Evaluation of Current and Alternative Harvest Control Rules for Blue Whiting Management using Hindcasting

A report commissioned by the Pelagic Advisory Council

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Executive summary

The Pelagic Advisory Council commissioned Laurie Kell and Polina Levontin of Sea++ to carry out a hindcast evaluation for blue whiting to assess the potential implications that different types of harvest control rules would have had given the observed dynamics of the stock. Managing the blue whiting stock has two major challenges: 1) shifts between different recruitment regimes, and 2) unstable assessments because of strong year-to-year variations in survey results.

A simulation framework was developed in R using FLR (Kell, et al., 2007) designed to build simulation models representing alternative hypotheses about stock and fishery dynamics. Code is available on the GitHub repository

An Operating Model (OM) was developed to run simulations of the stock under the different HCRs. The OM was conditioned on the current ICES stock assessment (ICES. 2018). A Beverton and Holt stock recruitment relationship with a steepness of 0.9 was assumed so that simulated recruitments were similar to those observed historically but if the stock crashed recruitment would also be impaired.

Two HRCs were implemented and simulation tested, namely

- HCR-I: The Standard ICES MSY rule using an Fmsy= 0.32 and an MSYBtrigger of 2.25 Mt
- HCR=II: The two-tier approach with the following parameters:
  - A lower bound of Fmin= 0.05 below Blim = 1.5 Mt;
  - A linear sliding scale with slope a1 =2.0 starting at B lim and ending at B1 Trigger = 2.25 Mt;
  - A standard level between Trigger B1 and Trigger B2 at F 0.1 =0.22;
  - A linear sliding scale with slope a2 =2.0 above B2 Trigger where B2 Trigger is 4.0 Mt;
  - An upper bound at higher stock sizes at F MSY =0.32

Both scenarios were executed with and without a stability mechanism of 20% down and 25% up when the stock is assessed to be above MSY Btrigger. Simulations start in the initial year (2000) and then the stock is projected forward using either of the two alternative HCRs and with or without bounding the variability in TACs. Uncertainty in stock assessments was taken at 0.3, derived from the retrospective analysis of the SAM assessment

Overall, the two-tier HCR (II) performed similar to the standard HCR (I), the main difference is the additional level of safety provided by HCR II which reduced F and catch at low biomass, i.e. in 2010-2015.

On the other hand, introducing bounds on the amount of change in TACs if the stock is above MSY Btrigger did lead to stock collapses, as the large reductions in stock biomass seen were driven by recruitment and the bounds resulted in F not being reduced quickly enough. In addition, the bounds prevented the TAC from being increased as the stock recovered. A

deterministic example of the working of the TAC bounds, showed that in 2010 the stock was still estimated above MSY Btrigger and therefore the bound on TAC decrease still applied. This resulted in a high fishing mortality for that year. The next year, the stock was below MSY Btrigger, so the bounds did no longer apply and the TAC was reduced substantially. In 2012 the stock was again above MSY Btrigger but because the bounds applied again, the catches remained low for a number of years. This demonstrates that the use of bounds in mitigating changes in TACs may have counter-intuitive and unwanted consequenses.

The simulations only considered historical conditions to ensure that a HCR is robust in practice, i.e. after implementation it will be necessary to simulate a range of hypotheses, e.g. about stock and recruitment and the relative importance of fishing versus environment on resource dynamics.

Introduction

A long-term management strategy was agreed for the North East Atlantic blue whiting stock by the European Union, the Faroe Islands, Iceland, and Norway in 2016 (Anon, 2016). ICES has evaluated the strategy and found it to be precautionary (ICES, 2016a). In addition the Pelagic Advisory Council (PELAC) has had a long involvement in the development of harvest control rules for blue whiting.

Managing the stock has two major challenges: namely 1) shifts between quite different recruitment regimes, and 2) unstable assessments because of strong year-to-year variations in survey results. The objective of this work is to carry out an evaluation of alternative harvest control rules (HCRs) that could have been applied to the blue whiting stock in the past in order to identify future management measures that are both precautionary and economically advantageous. Where a HCR determines the target F for setting a total allowable catch (TAC) based on an assessment of stock status and precautionary and limit reference points (Figure 1).

The HCRs are evaluated by conducting simulations using a hindcast with the most recent ICES stock assessment. In a hindcast the most recent years in the assessment are removed and the stock projected under a candidate HCR. The performance of the alternative HCRs can then be compared with the historical outcomes, allowing stakeholders to evaluate the relative performance of alternative HCRs for multiple management objectives.

During development of the simulation framework example results will be presented to stakeholders, following feedback on the procedure used, the relevance of the results and the analysis conducted the simulations and the report will be finalised.

Material and Methods

An Operating Model (OM) was developed to run simulations of the stock under the different HCRs. Where the OM is a mathematical model used to describe resource dynamics in simulation trials and was conditioned on the current ICES stock assessment (ICES. 2018). The assessment provides values for the assumed biological parameters (weights at age, natural mortality, and maturity-at-age), estimates of historical fishing mortality and numbers-at-age, and historical recruitment and selection patterns. Uncertainty in the historical estimates and starting conditions are generated from the stock assessment variance-covariance matrix.

Uncertainty

Recent applications for Marine Stewardship Certification for blue whiting[1] raised the usual questions about the reliability of the assessment, especially when it comes to estimation of SSB. These may stem from uncertainty about ageing and assumptions about stock structure. There is also concern that recruitment estimates, which depend on survey estimates, are strongly affected

1 https://fisheries.msc.org/en/fisheries/faroese-pelagic-organization-north-east-atlantic-blue-whiting/@@assessments

by observation error. It is also suggested that exploitation in recent decades may have contributed to recruitment variability as theoretical models predict that at higher exploitation levels boom and bust recruitment cycles are more common. The assessment therefore may only account for a limited number of sources of uncertainty, particularly since there are relatively large updates to the estimates of F and SSB as new data becomes available (Figure 2).

Previous HCR Evaluations

A number of HCRs have been evaluated for blue whiting. In 2012 Skagen (2012ab) evaluated HCRs for objectives related to economic viability and stability of catches while making sure that the risk to the stock is low, defined by the probability of falling below B_{lim} at least once over a period of 10 years during a 30 year simulation period. Simulations showed that a two tier HCR (figure 3) could achieve management objectives with the following parameters $B_{trigger1}$ = 4.0 million tonnes, $B_{trigger2}$ = 5.0 million tonnes, the fist slope in the HCR = 1.5 and the second = 4, while the maximum F is 0.12 or a TAC in the range of 400 - 500 thousand tonnes.

Following a request from NEAFC similar HCRs were evaluated (Figure 4) but with updated reference points. A Multistage HCR was shown to contribute to inter annual variability in catches. In this evaluation the maximum F was set to the new target of F_{MSY} = 0.3 and the first biomass trigger point was reduced to 2.35 million tonnes with the second trigger point at 4 million tonnes. This rule was found to be precautionary, even though it would not have been seen as ‘precautionary’ a year ago even though risk criteria had not changed.

Both exercises calculated the probability of falling below the same absolute threshold of B_{lim} of 1.5 million tonnes of biomass and the risk acceptance level was similar - less than 5% of falling below B_{lim} in simulations over a 10 year period.

Again the 2016 evaluation of HCRs identified variability in recruitment and the limitations in our ability to know the state of the stock at the time of making a decision due to imprecision in the assessments. The evaluations in 2016 used past advice uncertainty (i.e. by comparing the updated assessment and historical estimates) rather than model derived estimates to parametrise assessment error. This is particularly relevant to the two tier HCR, since in order to decide which segment of the rule is relevant one needs to know whether the stock is at a high or low productivity regime.

Even though a simple HCR with B_{lim}, $B_{trigger}$ and F_{MSY} (1.5 mt, 2.25 mt and 0.32) was found precautionary, a reviewer raised questions over the ICES definition of F_{MSY} and the simplified stock recruitment relationship used in the evaluation, alerting the Workshop on Blue Whiting Long Term Management Strategy Evaluation (WKBWMSE, ICES, 2016a) group to the possibility that this HCR may expose the stock to higher levels of risk than the modelling suggests. In particular, yield per recruit analysis suggests that F_{MSY} of 0.32 is at the upper limit of the estimated range, the lower limit is 0.19 and notes that the current precautionary management reference points (F_{pa} = 0.58) have greater than 5% chance of SSB falling below Blim.

