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Update of the Management Strategy Evaluation for Redfish stock in NAFO Divisions 3LN

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Abstract

An ASPIC based MSE was presented for the Redfish 3LN stock in 2014. The range of operating models in the management strategy evaluation (MSE) included different formulations of the surplus production models. Four harvest control rules (three catch based and one F-based) were evaluated against three performance metrics. The Commission requested that the Scientific Council, carry out a scoping exercise to provide guidance to the WG-RBMS on the process of conducting of a full review/evaluation of the management strategy of Div. 3LN redfish. As part of addressing the request, this work is an update of the original MSE with data up to 2021. Results from the explorations show that the outputs from the operating models differ between each other considerably based on treatment of data and use of different priors for the key parameters. However, the performance of the harvest control rules are quite consistent between the different operating models. The performance criteria exceeded the agreed limits only in the case of one HCR where a high constant total allowable catch of 20,000 tonnes was applied. Considerable effort was put into updating the data input and model output code using the R2OpenBugs software to allow ease in further exploration of production models in the ongoing MSE process, however the code for the operating models have not been changed.

Introduction

The Commission requested that the Scientific Council, carry out a scoping exercise to provide guidance to the WG-RBMS on the process of conducting of a full review/evaluation of the management strategy of Div. 3LN redfish. This is an effort to support that process by updating the existing MSE for the stock.

A Stock Production Model Incorporating Covariates (ASPIC; Prager, 1994) has been used for management of the stock since 2008 (Ávila de Melo and Alpoim 2010; Ávila de Melo et al. 2014; Dauphin et al. 2014). Model formulations and data input were evaluated several times in an effort to achieve better model diagnostics (Ávila de Melo and Alpoim 2010, Ávila de Melo et al. 2012). The final major exploration of the ASPIC model formulations (especially the data series used in the model) was performed leading up to the 2014 assessment (Ávila de Melo et al. 2014). Analysis of various formulations explored and the influence of key data series have been discussed in detail in Ávila de Melo et al. (2014) and this work determined the core formulations of the operating models to be explored in the first MSE initiated for the stock. In 2014, Management Strategy Evaluation (MSE) of the stock was completed (Dauphin et al. 2014). The 2014 MSE involved six operating models (OMs), four harvest control rules (HCR), and three performance metrics.

The scoping exercise for the new MSE for the Div. 3LN redfish stock is being initiated at a time when NAFO experts who led the development of the assessment model and operating model structures, and formalized the MSE have retired and/or moved on to other positions. Several members of the team initiating the current project are new to work on this stock. This exercise is an effort to fully familiarize ourselves with the existing stock assessment research and the data on the stock. By bringing the existing surplus production based MSE up to date, it gives the opportunity to continue the current body of work on full stock model while efforts continue to develop more sophisticated age/length based models that can provide a more comprehensive picture of the stock structure.

However, it is prudent to recognize that it is challenging to develop stock assessment models for redfish stocks due to the following key aspects of the population dynamics. The species is slow growing and therefore difficult to age with reliability. The stocks in Northwestern Atlantic are a mix of species (mainly *Sebastes mentella* and *S. fasciatus*) that are difficult to separately identify; hence data (in most cases) are available as aggregate redfish species. In Div. 3LN, species *S. mentella* is understood to be more dominant than *S. fasciatus* (Ávila de Melo et al. 2014). There are differences in growth and habitat associations of the species, but not enough to reliably partition the data between species. To add to this complexity is the sporadic nature of recruitment of the species which makes it very difficult to explore stock and recruitment patterns. Due to these challenges, redfish stocks are predominantly managed based on survey trends (Cadigan et al. 2022) and only few stocks have surplus production (Ávila de Melo et al. 2014; McAllister and Duplisea 2012) or age/length based models developed for redfish stocks (Ávila de Melo et al. 2017; Duplisea et al. 2016; Licandeo et al. 2020; NOAA 2020) developed.

Methods

All the six OMs in the original MSE were built within a surplus production model framework. The first two OMs were the two latest accepted formulations of the ASPIC model (the ASPIC model accepted in 2012 and the ASPIC model revised and adopted in 2014). Four of the remaining OMs were developed using the surplus production model structure, but within a Bayesian framework. This allowed the application of priors on the various parameters in the model. These OMs were developed using OpenBugs software.

In 2022, we updated the MSE from 2014 with most recent data (up to 2021). The first two OMs exist in the ASPIC software platform alone and are not part of this exploration. The code for the operating models was not modified; however the code for passing data to the OpenBugs program and code for processing the simulation output from the OpenBugs program was updated to a more streamlined version using the 'R2OpenBugs package.

Operating models

A summary of the operating models is provided in Table 1.

ASPIC 2012: The surplus production model formulation in ASPIC software that was approved as an assessment model in 2012. This model was an update on the 2010 version of ASPIC where some of data that were outliers were removed (years 1985-1990 from the DFO-RV spring survey, years 1995 and 2010 from the DFO-RV autumn survey for division 3L, and years 1990 and 1992 from the DFO-RV autumn survey for division 3N were omitted). This model did not use any of the Spanish surveys.

ASPIC 2014: Several updates were made to the ASPIC model adopted in 2014. The model uses a fixed value of 21,000 tonnes (average from 1980-1995) as the maximum sustainable yield (MSY). ASPIC 2012 model used the DFO-RV autumn 3L and 3N surveys separately, the ASPIC 2014 used the combined series for DFO-RV autumn 3LN survey from 1991 onwards (data for year 1990 was omitted). The DFO-RV autumn 3L data for three years 1986, 1986 and 1990 was included). The Spanish 3N survey was included. This is the model formulation used for the assessment of the stock up until the NAFO Scientific Council meeting in 2022, wherein it was concluded that the model outputs were not sufficiently reliable to provide advice on.

