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Redfish Div. 3M: Biological Reference Points and advice under the PA alternative framework

By

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Abstract

The three alternative frameworks developed under the NAFO Precautionary Approach Working Group (PA-WG) were tested on the following three NAFO stocks: Div. 3M Cod, Div. 3LNO Yellowtail flounder and Div. 3M Redfish. On the current study the testing of these alternative frameworks on Div. 3M Redfish is presented. In order to estimate the biological reference points (BRPs) for this stock, mainly the ones in relation to total biomass (4+) and several methods were applied: EQSIM; FLBRP; knobi and SPiCT. Taking into account the results from the different methods and the absence of a SSB-recruitment relationship well defined for this stock, the decision was to use on the current test the BRPs from the knobi (production model) and assume *Flim=F0.1* taken the value of 0.067 estimated from the results of the last XSA approved assessment model (2021). The alternative advice produced from the different three options of the PA framework were the same and resulted in a lower TAC advice, when compared with the original TAC advice released for this stock in 2021. This application exercise allowed to identify some of the limitations of PA framework in its current version. In the future, some improvements are expected to be included in order to allow the NAFO PA framework to be used as an important management tool for all the exploited stocks on the Northwest Atlantic.

Introduction

NAFO Precautionary Approach Working Group (PA-WG) agreed to develop three alternative frameworks based on the conclusions of the NAFO Joint Commission and Scientific Council Precautionary Approach Framework Workshop (NAFO, 2023) and apply the three different framework options to a selection of NAFO stocks to produce the alternative advice to be presented at the July 2023 WG-RBMS meeting (NAFO, 2022):

Option 1: With an intermediate biomass reference point (Bbuffer) defined in order to avoid approaching Blim.

Option 2: With an intermediate biomass reference point (Btrigger) defined based on not moving away from the target biomass.

Option 3: With two intermediate reference points. With a Bbuffer with a low probability that the biomass will be less than Blim and with a Btrigger similar to option 2.

The three NAFO stocks chosen were the following: Cod Div. 3M, Yellowtail flounder Div. 3LNO (Garrido et al., 2023) and Redfish Div. 3M.

On this document are presented the several exploratory analyses performed to estimate the biological reference points (BRPs) of the Div. 3M redfish stock and the corresponding estimated BRPs. Furthermore, the three alternative NAFO PA frameworks were applied based on the estimated BRPs and the alternative advice for the Div. 3M redfish stock was presented.

Material and Methods

Div. 3M Redfish input data. The data used for estimating the Div. 3M redfish stock BRPs is the same used as input data for the 2021 stock assessment model (Alpoim et al., 2021). The data is from 1989 to 2020, structured for the age groups 4 to 19+. In Figure 1 is represented the data in @FLSTOCK object R-file format that was used on the current work.

The recruitment estimate (in millions), the spawning stock biomass (tonnes), the catches (tonnes) and the fishing mortality for the ages 4 to 19+ for the whole period (1989 until 2020) are shown in Figure 2.

On the current study four methods implemented in the following R-packages have been explored: EQSIM (R-libraries: FLCore and msy); FLR class for biological reference points (R-libraries: FLBRP); Known Biomass Production Model (KBPM) fit (R-library: knobi); and the Stochastic Surplus Production Model in Continuous Time (R-library: SPiCT). The two methods used to estimate the biological reference points based on the stock-recruitment relation (EQSIM and FLBRP) use as input the spawning stock biomass. The production models applied (knobi and SPiCT) use as input the total biomass.

EQSIM. Eqsim is a stochastic equilibrium software that may be used to explore MSY reference points (Simmonds et al. 2019). Productivity parameters (i.e. year vectors for natural mortality, weights-at-age and maturities) as well as selection are re-sampled at random from user specified range of years from the assessment. Fixing these parameters to an average over specified years can also be set by the user. Recruitments are re-sampled from their predictive distribution. Uncertainty in the stock-recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland et al. 1997). In addition, assessment errors can be emulated by applying a user-specified error (CV and autocorrelation) to the intended target fishing mortality.

The eqsim approach consists of three components: [1] Estimate the stock recruitment relationship; [2] Simulate a stock to equilibrium and continue simulating for some years; and [3] Calculate reference points from the simulated stock at equilibrium (usually the last 30 years of the runs are used).

FLR class for biological reference points. FLBRP R-package is an R-tool (Kell and Scott, 2021) which was used to calculate the set of reference points, based on an estimate of stock status from the last stock assessment (2021) to produce the FLStock object (see Figure 1).

Known Biomass Production Model (KBPM). knobi R-package is an R-tool used to compute a surplus production models named as known-biomass production models (KBPM) (Paz et al. 2023).

The surplus production curve is fitted using the observed catch time series and the total biomass or the spawning stock biomass (SSB) estimates derived from the fit of a data-rich stock assessment model. The surplus production models (SPMs) framework and then based on this background the KBPM formulation is described.

However, traditional SPMs are one of the most widely used data-limited (or data moderated) assessment models (MacCall, 2002). Their general structure relates directly to Russell's formulation of the stock dynamics (Russel, 1931):

$$B_{t+1} = B_t + f(B_t) - C_t \qquad (1)$$

where *Bt* is the stock biomass at the beginning of year *t*, *Ct* is the biomass caught during year *t* and *f(Bt)* is the biomass production function.

There are many formulations of the biomass production function *f(Bt)*, among which the general Pella-Tomlinson (1969) is widely used:

$$f(B_t) = \frac{r}{p} B_t \left(1 - \left(\frac{B_t}{K}\right)^p\right) \qquad (2)$$

where *r* is the intrinsic population growth rate, *K* is the virgin biomass and *p* is the asymmetry parameter, which allows non-symmetrical production curves and, consequently, maximum production different from *K/2*.

SPMs link the population dynamics (equation 1) with the observations through the relation between the catch and the stock biomass across the catchability coefficient (q).

$$\hat{I}_t = \frac{C_t}{E_t} = qB_t \qquad (3)$$

where *It* is the value of the relative biomass index for year *t*, notation ˆ denotes an estimated value and q is the catchability coefficient, which scales the modeled stock biomass to match the trends in catch rates.

An alternative line of research based on surplus production models named known-biomass production models (KBPM) was developed (Paz et al. 2023). The basis of the KBPM model is the idea that the annual surplus production in an unfished stock is equal to *Bt+1-Bt*, and on a fished stock, the calculation of surplus production is totally depending on the catch data available.

$$SP_t = \bar{B}_{t+1} - \bar{B}_t + C_t \qquad (4)$$

where *SPt* is the surplus production during year t, $\bar{B}t$ is the average biomass or *SSB*, $\bar{B}t=(Bt+Bt+1)/2$, $\bar{B}t+1=(Bt+1+Bt+2)/2$ and *Ct* represents the catch during year *t*.

In contrast to the traditional SPMs, KBPMs use as input data a biomass time series, estimated using another stock assessment model, instead of a biomass index.

Once, the surplus production is calculated using the known average biomass (of two consecutive years) and the observed catch on equation (4), the KBPMs are fitted as:

$$SP_t = \frac{r}{p} \bar{B}_t \left(1 - \left(\frac{\bar{B}_t}{K}\right)^p\right) \qquad (5)$$

Schaefer (1954) model corresponds to *p=1* (symmetric production curve and *SPmax=K/2*).

Stochastic Surplus Production Model in Continuous Time. SPiCT R-package fits a type of stochastic surplus production model in continuous time (Pedersen and Berg, 2017).

Results and Discussion

EQSIM. The initial setup definitions for the EQSIM model fit: stock-recruitment model assumed was the Ricker model (Ricker, 1975), number of simulations 1000, for the regime shift parameter 1 was assumed, for the time series period considered two setups have been tested: (a) using the whole data series for the stock, from 1989 to 2020 and (b) removing the period from 1989 until 1996. The option of testing two different time periods was to compare the results on the biological reference points by applying the whole data analysis, with the period after 1997 when a regime shift on the production pattern of the stock was observed. There is a clear difference in the stock trends on the periods before versus after 1997 (Figure 2).

Stock recruitment model adjusted to the Div. 3M redfish stock data for the selected periods: 1989 – 2020 and 1997 – 2020 is shown in Figure 3. The reference points values estimated from the EQSIM fit are shown in Table 1. The $F_{0.05}$ estimated was 0.11 (1989-2020) and 0.149 (1997-2020); F_{MSY} was estimated as 0.239 (1989-2020) and 0.184 (1997-2020) (Table 1 and Figure 4) based on the mean landings. Based on the median landings: F_{MSY} was estimated as 0.209 (1989-2020) and 0.34 (1997-2020) (Figure 5). The B_{MSY} ranged from 28061 to 14799 (1989 – 2020) and from 24752 and 13096 (1997-2020) (Figure 6 and Figure 7).

FLRBRP. The initial setups defined for the FLRBP model fit were the following: stock-recruitment model assumed was the Ricker model for the whole stock time series, from 1989 to 2020.

Stock recruitment model adjusted to the Div. 3M redfish stock data and the respective residuals, for the whole time series (1989 – 2020), is shown in Figure 8. The SSB-Recruits plot show that the highest values of recruits in the case of this stock were produced when the stock was at low levels of SSB. Estimated reference points from the model fit (FLRBRP fit results) are in Table 2.

knobi. The initial setup definitions for the knobi model fit of the surplus production model uses the Schaefer approximation model (Schaefer, 1954) for the whole data series from 1989 to 2020. The F trajectory, the average biomass, catch data and the surplus production by year is represented in Figure 9. Figure 10 represents the trajectories of Catch over fishing mortality (F), F over the average Biomass ($\bar{B}$) and Catch over the average Biomass, on those figures some extreme values, represented outside the boundaries of the confidence intervals (grey lines), are visible specifically on average B across F and Catch.

The surplus production curve represented in function of the Biomass, in Figure 11, shows that on the initial time series period and on the most recent year higher biomass values has been observed. The catches were also higher at the beginning of the time series (Figure 12).

The estimated reference points from knobi are presented on Table 3.

The relative fishing mortality over the years is represented on Figures 13 and 14, since 1997 the F is at a lower level than the $FMSY$ estimated by the knobi model. Since 2005, the Biomass is above the $BMSY$ (Figures 15 e 16).

SPiCT. The initial setup definitions for the SPiCT model fit of the surplus production model uses the Schaefer approximation model for the whole data series from 1989 to 2020 (Figure 17).

Model diagnostics are shown in Figure 18. The residual diagnostics of the model were appropriate. The One Step Ahead (OSA) residuals were not significant different from zero and therefore not biased (above figure row). Testing of multiple lags (here 4) show no significant autocorrelation of the residuals (ACF). The residuals were normal distributed. Only the Shapiro p-value from the catch data indicates some concerns on the results of the model, which reflect the higher catches observed at the beginning of the time-series for this stock.

In figure 19 and table 4 the production curve, estimated biomass and fishing mortality are presented. The uncertainty around the absolute and the relative fishing mortality are high.

Retrospective plots of fishing mortality and fishable biomass of five years show high consistency (Figure 20) but huge confidence limits. The Mohn's rho estimated values of -0.068 and 0.172, which give indication of a good retrospective pattern.

Models comparison. On table 5 the estimated target reference points by the different model approaches is presented.

Biological Reference Points. Based on the results from the current study, to apply the PA alternative framework, the BRPs estimated from the knobi model (*FMSY* and *BMSY*) will be used and *Flim* will be assumed as *F0.1*, given by the value estimated in 2021 by the last approved assessment for this stock. On the next table, the values used to apply the NAFO PA alternative framework for Div. 3M redfish stock for the 3 different options, are presented.