The difficulty in estimating and modelling stock recruitment relationship was also noted, this has implications for reference points and MSE evaluation approach more generally. Given that modelling relies heavily on the assumption of stock recruitment relationship and that this relationship is the key unknown raises the question whether simulation exercises of this type are the right approach to help formulate a risk based management system.

Perception that recruitment is largely independent of biomass and henceforth for the most part fishing pressure makes it tempting to exploit the stock in adaptive ways, riding the waves of recruitment bounty. However, not being able to reliable tell whether one is at the top of the wave or the bottom makes such surfing a potentially precarious proposition not just for the stock but the fishery. There are associated costs of keeping a potential redundancy in the fishing capacity and adjusting to sudden expansion and downsizing of catch opportunities. Additionally, other economic and social concerns might be relevant too. Will the lack of stability inherent in a bimodal management strategy have impacts on employees in the fishery or the profitability of the industry through price fluctuations? Further, there seems to be little information on whether there are other species dependent on the boom and bust cycles of blue whiting and what dampening those cycles through fishing might cause in the wider ecosystem.

It was noted (ICES 2016a) 'The TAC advice for blue whiting has fluctuated significantly in recent years. Reductions of more than 90% have been followed by increases exceeding 800%. Such instability negatively affects the economic viability of fisheries targeting this stock (if the advice is implemented), and increases the scepticism amongst stakeholders about the scientific basis for the advice. The cause of this variability can be sourced to the large year effects in the acoustic survey estimates of abundance. This lack of precision in assessment, leading to highly variable advice, demands a management solution that counteracts this variability and dampens-down the between year fluctuations.'

Methods

An MSE framework was developed based on the ICES assessment. The OM was condition on the last assessment, an aged based state space analytical assessment (SAM; Berg and Nielsen, 2016) that uses catch-at-age for both the historical assessment and the forecast.
All coding was done in R using FLR (Kell, et al., 2007) designed to build simulation models representing alternative hypotheses about stock and fishery dynamics. Code will be made available on the GitHub repository and the stock assessment will be based on the blue whiting assessment at .

Harvest Control Rules

The two HRCs were implemented and simulation tested, namely

HCR-I: The Standard ICES MSY rule using an Fmsy= 0.32 and an $MSY_{Btrigger}$ of 2.25 Mt

HCR=II: The two-tier approach with the following parameters:

i. A lower bound of F_{min}= 0.05 below B_{lim} = 1.5 Mt;
ii. A linear sliding scale with slope a_1=2.0 starting at B_{lim} and ending at $B^1_{Trigger}$ = 2.25 Mt;
iii. A standard level between Trigger $B^1_{Trigger}$ and $B^2_{Trigger}$ at $F_{0.1}$=0.22;
iv. A linear sliding scale with slope a_2=2.0 above $B^2_{Trigger}$ where $B^2_{Trigger}$ is 4.0 Mt; and
v. An upper bound at higher stock sizes at F_{MSY}=0.32. The upper bound was taken as $B^2_{Trigger}$ + 30%, i.e. 5.2 Mt

Both scenarios will be executed with and without a stability mechanism of 20% down and 25% up when the stock is assessed to be above B_{lim}. When the stock is below B_{lim}, no stability mechanism will be used.

Since 2016, the assessment has used a preliminary estimate of catch-at-age in the year in which the assessment is carried out to supplement information from the acoustic survey conducted in the spring. In most recent years more than 90% of the annual catches of the age 3+ fish are consistently taken in the first half of the year, which makes it reasonable to estimate the total annual catch-at-age from preliminary first semester data. This is expected to provide an assessment that is more robust to the year effects sometimes observed in the survey index from the International Blue Whiting Spawning Stock Survey (IBWSS). The HCR was therefore simulation tested using as input the value of SSB in the "current" year to set the TAC in the next year. The reference points in the HCR were those agreed on the long-term management strategy was agreed by the European Union, the Faroe Islands, Iceland and Norway in 2016 (Anon, 2016) and evaluated by (ICES, 2017)

OM Conditioning

Operating Model exploring uncertainty in assessment

In the simulations in each year historical assessment errors is used to scale biomass to mimic uncertainty in the assessment. A total allowable catch (TAC) was then set according to the HCR under evaluation and the stock projected forward using the OM. In other words, we simulate annual assessments based on the ‘true’ state of the stock with assessment error rather than mimic assessment procedure itself which would require simulating data using an Observation Error Model (OEM) and conducting an assessment model to estimate inputs to the HCR.

Simulations start in an initial year (2000) and then the stock is projected forward using either of the two alternative HCRs. In addition, a simple projection is made at the F_{MSY} level for comparison and to check that the model is set up correctly.

The time series from the assessment are shown in figure 5, these include estimation error from the SAM covariance matrix. The values of mass, M and maturity-at-age assumed in and selectivity-at-age estimated by the assessment are shown in Figure 6. M was fixed at 0.2 and maturity was not assumed to vary over time. Changes have been seen, however, in both mass-at-age and selection pattern. Figure 7 shows the time series of stock mass-at-age and selectivity-at-age. There appears to have been an increase in selectivity for older and a decrease for younger ages.

To understand the nature of the age dynamics the relative catch and stock numbers-at-age (i.e. number-at-age scaled by the mean number for that age) are plotted in figures 8 and 9 respectively. These show that the population tends to be dominated by strong year classes, for example around 2000 there were a number of strong age-classes. The strong year class in 1989, suggest that there may be an ageing problem from age 6 onwards.

Cross-correlation is used to separate the influence of recruitment on SSB from the influence of SBB on recruitment. If recruitment estimates are lagged to the year of fertilisation, the correlation at zero lag represents the influence of SBB on recruitment. Negative lags represent the influence of recruitment 1,2,3,. . . years in the past on the current year's SSB If the influence of recruitment on SRP is much larger than the influence of SSB on recruitment, it is possible that recruitment is environmentally driven, even if there is an apparent stock–recruit relationship (Gilbert 1997). Therefore, only if SSB has a larger and significant influence on recruitment than recruitment does on SSB, then the existence of a stock–recruitment relationship is unequivocal. The cross correlations are plotted in Figure 10 and the negative lags suggest that SSB is driven by recruitment.

Cross-correlation were also explored for exploitable biomass and recruitment (Figure 11), the largest correlation is seen for a lag of 1 showing that catches are dominated by recent year classes.

Stock Recruitment Relationship

Two forms of stock recruitment relationships were fitted to the stock assessment estimates, i.e. and segmented regression (Figure 12) and Beverton and Holt, in the case of the Beverton and Holt two fits were made where steepness was estimated and fixed at 0.9 (Figures 13 and 14 respectively). Although low recruitment is more likely to occur when the biomass is low, it can occur even when biomass is above 5 million tonnes.

The residuals about the fitted functional forms are shown in figures 15, 16 and 17. Changes in recruitment regimes were identified (i.e boxes) using a sequential t-test algorithm for regime shifts (Rodionov 2004). The regimes are similar in all cases.

Figure 18 shows the autocorrelation in the recruitment deviates from the Beverton and Holt relationship, while figure 19 shows an example of a simulated time series of recruitment.

Productivity

Combining the stock recruitment relationship fitted above with the biological parameters and selection patterns allows the expected dynamics and corresponding reference points to be derived; Figures 20, 21 and 22 show equilibrium SSB and catch against F and recruitment and yield against SSB. The maxima of the Yield v SSB curve provides an estimate of Maximum Sustainable Yield (MSY).

Changes in recruitment, growth and selection pattern will cause changes in productivity and hence reference points. As an exploration of the impact on reference points $F_{0.1}$ scaled by mean recruitment was calculated using a 3 year window for recruitment and mass and selection-at-age. The resulting time series are shown in figure 23.

$F_{0.1}$ is based on a yield/spawner-per-recruit analysis, where yield and SSB are scaled by the average recruitment therefore the level of yield and SSB are driven by recruitment and vary by a factor of four. The value of $F_{0.1}$ is determined by the selection pattern and mass-at-age (since M and maturity-at-age are assumed not to vary over time).

