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PRELIMINARY ASSESSMENT OF THE MEDITERRANEAN SWORDFISH STOCK BY MEANS OF BAYESIAN SURPLUS PRODUCTION MODELS

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SUMMARY

Biomass and MSY estimates for the Mediterranean swordfish stock were obtained from two Bayesian surplus production models (namely "SPiCT" and "JABBA") fitted to a time series of catch data and standardized CPUE indexes obtained from the Greek surface longline fleet targeting swordfish. Results demonstrated rapid biomass decreases from the middle 1980s up to 2010, while the opposite trend was found for fishing mortality. Current (2015) biomass is lower than B_{MSY}, while F is at optimum levels. Given that uncertainties regarding the exploitation pattern seem to have affected the previous age-based assessments, application of Bayesian production models may provide valuable information for the management of the stock.

RÉSUMÉ

Les estimations de la biomasse et de la PME pour le stock d'espadon de la Méditerranée ont été obtenues à partir de deux modèles bayésiens de production excédentaire (à savoir «SPiCT» et «JABBA») ajustés à une série temporelle de données de capture et d'indices de CPUE standardisés obtenus à partir de la flottille palangrière de surface grecque ciblant l'espadon. Les résultats ont démontré une diminution rapide de la biomasse entre le milieu des années 1980 jusqu'en 2010, tandis que la tendance inverse a été observée en ce qui concerne la mortalité par pêche. La biomasse actuelle (2015) est inférieure à BPME, tandis que F se situe à des niveaux optimaux. Étant donné que les incertitudes concernant le modèle d'exploitation semblent avoir affecté les évaluations précédentes basées sur l'âge, l'application de modèles de production bayésiens peut fournir des informations précieuses pour la gestion du stock.

RESUMEN

Las estimaciones de biomasa y de RMS para el stock de pez espada del Mediterráneo se obtuvieron mediante dos modelos de producción excedente bayesianos («SPiCT» y «JABBA») ajustados a una serie temporal de datos de captura e índices de CPUE estandarizada obtenidos de la flota de palangre de superficie griega que se dirige al pez espada. Los resultados demostraron rápidos descensos de biomasa desde mediados de los 80 hasta 2010, mientras que para la mortalidad por pesca se halló la tendencia opuesta. La biomasa actual (2015) es inferior a B_{RMS} mientras que F se encuentra en niveles óptimos. Teniendo en cuenta que las incertidumbres respecto al patrón de explotación parecen haber afectado a las evaluaciones anteriores basadas en la edad, la aplicación de modelos de producción bayesianos podría aportar información valiosa para la ordenación del stock.

KEYWORDS

Swordfish, Mediterranean, Stock assessment

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1. Introduction

Swordfish (*Xiphias gladius*) is a large pelagic species of high commercial value heavily exploited all over the Mediterranean basin. ICCAT assessments have shown rapid stock biomass declines in the middle 1980s, and small fluctuations afterwards. The stock is considered to be overexploited in terms of biomass and fishing mortality target reference points (Anon, 2015; 2017), and a series of management measures have been employed aiming to assist stock recovery. At the same time, however, estimates of optimum biomass levels and maximum sustainable yield (MSY) have been considered quite uncertain owing to limitations in the data that have been used in the previous age-based assessments (Anon, 2017).

In the present work, we attempt to provide a preliminary assessment of the Mediterranean swordfish stock by means of Bayesian surplus production models that utilize catch and CPUE time series of data that were available in the latest assessment carried out by ICCAT scientists (Anon, 2017).

2. Methods

2.1 Empirical data for the swordfish stock assessment

We used a pair of empirical time series that were available in the latest ICCAT assessment (Anon, 2017): annual observations of catch, covering the period 1950–2015 (**Figure 1A**); and standardized CPUE estimates from the Greek drifting surface longline fleets for the period 1987–2015, with three observations missing (**Figure 1B**).

Our initial aim for model fitting was to simultaneously input two additional CPUE series, that is, from the Spanish and Moroccan fisheries, given that they were used in the latest age-based ICCAT assessment. Usage of these two datasets was prohibited though, because the Spanish series was expressed in terms of number of fish, and the Moroccan series performed poorly at model diagnostics when fitted alone (with a consequent inability of model convergence). The Greek CPUE data series used herein was standardized by means of Generalized Linear Modelling, taking into account the year, month, gear type, fishing area, and changes of catchability in the fisheries (Tserpes & Peristeraki, 2017).

2.2 Stock assessment model settings

The two models of the present study were SPiCT (Pedersen and Berg, 2017), and JABBA (Winker et al., 2018). Both models are formulated under the Bayesian state-space surplus production modelling framework. As state-space models, they comprise an equation for the process underlying the temporal change of biomass states, and an equation for the observations (Newman et al., 2014). Regarding the Bayesian estimation of parameters and states, the maximization of the joined posterior distribution is undertaken through Laplace approximation in SPiCT, and through Markov Chain Monte Carlo (MCMC) simulations in JABBA. Unless otherwise stated, we used the default settings and priors in the respective downloaded R packages (SPiCT version 1.2.7, and JABBA version 1.1).