Reference Points	**Option 1**	**Option 2**	**Option 3**
Flim= F0.1	0.067	0.067	0.067
Ftarget=0.75* *Flim*	0.050	0.050	0.050
Blim =0.3* *BMSY*	33768	33768	33
Bbuffer=2* *Blim*	67536		
Btrigger =0.8* *BMSY*		90049	90049
Bbuf2 =(*Blim* + *Btrig*)/2			61909
BMSY[1]			112561

FMSY =0.128 [1]
[1] based on knobi outputs.

The trajectory of total biomass (4+) and fishing mortality from the Div. 3M redfish stock assessment time-series is projected on Figure 21. The different options of the PA alternative framework are represented in Figure 22 (Option 1), Figure 23 (Option 2) and Figure 24 (Option 3). In the three options the last assessment falls down in the safe zone.

On the case of the safe zone, the PA management strategies actions proposed for the different options regarding the quality management or the harvest control rule (HCR) are the same as presented above.

Option	**PA Zone**	**Quality management actions**	**HCR**
Option 1	**Safe (*B*>*Bbuffer* and *F*< *Ftarget*)**	*F* equal or below *Ftarget*.	*F* equal or below *Ftarget*.
Option 2	**Safe (*B*>*Btrigger* and *F*< *Ftarget*)**		
Option 3	**Safe (*B*>*Btrigger* and *F*< *Ftarget*)**		

The figures (Figure 21, 22, 23 and 24) show that since 2007 high values of the explored biomass (4+) were observed, in some particular years (2007, 2011, 2012 and 2018) with an *F* above *Flim*, which may indicate that the *Flim* assumed as *F0.1* for this stock is too low, because puts the stock on the overfished zone. In the future, on the revision of the PA, *Flim* should be set as *FMSY* and be set as *Ftarget* as *F0.1*.

Conclusions

The advice based on these PA alternative frameworks is provided for the Div. 3M redfish. The total allowable catches (TAC 2022 and TAC 2023) from the original advice (NAFO, 2021) and from the PA alternative frameworks advice are presented in the next summary table:

	Management Strategies	**F**	**TAC 2022**	**TAC 2023**
Original advice	-	0.067	10.9	11.2
PA Option 1, 2 and 3 advice	**Quality management actions and HCR**	0.050	8.3	8.8

The TAC was estimated assuming the average beaked redfish proportion in the 2019-2021 Div. 3M redfish catch as 0.979, following the same approach as the original advice.

On the current exercise performed on the Div. 3M redfish, the application of the PA alternative frameworks resulted on a lower TAC.

The *Flim* in the exercise as takes the same value as *F0.1*, based on an annual estimation from the 3M beaked redfish XSA assessment model, in this sense this value shouldn't be interpreted as an insurmountable point in terms of stock management. The *Flim/F0.1* from the XSA is used for the short term forecast projections and to evaluate different catch options for advice. In the future, *Flim/F0.1* must be determined based also on the application of a stock production model.

Regarding the biological reference points for the biomass, mainly the two proposed for testing in option 3, *Btrigger* and *Bbuf2*, some caveats should be considered, particular on their application to this stock.

The current exercise was performed to evaluate the applicability, of the three different PA alternative frameworks, in a concrete case study for a stock without a SSB-recruitment relation and no formal approved biological reference points for biomass. This exercise allowed to identify some of the limitations of PA framework in its current version. In the future, some improvements are expected to be included, in order to allow NAFO PA framework to be used as an important management tool for all the exploited stocks on the Northwest Atlantic.

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Tables

Table 1. Reference points values estimated for the Redfish Div. 3M by EQSIM.

	F0.05	F0.10	F0.50	medianMSY	meanMSY	FCrash05	FCrash50	Period
F	0.110	0.149	0.297	0.239	0.239	0.367	0.533	1989-2020
catch	10411	12024	11399	12734	12734	8162	549	1989-2020
B	36389	29367	11998	17661	17661	6525	268	1989-2020
F	0.149	0.221	0.441	0.386	0.184	0.588	0.827	1997-2020
catch	15284	18730	19401	20653	17109	12716	930	1997-2020
B	37694	28513	12001	15245	32887	5363	242	1997-2020

Table 2. Reference points values estimated for the Redfish Div. 3M by FLRBRP.

harvest	yield	rec	ssb	biomass	revenue	Model S-R	Period
virgin	0.000	0	39800	62800	143000	Ricker	1989-2020
msy	0.203	13300	83600	20700	93900	Ricker	1989-2020
crash	0.372	0	0	0	0	Ricker	1989-2020
F0.1	0.089	9410	70800	38700	125000	Ricker	1989-2020
Fmax	0.370	408	2480	249	1840	Ricker	1989-2020
spr.30	0.107	10500	74800	35400	121000	Ricker	1989-2020

Table 3. Reference points values estimated for the Redfish Div. 3M by knobi.

RBP	Value	Period	Model
r	0.2574	1989-2020	Schaefer
k	225122	1989-2020	Schaefer
Bmsy	112561	1989-2020	Schaefer
Fmsy	0.128	1989-2020	Schaefer
MSY	14487	1989-2020	Schaefer
Msyoverk	0.064	1989-2020	Schaefer

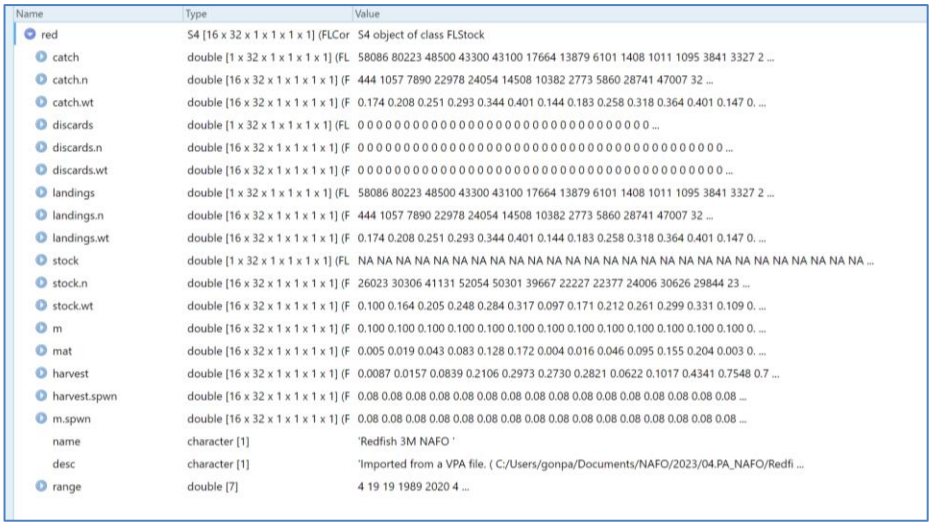
Table 4. Results from the SPiCT model adjusted to the Redfish Div. 3M.

Model	parameter	estimates	w	95%	CI	
	estimate	cilow	ciupp	log.est		
	alpha	0.648	0.249	1.685	-0.43	
	beta	0.161	0.029	0.903	-1.83	
	r	0.235	0.059	0.934	-1.45	
	rc	1.034	0.049	21.975	0.03	
	rold	0.432	0.043	4.328	-0.84	
	m	185922	1836	18831370	12.13	
	K	1525372	8872	262265200	14.24	
	q	0.503	0.003	95.625	-0.69	
	n	0.455	0.037	5.576	-0.79	
	sdb	0.365	0.231	0.579	-1.01	
	sdf	0.536	0.392	0.732	-0.62	
	sdi	0.237	0.125	0.448	-1.44	
	sdc	0.086	0.017	0.447	-2.45	
Deterministic	reference	points	(Drp)			
	estimate	cilow	ciupp	log.est		
	Bmsyd	359776	1196.702	108162900	12.793	
	Fmsyd	0.52	0.024306	11	-0.660	
	MSYd	185922	1835.614	18831370	12.133	
Stochastic	reference	points	(Srp)			
	estimate	cilow	ciupp	log.est	rel.diff.Drp	
	Bmsys	334376	1257.685	88899290	12.720	-0.076
	Fmsys	0.53	0.027	11	-0.630	0.030
	MSYs	178547	1754.112	18173840	12.093	-0.041
States	w	95%	CI	(inp$msytype:s)		
	estimate	cilow	ciupp	log.est		
	B_2020.94	948521	5072	177367700	13.763	
	F_2020.94	0.01	0.00	1.65	-4.749	
	B_2020.94/Bms	2.84	0.48	16.70	1.043	
	F_2020.94/Fmsy	0.02	0.00	2.96	-4.119	
Predictions	w	95%	CI	(inp$msytype:s)		
	prediction	cilow	ciupp	log.est		
	B_2022.00	994914	5329	185741500	13.810	
	F_2022.00	0.009	0.00	1.84	-4.749	
	B_2022.00/Bms	2.975	0.49	17.96	1.090	
	F_2022.00/Fmsy	0.016	0.00	3.31	-4.119	
	Catch_2021.00	8426	3104	22870	9.039	
	E(B_inf)	1291306	NA	NA	14.071	

Table 5. Redfish Div. 3M: Summary of the estimated target biological reference points by the different models and from the following stock assessment approved models: 2017, 2019 and 2021 (Ávila de Melo et al. 2017; Ávila de Melo et al. 2019; Alpoim et al. 2021).

BRPs	EQSIM (1989 – 2021)	FLRBRP	knobi	SPiCT	2021 assessment	2019 assessment	2017 assessment
$F_{0.05}$	0.11		0.064	0.068			
$F_{0.1}$	0.149	0.0889	0.1158	0.1222	0.0669	0.0911	0.086
F_{MSY}	0.239	0.203	0.1287	0.1359			
F_{max}	0.34	0.37			0.2997	0.1883	0.163
$B(F_{0.05})$	36389						
$B(F_{0.1})$	29367	38700					
B(Fspr.30)		35400					
$B(F_{MSY})$	17660	20700					
B_{MSY}		83600	112561				
MSY			14487				

Figures



Name	Type	Value
red	S4 [16 x 32 x 1 x 1 x 1 x 1] (FLCor	S4 object of class FLStock
catch	double [1 x 32 x 1 x 1 x 1 x 1] (FL	58086 80223 48500 43300 43100 17664 13879 6101 1408 1011 1095 3841 3327 2 ...
catch.n	double [16 x 32 x 1 x 1 x 1 x 1] (F	444 1057 7890 22978 24054 14508 10382 2773 5860 28741 47007 32 ...
catch.wt	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.174 0.208 0.251 0.293 0.344 0.401 0.144 0.183 0.258 0.318 0.364 0.401 0.147 0. ...
discards	double [1 x 32 x 1 x 1 x 1 x 1] (FL	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 ...
discards.n	double [16 x 32 x 1 x 1 x 1 x 1] (F	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 ...
discards.wt	double [16 x 32 x 1 x 1 x 1 x 1] (F	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 ...
landings	double [1 x 32 x 1 x 1 x 1 x 1] (FL	58086 80223 48500 43300 43100 17664 13879 6101 1408 1011 1095 3841 3327 2 ...
landings.n	double [16 x 32 x 1 x 1 x 1 x 1] (F	444 1057 7890 22978 24054 14508 10382 2773 5860 28741 47007 32 ...
landings.wt	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.174 0.208 0.251 0.293 0.344 0.401 0.144 0.183 0.258 0.318 0.364 0.401 0.147 0. ...
stock	double [1 x 32 x 1 x 1 x 1 x 1] (FL	NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA ...
stock.n	double [16 x 32 x 1 x 1 x 1 x 1] (F	26023 30306 41131 52054 50301 39667 22227 22377 24006 30626 29844 23 ...
stock.wt	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.100 0.164 0.205 0.248 0.284 0.317 0.097 0.171 0.212 0.261 0.299 0.331 0.109 0. ...
m	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.100 0.100 0.100 0.100 0.100 0.100 0.100 0.100 0.100 0.100 0.100 0.100 0.100 0. ...
mat	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.005 0.019 0.043 0.083 0.128 0.172 0.004 0.016 0.046 0.095 0.155 0.204 0.003 0. ...
harvest	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.0087 0.0157 0.0839 0.2106 0.2973 0.2730 0.2821 0.0622 0.1017 0.4341 0.7548 0.7 ...
harvest.spwn	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 ...
m.spwn	double [16 x 32 x 1 x 1 x 1 x 1] (F	0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 0.08 ...
name	character [1]	'Redfish 3M NAFO '
desc	character [1]	'Imported from a VPA file. (C:/Users/gonpa/Documents/NAFO/2023/04.PA_NAFO/Redfi ...
range	double [7]	4 19 19 1989 2020 4 ...