ASPIC-BAYES 2012: This is a Bayesian formulation of the ASPIC 2012 model. Priors are included for the carrying capacity (K), MSY, and parameters for the survey catchability and observation error for the surveys.

ASPIC-BAYES 2014: This is a Bayesian formulation of the ASPIC 2014 model. Priors are included for all parameters except MSY which is fixed at 21,000 tonnes.

ASPIC-BAYES FULL: This model includes some of the data that were excluded in the previous two models. However, calling the model 'full' is not fully accurate. This model formulation also omitted years 1985-1990 from the DFO-RV spring survey. Similar to ASPIC 2012 formulation, DFO-RV autumn survey from 3L and 3N are included separately; year 2010 data for the DFO-RV autumn survey for division 3L was included but data for year 1995 for this survey was omitted). Data from the Spanish survey for both the divisions 3L and 3N were included. Priors applied to K and MSY had higher variance (i.e. less informative priors were used in setting up this model).

BAYES SPATIAL: As expected, separate surveys for divisions 3L and 3N where available were included separately (DFO-RV spring and autumn surveys and the Spanish surveys). Some years are omitted from these surveys. This model formulation is the only one that includes the summer 3N survey. More details are available in Table 2. This model estimates a separate K parameters for divisions 3L and 3N and the priors applied to both these parameters are not very informative. This is the only formulation which applies a prior on intrinsic rate of growth 'r' parameter for the stock. This allows separate MSY estimation for each of the divisions.

Harvest control rules

Four harvest control rules were explored using the four OMs. These management procedures were developed as part of the modelling and MSE exercise in 2014 (Ávila de Melo et al., 2014; Dauphin et al. 2014). Also to be noted with each of the HCR evaluations is that the analyses assumes that the TAC will be taken by the fishery. Since the current catch levels are higher than 2014 when the HCRs were designed, the stepwise HCRs start at levels close to the current catches (Figure 1).

1. Stepwise HCR: increase TAC in constant increments (1900 tons) to a maximum of 20000 tons.
2. Stepwise slow HCR: similar to HCR 1 but increments every second year to a maximum of 18100 tons
3. Constant TAC HCR: Constant TAC (20000 tons)
4. Constant F HCR: Constant F (2/3 F_{MSY})

Performance metrics

The management procedures were evaluated using three performance metrics. These performance metrics were also developed as part of the modelling and MSE exercise in 2014 (Ávila de Melo et al., 2014; Dauphin et al. 2014).

1. Low (30%) probability of exceeding F_{MSY} in any year
2. Very low (10%) probability of declining below B_{Lim} in the next 7 years
3. Less than 50% probability of declining below 80% B_{MSY} in the next 7 years

Results

Operating models

Since the MSE was being revisited after a long period of time (> 5 years) and since changes were made to the input and output code, the 2014 MSE was repeated to check that the same output could be reproduced. The MSE were updated twice, once in 2021 and again in 2022. In total there are four sets MSE outputs presented, one original 2014 MSE, repeat run of 2014 MSE, 2021 update and 2022 update. The BAYES-SPATIAL model could not be rerun in 2022 due to issues with the indexing of data[1].

There were considerable differences in the posterior distribution for the estimated and derived parameters between the OM formulations (Figures 2-6). More data were used in the BAYES-FULL and BAYES-SPATIAL model and this is reflected in the wider posterior estimates for K and MSY from these models. In the repeat of the ASPIC-BAYES-2014 and ASPIC-BAYES-FULL, the parameter estimates for the repeat runs of the MSE 2014, MSE 2021, and MSE 2022 were different from the original run. It was not possible to diagnose the cause of this difference; this likely points to likely some difference in data points used between the different iterations. The K posterior from the MSE 2014 repeat, MSE 2021, and the MSE 2022 runs are similar to the distribution from the ASPIC 2014 model. Using all the data in ASPIC_BAYES_FULL leads to much wider distributions of estimates of K, MSY, BMSY etc. again indicating that certain data points have large influence on the model estimates.

In terms of consistency between runs, the BAYES-ASPIC-2012 formulation was the most consistent. The outputs from the BAYES-SPATIAL were also fairly consistent, with not much difference in parameter posterior estimates between iterations. The posterior distribution is wider for the spatial model but the posterior mode is smaller than the BAYES-ASPIC-2012 formulation.

The estimate of parameter 'r' from the aspic assessment model is 0.23 (0.19-0.25). The posterior estimates of 'r' parameter from the MSE iterations show similar estimates from the BAYES-SPATIAL model. These estimates are high compared to the estimate of r around 0.12 from McAllister and Duplisea 2012. The lowest 'r' value is obtained from the BAYES-FULL model. The distributions of posteriors for B_MSY and F_MSY follow the distributions of K and r respectively.

Performance of harvest control rules

The report presents the harvest control rule application to each of the OMs from the 2022 MSE run. For the spatial model, the outputs from the 2021 MSE run are presented. Across all OM, the constant F HCR was found to be the most conservative based on both the fishing mortality and biomass based performance metrics (Figure7-9). The constant TAC HCR resulted in highest values of F in the projection. In the ASPIC-BAYES-2014 OM, resulting F exceeded the FMSY in about half-way through the projection. This was reflected in the biomass projection where there was higher than 10% probability of being above Blim towards the end of the projection. The stepwise HCRs allowed a slower increase in the TAC than under the constant TAC HCR. Hence, the F values increased slowly over the projection period; with stepwise-slow HCR showing a slower increase than the stepwise HCR as expected. Under the ASPIC-BAYES-2014 OM, F in stepwise HCR exceeded FMSY and the probability of B<Blim exceeded 10%. Although there was considerable difference between the levels of F/FMSY and B<Blim realized under the different combinations of OMs and HCRs tested, the stepwise-slow HCR did not exceed the performance metrics criteria in any of the explorations.

