i + Icec_i + Foodc_i) \cdot E_{ANE,i,t} \cdot NB_{ANE,i}$ for Spanish seines and $SC_{ANE,i,t} = (Baitc_i + Icec_i + Foodc_i + SSV_i) \cdot E_{ANE,i,t} \cdot NB_{ANE,i}$ for French seines and trawlers, where $Fuelc$, $Baitc$, $Icec$, $Foodc$, and SS stands for fuel, bait, ice, food, and social security costs paid by the vessel (in €), respectively, E_{ANE} corresponds to the effort by vessel and NB_{ANE} to the number of vessels targeting anchovy.

The vessels (VS) and crews share (VS) for the given fleet follows respectively:

$$VS_{sp,i,t} = \varphi_i \cdot RTBS_{sp,i,t}, \text{ with } sp \in \{a, o\} \qquad \text{(S10)}$$

$$CS_{sp,i,t} = (1 - \varphi_i) \cdot RTBS_{sp,i,t}, \text{ with } sp \in \{a, o\} \qquad \text{(S11)}$$

Where φ_i corresponds to the percentage owned by the vessel holder.

Based on the previous equations the fleet cash flow (FCF) was: $FCF_{i,t} = VS_{ANE,i,t} + VS_{OTH,i,t} - (FC_i - SSV_i) \cdot NB_{ANE,i}$ for the French fleets and $FCF_{i,t} = VS_{ANE,i,t} + VS_{OTH,i,t} - FC_i \cdot NB_{ANE,i} - \left(Fuelc_i \cdot NB_{a,i}\right)$ for the Spanish fleet, where FC[‡] stands for the fixed costs and SSV for social security paid by the vessel.

Due to the relative importance of the fuel cost in the total fishing cost and the evolution on fuel prices from the previous years, it was assumed that $Fuelc_i \sim N\left(mean_{Fuelc_i}, \theta_{Fuelc_i}\right)$. Moreover, the uncertainty was also extended to fixed costs, that is $FC_i \sim N\left(mean_{FC_i}, \theta_{FC_i}\right)$.

Variable costs are useful to establish the minimum TAC required to maintain the fleet in the very short run, which in the worst situation, would imply losing no more than fixed costs. Since this situation is not stable, in the long run (as the fleet would disappear), the relevant parameter to have in mind is the economic break-even (EBE_i), see Equation (S12).

$$Y_{EBE_i} = median\left(\frac{FC_i}{P_{t,i} - AVC_{t,i}}\right) \Rightarrow QUOTA_{EBE_i} = \frac{FC_i}{P_{t,i} - AVC_{t,i}}, \qquad \text{(S12)}$$

---

[*] The operating cost data for the Basque purse seines have been derived from a homogeneous vessel type performance operating in the anchovy fishery during the years 2000-2004 and are in deflated prices (in €, corrected relative to year 2007).

[†] For the Spanish fleet, a simplification of the shared system has been considered given that the shared costs systems differ between regions.

[‡] Social security cost paid by the vessel owner.

Supplement 2. Age-structured model

Main differences with respect to the two-stage model are detailed in this section.

Operating Model

In this case the system was modelled considering one unique anchovy stock and one fleet operating in two seasons along the year (corresponding to the two semesters of the year).

The biological operating model (OM) was age-structured and the population was projected using Pope's approximation to the Baranov equation (Pope 1972) by semesters. The population is divided into four age classes: the recruits (individuals at age 0) and adults at ages 1 to 3^+. Individuals were considered fully mature at age 1. Natural mortality was assumed different for each age class (ICES 2013a, Uriarte et al. 2016) still constant across years and semesters.

It was assumed that recruitment (number of individuals at age 0) enters the population at the beginning of the second semester and was modelled as a function of the spawning stock biomass at the middle of the year, using a Ricker stock recruitment relationship fitted to the 1987 to 2007 data (ICES 2013b).