Assessment Error

A feature of the blue whiting assessment is unstable stock estimates because due to strong year-to-year variations in survey results. Assessment error was therefore explored by conducting a retrospective analysis and projection based on the 2018 stock assessment. The assessment was performed in each year from 2009 through to 2018, assessments prior to 2009 did not converge. Then the stock was projected through to 2018 based on the values of recruitment estimated in 2018 and the reported catches. The time series of catch, recruitment, spawning stock biomass and fishing mortality are shown in Figure 24.

The error in F and SSB values were simulated assuming a multivariate lognormal distribution. There is a strong correlation between the error in SSB and F, as seen in figure 25.

Scenarios

Only a single OM was evaluated, namely

- Selection pattern, M, mass and maturity-at-age were derived from the 2018 assessment
- Stock recruitment was modelled as a Beverton and Holt functional form estimated from the 2018 assessment with a steepness fixed at 0.9.
- Recruitment in the HCR simulations were derived from the fitted stock recruitment relationship plus the recruitment deviate estimated in the year being simulated.

A number of scenarios were run for the HCR; namely

- HCR with a F_{MSY} target
- HCR with a F_{MSY} target and assessment error
- HCR I with assessment error
- HCR II with assessment error
- HCR I with TAC bounds of [0.8, 1.25] with observed recruitment deviates and assessment error
- HCR II with TAC bounds of [0.8, 1.25] with observed recruitment deviates and assessment error

In addition a projection at F_{MSY}=0.32 was run for reference

All simulations started in 2000, with the HCR being applied first in 2001.

Results

First the time series are summarised, the behaviour of HCR is explored and then summary statistics presented.

Summary statistics includes

i. Median total catch over the whole time period
ii. Median interannual variability over the whole time period
iii. Median stock size by year (and variability)
iv. Median recruitment by year (and variability)
v. Median catch by year (and variability)
vi. The number of years when the stability mechanism was applied
vii. The median Inter-Annual Variability per iteration

The results are also stored in relational database form so that additional analysis can be conducted.

Time Series

As a benchmark the ICES assessment was projection from 2001 onwards at the F_{MSY} level and compared to an example simulation of the HCR with an F target (F_{tar}) of F_{MSY} with no biomass triggers and no assessment error for a deterministic HCR (i.e. with no assessment error and with actual recruitment estimates) in Figure 26.

Fishing mortality in the past has been higher than F_{MSY} apart from a period from 2009 to 2013. Catches under the F_{MSY} projection have correspondingly been above and below the reported catches and projected SSB has followed recruitment. Under the HCR with only F_{MSY} (i.e. without biomass triggers) F is shows slight variability due to setting the TAC via a short-term projection.

Figure 27 compares the results from the stochastic (1000 realisations) and the deterministic HCRs, and shows the large impact of assessment error on the results.

Next the performance of the different HCRs are evaluated; figure 28 compares the two HCRs without TAC bounds, and Figures 29 and 30 compares HCR I & II respectively with and without TAC bounds.

The performance of the four HCRs are summarised in Figure 31. The main points are that HCR II reduces F during periods of low recruitment and that bounds can cause stock collapse due to shifts in recruitment.

HCRs

The behaviour of the HCRs are examined by plotting F against SSB for by year. First in Figure 32 the values of F and SSB from the assessment and HCR are plotted to ensure the simulations are behaving as expected; each value of SSB should result in a value of F consistent with the HCR. Next the values of F and SSB from the OM are overlaid on the values from the assessment and the HCR (Figure 33). The red line indicates the values of F set by the HCR for any particular value of SSB. The reason for the uncertainty (i.e. the scatter of points) is due to the F being using in a short-term projection to set the TAC.

Figures 34 and 35 then show the results of HCR I and IIs run with assessment error for each year. The main difference between the performance of the HCRs is as a result of a low recruitment period. Therefore Figures 36 and 37 show the results from 2012, when the stock was at a low level and F was reduced by the HCR. It can be seen that HCR II reduces the target F and hence catch due to the low stock size.

Summary Statistics

Figure 38 summarise total catch, and the AAV and variance in total catch over the simulated period for HCR I and II with and without bounds. The “violins” show the actual distributions and the box plots the first and third quartiles (the 25th and 75th percentiles), while the upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the box edges (where IQR is the inter-quartile range, or distance between the first and third quartiles).

Figure 39 summaries AAV for SSB, F and catch, while Figure 40 shows the percentage in each year when the stability mechanism was applied for the HCR with bounds. Finally Figure 41 shows the probability that SSB falls below Bpa and Figure 42 the probability it falls below Blim.

Figure 43 shows the time series from a simulation of HCR I for a single Monte Carlo run without assessment error both with and without bounds; the horizontal line shows the Bpa level. Figure 44 demonstrates the effects of applying bounds on TAC change when the stock falls below Bpa. The effect of the bounds is first seen in 2007 when the TAC is prevented falling below 80% of the previous years TAC. This causes SSB to fall below Bpa in 2010, at which point the bounds are no longer applied and the TAC is based on the F set by the HCR. This results in a much reduced TAC and a recovery of the stock above Bpa in 2012, at which point the bounds are reapplied and preventing catches from increasing to the level seen for HCR I without bounds even though SSB has recovered. The simulations are therefore important in showing unintended consequences that are difficult predicted in advance.

Figure 45 is an example of a comparison of historical stock trends with an escapement harvesting strategy (take all biomass>Bpa) and an F cap of 0.6. This is presented as a potential different type of HCR compared to the standard F based HCRs.

The 4 HCR scenarios are summarised in table 2 and compared to the historical time series and an idealised projection at F_{MSY}.

Discussion and conclusions

Managing the blue whiting stock has two major challenges: 1) shifts between different recruitment regimes, and 2) unstable assessments because of strong year-to-year variations in survey results.

- A Beverton and Holt stock recruitment relationship with a steepness of 0.9 was assumed so that recruitments in the projections were similar to those observed historically but if the stock crashed recruitment would also be impaired.
- A large assessment error without any particular bias, was assumed in stock estimates when setting HCR.
- It is likely that assessment error will vary depending on a number of factors, e.g. if F varies, the strength of incoming year classes and serial correlation in assessment datasets. To model these would require a MSE with a management procedure, i.e. that models the data and assessment processes as well as the HCR.
- HCR II performed similarly to HCR I, the main difference is the additional level of safety provided by HCR II which reduced F and catch at low biomass, i.e. in 2010-2015
- The bounds evaluated caused stock collapse, as the large reductions in stock biomass seen were driven by recruitment and the bounds resulted in F not being reduced quickly enough.
- After a stock collapse the use of bounds prevented the TAC being increased as the stock recovered.
- Dynamics largely driven by incoming year-classes, i.e. catches are high for up to 3 years following a large recruitment.
- M was fixed at 0.2 in all years and at all ages. It may be expected that M would vary between ages and years in a stock that exhibits large variations in recruitment and density.

- The assumptions about M will also have important impacts on the stock dynamics, e.g. due to density dependence and resonant cohort effects.
- The simulations only considered historical conditions to ensure that a HCR is robust in practice, i.e. after implementation it will be necessary to simulate a range of hypotheses, e.g. about stock and recruitment and the relative importance of fishing v environment on resource dynamics.
- If dynamics are recruitment driven what are appropriate reference points?
- Could use STARS algorithm to detect regime shifts, but how to make it part of a HCR?
- Appropriate MPs also depend on the data, to evaluate this

More sources of uncertainty and a range of alternative HCRS could be evaluated. Further, a stakeholder communication strategy could be developed using an interactive visualization tool such as the shiny app that Sea++ had developed for North Atlantic Swordfish ().

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Tables

Table 1. Reference points, values, and their technical basis.