In terms of overall performance over the next seven years of projection, only one HCR (high constant TAC of 20,000 tonnes) exceeded the criteria established for the performance metrics (Table 3). Performance of all

[1] The model indexes the 3L and 3N Spanish surveys together and in 2022, a data point was available for 3N in 2022 but not for 3L. The model would have to be updated to deal with this small issue.

other HCRs was within the accepted range for the performance metrics. The appendix includes plots of projection outputs from the HCRs under the different OMs.

Conclusion

There are many different survey time series that are available for this stock. The first conclusion from this exploration is that differences between treatment of data (choice of survey time-series and elimination of outliers) between operating models has a large influence on the outputs derived from the models. Hence completing a thorough data review is important before diving into a modelling exercise. The update of the surplus production based MSE allows the continued exploration of surplus production models for the MSE. At the previous MSE, the step-wise slow HCR was adopted. Given that the current TAC is at the maximum level of the step-wise HCR, there is need to revisit the step levels adopted in this HCR. Since redfish is a long lived species, there is need to consider long term performance metrics. However the new MSE is also an opportunity to explore other model structures that could model the length/age structure of the population. It is also an opportunity to develop an updated set of harvest control rules and to develop performance metrics that represent the current objectives for the management of the stock.

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Tables

Table 1. Summary of operating models

Model number	1	2	3	4	5	6
Model names	2012 ASPIC approved assessment model	2014 ASPIC approved assessment model	ASPIC-BAYES-2012	ASPIC-BAYES-2014	ASPIC-BAYES-FULL	BAYES-SPATIAL
Key aspects	Model formulation based on Ávila de Melo and Alpoim, (2010) Some data considered as outliers were removed.	2014 application of first model developed to resolve issues with fitting annual biomass jumps in surveys	Bayesian application of 2012 ASPIC Model formulated as closely as possible to 2012 ASPIC	Bayesian application of 2014 ASPIC	Full time series of all surveys and catch data are used. Parameter constraints implement ed in ASPIC-BAYES-2014 relaxed	Spatial model that fit to survey and catch data for 3L and 3N divisions separately. Full data, no outliers removed
Commercial and survey data	Data sets used in the different OMs are different. Several outliers removed in several cases. For a summary see Table 2					
Parameter constraints	MSY (5,000-50,000) K(10^5 – 10^6) F_{max}=6	MSY fixed at 21,000t	MSY and K(censored lognormal prior) K ~200K (100-1000K) MSY~15K (5-50K)	MSY fixed at 21,000t K: logN prior K ~200K (100-1000K)	Less-informative priors for K and MSY, although K still censored similarly to previous models, no upper limit on MSY	K priors for K_3L and K_3N, censored upper limit of 10^6, Model re-parametrized with prior on r (censored gamma prior) MSY~0.05(0.001-2)

Table 2. Summary of data used in operating models. Note that table does not provide full details, several outliers removed from different series. *The Bayes_spatial model fits to the CPUE time-series, although earlier versions where the model was described do not indicate that the aggregate CPUE series is fitted in the spatial model.

DATA/MODELS		2012 ASPIC approved assessment model	2014 ASPIC approved assessment model	ASPIC-BAYES-2012	ASPIC-BAYES-2014	ASPIC-BAYES-FULL	BAYES-SPATIAL
Commercial	CPUE	Yes	Yes	Yes	Yes	Yes	Yes
	Catch 3LN	Yes	Yes	Yes	Yes	Yes	
	Catch 3L						Yes
	Catch 3N						Yes
Surveys Ongoing	CAN spring3LN	Yes (1985-1990 discarded)	Yes (1985-1990 discarded)	Yes (1985-1990 discarded)	Yes (1985-1990 discarded)	Yes (1985-1990 discarded)	
	CAN autumn3LN		Yes		Yes (1990 discarded)		
	CAN autumn3L	Yes	Yes (1985-1986, 1990)	Yes (1995, 2010 discarded)	Yes (1985-1986, 1990)	Yes (1995 discarded)	Yes
	CAN autumn3N	Yes		Yes (1990, 1992, 2011 discarded)		Yes (1990, 1992 discarded)	Yes (1990 discarded)
	CAN spring3L						Yes (1986-1990 discarded; 1980 and 1985 value used)
	CAN spring3N						Yes (1985-1990 discarded)
	Spanish 3N		Yes		Yes	Yes	Yes
	Spanish 3L					Yes	Yes
Earlier surveys	Russian 3LN	Yes	Yes	Yes	Yes	Yes	Yes
	winter3L	Yes	Yes	Yes	Yes	Yes	Yes
	summer3L	Yes	Yes	Yes	Yes	Yes	Yes
	summer 3N						Yes

Table 3. Performance of harvest control rules. Table shows number of years (out of 7 projected years) where criteria are exceeded.

model	HCR	Probability (F>FMSY) >0.3	Probability (B<Blim) >0.1	Probability B/80%Bmsy>0.5
ASPIC-BAYES 2012	HCR_constantF	0	0	0
	HCR_highTAC	0	0	0
	HCR_stepwise	0	0	0
	HCR_stepwise_slow	0	0	0
ASPIC-BAYES 2014	HCR_constantF	0	0	0
	HCR_highTAC	3	0	0
	HCR_stepwise	0	0	0
	HCR_stepwise_slow	0	0	0
BAYES SPATIAL	HCR_constantF	0	0	0
	HCR_highTAC	0	0	0
	HCR_stepwise	0	0	0
	HCR_stepwise_slow	0	0	0
ASPIC-BAYES FULL	HCR_constantF	0	0	0
	HCR_highTAC	0	0	0
	HCR_stepwise	0	0	0
	HCR_stepwise_slow	0	0	0