The parameters of the OM were based on the most recently available results of the Bayesian biomass-based model including catches (CBBM) (Ibaibarriaga et al. 2011, ICES 2014), which consist of an extension of the BBM assessment model. The main differences of this model relative to the BBM are that: (i) catches are modelled (obtaining estimates of selectivity at age); and (ii) growth and mortality are disaggregated by age. The Markov Chain Monte Carlo (MCMC) draws were used to account for all the uncertainty from the assessment. Mean weights were derived from the stock weights in spring (observed in the surveys) considering the growth at age estimated in the assessment and assumed equal for ages 2 and 3^+. Initial population in numbers at age, in January 2013, was inferred from the past recruits at age 1, given by the CBBM (in mass) divided by mean weight at age and projected forward according to fishing and natural mortalities on a half-year basis (STECF 2014). Half-yearly natural mortality rates and growth parameters were set as in CBBM (i.e. $M = 0.4$ for ages 0-1 and 0.6 for older fish and $G_1 = 0.54$, $G_{2+} = 0.24$). Half-yearly fishing mortality at age and selectivity at age 1 were also estimated in the assessment, whereas selectivity at age 2^+ was set equal to 1 and selectivity of age 0 was set equal to 0.05 in the second semester in accordance with previous age structured seasonal assessments on this stock (ICES 2005, Uriarte 2005).

Management Procedure

Management was not model-based and a short-cut approach was used instead. Observation and assessment uncertainty were considered jointly in the observation error model (OEM) and the perceived SSB that is required for taking decision on the harvest was generated differently from the previous management plan, as for the new HCR this required the expected SSB in May *y+1* (for the management period running from January to December of year *y)*. This SSB is derived from the estimates of biomass at age 1 (i.e. the age 0 recruits from year *y-1*) and at age 2^+ (adults surviving from previous year), given the potential expected catches. These estimates are simulated independently as a random observation of each of the biomasses generated from a lognormal distribution, with mean equal to age 1 and age 2^+ biomasses at the beginning of the year *y+1* from the OM (in log scale), respectively, and a standard deviation based on a $CV_{B.obs} = 0.25$, as in the previous simulations. The basis of an independent observation for these two age groups is the fact that assessment is informed by different sources for each of them; age 1 recruits by the autumn survey on juveniles (JUVENA) and age 2+ from the spring surveys on spawners. Given the approach taken in the OEM, we assumed that $CV_{B.obs}$ is the same independently of when the assessment is carried out (either in June or December).

Implementation model

Management advice was generated based on several HCRs. The HCRs considered establish the annual TAC (in tonnes) as a constant proportion of the latest estimate of SSB, for the July-June management calendar, or of the expected SSB during the management period, for the January-December management calendar. For the January-December management calendar, for estimating the expected SSB a short-term forecast needs to be carried out as a function of the expected catches. In that short-term forecast, the following assumptions were made: (i) the selectivity at age used for the first semester was 0.48 and 1 for ages 1 and 2^+, respectively, which corresponds to the medians of the last assessment; and (ii) the percentage of catches in the first semester was assumed to be 0.6.

The implementation model remains unchanged relative to the previous approach. Due to the lack of data, the effort dynamics was not simulated and therefore within the OM, the TAC was split into semesters according to historical values 1992-2004 and 2011-2012 (i.e. 60% in the first semester). Total catches by semester were disaggregated by age using the different selectivity patterns at age.

Economic model

The anchovy price was estimated differently for the first and second semester. In the first semester, the expected price, $\hat{P}_y$, was estimated using a price function which considers a linear relationship between landing and prices in this semester, in the log scale:

$$P_{sem1} = a + b \cdot log(L_{sem1}), \qquad (S13)$$

where P_{sem1} is the average price and L_{sem1} is the total landings, in the first semester, and b is the price elasticity. The estimated parameters are presented in Table 4. For the second semester, anchovy prices were fixed at 1.5 €/kg, the average price between 2010 and 2013, as no model could be fitted to the data.

Table S4. Estimated parameters for the demand function for the first semester, conditioned to 2010-2013 data.