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	2250000 t	B_{pa}	ICES (2013a, 2013b, 2016a)
	F_{MSY}	0.32	Stochastic simulations with segmented regression stock–recruitment relationship	ICES (2016a)
Precautionary approach	B_{lim}	1500000 t	Approximately B_{loss}	ICES (2013a, 2013b, 2016a)
	B_{pa}	2250000 t	B_{lim} exp(1.645 × σ), with σ = 0.246	ICES (2013a, 2013b, 2016a)
	F_{lim}	0.88	Equilibrium scenarios with stochastic recruitment: F value corresponding to 50% probability of (SSB < B_{lim})	ICES (2016a)
	F_{pa}	0.53	Based on F_{lim} and assessment uncertainties. F_{lim} exp(-1.645 × σ), with σ = 0.299	ICES (2016a)
EU–Faroes–Iceland–Norway long-term management strategy	SSB_{MGT_lower}	1500000 t	B_{lim}	Anon (2016)
	SSB_{MGT}	2250000 t	B_{pa}	
	F_{MGT_lower}	0.05	Arbitrary low F	
	F_{MGT}	0.32	F_{MSY}	

Table 2. Summary of HCR scenarios and comparison to the historical and an idealised F_{MSY} projection.

Median Catch

Scenario	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
FMSY	1412	1151	1359	1643	1734	1766	1839	1535	1283	1045	880	721	614	627	712	855	970	1141	1359	22645
HCR I	1412	1772	1341	1671	1897	1816	1816	1566	1118	814	575	556	498	602	734	961	1202	1379	1338	23069
HCR I with Bounds	1412	1772	1417	1685	1695	1772	1841	1771	1537	1249	907	185	119	209	299	395	495	619	773	20151
HCR II	1412	1772	1119	1691	1971	1868	1850	1624	1079	605	440	445	404	463	569	750	1019	1467	1466	22014
HCR II with Bounds	1412	1772	1417	1685	1649	1772	1823	1772	1542	1259	907	158	107	167	228	290	363	454	566	19341
Historical	1412	1772	1557	2365	2401	2018	1956	1612	1252	635	540	104	376	614	1148	1391	1181	1555	1713	25601

Median SSB

Scenario	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
FMSY	4241	4589	5901	7287	7571	7455	7247	5803	4563	3599	3061	2678	2606	2854	3136	3771	4725	5474	5685
HCR I	4241	4608	5576	6952	7210	6847	6483	5030	3743	2858	2511	2471	2601	2970	3306	3917	4740	5232	5114
HCR I with Bounds	4241	4608	5576	6789	7180	7048	6778	5368	3961	2719	2007	1811	2180	2769	3354	4352	5596	6722	7561
HCR II	4241	4608	5576	7137	7414	7051	6674	5179	3853	3045	2838	2837	2955	3332	3705	4388	5224	5721	5617
HCR II with Bounds	4241	4608	5576	6792	7242	7110	6889	5487	4038	2804	2076	1851	2212	2826	3467	4540	5894	7086	8028
Historical	4241	4608	5410	6867	6749	5979	5828	4686	3632	2788	2716	2713	3433	3711	3920	4055	4631	5536	5493

Median F

Scenario	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
FMSY	0.48	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
HCR I	0.48	0.47	0.34	0.35	0.38	0.38	0.37	0.40	0.37	0.33	0.25	0.26	0.25	0.29	0.31	0.35	0.41	0.42	0.37
HCR I with Bounds	0.48	0.47	0.40	0.34	0.34	0.35	0.35	0.42	0.49	0.56	0.44	0.12	0.07	0.10	0.11	0.11	0.12	0.12	0.11
HCR II	0.48	0.47	0.28	0.35	0.38	0.38	0.37	0.40	0.33	0.22	0.16	0.17	0.17	0.18	0.19	0.22	0.30	0.40	0.36
HCR II with Bounds	0.48	0.47	0.40	0.34	0.34	0.34	0.34	0.42	0.48	0.55	0.43	0.09	0.06	0.08	0.08	0.08	0.08	0.08	0.08
Historical	0.48	0.47	0.47	0.50	0.54	0.51	0.46	0.46	0.40	0.26	0.18	0.05	0.11	0.20	0.39	0.52	0.47	0.47	0.45

Annual Average Variation in Catch

Scenario	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
FMSY	-19%	19%	21%	5%	2%	4%	-16%	-17%	-18%	-16%	-19%	-14%	2%	13%	20%	14%	17%	20%	14%
HCR I	25%	-24%	27%	13%	-4%	0%	-11%	-27%	-28%	-32%	-9%	-10%	20%	21%	31%	28%	15%	0%	18%
HCR I with Bounds	25%	-20%	6%	20%	10%	10%	-8%	-20%	-20%	-20%	-20%	10%	25%	25%	25%	25%	25%	25%	19%
HCR II	25%	-37%	40%	18%	-6%	-1%	-14%	-35%	-35%	-27%	-1%	-6%	16%	26%	38%	35%	23%	0%	21%
HCR II with Bounds	25%	-20%	3%	22%	12%	11%	-5%	-20%	-20%	-20%	-20%	7%	25%	25%	25%	25%	25%	25%	19%
Historical	25%	-12%	52%	1%	-16%	-3%	-18%	-22%	-49%	-15%	-81%	262%	63%	87%	21%	-15%	32%	10%	44%

Figures

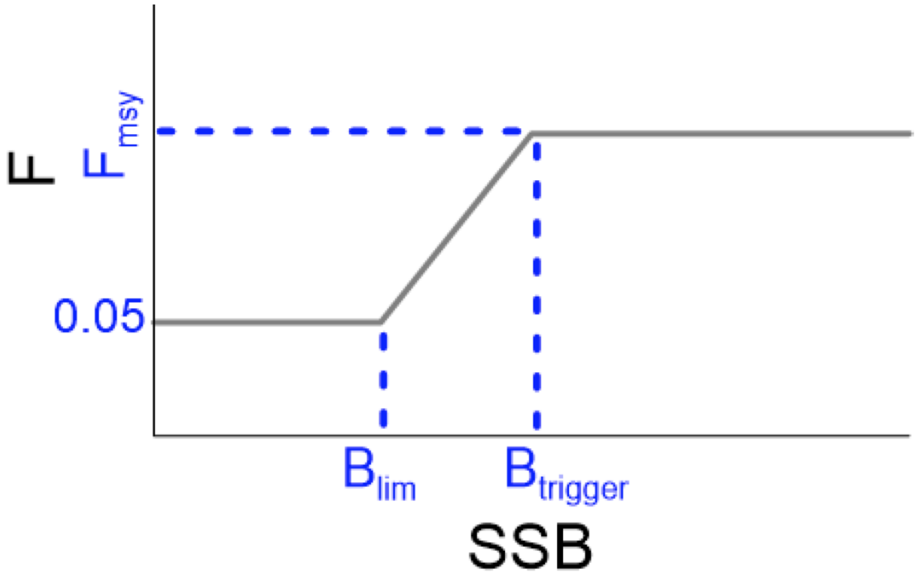

Figure 1. HCR I evaluated during this study (based on the 2016 NEAFC request to ICES)

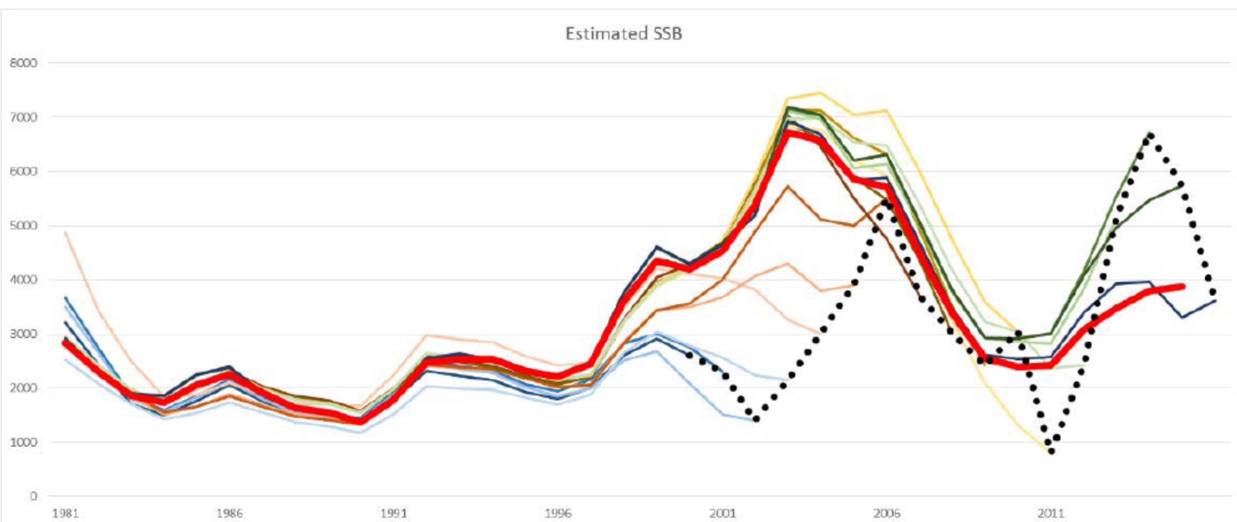

Figure 2. Blue whiting SSB as estimated by the last 18 assessments of the stock (conducted in 1999-2015, plus IBPBLW 2016). Time series include forecasted values for y+1 (except for IBPBLW). Prior to 2006 SSB was not estimated for Jan 1. Dotted line = forecasted SSB values from each assessment (i.e. what advice was based on); Red line = IBPLW_2016 assessment (i.e. current 'best' estimate; ICES, 2016a).