Figure 1. Redfish in Div. 3M: view of the @FLSTOCK object input R-file with the data used as input to determine the BRPs.

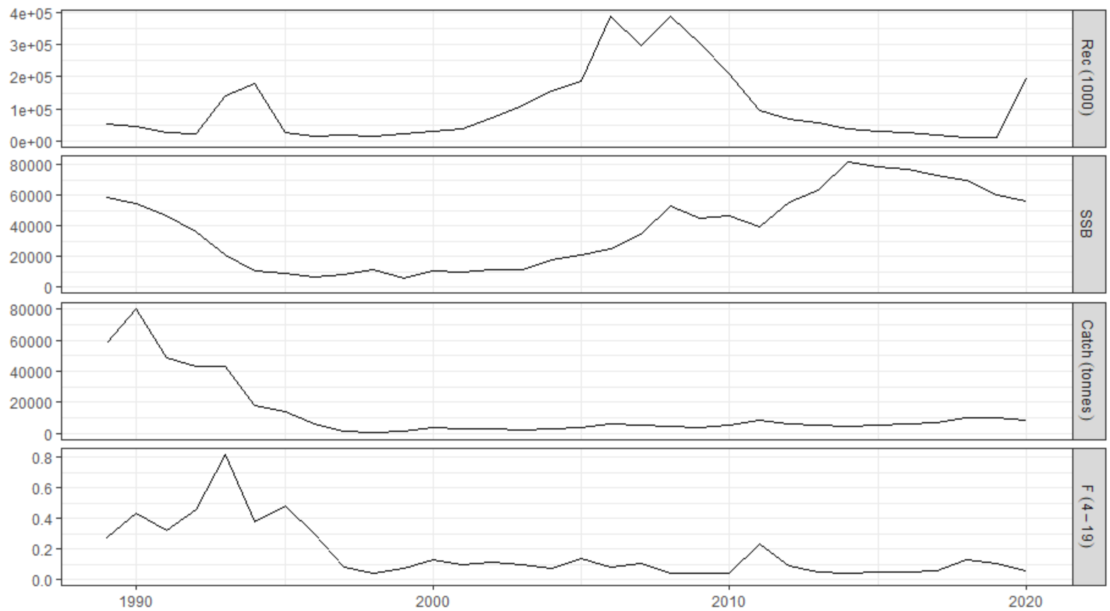


Figure 2. Redfish in Div. 3M: recruitment (millions), SSB, catch (tonnes) and F (4-19) from 1989 until 2020.

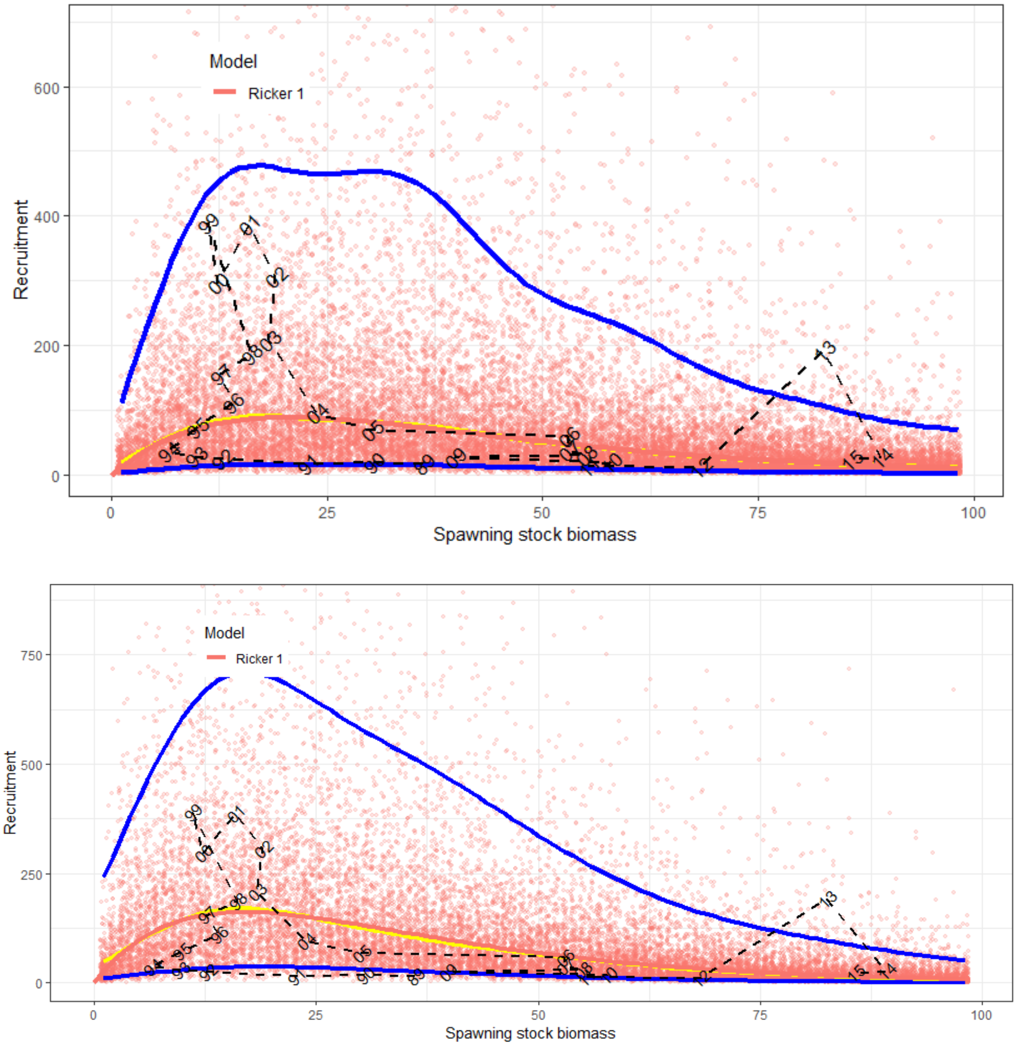


Figure 3. Redfish in Div. 3M: Stock recruitment model adjusted to the redfish 3M stock data for the selected periods: 1989 – 2020 (upper plot) and 1997 – 2020 (bottom plot).

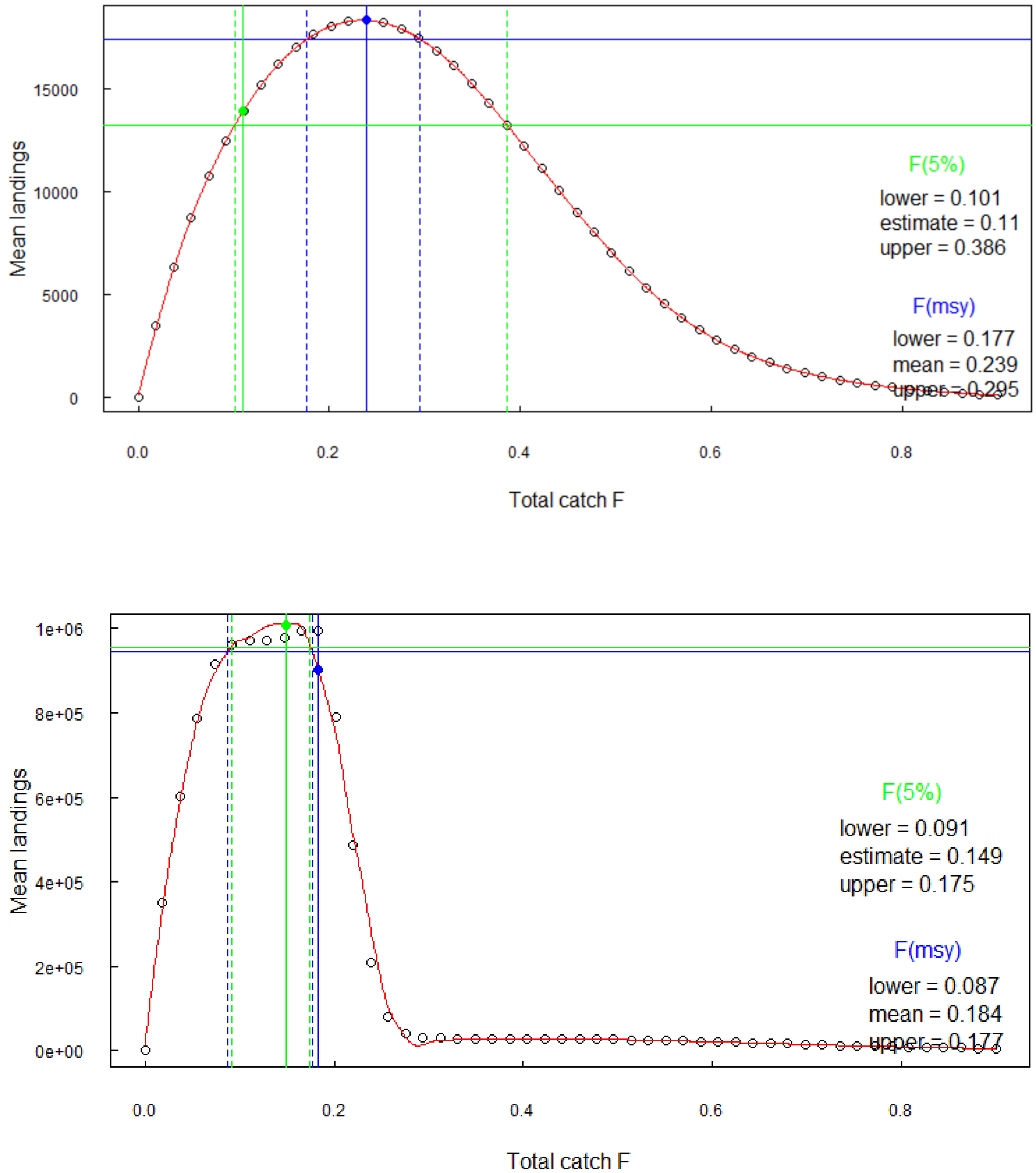


Figure 4. Redfish in Div. 3M: Mean landings. $F_{0.05}$ and F_{MSY} biological reference points estimates (lower, estimate and upper) by EQSIM, for the selected periods: 1989 – 2020 (upper plot) and 1997 – 2020 (bottom plot).

