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APPLICATION OF THE DLMTOOL KIT FOR SMALL TUNAS: A CASE STUDY

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SUMMARY

This paper presents a preliminary exercise of Management Strategy Evaluation (MSE) using the DLMtool toolkit to test the performance of a variety of management procedures (MPs) for the Northwest Atlantic wahoo. In this analysis, nine management procedures (MP) were selected to be included in the MSE run in order to evaluate the performance of each MP and its effectiveness for management advice. The chosen MPs were based on catch ("AvC","CC1","SPMSY" and "DBSRA"), length ("LBSPR","minlenLopt1" and "matlenlim"), and fishing effort controls ("curE" and "curE75"). Our preliminary results show that catch-based methods are the most acceptable with respect to the pre-established threshold values for the performance metrics. Simulations of the length-based and fishing effort control methods did not present satisfactory results with respect to the annual variability in yield and probability of spawning biomass being higher than spawning biomass at maximum sustainable yield. However, results must be interpreted with caution given the high uncertainty in the parametrization of the operating model, which might be strongly influence the performance of MPs.

RÉSUMÉ

Ce document présente un exercice préliminaire d'évaluation de la stratégie de gestion (MSE) utilisant la boîte à outils DLMtool pour tester les performances de diverses procédures de gestion pour le thazard-bâtard de l'Atlantique Nord-Ouest. Dans cette analyse, neuf procédures de gestion (MP) ont été sélectionnées aux fins de leur inclusion dans le scénario de MSE afin d'évaluer la performance de chaque procédure de gestion et leur efficacité pour formuler un avis de gestion. Les procédures de gestion retenues étaient fondées sur la capture (AvC, CC1, SPMSY et DBSRA), la taille (LBSPR, minlenLopt1 et matlenlim) et les contrôles de l'effort de pêche (curE et curE75). Nos résultats préliminaires montrent que les méthodes basées sur la capture sont les plus acceptables en ce qui concerne les valeurs de seuil préétablies pour les mesures de la performance. Les simulations des méthodes de contrôle de l'effort de pêche et reposant sur la taille ne présentaient pas de résultats satisfaisants en ce qui concerne la variabilité annuelle de la production et la probabilité que la biomasse du stock reproducteur soit supérieure à la biomasse du stock reproducteur au niveau de la production maximale équilibrée. Cependant, les résultats doivent être interprétés avec prudence compte tenu de la grande incertitude entourant la paramétrisation du modèle opérationnel, qui pourrait influencer fortement les performances des procédures de gestion.

RESUMEN

Este documento presenta un ejercicio preliminar de la evaluación de estrategias de ordenación (MSE) utilizando la herramienta DLMtool para probar el funcionamiento de diversos procedimientos de ordenación (MP) para el peto del Atlántico noroccidental. En este análisis, se seleccionaron nueve MP para incluirlos en el ensayo de la MSE con el fin de evaluar el desempeño de cada uno y su eficacia en el asesoramiento en materia de ordenación. Los MP elegidos se basaban en la captura ("AvC","CC1","SPMSY" y "DBSRA"), la talla ("LBSPR","minlenLopt1" y "matlenlim"), y en los controles del esfuerzo pesquero ("curE" y "curE75"). Los resultados preliminares muestran que los métodos basados en la captura son los más aceptables respecto a los valores umbral preestablecidos para la medición del desempeño. Las simulaciones de los métodos de control del esfuerzo pesquero y basados en la talla no presentaron resultados satisfactorios con respecto a la variabilidad anual en el rendimiento y la probabilidad de que la biomasa reproductora

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sea superior a la biomasa reproductora en el rendimiento máximo sostenible. Sin embargo, los resultados deben interpretarse con precaución teniendo en cuenta la elevada incertidumbre en la parametrización del modelo operativo, que podría afectar en gran medida al desempeño de los MP.

KEYWORDS

Atlantic, Wahoo, Data-limit model

1. Introduction

The fishes commonly referred as “small tunas” (e.g. mackerels and bonitos) are an important source of wealth and food security in the whole Atlantic (Lessa *et al.*, 2009; Majkowski, 2007; Isaac *et al.*, 2012). However, although members of this group have been showing decline in biomass (Juan-Jordá *et al.*, 2015), and were assigned as “moderate to high risk” of being overfished or subject to overfishing in a recent qualitative risk assessment (Lucena-Frédou *et al.*, 2017), most of the Atlantic small tuna are unassessed and unmanaged (Juan-Jordá *et al.*, 2015; Pons *et al.*, 2018). Recently, Pons *et al.* (2019a) estimated, for the first time, a proxy of the current stock status of ten stocks of small tunas in the Atlantic Ocean based on the length-based methods LBSPR (length-based spawning potential ratio LBSPR, Hordyk *et al.*, 2015a) and LIME (length-based integrated mixed effects model, LIME, Rudd and Thorson, 2018). Although their study is an incontestable advance in the assessment of Atlantic small tunas, there remains a wide uncertainty in estimates and differences in results derived from both methods. In addition, Pons *et al.* (2019b, SCRS/2019/040) presented catch-based methods that showed high uncertainty and discrepancy in stock status estimations for small tunas.

Management strategy evaluation (MSE), a risk-based approach that accounts for uncertainties in population and exploitation dynamics (Bunnefeld *et al.*, 2011; Butterworth & Punt, 1999; Punt *et al.*, 2016), could be used to develop robust management frameworks for small tunas (Pons *et al.*, 2019a). The modelling framework was formalized in the R environment with the R package ‘DLMtool’ (Carruther *et al.*, 2014; Carruthers & Hordyk, 2018) (‘the package’) with the main aim to use the MSE in support of decision-making in data-limited fisheries.