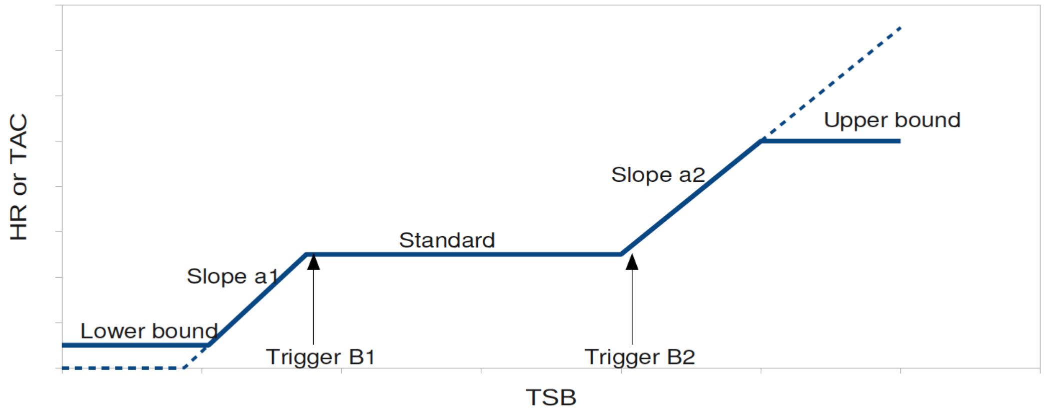
HR or TAC
Upper bound
Slope a2
Standard
Slope a1
Lower bound
Trigger B1
Trigger B2
TSB

Figure 3. From Skagen (2012), who evaluated a two tier HCR and found it to be precautionary with roughly these parameters: Trigger B1 = 4 Mt, Trigger B2 = 5 Mt and Upper bound F = 0.12 or TAC of about 500 thousand tonnes.

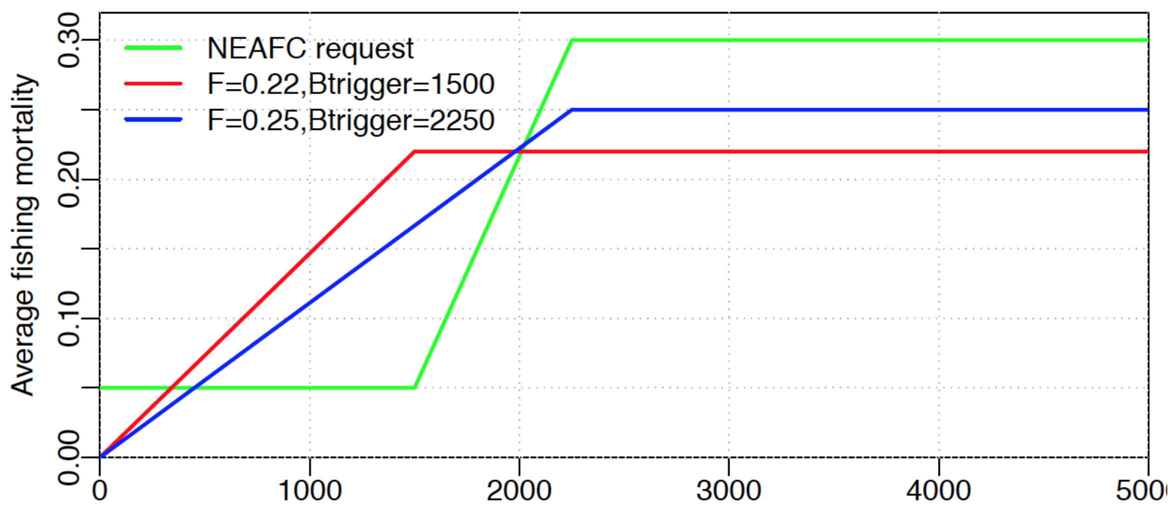

Figure 4. Alternative HCRs evaluated as part of MSE of long term management plans in 2016 (WKBMS 2016).

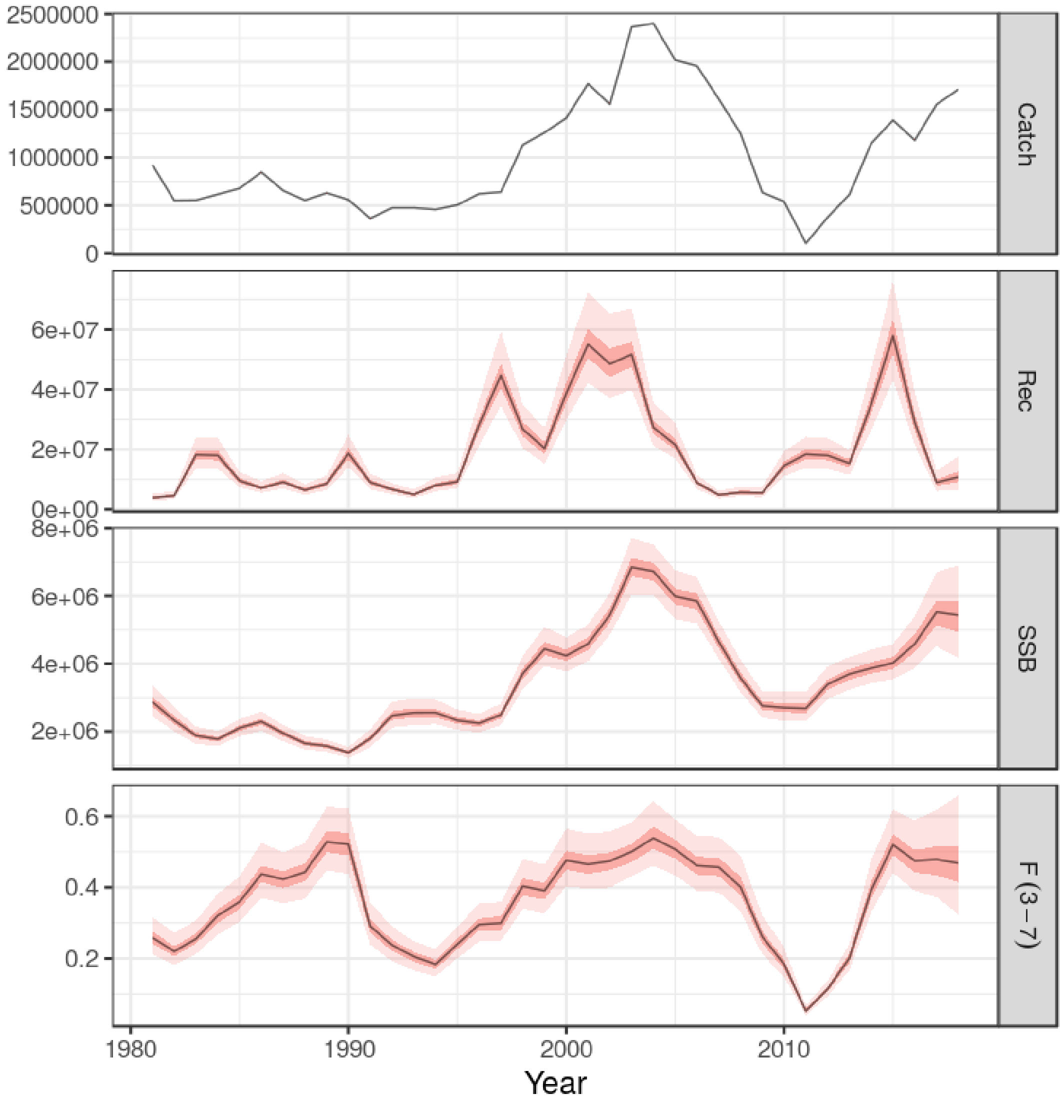

Figure 5 Time series estimates of catch, recruitment, spawning stock biomass and fishing mortality from the 2018 stock assessment.