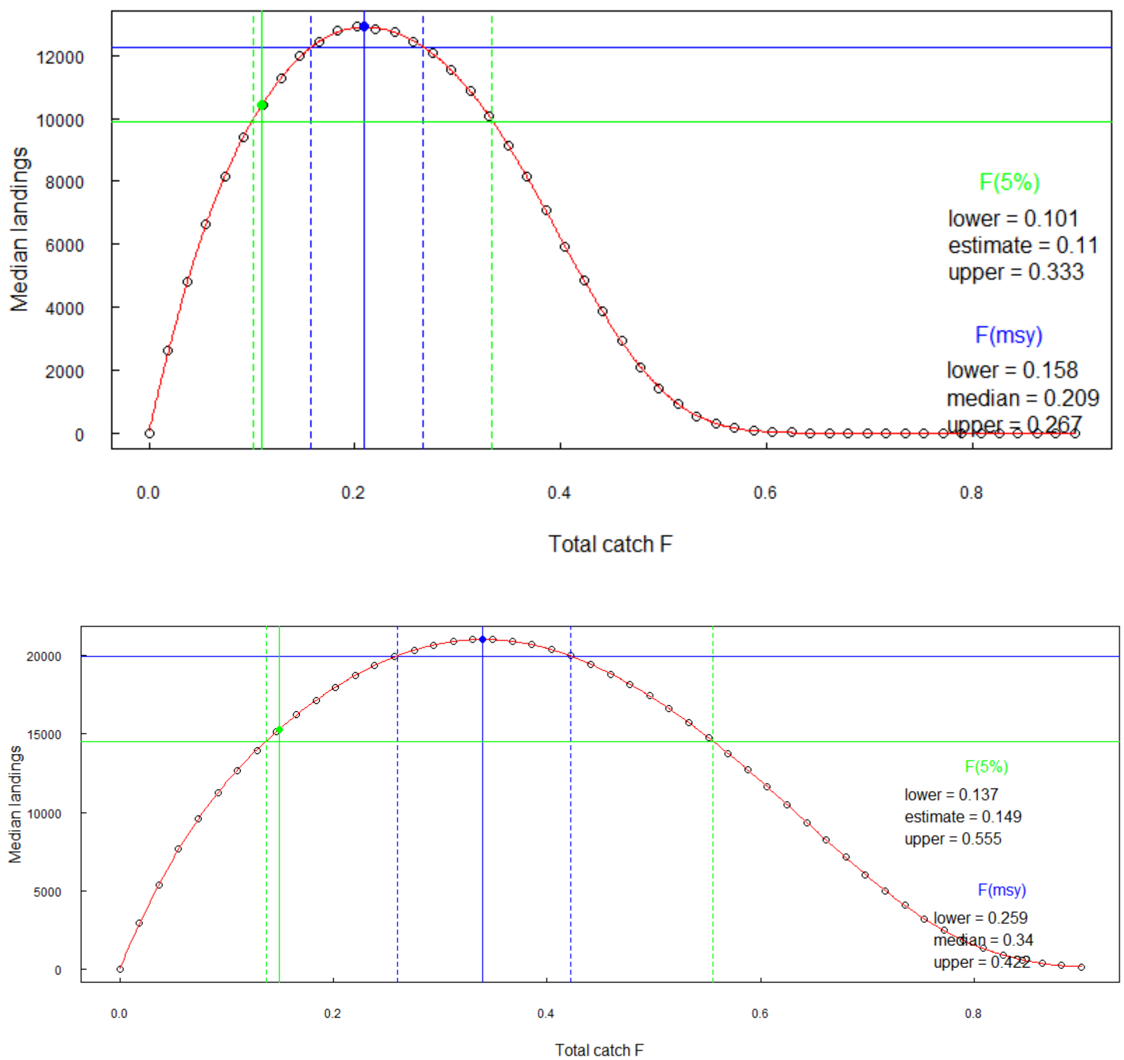
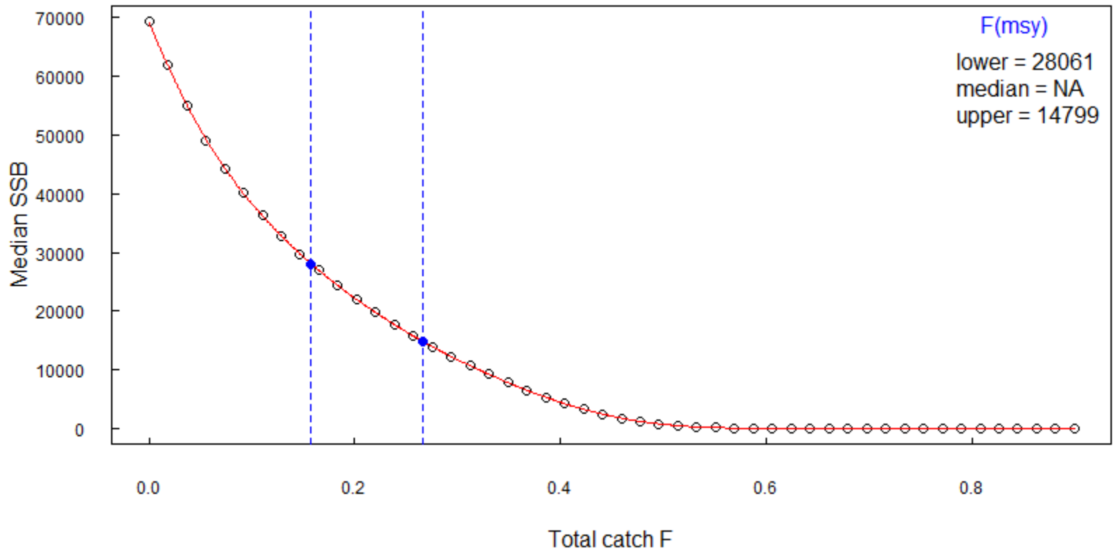


Figure 5. Redfish in Div. 3M: Median landings. $F_{0.05}$ and F_{MSY} biological reference points estimates (lower, estimate and upper) by EQSIM, for the selected periods: 1989 – 2020 (upper plot) and 1997 – 2020 (bottom plot).



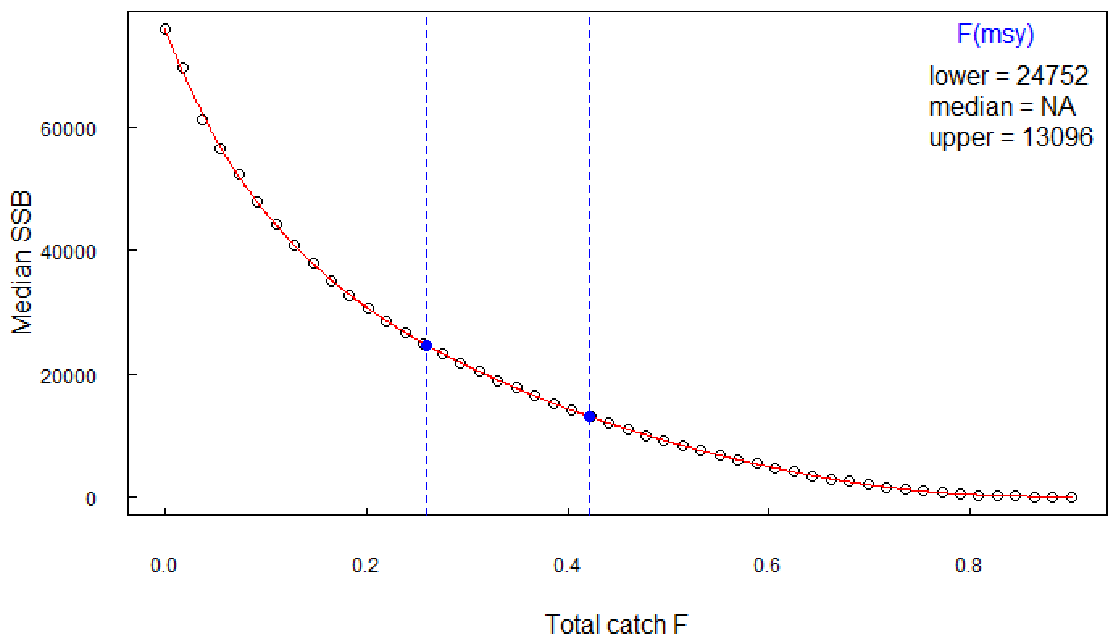


Figure 6. Redfish in Div. 3M: Median SSB. B_{MSY} biological reference points estimates (lower and upper) by EQSIM, for the selected periods: 1989 – 2020 (upper plot) and 1997 – 2020 (bottom plot).

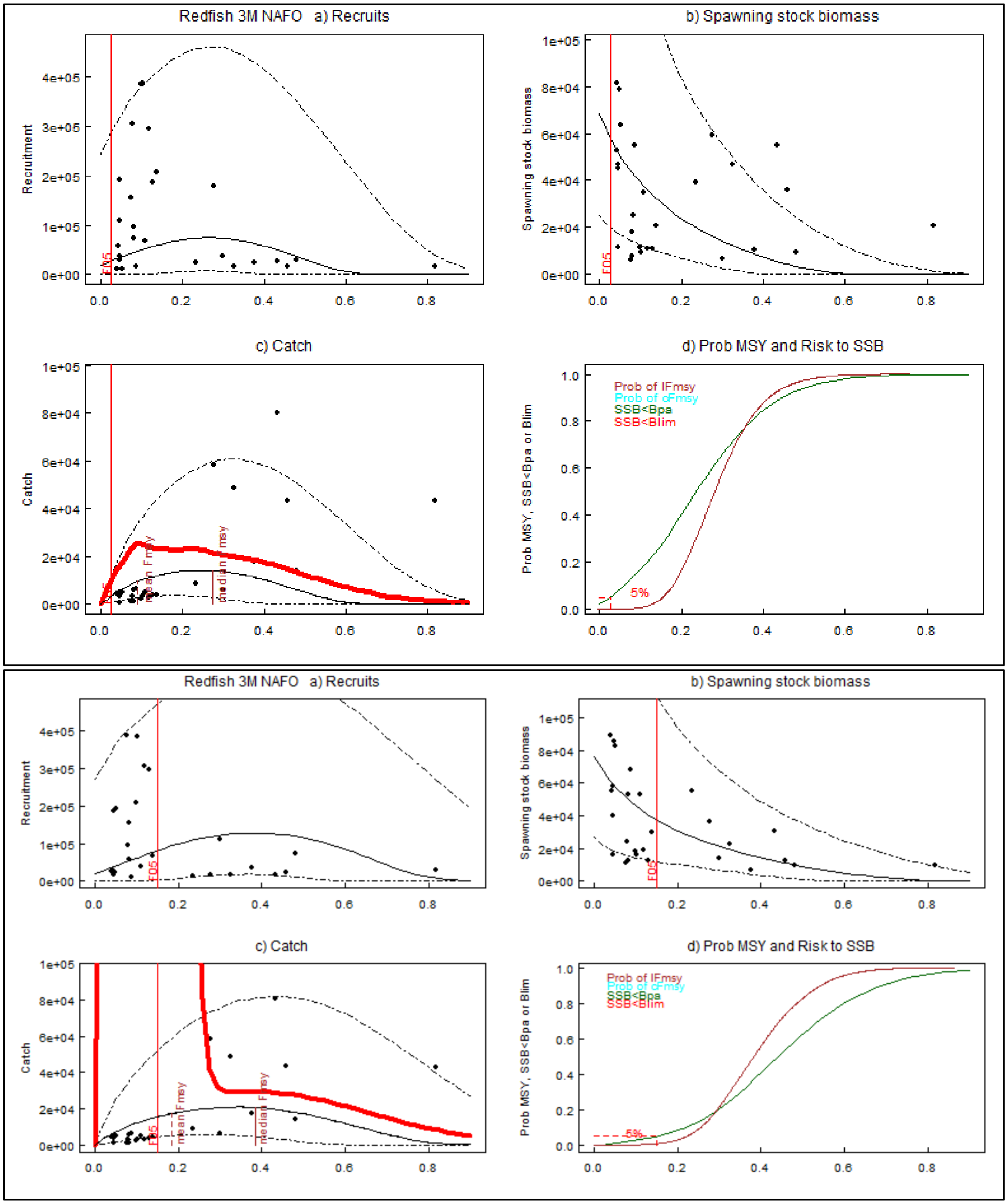


Figure 7. Redfish in Div. 3M: results of the biological reference points estimates for the selected periods: 1989 – 2020 (upper plot) and 1997 – 2020 (bottom plot) across a) Recruits, b) Spawning Stock biomass, c) Catch and d) Probability MSY and Risk to SSB.