Parameter	**Value**	**Std. error**	**p-value**	**R²**
a	12.0040	1.7362	7.16e-06	0.6681
b	-0.6613	0.1246	1.10e-04	

Supplement 3. Summary statistics

The main performance statistics used to evaluate the different HCRs were as follows:

a) Median Spawning Stock Biomass across years and iterations.

b) Probability of SSB being below B_{lim} in any randomly chosen year of the projection period. Sometimes also referred to as biological risk:

$$P(SSB < B_{lim}) = \frac{\sum_{iter,i} I\left[SSB_{iter,y} < B_{lim}\right]}{N_{iter} \cdot N_y} \qquad (S14)$$

c) Probability of the fishery being closed (i.e. TAC=0) in any randomly chosen year of the projection period:

$$P(closure) = \frac{\sum_{iter,i} I\left[TAC_{iter,y} = 0\right]}{N_{iter} \cdot N_y} \qquad (S15)$$

d) Expected average catch (in biomass) across the projection years:

$$\bar{C} = \frac{\sum_{iter,i} C_{iter,y}}{N_{iter} \cdot N_y} \qquad (S16)$$

e) Expected average standard deviation of the catch (in biomass) across the projection years:

$$\frac{\sum_{iter,y} sd_y(C_{iter,y})}{N_{iter}} = \frac{\sum_{iter,y} \sqrt{\frac{\sum_y (C_{iter,y} - \bar{C}_{iter})^2}{N_y - 1}}}{N_{iter}} \qquad (S17)$$

f) Discounted present value of landings. This is estimated as the present value of the catches (median and percentiles) multiplied by the estimated price. The future amount value of landings has been discounted to reflect its current value.

$$DPV = \sum_{y=1}^{Y} \frac{\hat{P}_y \cdot C_y}{(1+r)^y} \qquad (S18)$$

In the equations above, $SSB_{iter,y}$ denotes the spawning stock biomass, $C_{iter,y}$ the catch (in biomass), $TAC_{iter,y}$ the TAC, $\hat{P}_y$ the average price, in year y and iteration $iter$, and r the discount rate (fixed at 0.05), whereas N_y and N_{iter} are the number of years in the projection period and the number of iterations in the simulation. $I[]$ is an indicator function that takes the value 1 if the condition within the brackets is fulfilled and 0 otherwise.

Supplement 4. Stock trajectories

Definition of a management plan in 2008

The selected HCR for the Bay of Biscay anchovy management plan (COM(2009) 399 FINAL) was Rule E with the following formulation:

$$TAC_{July_y - Jun_{y+1}} = \begin{cases} 0 & , \quad \text{if } \widehat{SSB}_y \leq 24{,}000 \\ 7{,}000 & , \quad \text{if } 24{,}000 < \widehat{SSB}_y \leq 33{,}000 \\ 0.3 \cdot \widehat{SSB}_y & , \quad \text{if } \widehat{SSB}_y > 33{,}000 \end{cases} \qquad (S19)$$

where $\widehat{SSB}_y$ is the estimate of SSB in year y.

Figure S2 shows the expected trajectories of stock development under Rule E with a harvest rate of 0.3 given two different scenarios of recruitment: (i) a recruitment generated by a Ricker stock-recruitment relationship; and (ii) a persistent low recruitment regime.