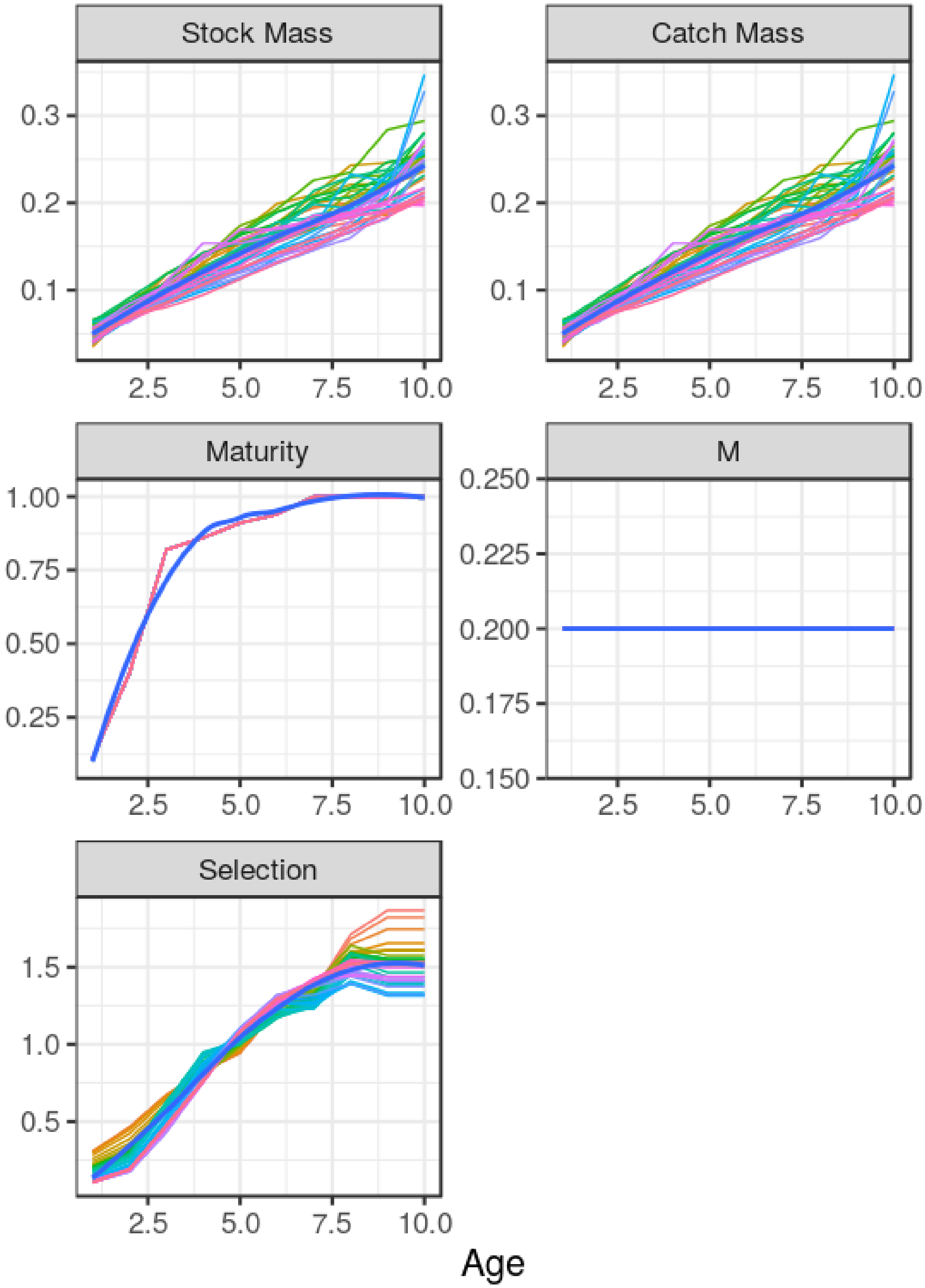

Figure 6 Stock mass, catch mass, maturity, natural mortality and selection pattern at-age

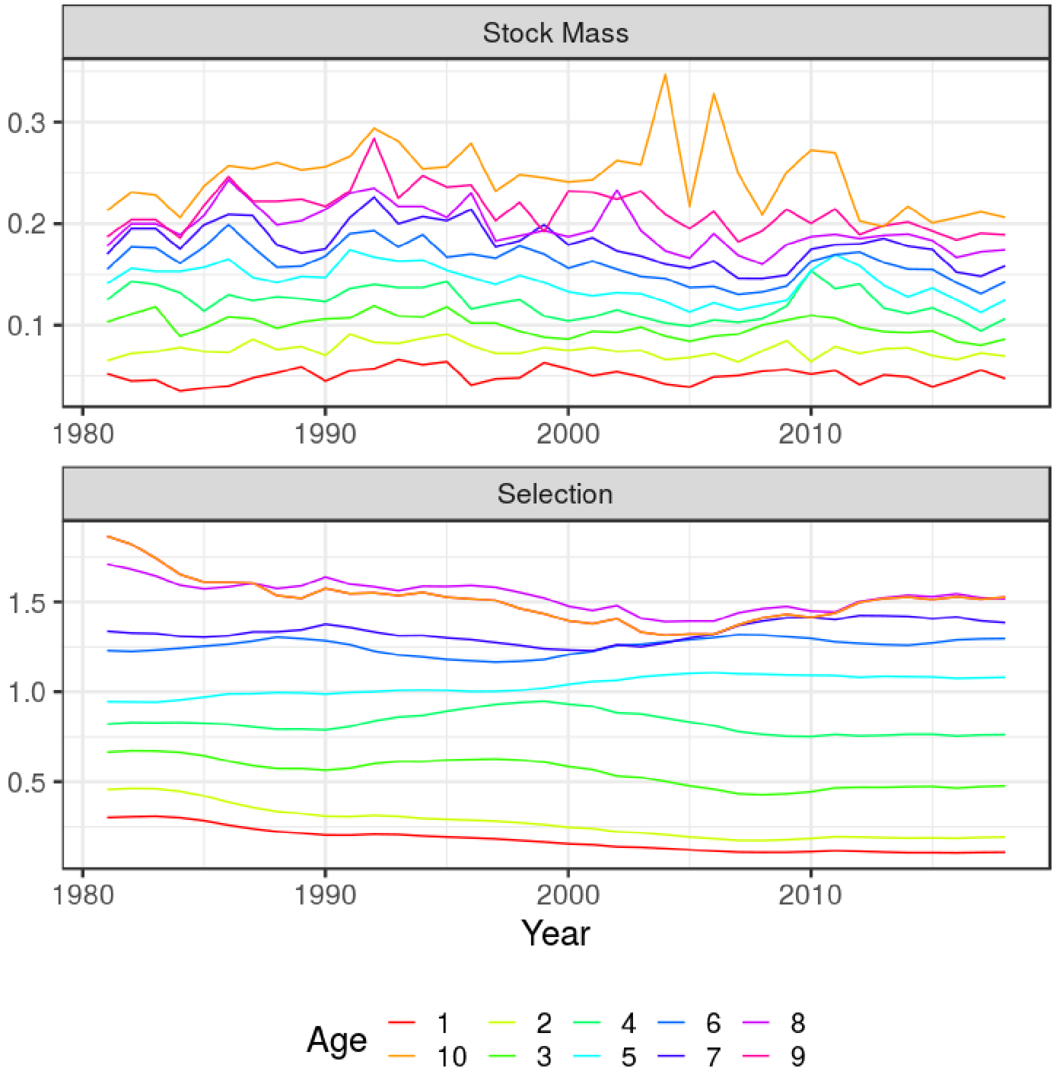

Figure 7 Stock mass, catch mass, maturity, natural mortality and selection pattern at-age