For comparability of results between the two models and between simulation and empirical data, we aimed to use the same settings for priors throughout. We assumed a logistic growth form for the process equation (fixed relevant shape parameter $n = 2$). To assist model convergence, we additionally specified a prior for the intrinsic rate parameter r of population growth. In specific, we set an r prior lognormal distribution of mean $\log(r) = \log(0.47)$, and $\log(r)$ CV of 0.49 ($\log(r)$ standard deviation of 0.46; estimated previously in Anon, 2015). Since JABBA requires the explicit specification of a prior for the biomass B relative to the carrying capacity K at the first year of the catch series, we assumed that for 1950, the first year of the catch series, B_{1950}/K follows a lognormal distribution with mean of log(1), and a $\log(B_{1950}/K)$ standard deviation of 0.05 in both models. Finally, JABBA requires additionally the specification of a prior for K which was set in a range of $5 \cdot 10^4$–$3.5 \cdot 10^5$ t. For the MCMC simulations in JABBA, two Markov Chains were initiated, and run for $1.5 \cdot 10^4$ steps, with a burn-in period of $1.5 \cdot 10^3$ steps.

2.3 Model evaluation

In the present work, we distinguish two types of input time series for the SPiCT and JABBA models (**Figure 2**): empirical data for the actual model fitting, and simulation data for model validation. The simulations aimed to identify any issues in estimability of parameters and states. The diagnostic tests contained in the SPiCT and

JABBA libraries, in conjunction with results from the simulations, would contribute to a more comprehensive evaluation of model robustness when fitted to empirical data.

Through the SPiCT library's diagnostics, we tested if—for both the catch and CPUE fits—the mean of the one-step-ahead residuals was different from zero, if there was empirical autocorrelation in the residuals, and if the residuals were not normally distributed. Additionally, the robustness of model fit to the addition of new observations was checked with a retrospective test of re-fitting the model after removing the 1–5 last years of the empirical observations. Through JABBA library's diagnostics, we examined the residual plots, the Root-Mean-Squared-Error (RMSE) for any systematic trend in the residuals, the MCMC convergence through trace plots, and the model fits after removing the 1–5 last years of the empirical observations (similarly to the retrospective analysis in SPiCT).

The diagnostic procedure with the simulations implemented the re-fitting of the SPiCT and JABBA models to simulated time series (**Figure 2**). In specific, the parameter estimates from initially fitting SPiCT/JABBA to the empirical data were given as parameter values to the state-space model which was run through SPiCT's function for producing simulation data. The simulations focused on the 1987–2015 period of available CPUE empirical data. For SPiCT, we provided values estimated from the initial SPiCT fitting to the empirical data for the following input list of parameters: logm, logK, logq, logn, logsdb, logsdf, logsdi, logsdc, logbkfrac, and logF0. The simulation's initial conditions of the last two variables, logbkfrac and logF0, were taken by the estimations of SPiCT from the empirical data for the year 1987, that is, B_{1987}/K and F_{1987}, respectively. For JABBA, we provided values estimated from the initial JABBA fitting to the empirical data for the following parameters: logm, logK, logq, logn, logsdi, logsdc, logbkfrac, and logF0. Note that the JABBA-estimated variances from the empirical data for the process and observation errors were fed as values for the index and catch noise components of the simulated state-space model (logsdi and logsdc, respectively).

We ran $N = 200$ simulations of the state-space model with parameter values as estimated by SPiCT/JABBA from the empirical data (200 simulations per SPiCT/JABBA modelling approach). Each simulation stochastically produced a pair of catch–index time series (**Figure 2**). We then re-fitted the respective model, SPiCT/JABBA, to the simulated catch–index data. Priors for the re-fitting were set as in the initial fitting to the empirical data, that is, $n = 2$, and mean $\log(r) = \log(0.47)$ with $\log(r)$ standard deviation of 0.46. Note that this time we set the B_{1987}/K lognormal distribution with a mean as estimated from the fit to the empirical data. Finally for JABBA, we set the same prior for K as in the initial fitting, i.e. in the $5{\cdot}10^4$–$3.5{\cdot}10^5$ t range. Thus, for checking the estimability of parameters and states, we compared the estimate coming from the model's initial fitting to the empirical data against the distribution of the $N = 200$ re-estimates. We indicatively made comparisons for six variables: the estimate versus the re-estimates of two parameters (r and K) and three reference points (B_{MSY}, F_{MSY} and MSY); and the mean error of the fitted versus re-fitted states to the respective empirical versus simulated index data, i.e. the empirical (simulated) minus the estimated (re-estimated) state value at year t, and averaged across t.