Figures

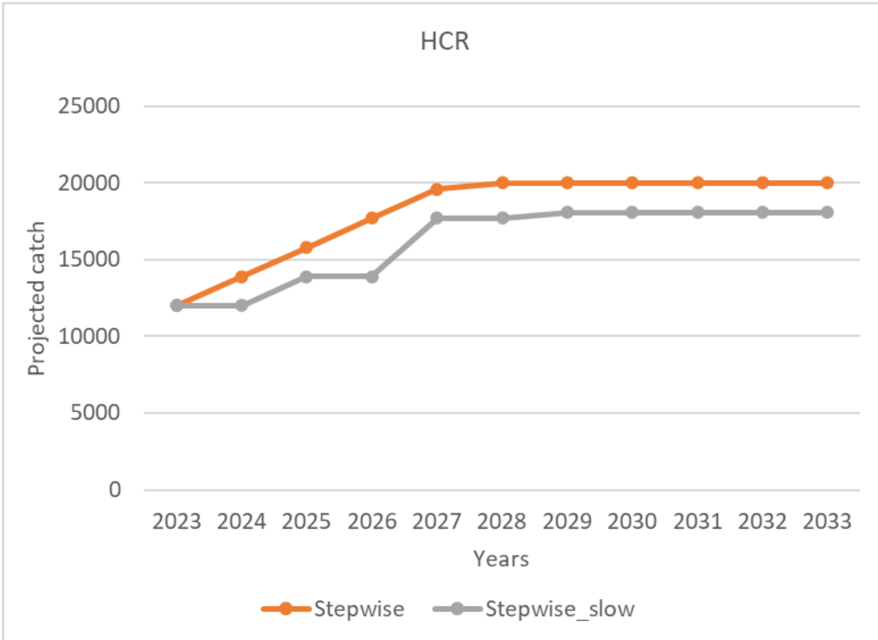


Figure 1. Stepwise and stepwise-slow harvest control rules applied in the 2021 and 2022 run of the MSE

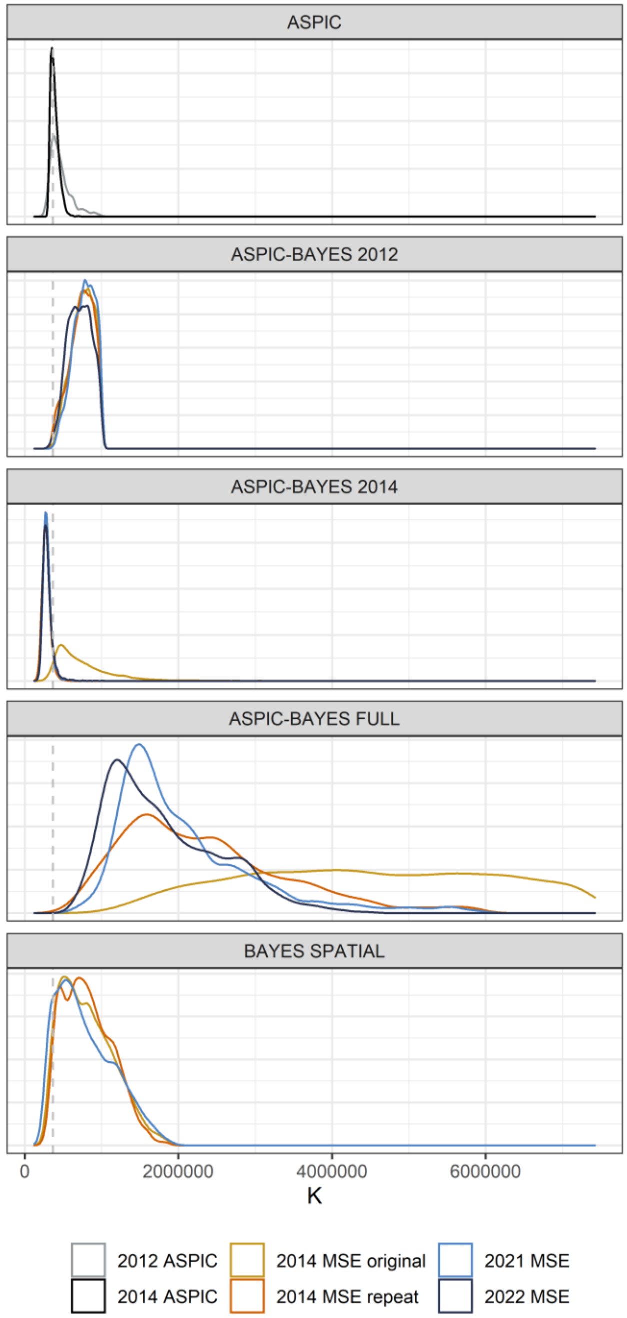


Figure 2. Posterior distribution of K. The grey dashed lines show the estimates from the 2021 run of the ASPIC assessment model.