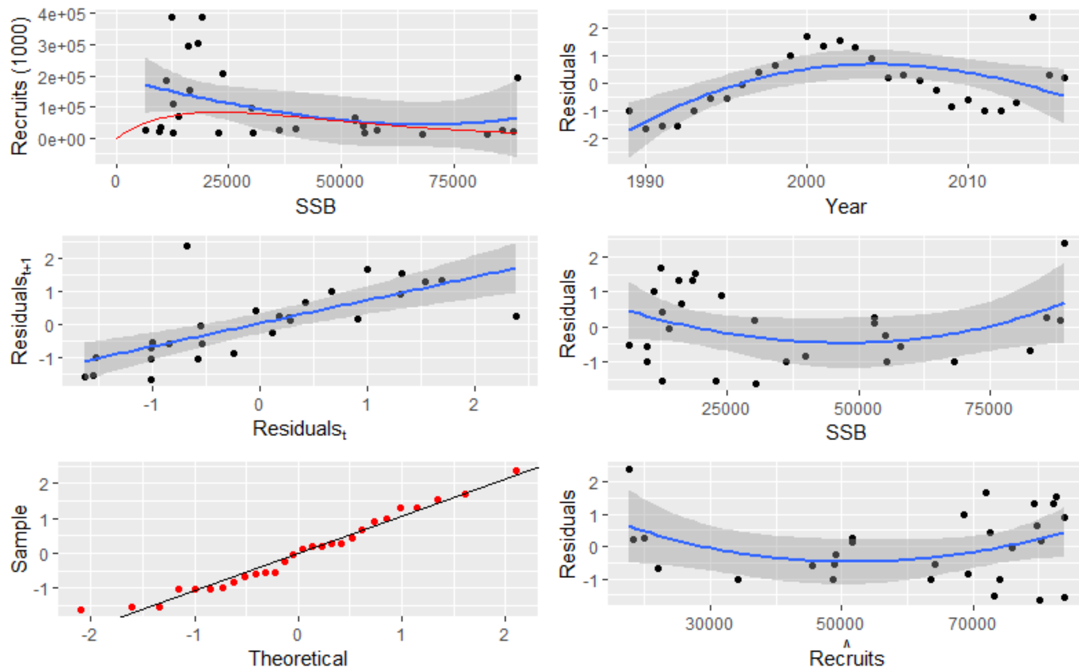


Figure 8. Redfish in Div. 3M: Ricker stock-recruitment model adjustment for the period from 1989 until 2020, with the residuals for SSB and Recruits data adjustment by applying FLRBRP.

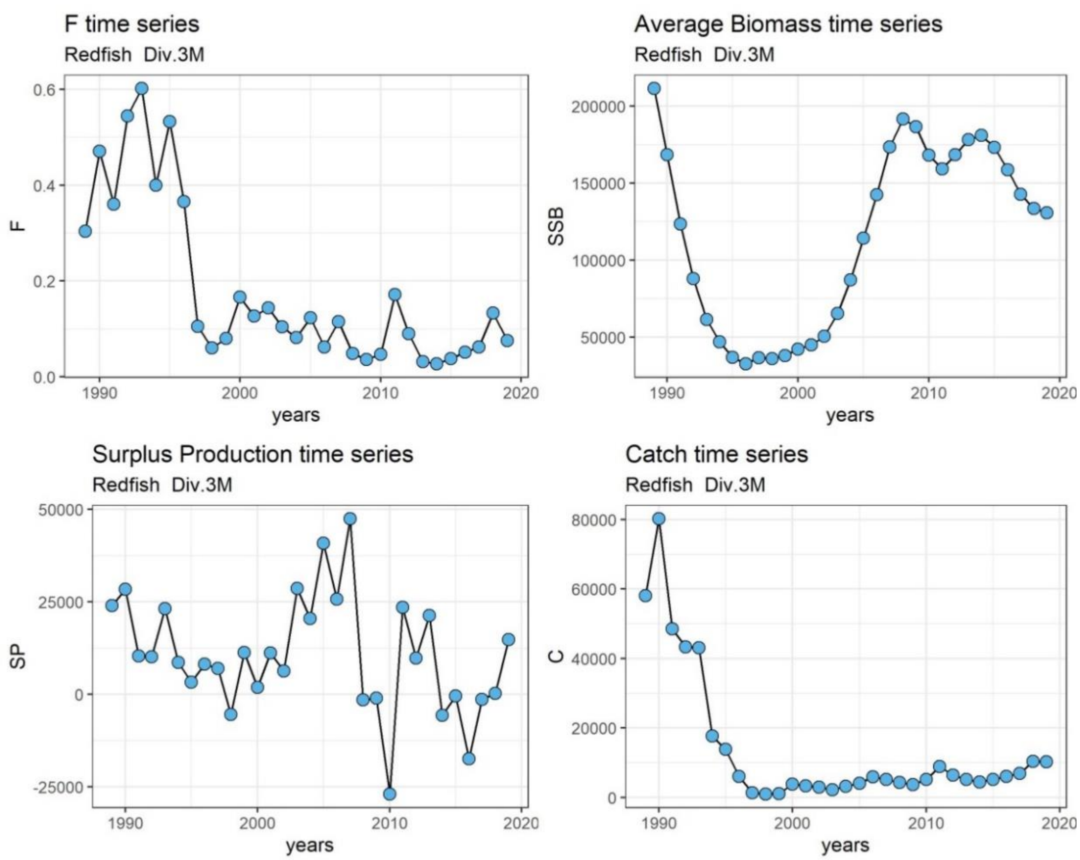


Figure 9. Redfish in Div. 3M: input data used to apply the knobi software.

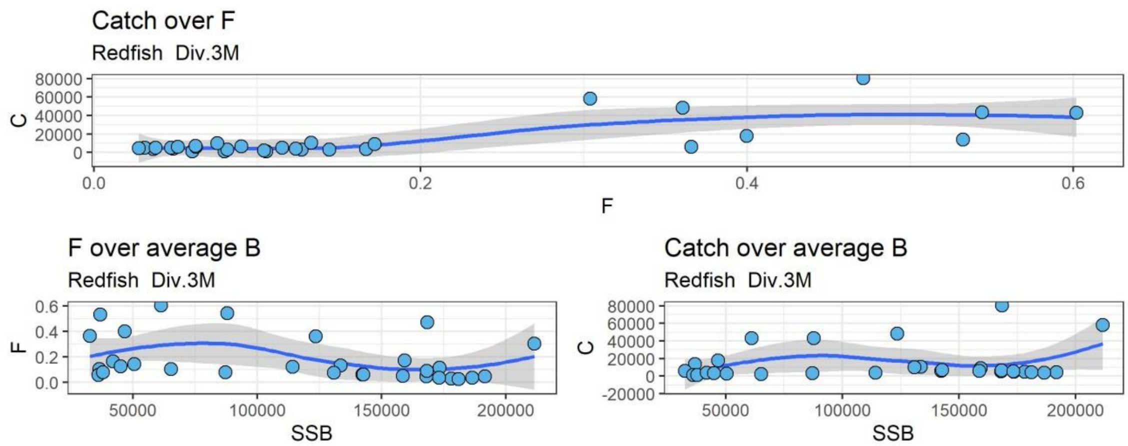


Figure 10. Redfish in Div. 3M: estimations of catch over F, F over average Biomass and catch over average Biomass (knobi R-package).

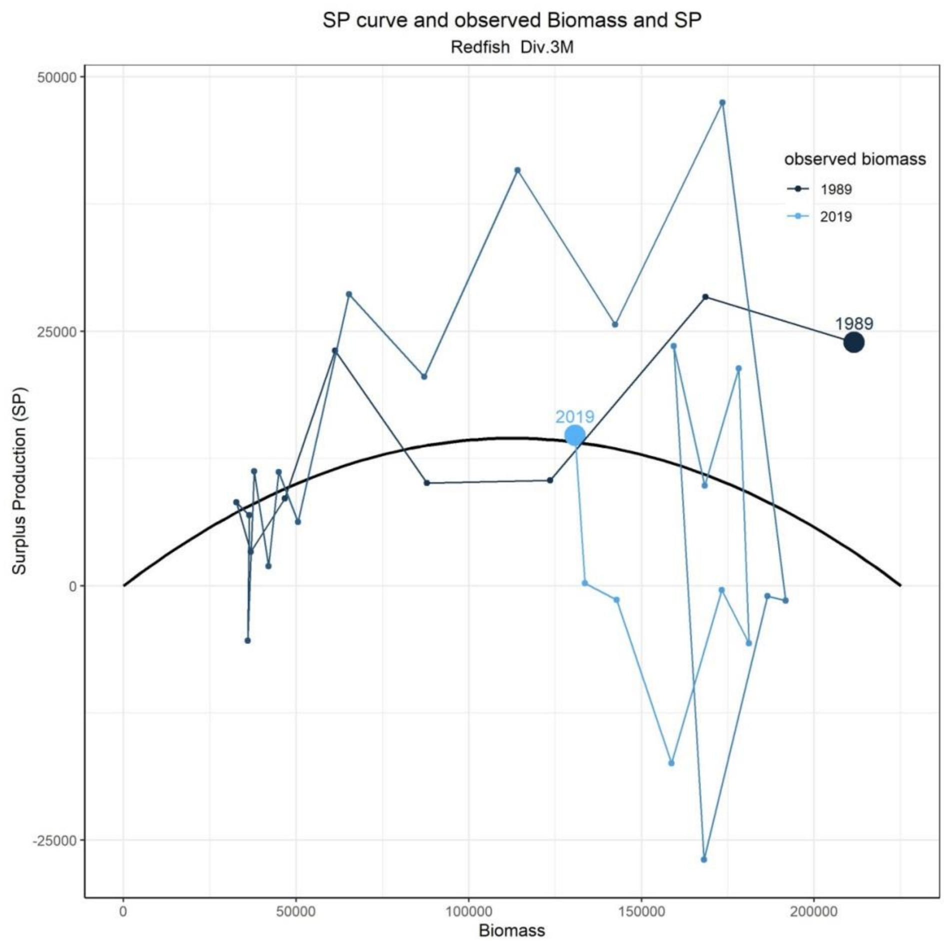


Figure 11. Redfish in Div. 3M: Surplus production curve and the observed biomass (knobi R-package).