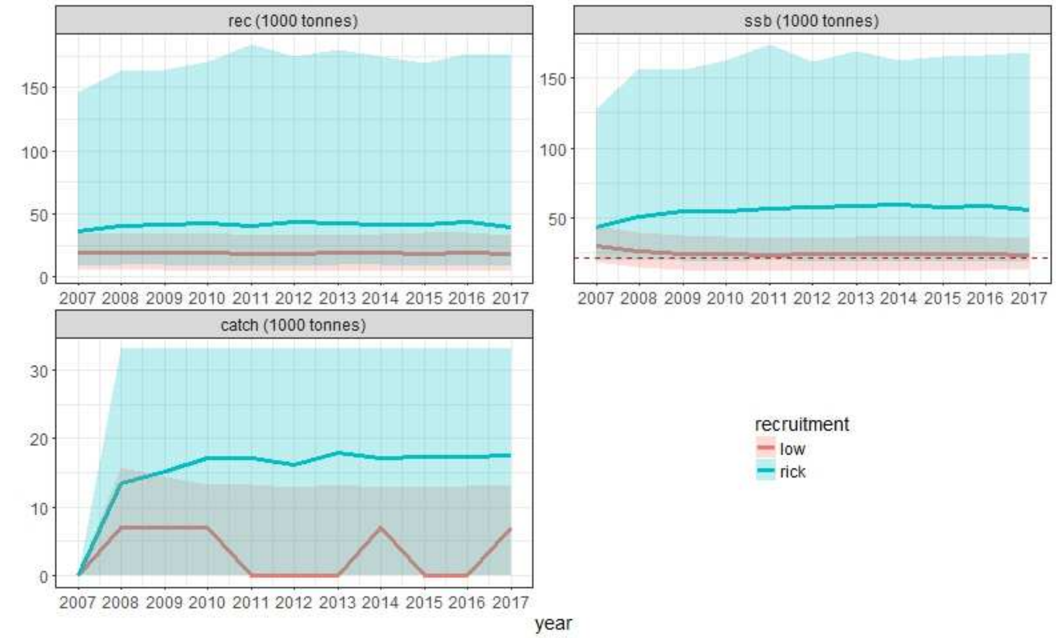

Figure S2. From top to bottom and from left to right recruitment (age 1 at the beginning of the year), spawning stock biomass, and annual catch (from July to June), in thousand tonnes, across years for Rule E with a harvest rate of 0.3 under different recruitment scenarios (in red, Ricker; and in green, persistent low recruitment). The solid line represents the median and the shaded area the 90% confidence intervals computed from the 5th and 95th percentiles. The horizontal dashed red line in the second panel is the biomass reference point B_{lim} (set at 21,000 tonnes).

Management plan revision in 2013

After the management plan revision, Rule G4 with a harvest rate of 0.45, see Equation (S20), was selected and applied in 2015. Figure S3 shows the expected trajectories of stock development under this HCR given two scenarios of recruitment (Ricker with and without a low regime period of 3 years).

$$TAC_{Jan_y-Dec_y} = \begin{cases} 0 & , \quad \text{if } \widehat{SSB}_y \leq 24{,}000 \\ 0.45 \cdot \widehat{SSB}_y & , \quad \text{if } 24{,}000 < \widehat{SSB}_y \leq 55{,}556 \\ 25{,}000 & , \quad \text{if } \widehat{SSB}_y > 55{,}556 \end{cases} \qquad (S20)$$

where $\widehat{SSB}_y$ is the expected SSB during the management period (i.e. in year y).