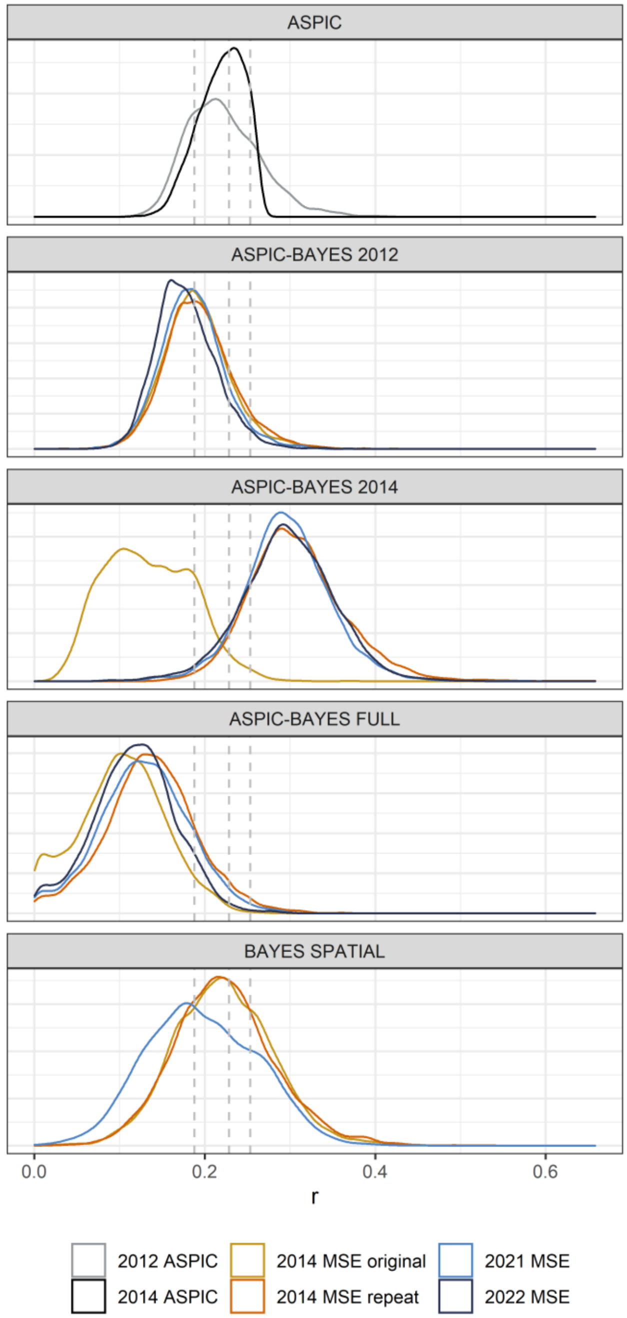


Figure 3. Posterior distribution of r. The grey dashed lines show the estimates from the 2021 run of the ASPIC assessment model.

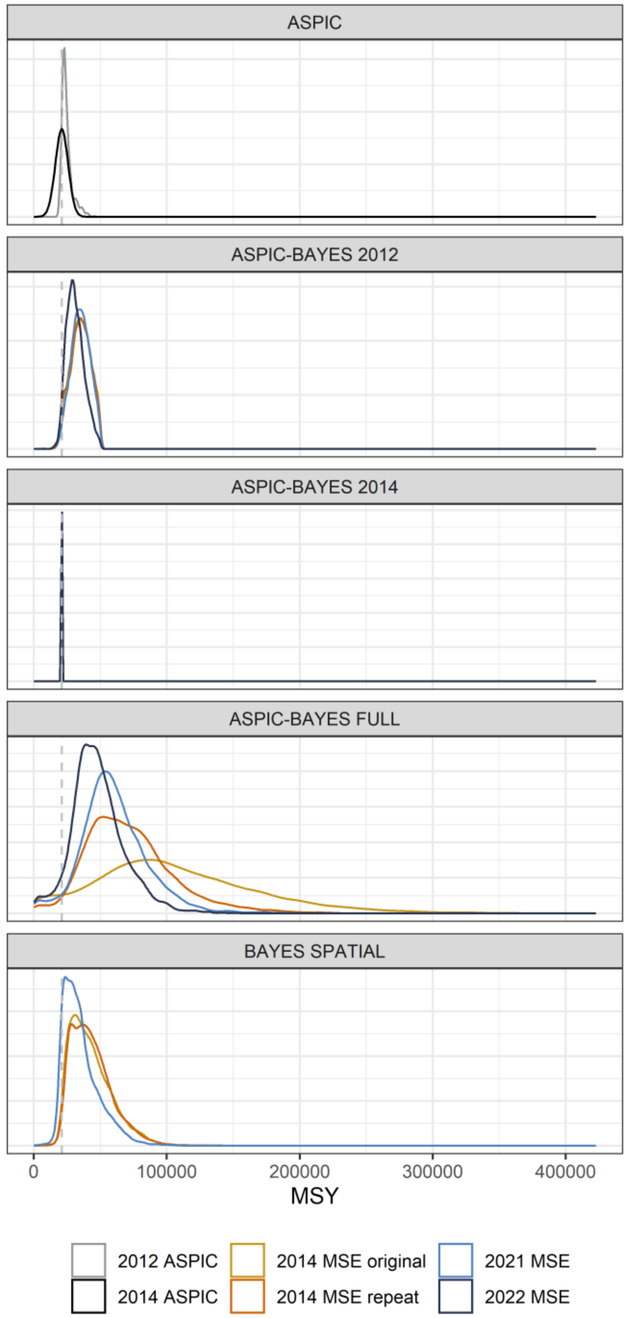


Figure 4. Posterior distribution of MSY. The grey dashed lines show the estimates from the 2021 run of the ASPIC assessment model.