The wahoo, *Acanthocybium solandri* (Cuvier 1832), is a large pelagic Scombridae with a circumglobal distribution in tropical, subtropical, and warm temperate waters (Collette and Nauen 1983), and is important to commercial and recreational fisheries throughout the Western Atlantic (Oxenford *et al.*, 2003). Recent data-limited approaches developed by Pons *et al.* (2019a) and Lucena Frédou *et al.* (2017) identified, respectively, the Northwest Atlantic stock as likely to be overfished and the South Atlantic stock categorized as high risk. However, despite its importance to many fisheries in the Atlantic Ocean, wahoo remains unmanaged, and this species should be considered as a priority to assess and management by ICCAT.

In this study, we developed a preliminary exercise of MSE using the DLMtool toolkit to test the performance of a variety of management procedures (MPs) for the Northwest Atlantic wahoo. We hope this initial exercise may improve the assessment of the wahoo in the Norwest Atlantic, but we mainly expect that this could be expanded to other species, contributing to the management and conservation of small tunas in the Atlantic Ocean.

2. Material and Methods

Following the MSE best practice of Punt *et al.* (2016), we carried out the analysis using the DLMTool package version 5.3 (Carruthers and Hordyk, 2019) implemented in R (R Development Core Team, https://www.r-project.org/). According to Carruthers and Hordyk (2018) and based on Punt *et al.* (2016), the application of DLMtool toolkit is separated into 6 steps. We performed the first 5 steps described below but we did not carry out the sixth step (Formal MP review) because it is beyond the scope of this study in the moment. We hope to carry out a complete assessment when the methodological main issues for its application on small tunas have been sorted out within the appropriate ICCAT forums (e.g. Small Tunas Working Group)

2.1. Selection of management objectives and performance metrics

We considered four performance measures:

- probability of not overfishing (**PNOF**; $F<F_{MSY}$);

- probability of spawning biomass being higher than half of spawning biomass at maximum sustainable yield (**P50**; $SB>0.5\ SB_{MSY}$);
- probability of spawning biomass being higher than spawning biomass at maximum sustainable yield (**P100**; $SB>SB_{MSY}$);
- probability of average annual variability in yield being lower than 20% (**AAVY**; *Prob. AAVY < 20%*);
- probability of average yield being higher than half of reference yield (**LTY**; *Prob. Yield > 0.5 Ref. yield*)

We defined acceptable management procedures as those that supported **PNOF**>70%, **P50**>90%, **P100**>70%, **AAVY**>50% and **LTY**>50%.

2.2. Selection of uncertainties/specification of operating model

The summary of Northwest Atlantic wahoo operating model (OM), including the range values and a brief description of each parameter/sub-model are shown in **Table 1**. For more details regarding how OM parameters were sampled, and simulated data were generated, we refer readers to Carruthers *et al.* (2014) and Carruthers and Hordyk (2018). The OM within DLMTool framework is specified by four classes of sub-models, with distinct components:

- *Population dynamics model (Stock)*: consists in a conventional age-structured model, single sex, two-area spatial model, that simulates several aspects of fish population dynamics (**Table 1; Appendix A**, **Figures A1** and **A2**).

- *Fleet dynamics model (Fleet)*: This model determines the pattern of exploration of the fishing fleet within MSE and includes several parameters, such as fishery's size-selectivity, historical changes in catchability and fishing effort. The DLMtool package offers some standard parameterizations for the fleet dynamics model which can be initially used to configure the model. In the present analysis we opted to use the *Generic_FlatE* fleet model, which is characterized by a generic fleet with stable fishing effort levels in recent years based in our limited knowledge of the fisheries in the area (**Table 1; Appendix A**, **Figure A3**). This is an important point to be discussed with the experts of these fisheries.

- *Observation model (Obs)*: the observation model simulates the imperfect knowledge of the MSE system, considering more than 90 management procedures and uncertainties generating several data for a wide range of biological parameters and time-series data (*e.g.* indices of abundance and total catch). In this simulation modeling exercise, we opted to use the *Imprecise_Biased* observational model (**Table 1;** all parameters with default values), which is characterized by a high-level of uncertainty regarding model parameters and it seems to be appropriate to most of the small tunas case studies in the Atlantic Ocean.

- *Implementation model (Imp)*: the implementation model contains parameters that control implementation error for the three principal types of management recommendation (e.g. output, input and size controls). In this simulation modeling exercise, we opted to use the *Overages* implementation model (**Table 1;** all parameters with default values), which simulates an imperfect implementation of management recommendations inside the MSE simulations.

2.3. Identification of candidate management procedures

In this analysis, nine management procedures (MPs) (**Table 2**) were selected to be included in the MSE run in order to evaluate the performance of each MP and its effectiveness for management advice. The chosen MPs were based on the viability of implementation as well as the availability of required input data for the Northwest Atlantic wahoo stock. Among the selected MPs, four of them are catch-based **("AvC","CC1","SPMSY"** and **"DBSRA"**); three are length-based **("LBSPR","minlenLopt1"** and **"matlenlim"**); and two are based on fishing effort controls (**"curE"** and **"curE75"**) (**Table 2**). For further details on MPs, we refer readers to Carruthers *et al.* (2014) and Carruthers and Hordyk (2018).

2.4. Simulation of the application of the management strategy evaluation

Our MSE simulation model was conducted with 5000 replicates for a projection period of 20 years. The stability/convergence of the model was evaluated using a single-function "*converge*" for each selected MP. This function tests if the order of MPs is changing in last 20 simulations and whether the average difference in performance metrics over last 20 simulations is higher than 0.5.