3. Results

3.1 Stock assessment by the two models

Model fitting to the empirical data returned similar estimates from SPiCT and JABBA, with moderately narrow 95% confidence intervals (**Table 1**). The estimate of the intrinsic growth rate r was around 0.1 lower than the specified prior mean, whereas the estimate of the carrying capacity K was centred in the 10^5 order of magnitude. The posterior densities of both r and K were narrower than their prior distributions, indicating that the empirical data were informative for these estimates. The estimates of reference points showed relatively less variation in comparison to the r and K estimates (**Table 1**). The estimates of B_{MSY} and MSY were centred in the 10^4 order of magnitude, with relatively low variability, especially for MSY. Both models estimated F_{MSY} similarly, and in an approximate confidence range of around 0.15.

Similar agreement between the SPiCT and JABBA models was also exhibited in the relatively narrow estimates of the temporal trends for the state of the fisheries (**Figure 3**). The estimated state of the relative biomass at the beginning of the time series data in the 1950s was around the carrying capacity, starting a decrease in the 1970s, with a sharper decrease in the middle 1980s, getting below B_{MSY} during the 2000s, but with an increasing trend after 2010 (**Figure 3A,B**). Correspondingly, the estimated impact of the fisheries was minimal in the 1950s, starting to increase in the 1970s, with a sharper increase in the middle 1980s, passing above F_{MSY} during the 2000s, but getting back around F_{MSY} during the last years (**Figure 3C,D**). Equivalently, the Kobe (phase) plots showed the passing of the stock from an underexploited status, to an overexploited one after the middle 1990s, but recovering until the last year 2015, and with a projection of entering a green phase in the future if the 2015 fishing pressure is maintained (**Figure 3E,F**). Lastly, the production curves were fitted satisfactorily to the observations given our assumption of a classical logistic growth form (shape parameter n = 2), revealing a similar trend of anti-clockwise passing towards overexploitation, but climbing back to MSY during the last years (**Figure 3G,H**).

3.2 Model evaluation

The diagnostic tests incorporated into the SPiCT and JABBA libraries indicated a satisfactory behaviour of the fits to the various assumptions and expectations for state-space surplus production models. For SPiCT, there was no indication of a non-zero mean, or of strong autocorrelations for the residuals, although we identified a statistically significant departure from normality of the residuals in the catch fit. Taking the complete picture of these diagnostics, we decided to continue with the SPiCT-based simulations, despite the identified normality departure from the empirical catch data. For JABBA, the residual plots and the RMSE score for the period 1987–2015 of the empirical index series did not show any systematic trend in the residuals, the MCMC trace plots showed satisfactory sampling via the mixing and convergence of the two chains. For both SPiCT and JABBA, the retrospective plots revealed a robust model fit (**Figure 4**). In general, given these basic diagnostic results for the SPiCT and JABBA fits to the empirical data, we acquired enough confidence on the robustness of the model fits, which enabled us to run simulations for complementing our validation analysis by examining the estimability of parameters and states.

The catch–index series generated by simulating the stochastic state-space model, with parameter values taken from the SPiCT/JABBA fits to the empirical data, were relatively close to the empirical series, and similar between SPiCT and JABBA (**Figure 5**). In some of the simulations though, the CPUE index reached the zero state, which could be a reason for estimability issues when fitting a model to such empirical series. Even for such differences between empirical and simulated time series, the re-estimates of both SPiCT and JABBA based on the simulation data were frequently close to the initial estimates based on the empirical data (**Figure 6**). Despite the general agreement between estimates and re-estimates, our simulation analysis pointed to some particular patterns which worth to be taken into account in the interpretation of stock assessments based on SPiCT and JABBA, at least for the current empirical dataset. For the parameter r, SPiCT had the tendency to return a higher estimate, given the left-centred initial estimate and the right-skewed distribution of r re-estimates from the simulations (**Figure 6A**). Correspondingly, similar pattern was exhibited and for F_{MSY} (**Figure 6D**). For the K parameter, estimates were well-centred in the distributions of re-estimates in both models, but SPiCT returned two K re-estimates which were far greater than the actual value fed to the simulated state-space model (**Figure 6B**). Note that these two K re-estimates did not come from any of the simulated time series which lead to zero CPUE index. Correspondingly, similar pattern in SPiCT emerged and for the B_{MSY} and MSY reference points (**Figure 6C,E**). Lastly, while SPiCT returned accurate fits to the simulated time series, JABBA inaccurately fitted underestimating state series in around 20 out of the N = 200 simulations (**Figure 6F**).