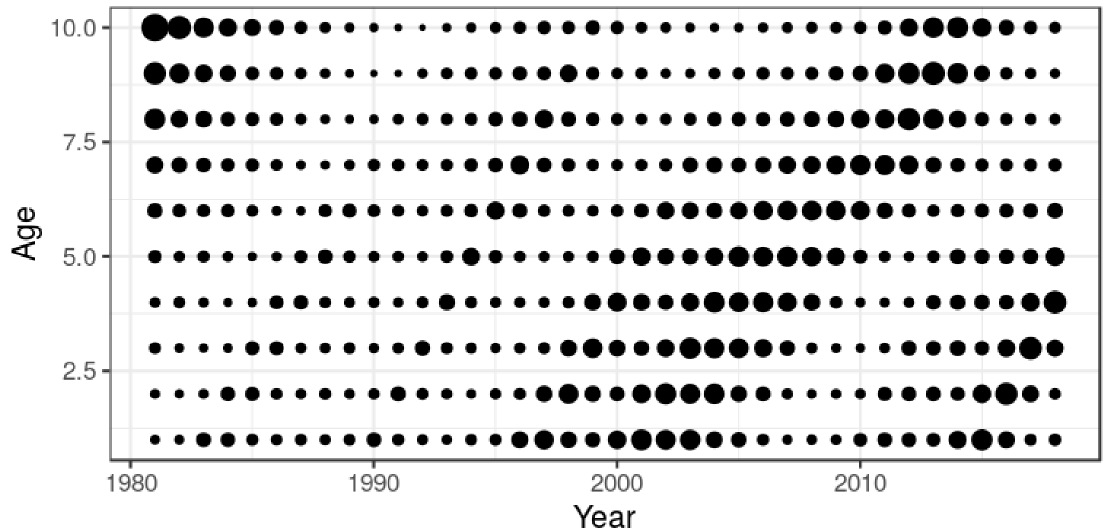

Figure 8 Relative stock numbers-at-age, i.e. numbers at an age scaled by mean numbers

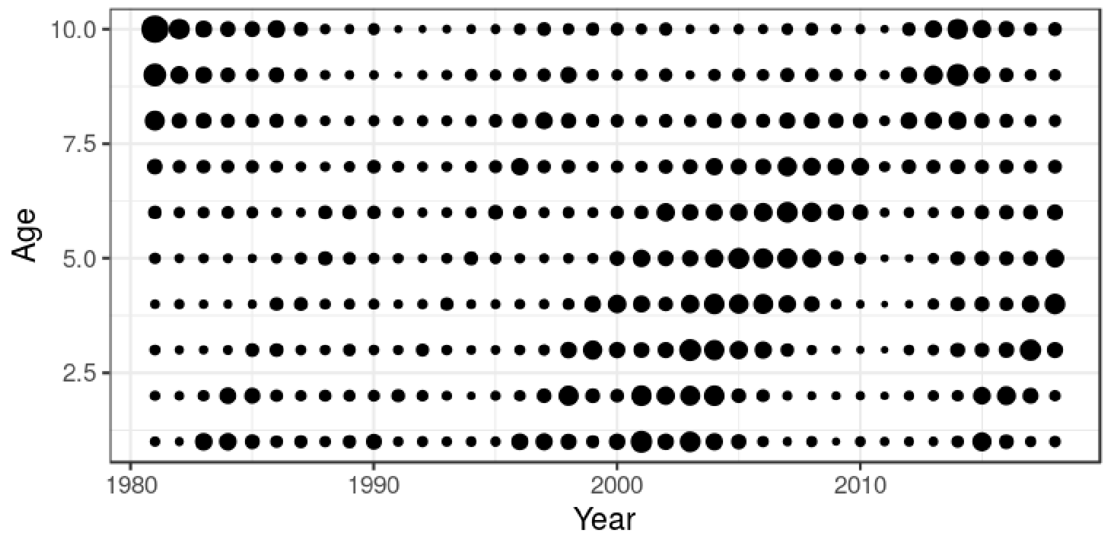

Figure 9 Relative catch numbers-at-age, i.e. numbers at an age scaled by mean numbers

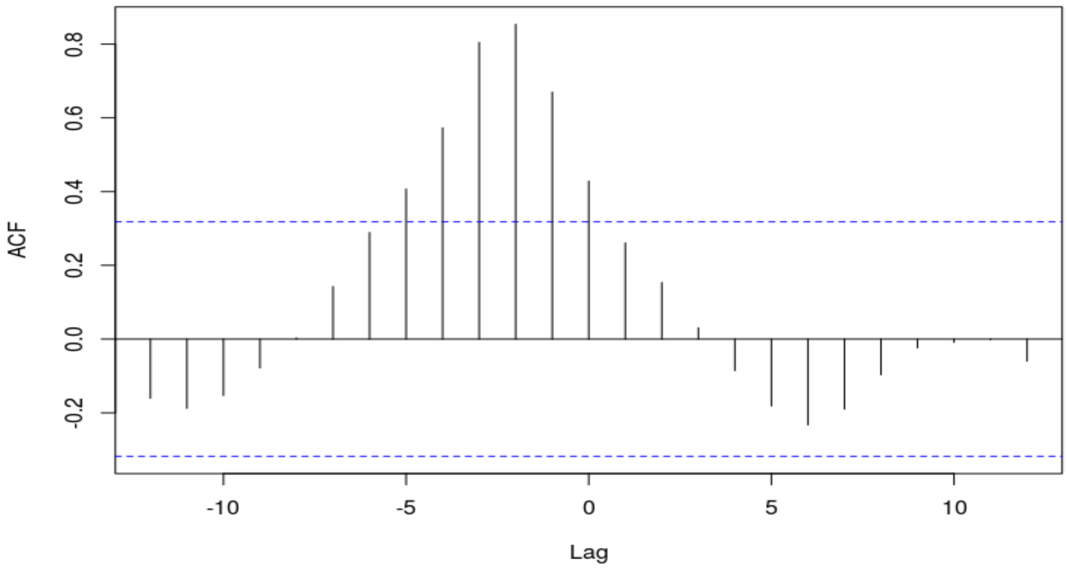

Figure 10 Cross correlations between **SSB** and **recruitment at age 1**, a positive lag of 1 would indicate the presence of a stock recruitment relationship, while a negative lag indicates that SSB is determined by past recruitment

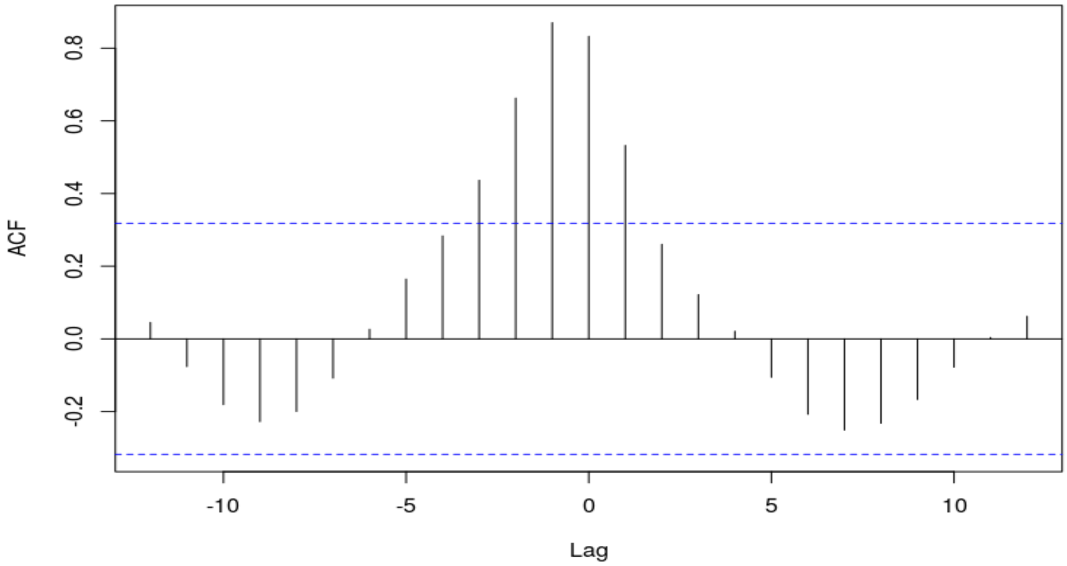

Figure 11 Cross correlations between **exploitable biomass** and **recruitment at age** 1, a positive lag of 1 would indicate the presence of a stock recruitment relationship, while a negative lag indicates that SSB is determined by past recruitment