2.5. Presentation of results and selection of a management strategy

We presented the results using different plots available in the DLMtool package, however we chose to exhibit the different management strategies for this stock without selecting a particular one (because we did not advance through the step 6; see Carruthers and Hordyk, 2018). Step 6 should be a discussion with stakeholders and it is beyond the scope of this preliminary exercise.

3. Results and Discussion

All tested models were able to converge satisfactory, and the number of interactions (simulations) were sufficient for stabilization of each selected MP inside the model. The performance of the numerical results for the performance metrics for the nine acceptable MPs are shown in the **Table 3**. Among the nine evaluated MPs for the Northwest Atlantic wahoo, only the catch-based methods ***AvC*** and ***CC1*** fully met the pre-established performance criteria (**Table 3**). Although the length-based and fishing effort control methods did not fall within acceptable performance criteria for the **AAVY** (less than 20%), the rest of the performance metrics were satisfactory met, except for ***LBSPR*** and ***CurE***, which also resulted less than 70% probability of **P100** (**Table 3**). In addition, **PNOF** for ***DBSRA*** MP was low (0.61) and, therefore, these MPs should be not considered a suitable method for management compared to the other alternatives.

The analysis of the trade-offs between the MPs (**Figure 1**) showed the performance with respect to four different metrics and indicated which methods passed the specified risk thresholds. In general, catch-based methods are the most acceptable with respect to the pre-established threshold values for the performance metrics, while simulations for the length-based and fishing effort control methods did not present satisfactory results with respect the annual variability in yield and probability of spawning biomass being higher than spawning biomass at maximum sustainable yield (**Figure 1**). MPs located within the red shaded areas did not meet performance metrics, while MPs located within the white areas met the thresholds of the performance metrics and, therefore, are considered more appropriate for the management of the Northwest Atlantic wahoo (**Figure 1**).

Figure 2 shows projection plots of trends in biomass (relative to B_{MSY}) and fishing mortality (relative to F_{MSY}) for the nine MPs. Colored lines represent the trajectory for 200 simulations, which was randomly sampled from the 5,000 replicates and the solid black line represents the median across these 200 simulations. In general, all MPs presented medians of biomass and fishing mortality projections that were above B_{MSY} ($B/B_{MSY} > 1$) and below F_{MSY} ($F/F_{MSY} < 1$), respectively (**Figure 2**). However, it is important to note that the median (black line) represents a summary of many simulations; and the median defines a point where half (50%) of the projections are higher and half the projections are lower than this point. Therefore, the median line is less variable than any single simulation.

Figure 3 depicts the Kobe plots for each MP and points represent the start and end of the stock trajectories for 1,000 simulations, which was randomly sampled from the 5,000 replicates. Numbers represent the proportion of time each management procedure spends in different parts of the Kobe space. In general, for all MPs, the stock trajectories presented a higher proportion of time within the ideal sustainability scenario (lower right corner of the Kobe plot space), with probabilities above 50% (**Figures 3**). ***SPMSY*** and ***curE75*** showed higher probabilities (>70%) of having the stock over B_{MSY} and below F_{MSY}.

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Table 1. Summary of Northwest Atlantic wahoo operating model for a preliminary exercise of MSE using the DLMtool package.

Parameter	Input values	Justification and source
		Stock model
maxage	9	McBride *et al.*, 2008
R0	1000	Unfished recruitment
M	c(0.43,0.60)	Pons et al (2019a)
Msd	c(0, 0.1)	M interannual variability up to 10%
Mgrad	c(-0.1, 0.1)	Long-term trends in M (M between -0.1 and 0.1 % per year)
h	c(0.7, 0.7)	Fixed in 0.7
SRrel	1	Beverton and Holt model for stock-recruitment relationship
L∞	c(155.21,216.04)	Range of the published information compiled in Juan-Jordá et al (2015)
k	c(0.152,0.47)	Range of the published information compiled in Juan-Jordá et al (2015)
t0	c(-1.172, -1.911)	Range of the published information compiled in Juan-Jordá et al (2015)
LenCV	c(0.1,0.15)	Coefficient of variation of length-at-age: bound considered a reasonable uncertainty
ksd	c(0.0,0.025)	Interannual variability in k parameter, bounded by reasonable estimate
kgrad	c(-0.1, 0.1)	Long-term trends in k (k between -0.1 and 0.1 % per year)
L∞sd	c(0, 0.025)	Interannual variability in L∞ parameter, bounded by reasonable estimate
L∞grad	c(-0.1, 0.1)	Long-term trends in L∞(L∞ between -0.1 and 0.1 % per year)
AC	c(0.2, 0.2)	Autocorrelation in recruitment deviations
A	2.00E-06	Beerkircher (2005)
B	3.24	Beerkircher (2005)
L50	c(83.25,101.75)	(Jenkins and McBride, 2009): bounded as +/- 10% of 92.5
L50_95	c(12,12)	Length increment from 50 percent to 95 percent maturity: 10% higher than 83.25
D	c(0.2, 0.6)	Stock depletion: based on Pons et al (2019a)
Perr	c(0.4, 0.6)	Magnitude of annual recruitment deviations
Size_area_1	c(0.5, 0.5)	A mixed stock is assumed
Frac_area_1	c(0.5, 0.5)	A mixed stock is assumed
Prob_staying	c(0.5, 0.5)	A mixed stock is assumed
Fdisc	c(0, 0.15)	Fraction of discarded fish that die: a high level of post release survival is assumed
		Fleet model
Fleet Type	*Generic_FlatE*	Assuming flat fishing effort in recent years
Spat_targ	c(1, 1)	We use the default assumption that effort distributed in proportion to density
L5	c(35,45)	Smallest length at 5% selectivity: bounded 50% lower than LFS
LFS	c(70,100)	Length at 50% selectivity: range values based on length distribution
Vmaxlen	c(1,1)	Sigmoid selectivity curve
		Observation model
Obs type model	*Imprecise_Biased*	All slots were bounded as default
		Implementation model
Imp type model	*Overages*	All slots were bounded as default

Table 2. Brief description of selected management procedures for the Northwest Atlantic wahoo MSE using the DLMtool package.