4. Discussion

Both applied models provided consistent time trend estimates indicating rapid biomass decreases from the middle 1980s up to 2010, while the opposite trend was found for fishing mortality. In that period, annual catches were mostly higher than the model estimated MSY (~ 13000 t). Since 2010, biomass showed slight increasing trends and fishing mortality was decreasing. Model estimates showed that current (2015) biomass is about 20% lower than B_{MSY}, while F is at optimum levels. Relative biomass and fishing estimates for the last year differ from those obtained from the latest ICCAT age-based assessment, which revealed a much higher level of overexploitation (Anon, 2017). Similarly, discrepancies are found for the MSY, which was previously reported to be up to 20000 t, a quantity, however, that has been hardly observed in the historical catches.

Improving assessment estimates for the Mediterranean swordfish stock has been considered of great importance, given that several uncertainties regarding the exploitation pattern seem to have affected the previous age-based assessments (Anon, 2019). In this context, alternative approaches such as Bayesian production models, which have been already applied for assessing the Atlantic swordfish stocks in the Atlantic, may provide valuable information for the management of the Mediterranean stock as well. In the present work, we have been using CPUE series from a fishery that exploits only the eastern part of the Mediterranean. Fitting the models with additional CPUE series from fisheries exploiting other Mediterranean areas would provide a more robust picture of the state of the stock.

References

Anon. 2015. Report of the 2014 ICCAT Mediterranean swordfish stock assessment meeting (Heraklion, Greece, 21–25 July 2014). Collect. Vol. Sci. Pap. ICCAT, 71(5): 1870–1979.

Anon. 2017. Report of the 2016 ICCAT Mediterranean swordfish stock assessment meeting (Casablanca, Morocco, 11–16 July 2016). Collect. Vol. Sci. Pap. ICCAT, 73(3): 1005–1096.

Anon. 2019. ICCAT report for biennial period, 2018–19. Part I (2018)-Vol. 2. SCRS: 182–192.

Newman, K.B., Buckland, S.T., Morgan, B.J.T., King, R., Borchers, D.L., Cole, D.J., Besbeas, P., Gimenez, O. and Thomas L. 2014. Modelling population dynamics. New York, Springer.

Pedersen, M.W. and Berg, C.W. 2017. A stochastic surplus production model in continuous time. Fish. Fish., 18(2): 226–243.

Tserpes, G. and Peristeraki, P. 2017. Swordfish abundance trends in the drifting surface longline Greek fisheries. Collect. Vol. Sci. Pap. ICCAT, 73(3): 1097–1102.

Winker, H., Carvalho, F. and Kapur, M. 2018. JABBA: Just Another Bayesian Biomass Assessment. Fish. Res., 204: 275–288.

Table 1. Estimates and 95% confidence intervals (CI) of SPiCT and JABBA models fitted to the empirical data.

Variable	SPiCT estimate (CI)	JABBA estimate (CI)
r	0.37 (0.17–0.8)	0.34 (0.19–0.6)
K	$1.42 \cdot 10^5$ ($7.31 \cdot 10^4$–$2.74 \cdot 10^5$)	$1.54 \cdot 10^5$ ($9.4 \cdot 10^4$–$2.41 \cdot 10^5$)
B_{MSY}	$7.07 \cdot 10^4$ ($3.65 \cdot 10^4$–$1.37 \cdot 10^5$)	$7.69 \cdot 10^4$ ($4.7 \cdot 10^4$–$1.2 \cdot 10^5$)
F_{MSY}	0.19 (0.09–0.4)	0.17 (0.1–0.3)
MSY	$1.31 \cdot 10^4$ ($1.14 \cdot 10^4$–$1.51 \cdot 10^4$)	$1.32 \cdot 10^4$ ($1.1 \cdot 10^4$–$1.49 \cdot 10^4$)
Current $B_{2015}/B_{\mathrm{MSY}}$	0.79 (0.56–1.12)	0.79 (0.54–1.12)
Current $F_{2015}/F_{\mathrm{MSY}}$	0.98 (0.56–1.71)	0.97 (0.63–1.48)