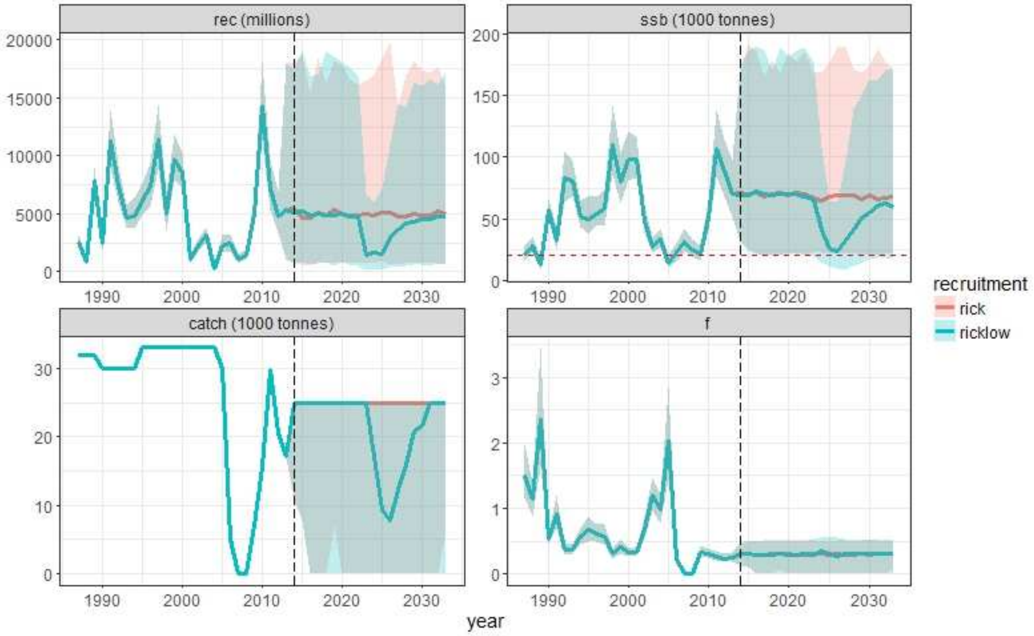

Figure S3. From top to bottom and from left to right recruitment (age 0 million of individuals at the beginning of the second semester), spawning stock biomass (in thousand tonnes), annual catch (thousand tonnes from January to December) and harvest rate (ratio between the annual catch and the spawning stock biomass) across years for Rule G4 with a harvest rate of 0.45 under different recruitment scenarios (in red, Ricker; and in green, Ricker with a low regime period of 3 years). The solid line represents the median and the shaded area the 90% confidence intervals computed from the 5th and 95th percentiles. The dashed vertical line is located at 2014, which is the first year of the projection period. The horizontal dashed red line in the second panel is the biomass reference point B_{lim} (set at 21,000 tonnes).

Since 2016, Rule G3 with a harvest rate of 0.4, has been applied to set Bay of Biscay anchovy TACs, see Equation (S21). Figure S4 shows the expected trajectories of stock development under Rule E with a harvest rate of 0.3 given different scenarios of recruitment.

$$TAC_{Jan_y-Dec_y} = \begin{cases} 0 & , \quad \text{if } \widehat{SSB}_y \leq 24{,}000 \\ 0.4 \cdot \widehat{SSB}_y & , \quad \text{if } 24{,}000 < \widehat{SSB}_y \leq 82{,}500 \\ 33{,}000 & , \quad \text{if } \widehat{SSB}_y > 82{,}500 \end{cases} \qquad (S21)$$

where $\widehat{SSB}_y$ is the expected SSB during the management period (i.e. in year y).