Management Procedure	***Description***	***Reference***
Catch-based methods		
Average Catch - **AvC**	TAC is average historical catches	*Carruthers et al. (2014)*
Constant Catch - **CC1**	TAC is average historical catch from recent years and is constant for all future projections	*Geromont e Butterworth (2015)*
Surplus Production MSY - **SPMSY**	Method for estimating MSY to determine the overfishing limit based on surplus production model. Based on catches and depletion, the model predicts viable K-r pairs to calculate the overfishing limit based on the Schaefer productivity curve.	*Martell and Froese (2012)*
Depletion-Based Stock Reduction Analysis - **DBSRA**	Method designed for determining a catch limit and management reference points for data-limited fisheries where catches are known from the beginning of exploitation	*Dick and MacCall (2011)*
Length-based methods		
Length-based spawning potential ratio - **LBSPR**	The spawning potential ratio (SPR) is estimated using the LBSPR method and compared to a target of 0.4.	*Hordyk et al. (2015a)*
Size limit management procedures - **minlenLopt1**	Sets the minimum length of fish caught to a fraction of the length that maximises the biomass	*Hordyk et al. (2015b)*
Size limit management procedures - **matlenlim**	Retention at length is set according to the size at maturity curve	*Hordyk et al. (2015b)*
Fishing effort control methods		
Fishing at current effort levels - **curE**	Set effort to 100% of that in final year of historical simulations	*Carruthers et al. (2014)*
Fishing at current effort levels - **curE75**	Set effort to 75% of that in final year.	*Carruthers et al. (2014)*

Table 3. Summary of the Northwest Atlantic wahoo management strategy evaluation results for selected MPs using the DLMtool package. Cell color coding is used to denote if the particular MP falls within acceptable performance metric criteria (see item 2.1; green – acceptable and red – not satisfied).

MPs	PNOF	P50	P100	AAVY	LTY
Length-based methods					
LBSPR	0.74	0.93	0.65	0.120	0.86
minlenLopt1	0.75	0.95	0.72	0.110	0.83
matlenlim	0.75	0.96	0.74	0.095	0.81
Catch-based methods					
AvC	0.70	0.95	0.76	0.630	0.78
CC1	0.71	0.95	0.76	0.640	0.76
SPMSY	0.81	0.98	0.86	0.110	0.43
DBSRA	0.61	0.98	0.81	0.450	0.74
Fishing effort control methods					
curE	0.75	0.93	0.66	0.130	0.85
curE75	0.87	0.97	0.78	0.150	0.80