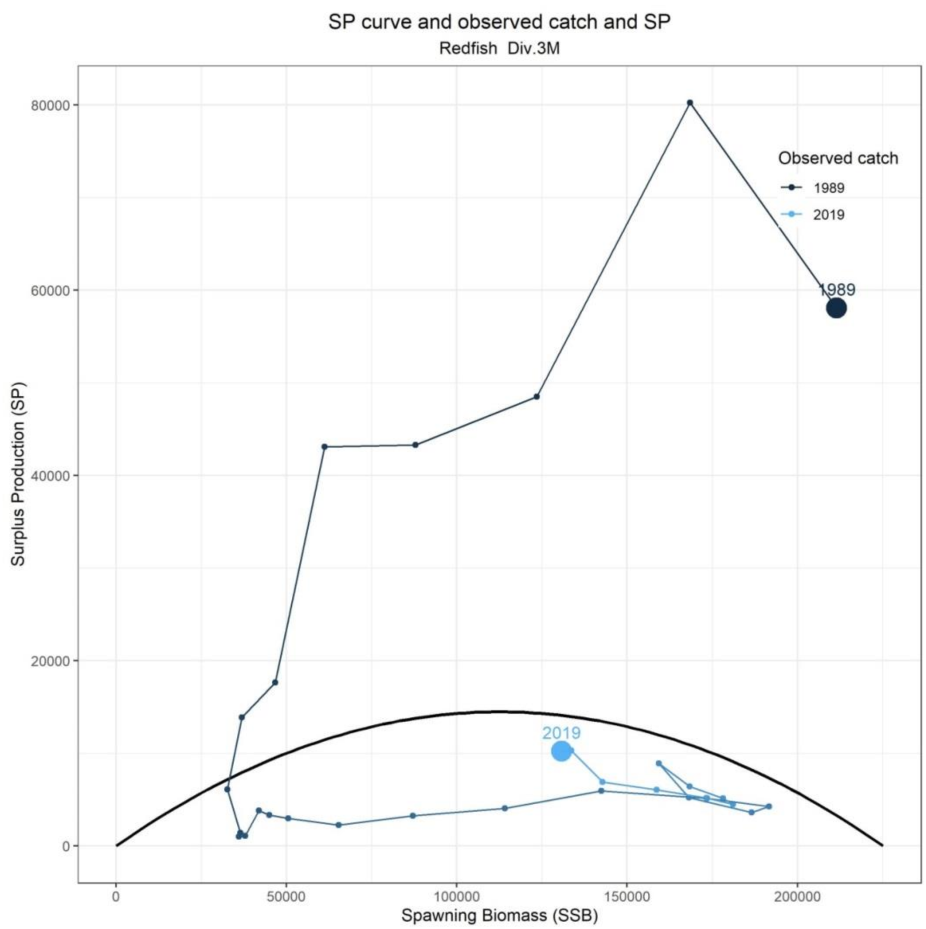


Figure 12. Redfish in Div. 3M: Surplus production curve and the observed catch (knobi R-package).

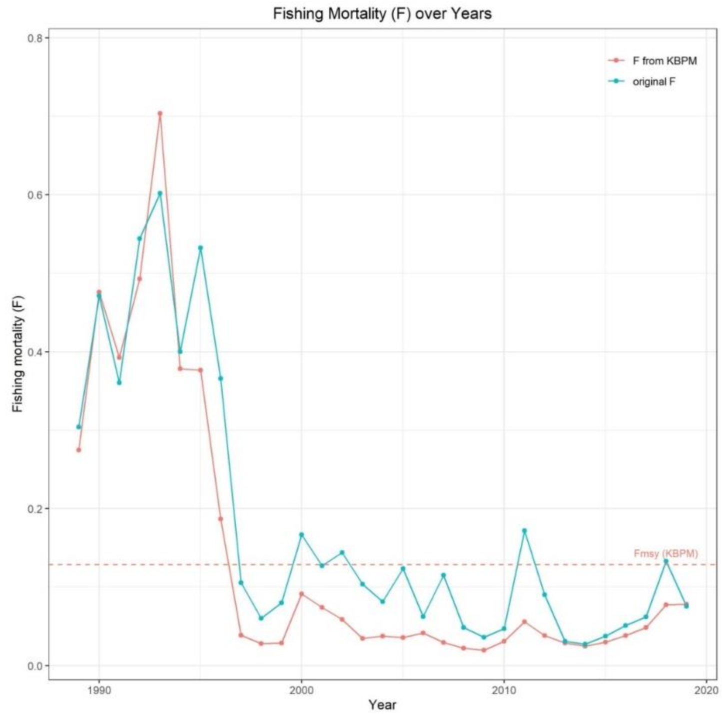


Figure 13. Redfish in Div. 3M: F observed (blue) versus F estimated based by the known-biomass production model for the period 1989-2019 (knobi R-package).

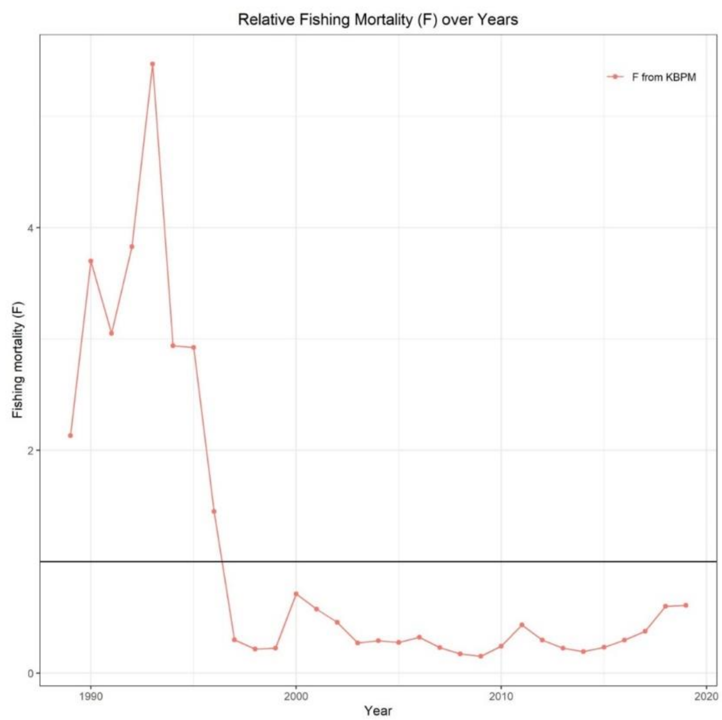


Figure 14. Redfish in Div. 3M: relative F from the known-biomass production model estimated for the period 1989-2019 (knobi R-package).

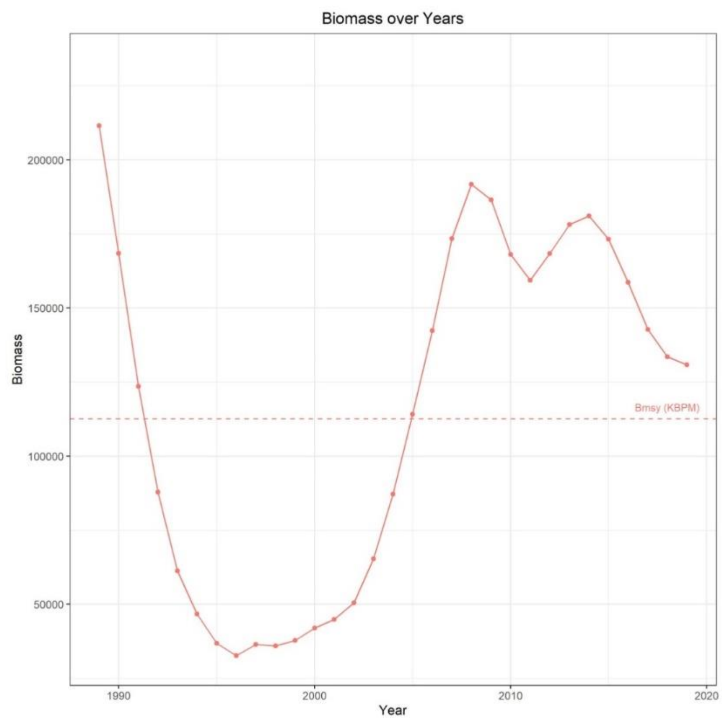


Figure 15. Redfish in Div. 3M: Biomass estimated by the known-biomass production model for the period 1989-2019 (knobi R-package).

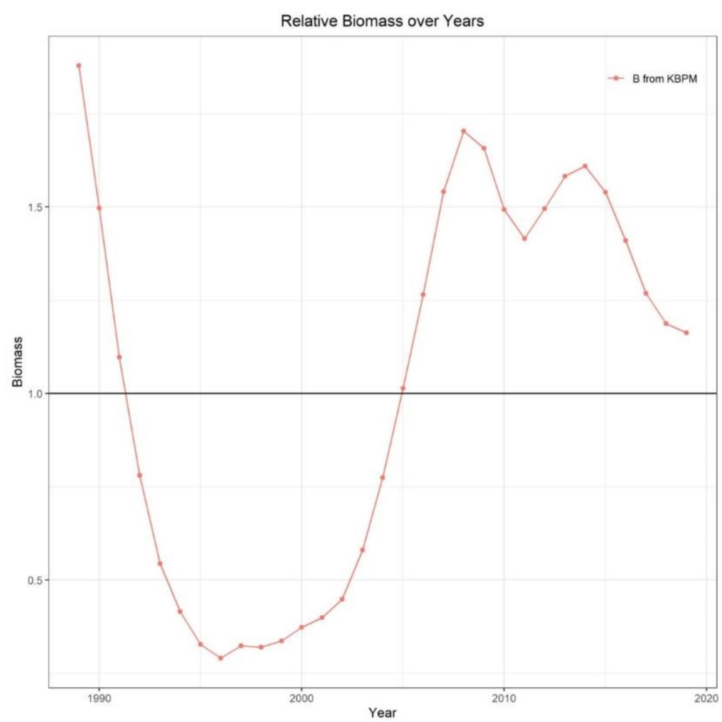


Figure 16. Redfish in Div. 3M: relative biomass by the known-biomass production model for the period 1989-2019 (knobi R-package).

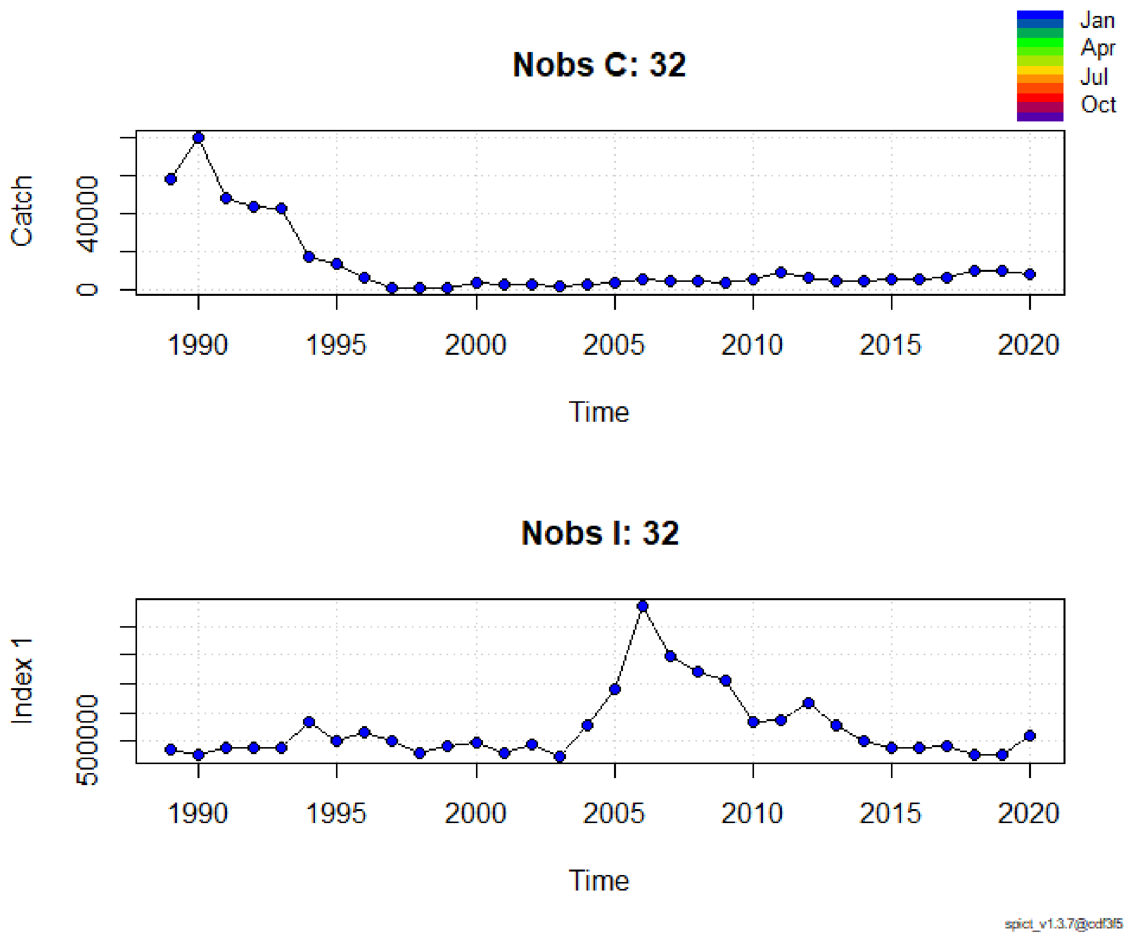


Figure 17. Redfish in Div. 3M: input data from 1989-2020 used on the SPiCT model.