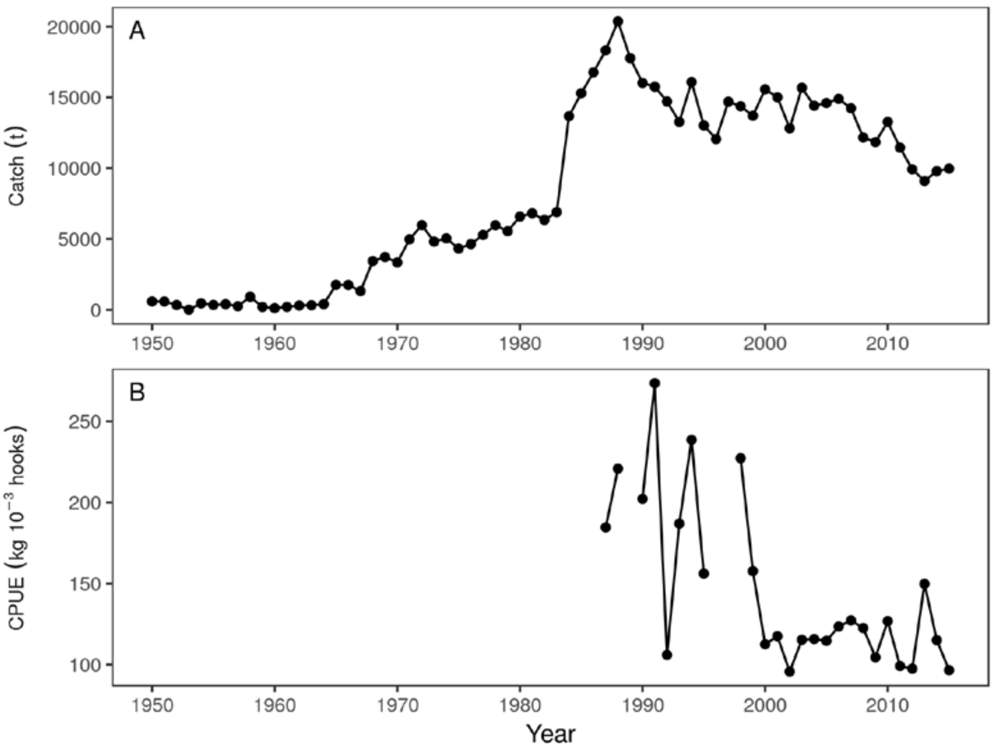

Figure 1. The empirical time series of data used as input for the SPiCT and JABBA models. (A) Mediterranean swordfish catches from 1950–2015. (B) Standardized CPUE estimates from the Greek drifting longline fisheries. Line segments connect consecutive annual observations.

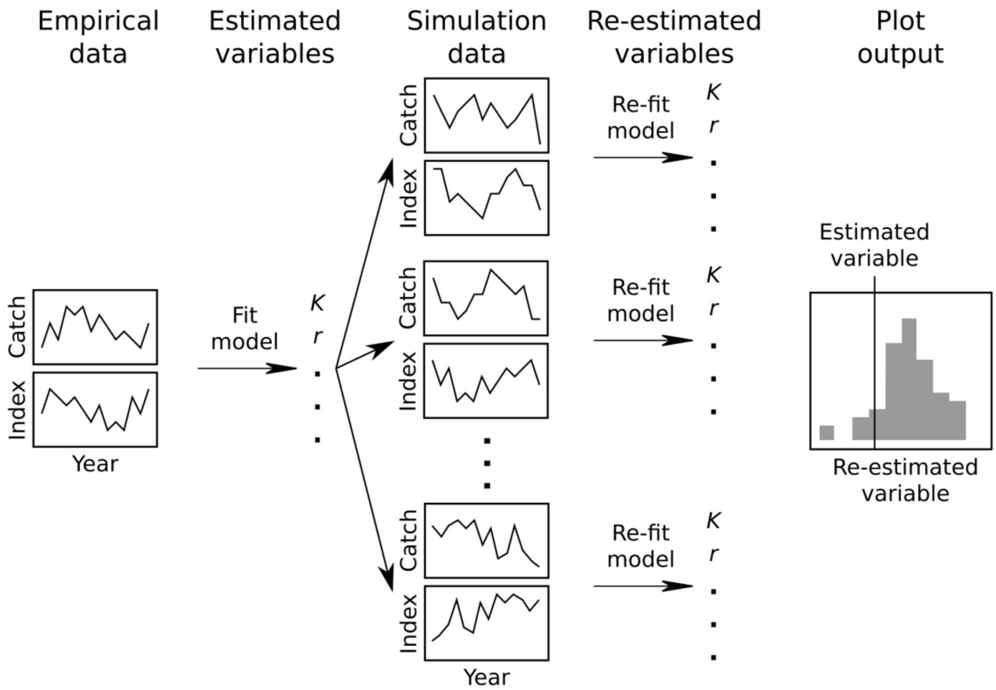

Figure 2. Diagram of the procedure for checking SPiCT/JABBA on the estimability of parameters and states. The branching arrows denote that parameter estimates from fitting the model to the empirical data were fed to the state-space model to simulate stochastically *N* pairs of catch–index series.