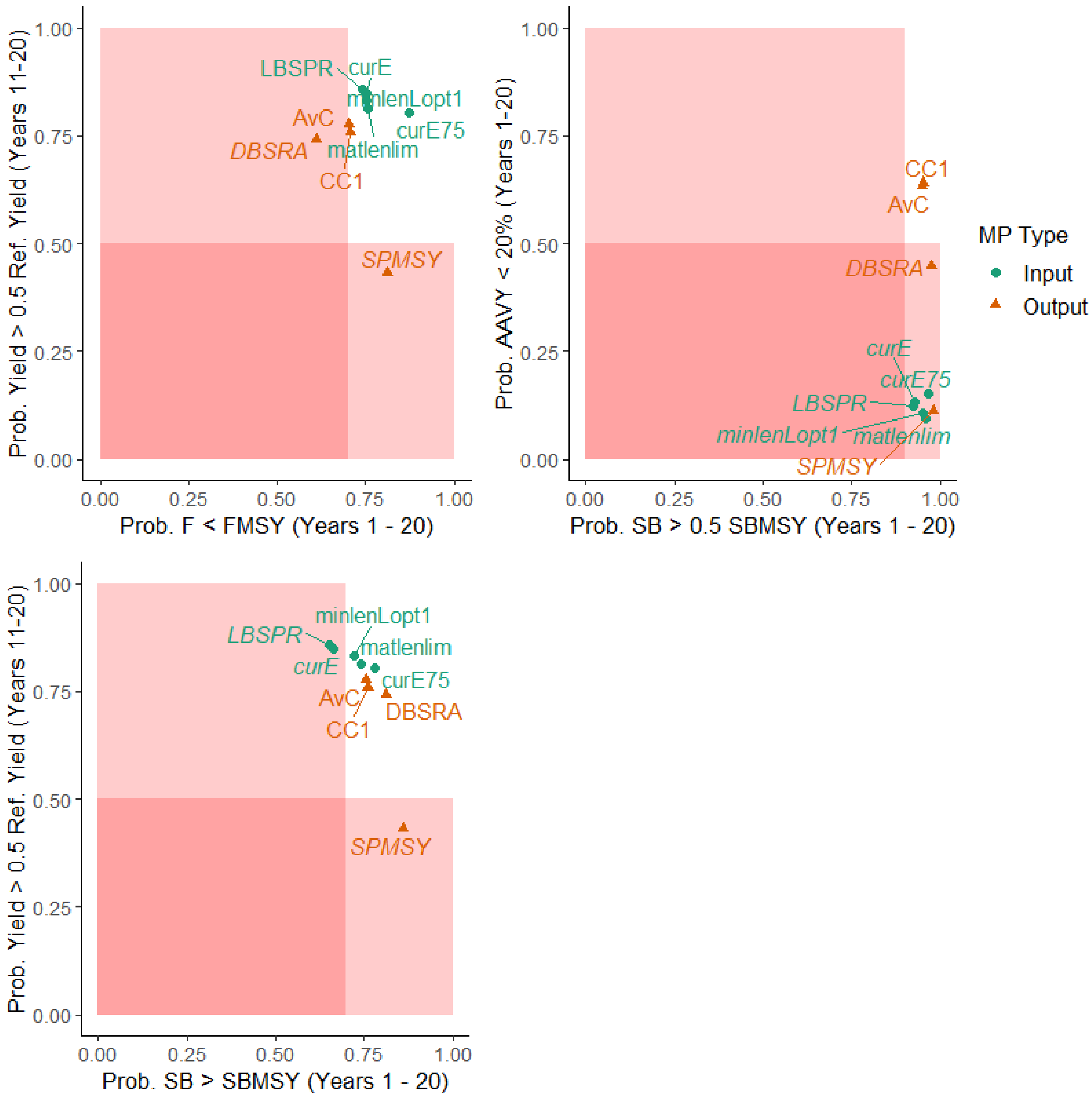

Figure 1. Trade-offs of Long-Term Yield (**LTY**; y axis) and Average Annual Variability in Yield (**AAVY**; y axis) against Probability of Not Overfishing (**PNOF**, x axis) and Probability of Spawning Biomass being higher Spawning Biomass at Maximum Sustainable Yield (**P50** and **P100,** $SB>0.5SB_{MSY}$, $SB>SB_{MSY}$, respectively; x axis). Red shaded area is used to denote if the particular MP falls within of not satisfied performance metric criteria (see item 2.1).

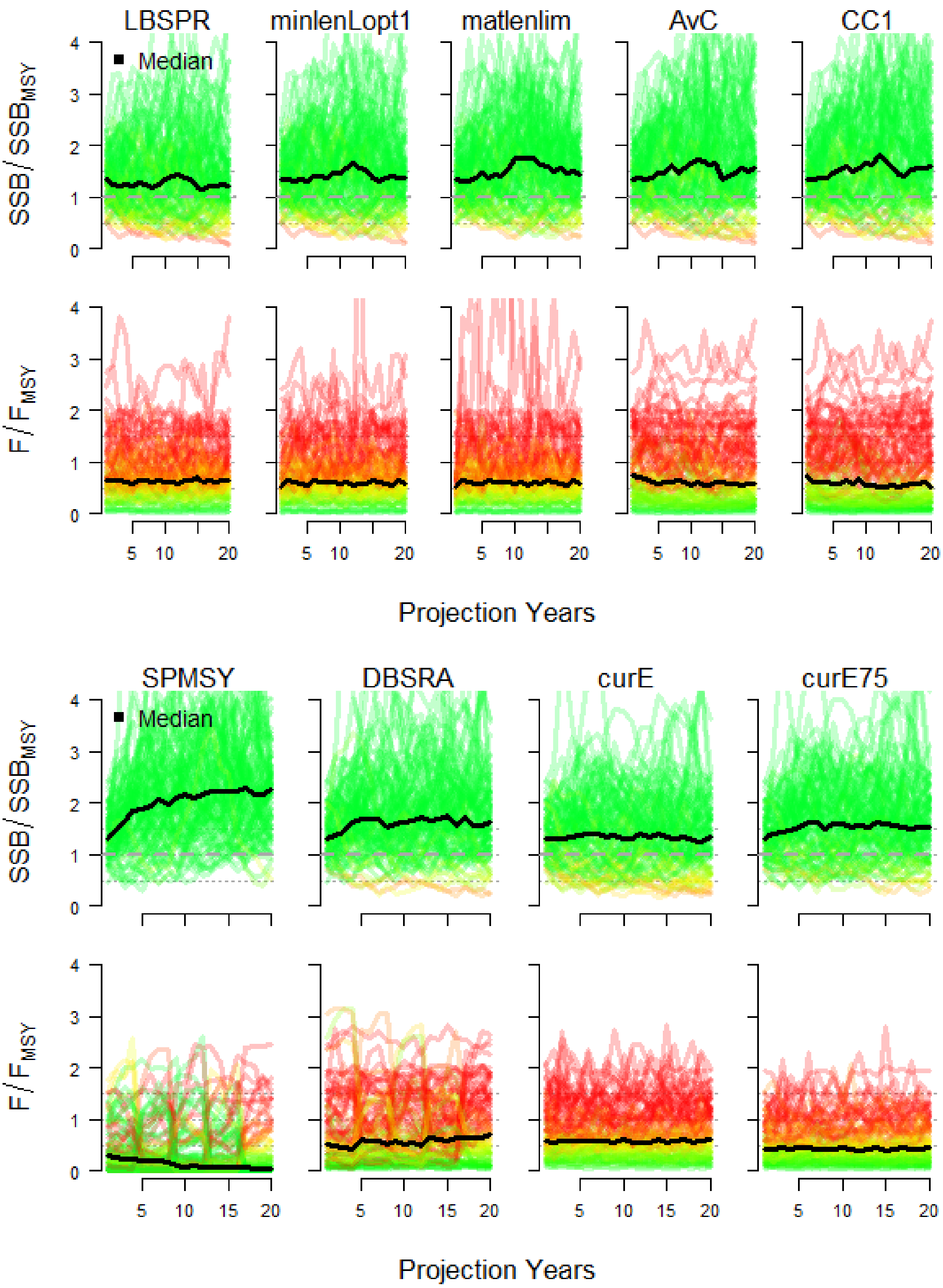

Figure 2. Projections plots for spawning biomass (*SSB*) relative to SSB_{MSY}, fishing mortality (*F*) relative to F_{MSY} from the MSE simulations. Colored lines represent 200 simulations that were randomly sampled from the 5,000 replicates and the solid black line represent the median across these 200 simulations. Green lines: good performance; yellow lines: regular performance; red lines: bad performance.