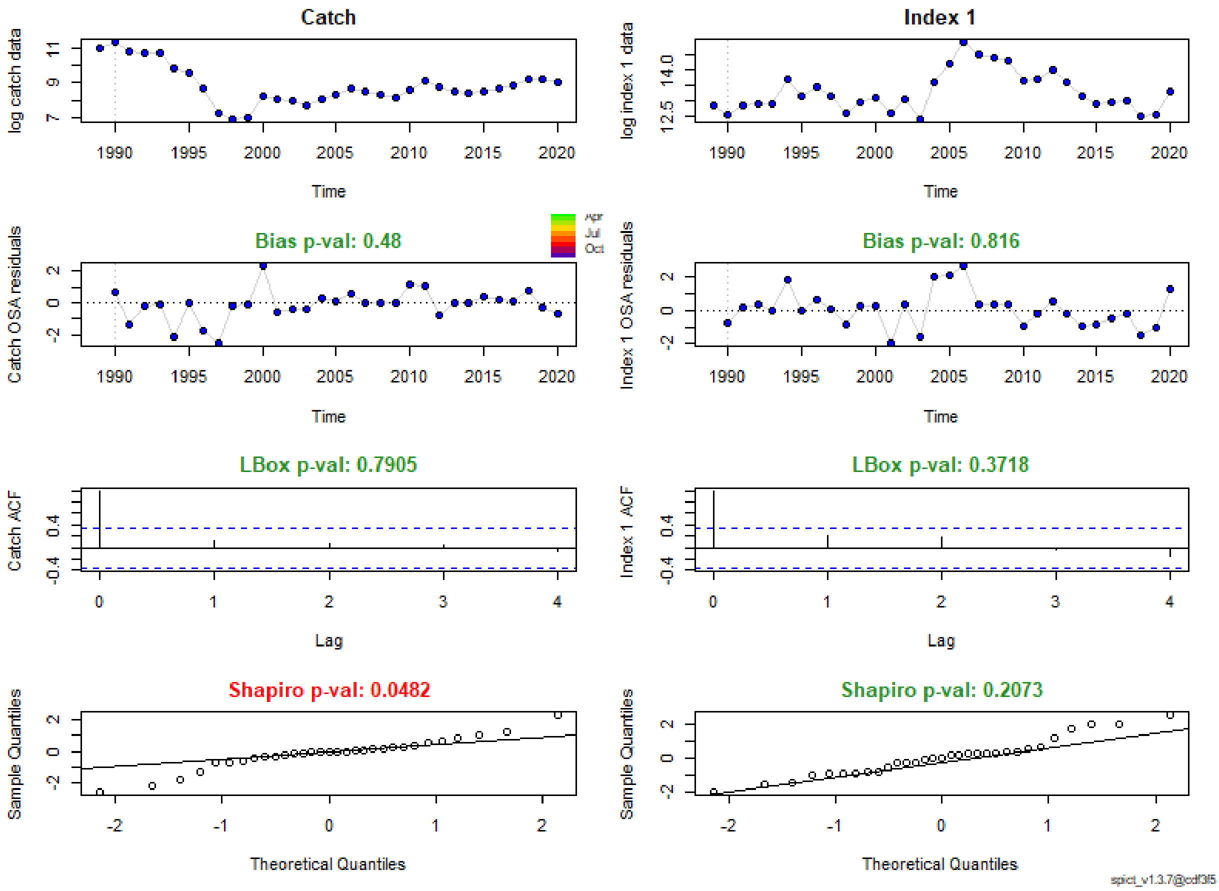


Figure 18. Redfish in Div. 3M: Diagnostics. First row show log of the input data series; catch and survey index. Second row "one step ahead" (OSA) residuals and a test for bias. Third row show the autocorrelation of the residuals including Ljung-Box test of multiple lags and tests for the individual lags. Fourth row show the results of Shapiro test for normality of the residuals (SPiCT model).

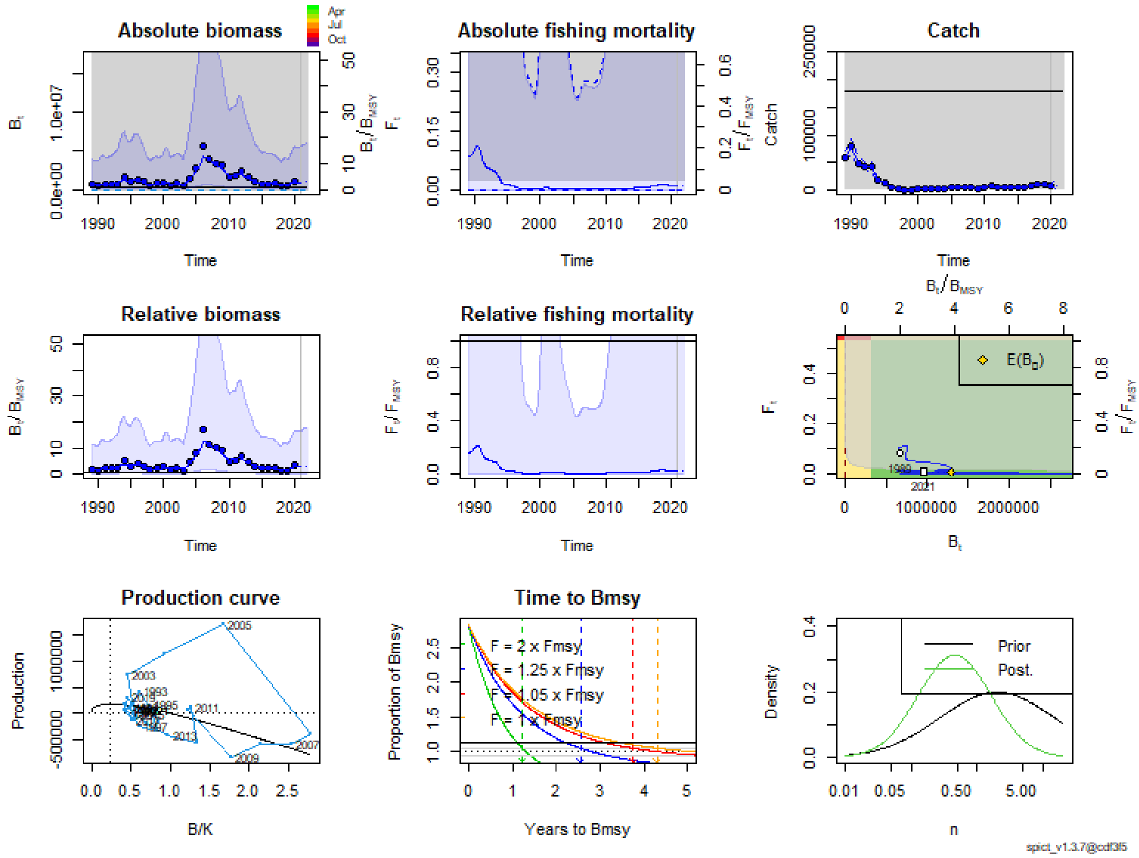


Figure 19. Redfish in Div. 3M: results from the stochastic surplus production model adjustment. Estimated biomass and annually averaged fishing mortality (solid blue lines) relative to estimated reference points with 95% CI (blue shaded region). Fishing mortality including within-year variation (shaded blue lines in middle column). Uncertainty of estimated reference points is represented by 95% confidence regions on the relative scale (grey-shaded region in right column). Production curve (SPiCT model).

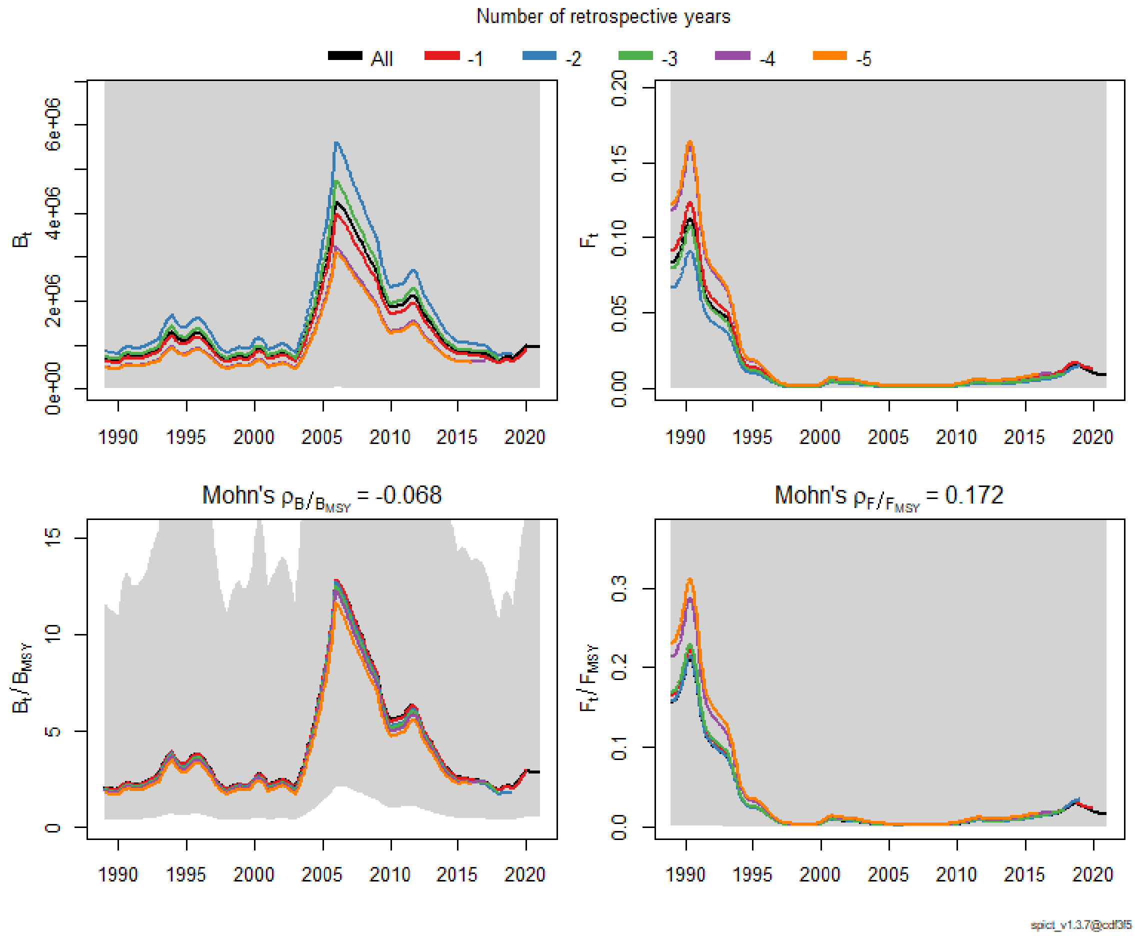


Figure 20. Redfish in Div. 3M: five years' retrospective plots of fishing mortality (absolute and relative) and fishable biomass (absolute and relative) in grey are indicated the confidence intervals (SPiCT model).