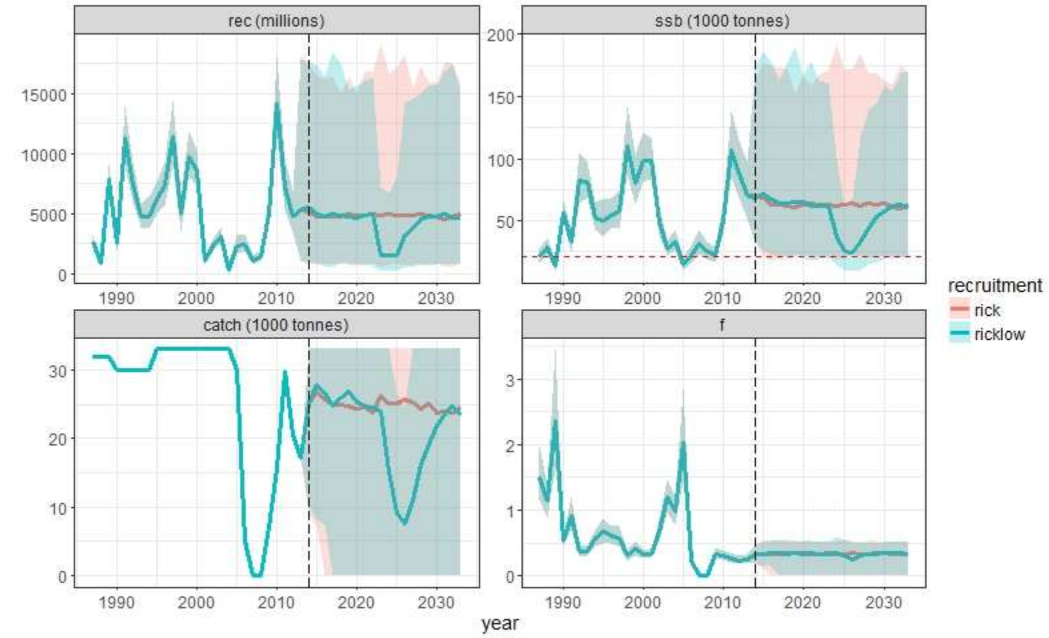

Figure S4. From top to bottom and from left to right recruitment (age 0 million of individuals at the beginning of the second semester), spawning stock biomass (in thousand tonnes), annual catch (thousand tonnes from January to December) and harvest rate (ratio between the annual catch and the spawning stock biomass) across years for Rule G3 with a harvest rate of 0.4 under different recruitment scenarios (in red, Ricker; and in green, Ricker with a low regime period of 3 years). The solid line represents the median and the shaded area the 90% confidence intervals computed from the 5th and 95th percentiles. The dashed vertical line is located at 2014, which is the first year of the projection period. The horizontal dashed red line in the second panel is the biomass reference point B_{lim} (set at 21,000 tonnes).

Supplemental references:

Ibaibarriaga L (2012) Bayesian methods to improve the assessment and management advice of anchovy in the Bay of Biscay. Lancaster University, Lancaster

Ibaibarriaga L, Fernandez C, Uriarte A (2011) Gaining information from commercial catch for a Bayesian two-stage biomass dynamic model: application to Bay of Biscay anchovy. ICES Journal of Marine Science 68:1435-1446

Ibaibarriaga L, Fernandez C, Uriarte A, Roel BA (2008) A two-stage biomass dynamic model for Bay of Biscay anchovy: a Bayesian approach. ICES Journal of Marine Science 65:191-205

ICES (2005) Report of the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy (WGMHSA). Vigo, Spain. ICES CM 2005/ACFM:08, 631 pp.

ICES (2007) Report of the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy (WGMHSA). ICES Headquarters. ICES CM 2007/ACFM:31, 725 pp.

ICES (2013a) Report of the Benchmark Workshop on Pelagic Stocks (WKPELA). ICES, Copenhagen, Denmark. ICES CM 2013/ACOM:46, 480 pp.

ICES (2013b) Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA). ICES, Bilbao, Spain. ICES CM 2013/ACOM:16, 677 pp.

ICES (2014) Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA). ICES, Bilbao, Spain. ICES CM 2013/ACOM:16, 600 pp.

Pita C, Silva A, Prellezo R, Andrés M, Uriarte A (2014) Chapter 9: Socioeconomics and management. In: Ganias K (ed) Biology and ecology of sardines and anchovies. CRC Press

Pope JG (1972) An investigation of the accuracy of Virtual Population Analysis using cohort analysis. ICNAF Res Bull 9:65–74

Schaefer MB (1954) Some aspects of the dynamics of populations important to the management of commercial marine fisheries. IATTC Bull 1:25–56

STECF (2014) Evaluation/scoping of management plans - Data analysis for support of the impact assessment for the management plan of Bay of Biscay anchovy (COM(2009)399 final). (STECF-14-05). Publications Office of the European Union, Luxembourg, ISBN 978-92-79-37843-0. EUR 26611 EN, JRC 89792, 128 pp.

Uriarte A (2005) Assessment of the Bay of Biscay anchovy by means of a seasonal separable VPA. ICES CM 2005/ACFM:08 (WD for the ICES WGMHSA 2005).

Uriarte A, Ibaibarriaga L, Pawlowski L, Massé J, Petitgas P, Santos M, Skagen D (2016) Assessing natural mortality of Bay of Biscay anchovy from survey population and biomass estimates. Canadian Journal of Fisheries and Aquatic Sciences:1-19