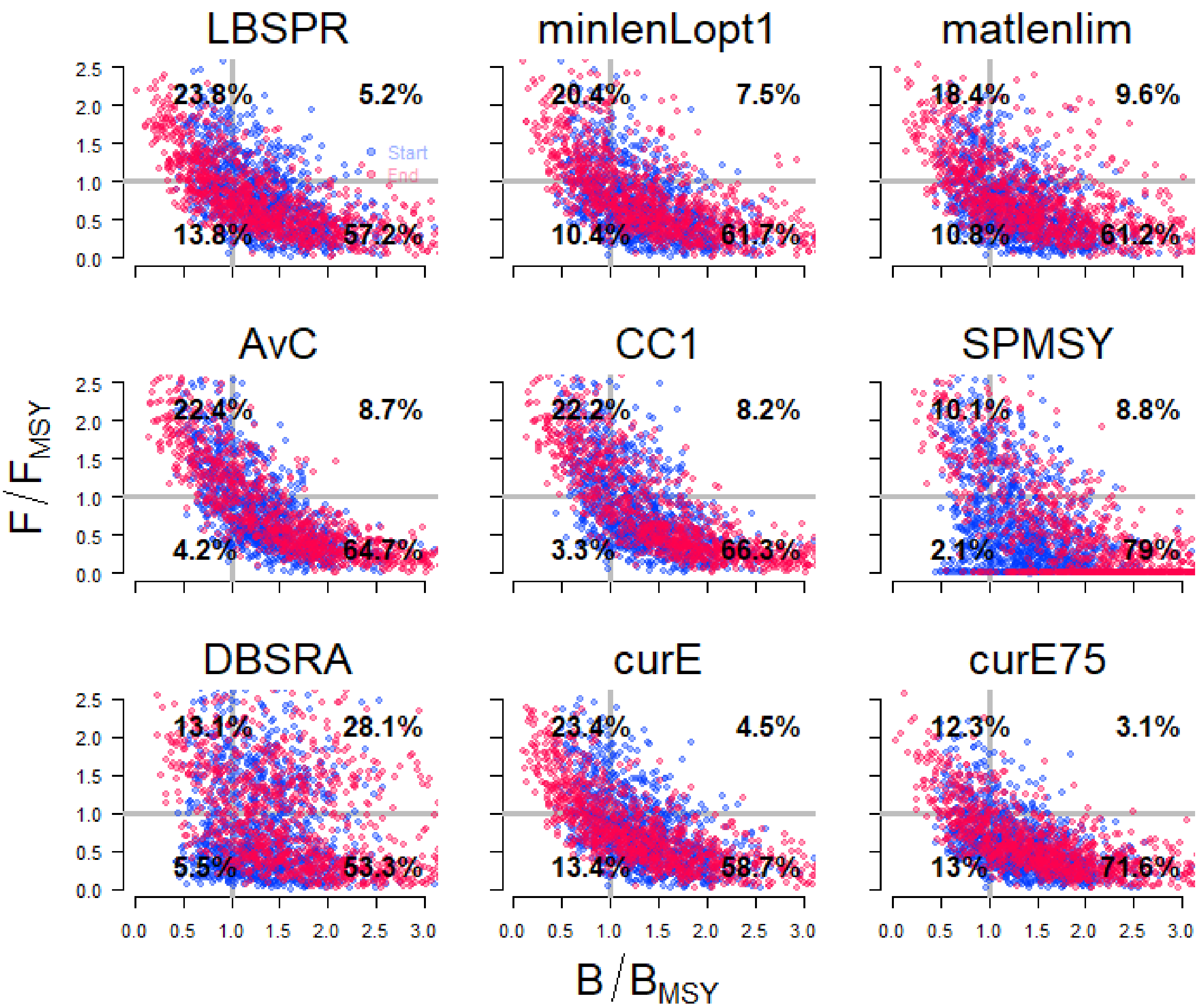

Figure 3. Kobe plots for stock trajectories (blue points/lines: start year; purple points/lines: end year) for 1,000 MSE simulations, which were randomly sampled from the 5,000 replicates. Numbers represent the proportion of time each management procedure spends in different parts of the Kobe space.