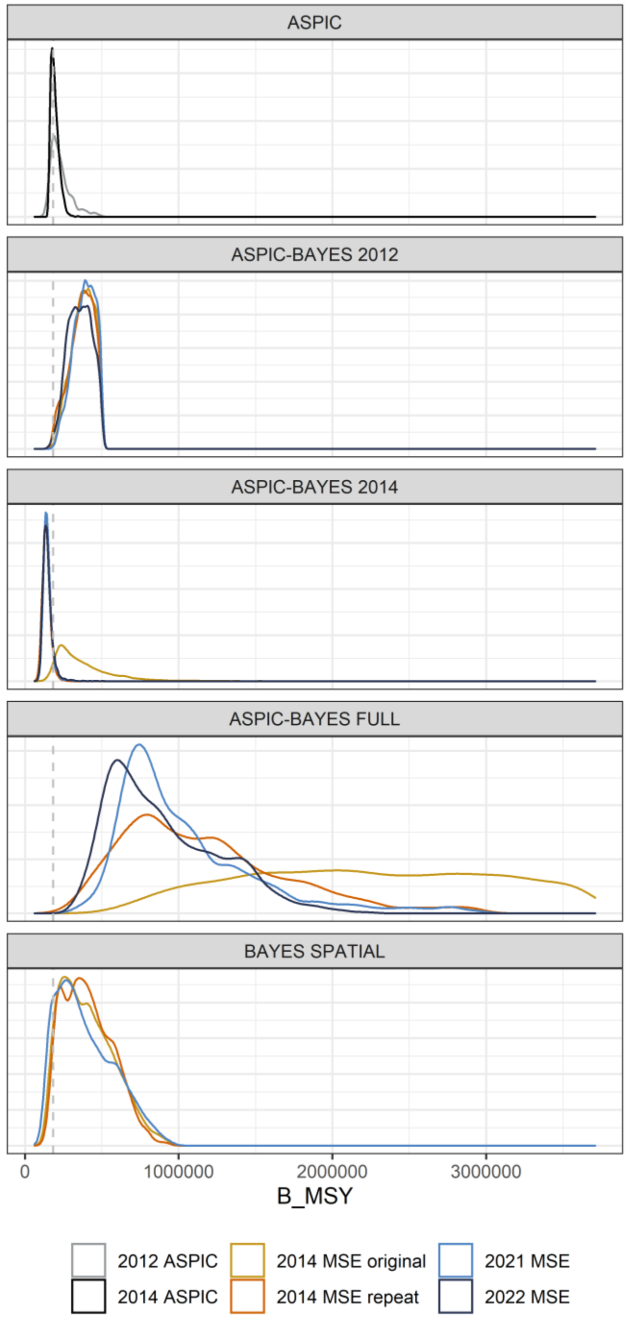


Figure 5. Posterior distribution of B_MSY. The grey dashed lines show the estimates from the 2021 run of the ASPIC assessment model.

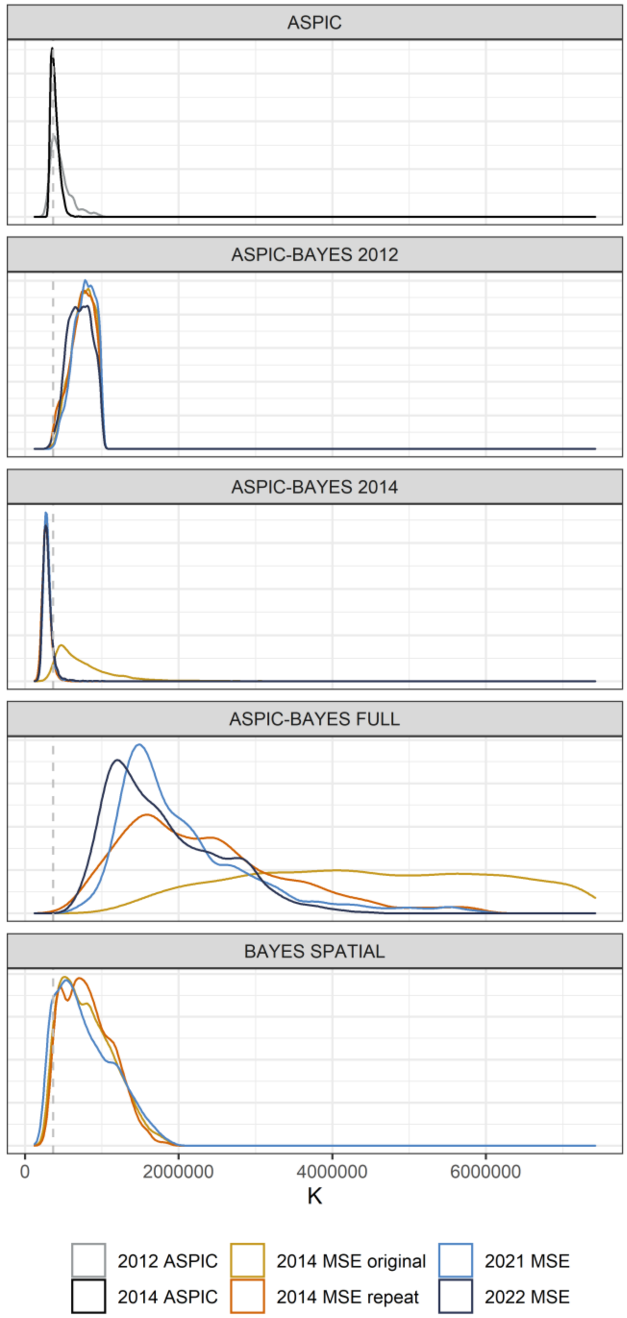


Figure 6. Posterior distribution of F_MSY. The grey dashed lines show the estimates from the 2021 run of the ASPIC assessment model.