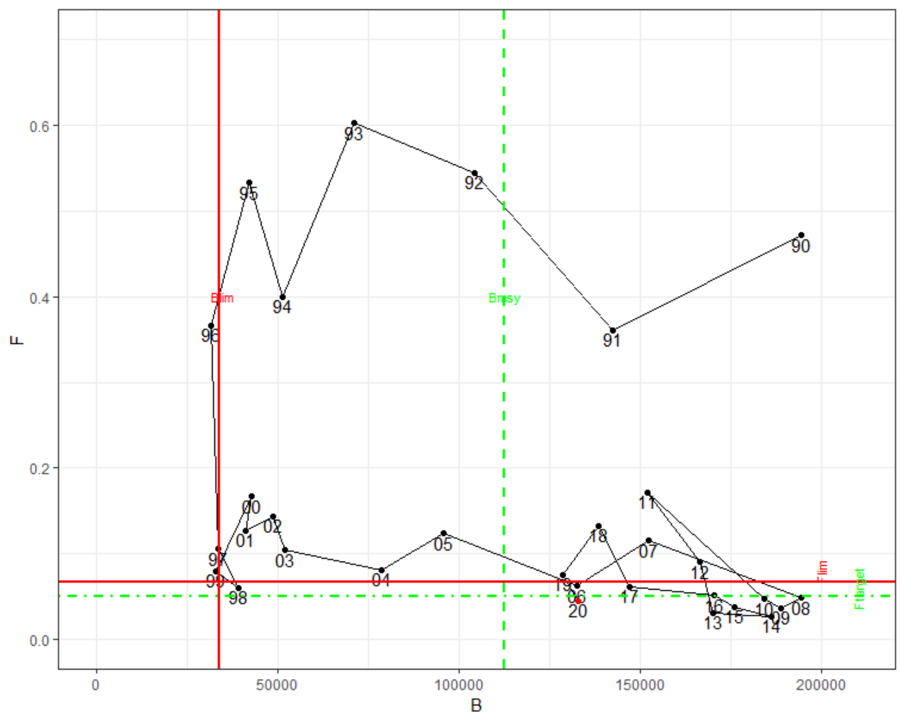


Figure 21. Redfish in Div. 3M: trajectory of total biomass (4+) and fishing mortality from 1990 until 2020. The red dot represents the point from the last approved XSA assessment (2020). **Blim**=33768 (vertical red line); **BMSY**=112561 (vertical green dashed line); **F0.1**=0.067 (horizontal red line); **Ftarget**=0.050 (horizontal green dashed line).

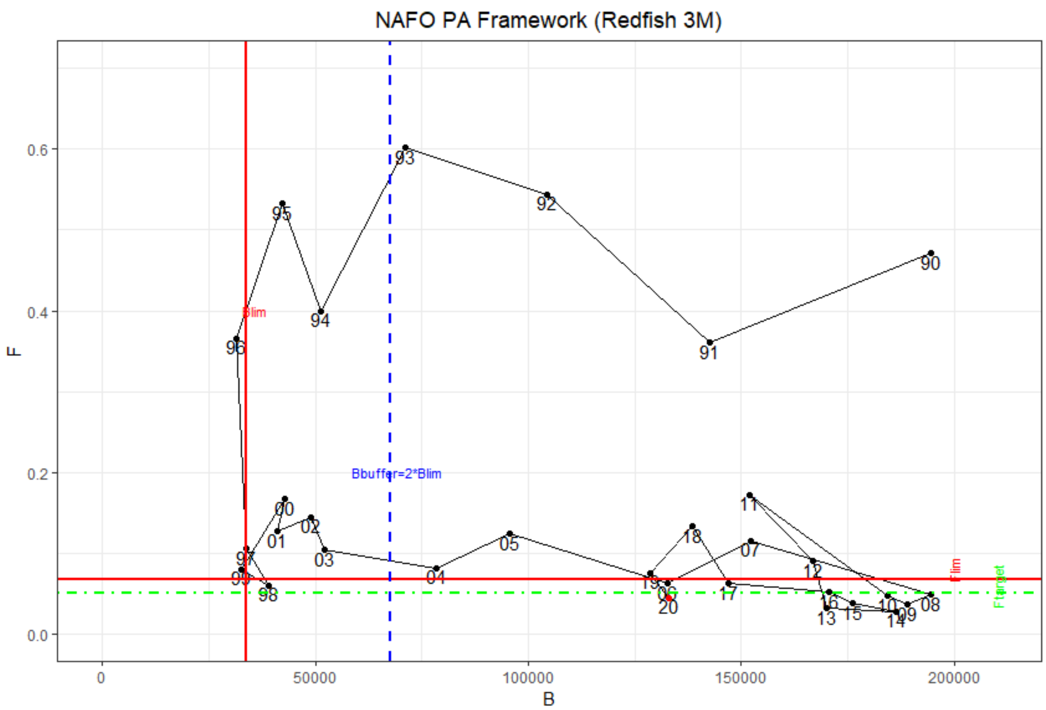


Figure 22. Redfish in Div. 3M: trajectory of total biomass (4+) and fishing mortality from 1990 until 2020. The red dot represents the point from the last approved XSA assessment (2020). Option 1 BRPs: **Blim**=33768 (vertical red line); **Bbuffer**=67536 (vertical blue dashed line); **F0.1**=0.067 (horizontal red line); **Ftarget**=0.050 (horizontal green dashed line).

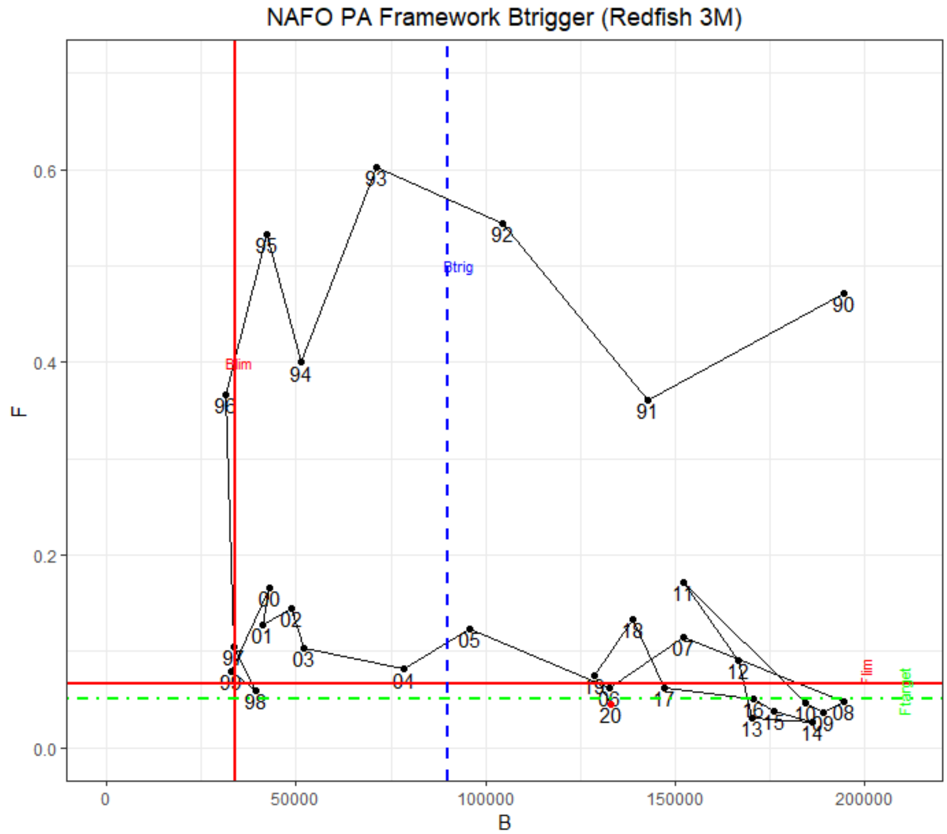


Figure 23. Redfish in Div. 3M: trajectory of total biomass (4+) and fishing mortality from 1990 until 2020. The red dot represents the point from the last approved XSA assessment (2020). Option 2 BRPs: **Blim**=33768 (vertical red line); **Btrigger**=90049 (vertical blue dashed line); **F0.1**=0.067 (horizontal red line); **Ftarget**=0.050 (horizontal green dashed line).

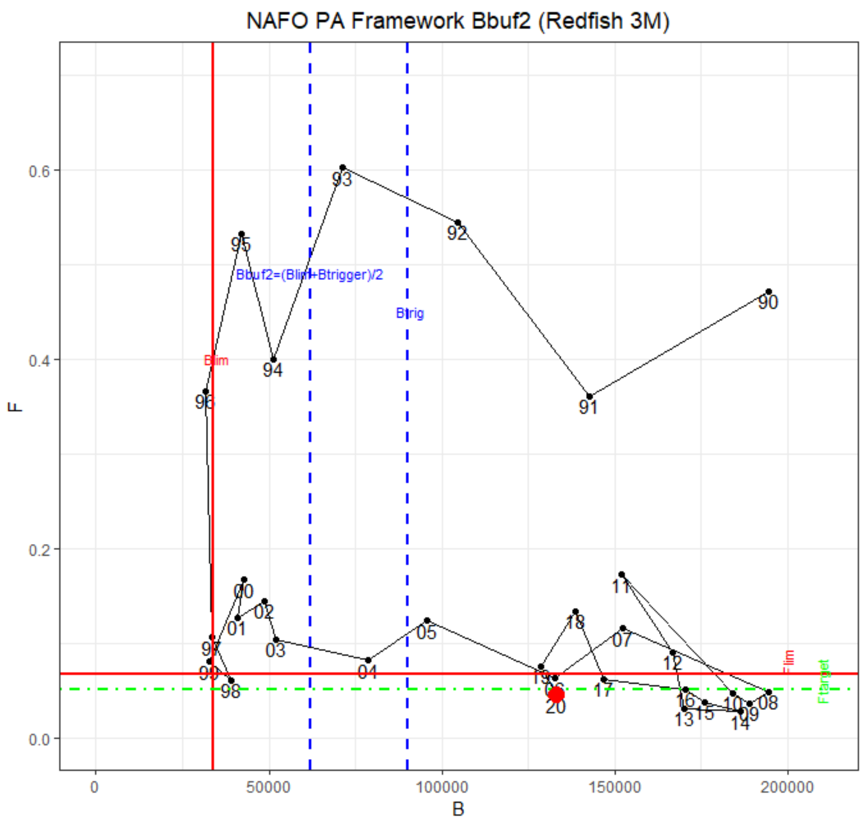


Figure 24. Redfish in Div. 3M: trajectory of total biomass (4+) and fishing mortality from 1990 until 2020. The red dot represents the point from the last approved XSA assessment (2020). Option 3 BRPs: **Blim**=33768 (vertical red line); **Bbuf2**=61909 (vertical blue dashed line); **Btrigger**=90049 (vertical blue dashed line); **F0.1**=0.067 (horizontal red line); **Ftarget**=0.050 (horizontal green dashed line).