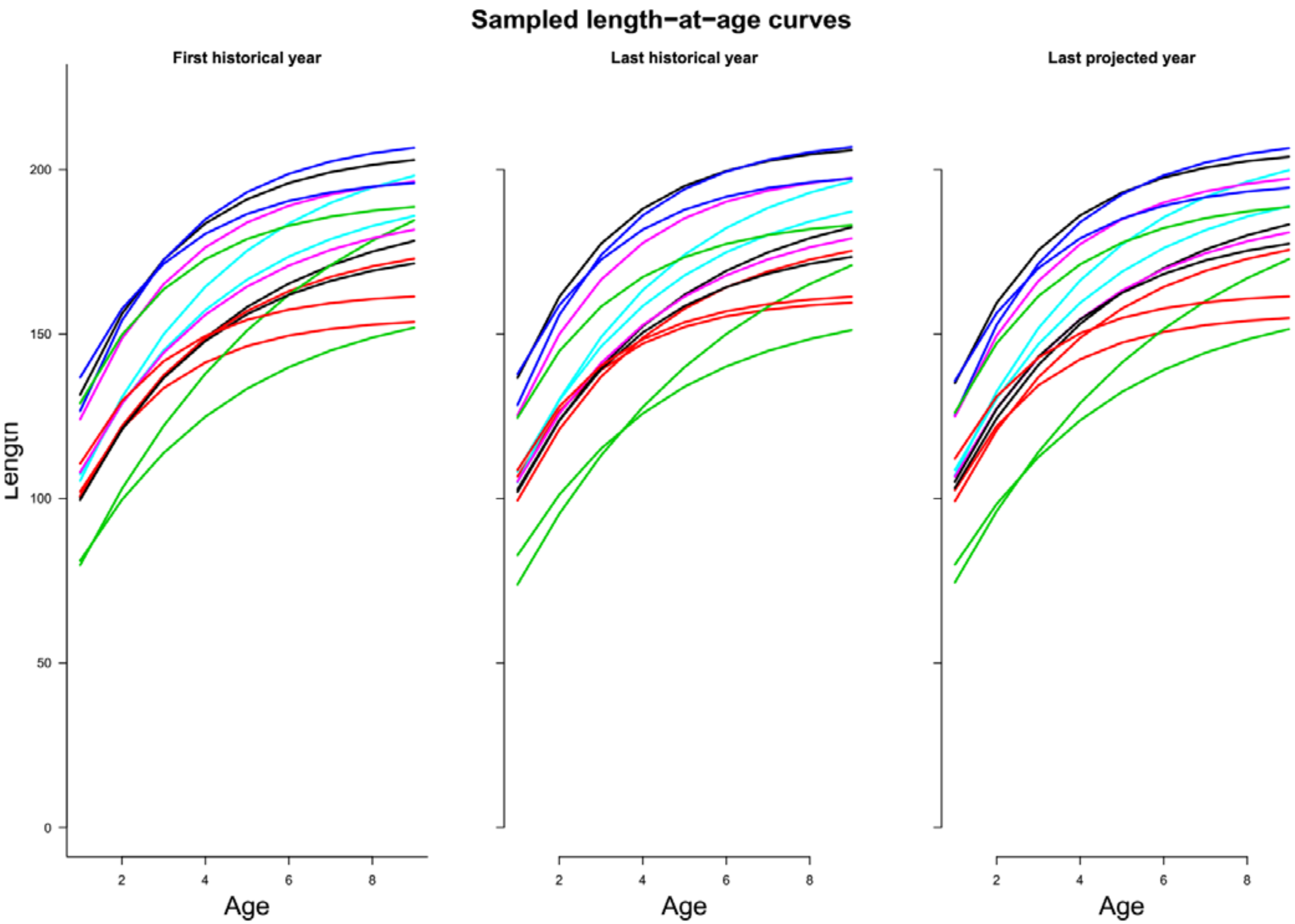

Figure A1. Sampled iterations of length at age curves of the population dynamics model *(Stock).*