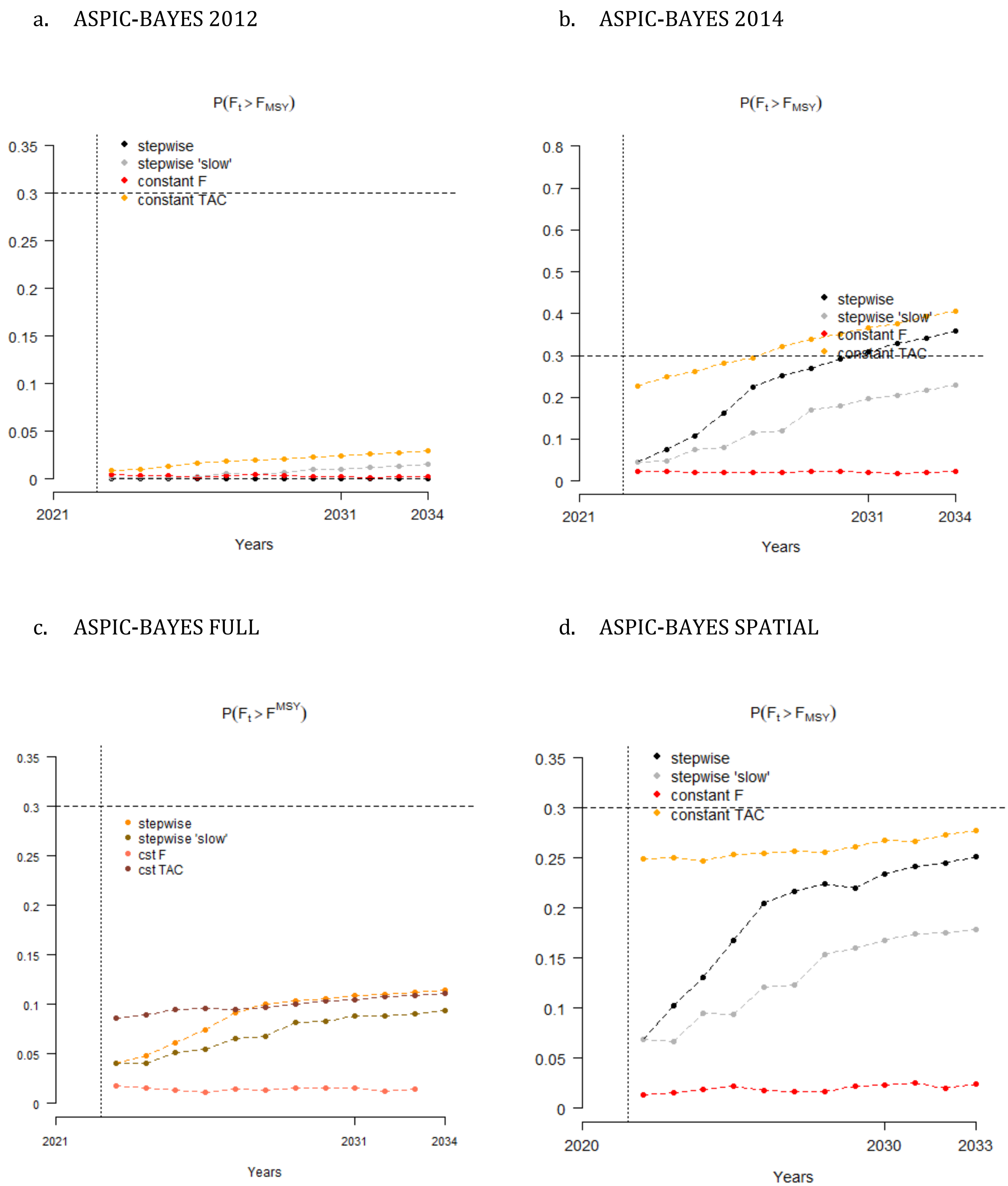
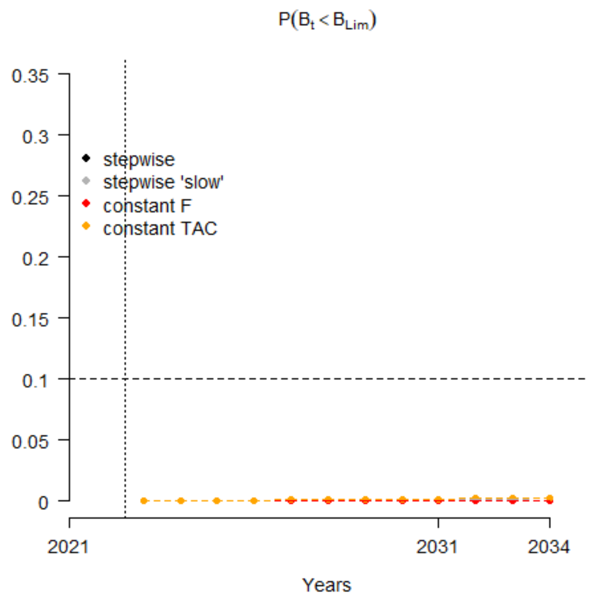
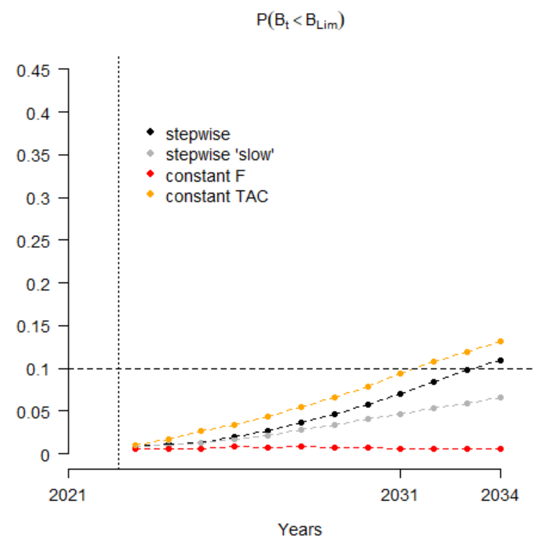


Figure 7. Performance metric probability of F/FMSY > 0.3. Each panel shows the outputs for a different operating model. Each line within a panel shows the performance of a harvest control rule.