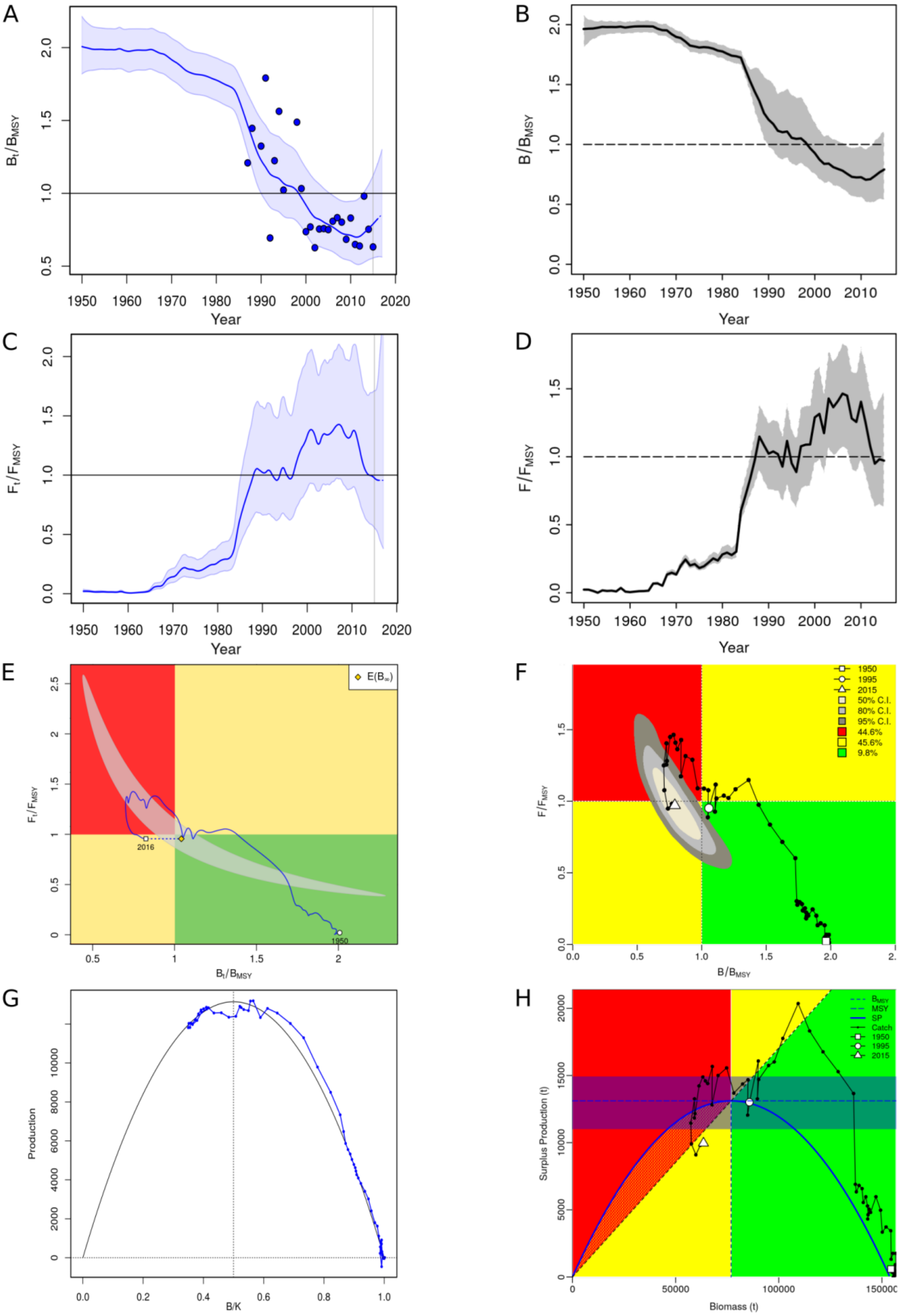

Figure 3. Indicative output from SPiCT (left column) and JABBA (right column) fitted to the empirical data. (A, B) Lines of the estimated relative biomass in time, and 95% confidence regions in shading; points in (A) are from the empirical CPUE observations. (C, D) Lines of the estimated relative fishing mortality in time, and 95% confidence regions in shading. (E, F) Kobe (phase) plots of relative fishing mortality over relative biomass estimates. (G, H) Fitted production curve over biomass *B* relative to the carrying capacity *K* for SPiCT (G), and over *B* for JABBA (H).