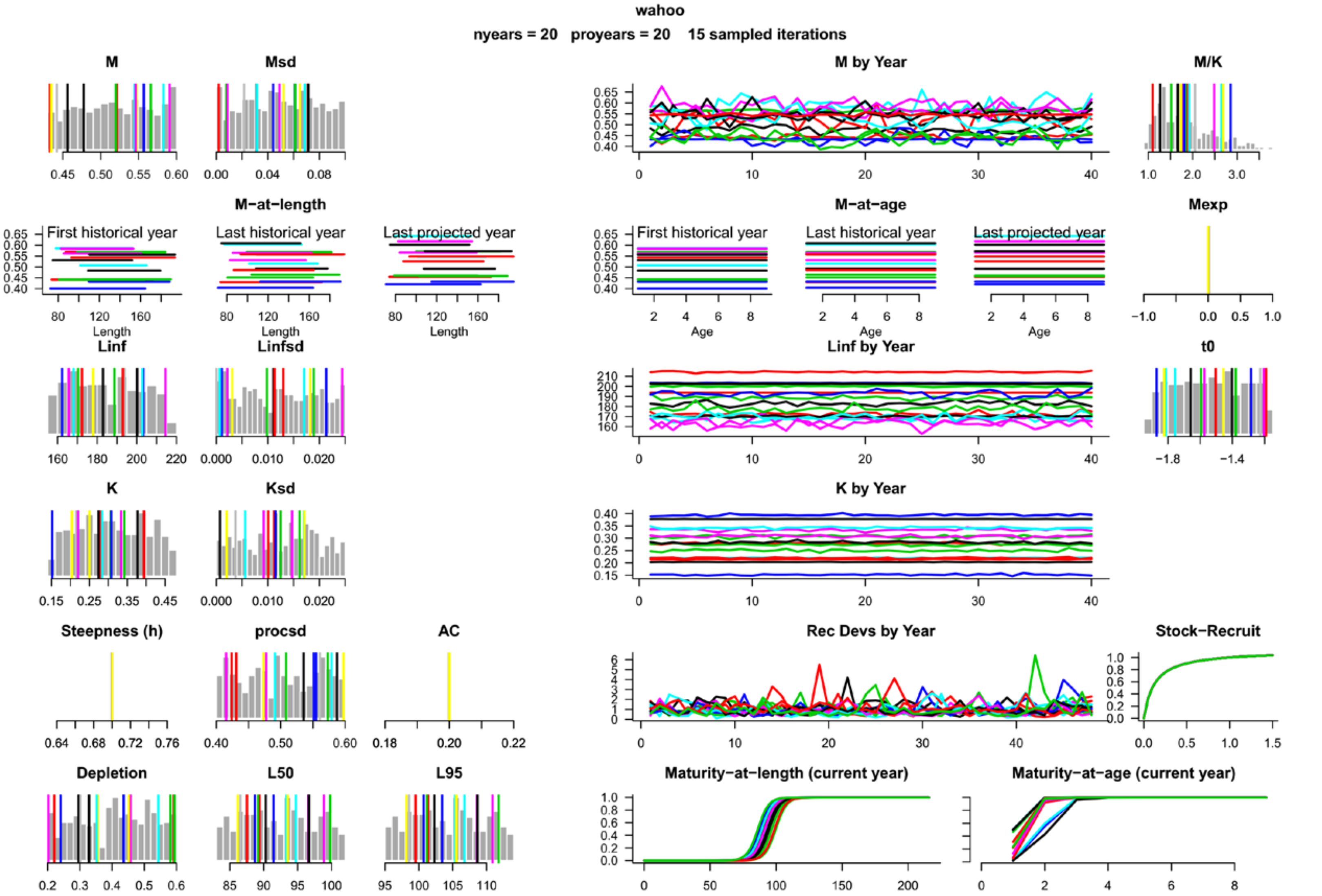

Figure A2. Summary of parameters of the *Population Dynamics Model (Stock).*

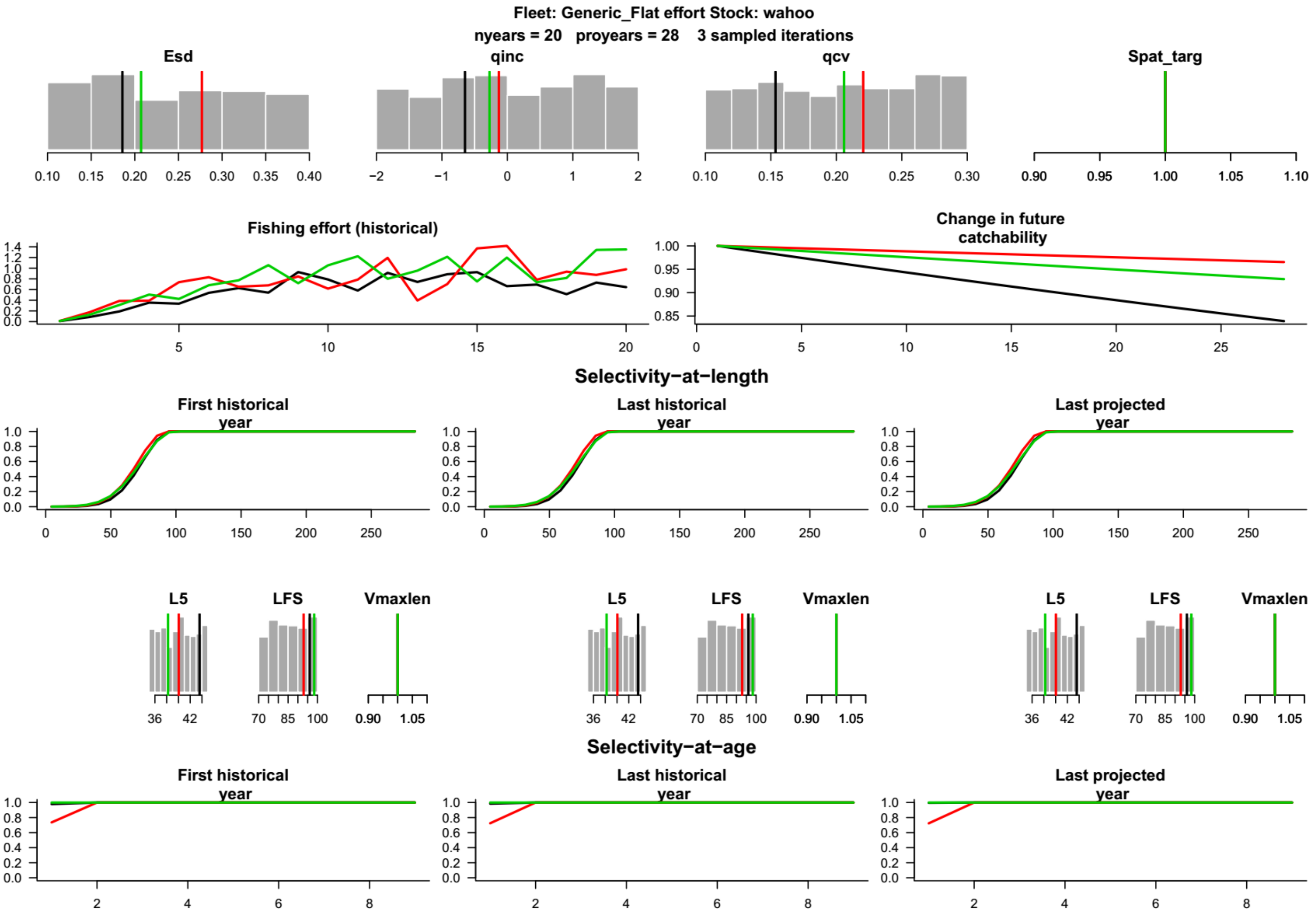

Figure A3. Summary of parameters of the *Fleet dynamics model (Fleet).*