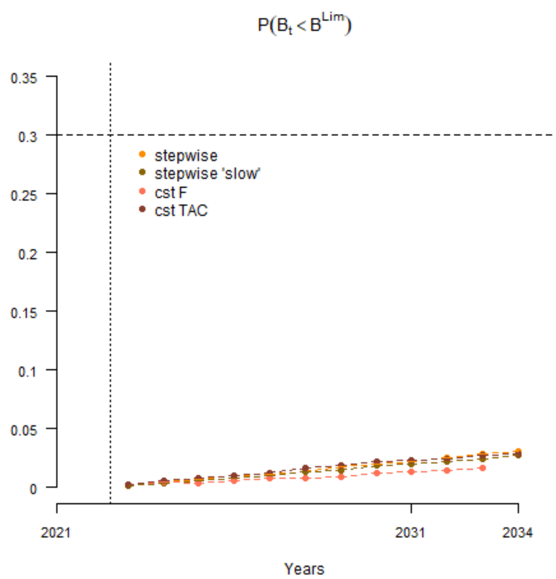
a. ASPIC-BAYES 2012



b. ASPIC-BAYES 2014



c. ASPIC-BAYES FULL



d. ASPIC-BAYES SPATIAL

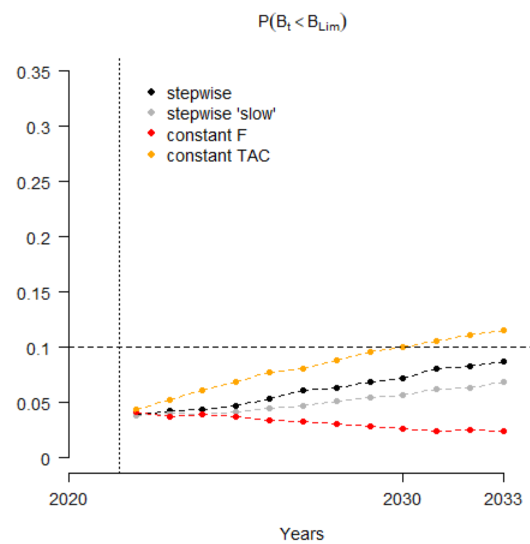


Figure 8. Performance metric probability of B<Blim > 0.1. Each panel shows the outputs for a different operating model. Each line within a panel shows the performance of a harvest control rule.

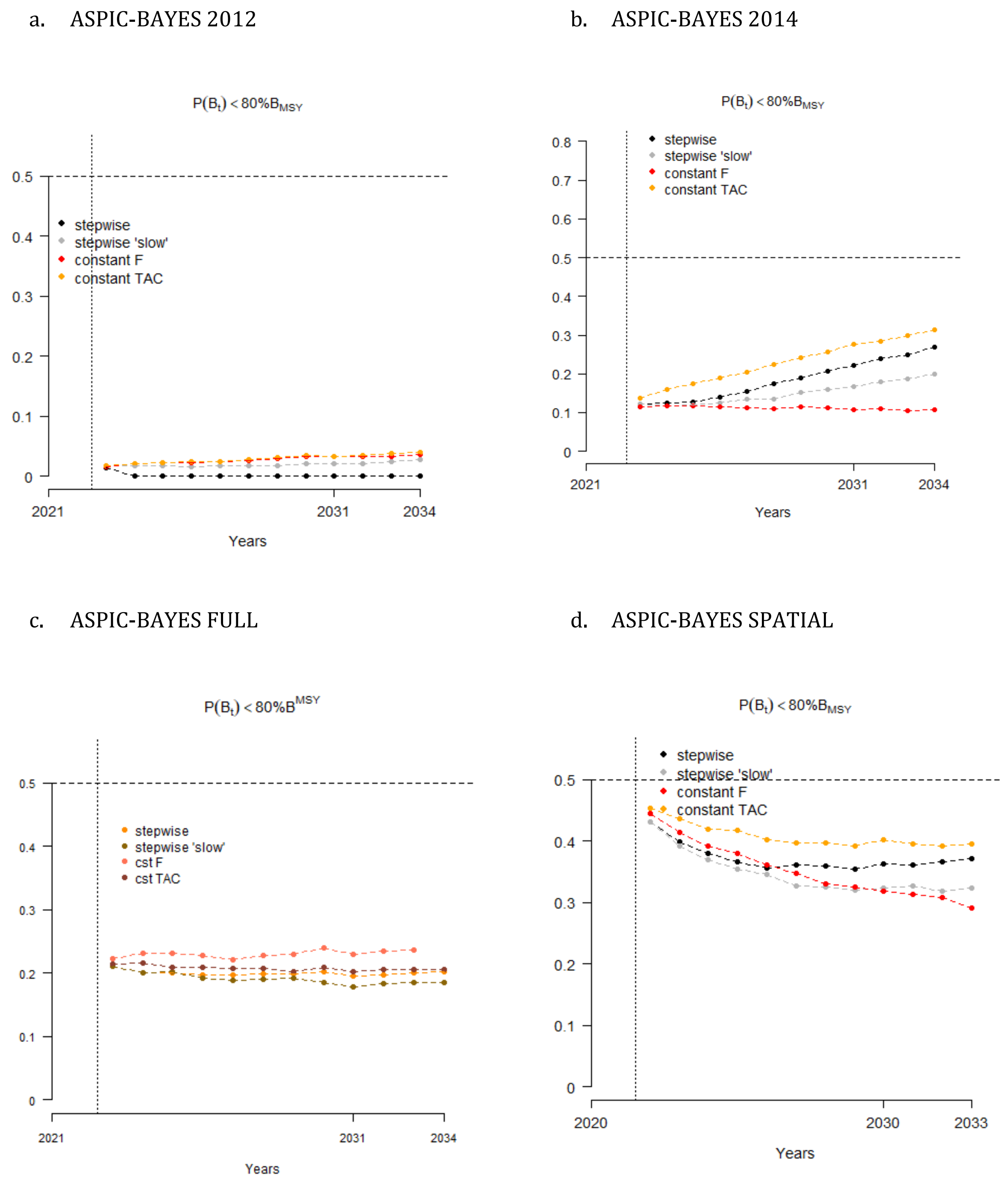


Figure 9. Performance metric probability of B/BMSY < 0.5. Each panel shows the outputs for a different operating model. Each line within a panel shows the performance of a harvest control rule.