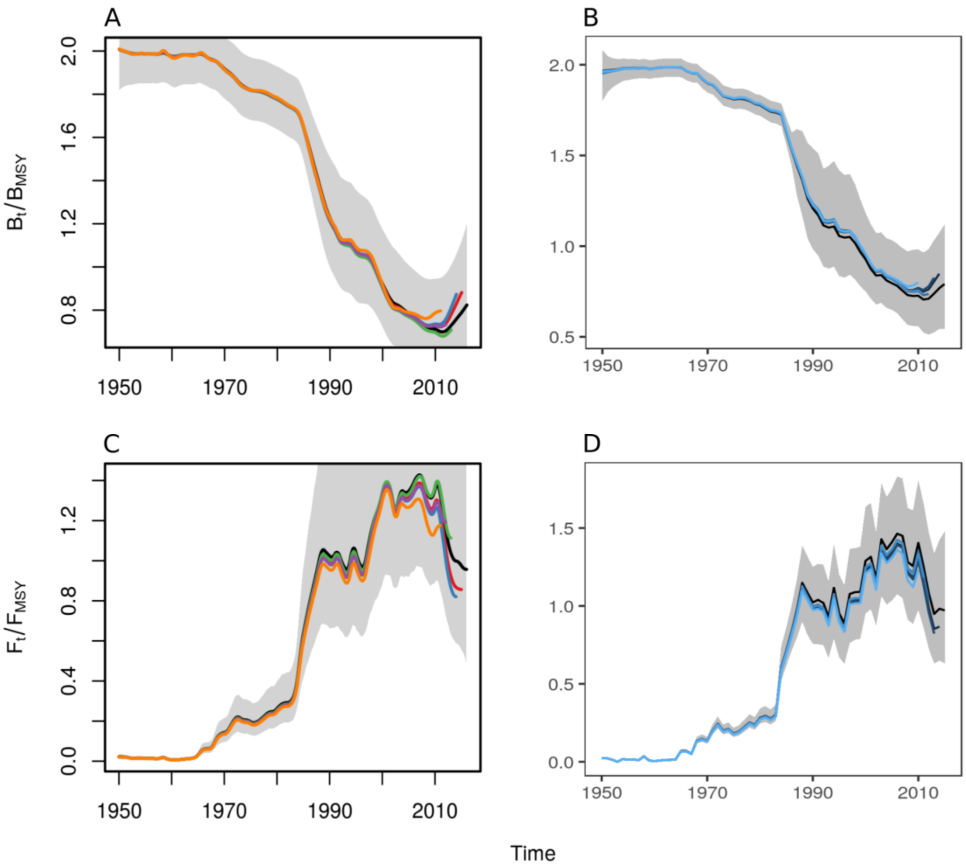

Figure 4. Retrospective plots from SPiCT (left column) and JABBA (right column). The models were re-fitted after removing the 1–5 last years of empirical observations. (A, B) Estimates of relative biomass. (C, D) Estimates of relative fishing mortality. In any panel, 95% confidence regions given with shading are for the estimates from the complete time series.

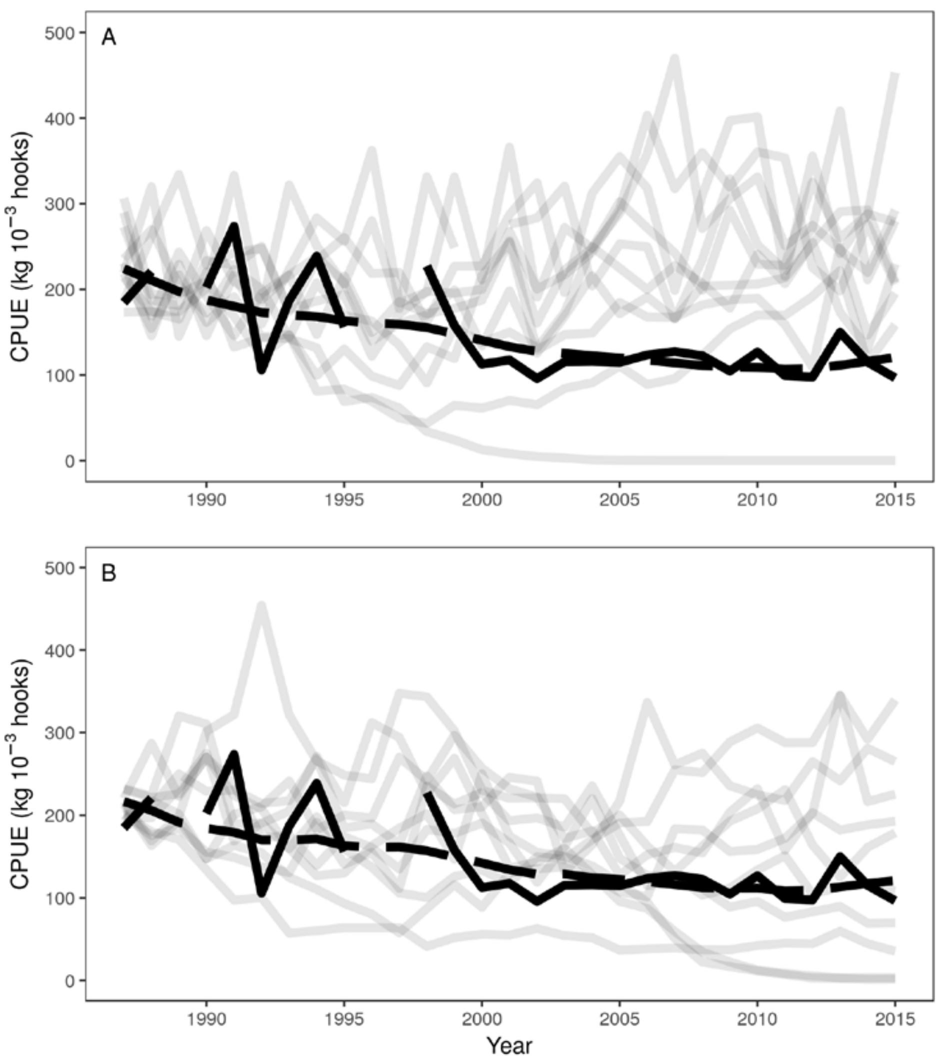

Figure 5. Empirical and simulated CPUE series for SPiCT (A) and JABBA (B). Black lines are for the empirical CPUE, black dashed lines are the estimated states by the model, and grey lines are generated CPUE series from "forward-run" simulations of the common state-space model with parameter values as estimated initially by SPiCT/JABBA from the empirical data (N = 10 simulations shown in each panel).

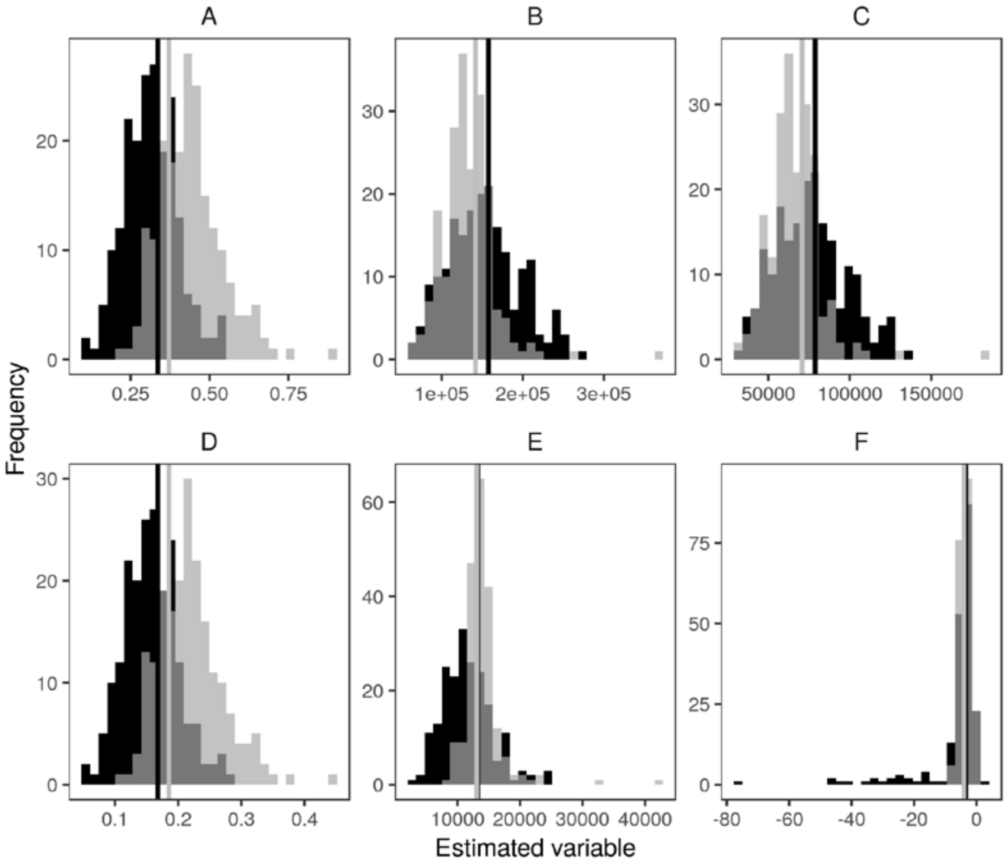

Figure 6. Indicative simulation results for checking estimability of parameters and states in SPiCT (grey) and JABBA (black). The estimated variables shown are: (A) *r*; (B) *K*; (C) B_{MSY}; (D) F_{MSY}; (E) MSY; and (F) Mean error in estimated states, taken as the difference of empirical/simulated minus estimated state value at year *t*, and averaged across *t*. A vertical line indicates the estimate coming from the model's initial fitting to the empirical data (grey for SPiCT, and black for JABBA). A histogram shows the distribution of the model's re-estimates, after refitting the model to N = 200 "forward-run" simulations of the common state-space model with parameter values as estimated initially from the empirical data. The SPiCT histograms are semi-transparent grey, i.e. SPiCT–JABBA overlaps appear in darker grey.