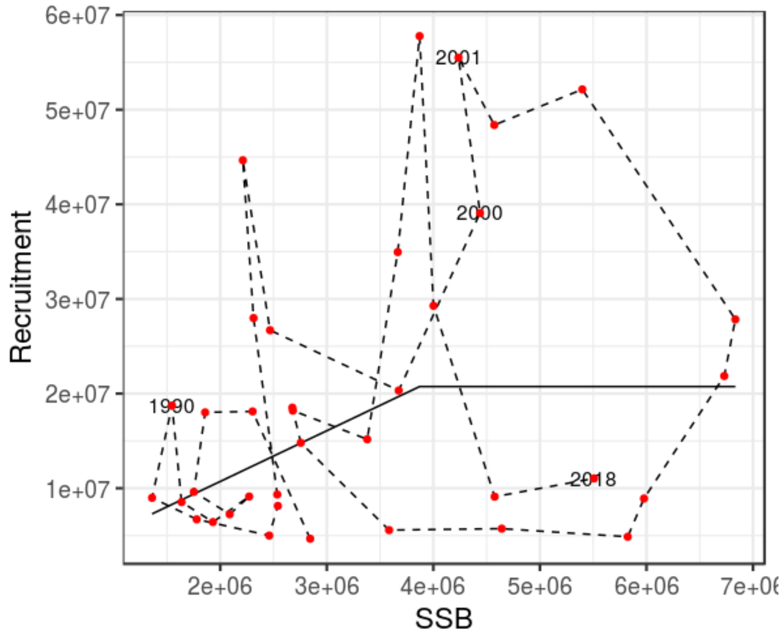

Figure 12 Estimates of SSB and recruitment with fitted segmented regression stock recruitment relationship

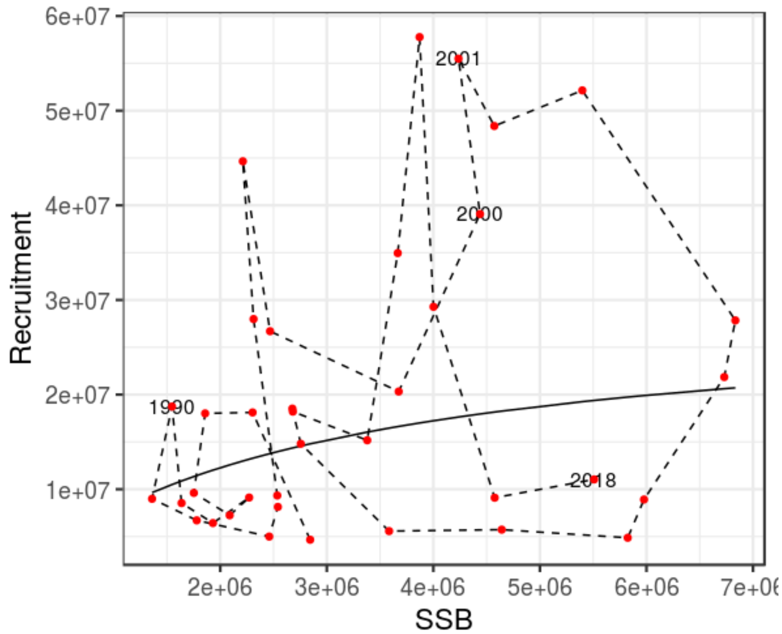

Figure 13 Estimates of SSB and recruitment with fitted Beverton and Holt stock recruitment relationship.

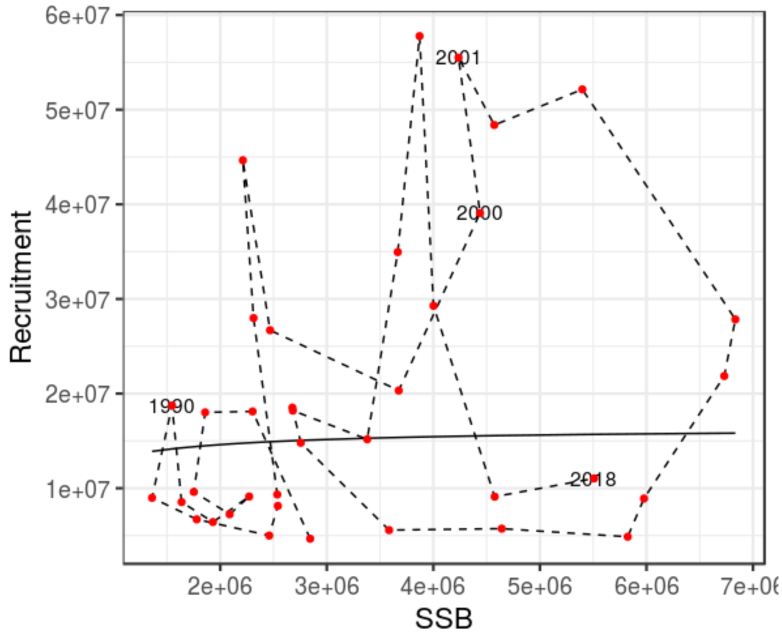

Figure 14 Estimates of SSB and recruitment with fitted Beverton and Holt stock recruitment relationship with a fixed steepness of 0.9

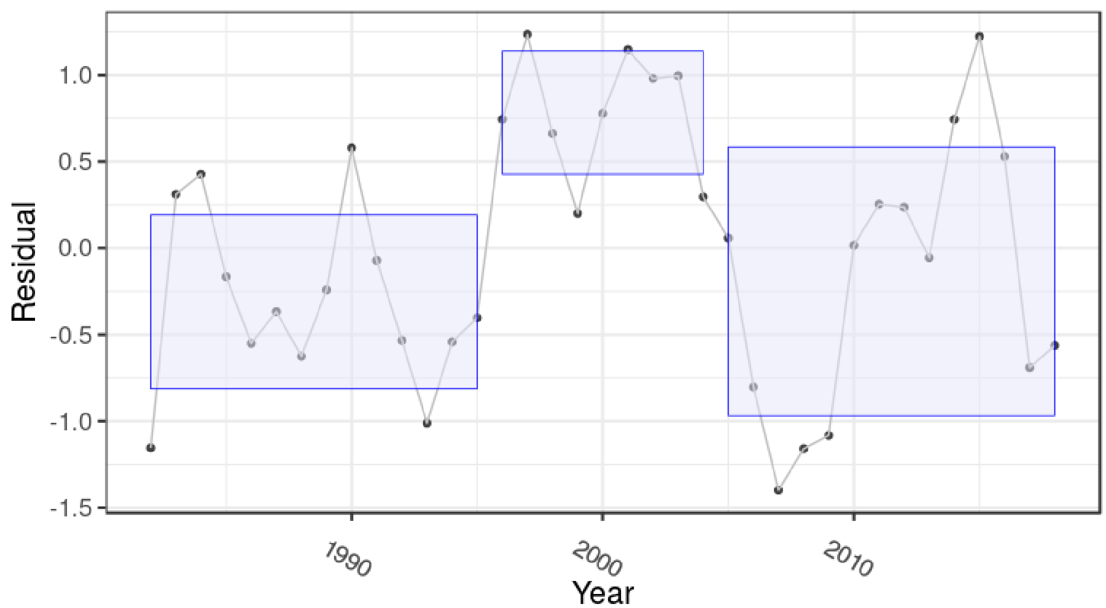

Figure 15 Recruitment deviates for Beverton and Holt stock recruitment relationship, with regimes estimated by STARS algorithm showing changes in mean and variance.

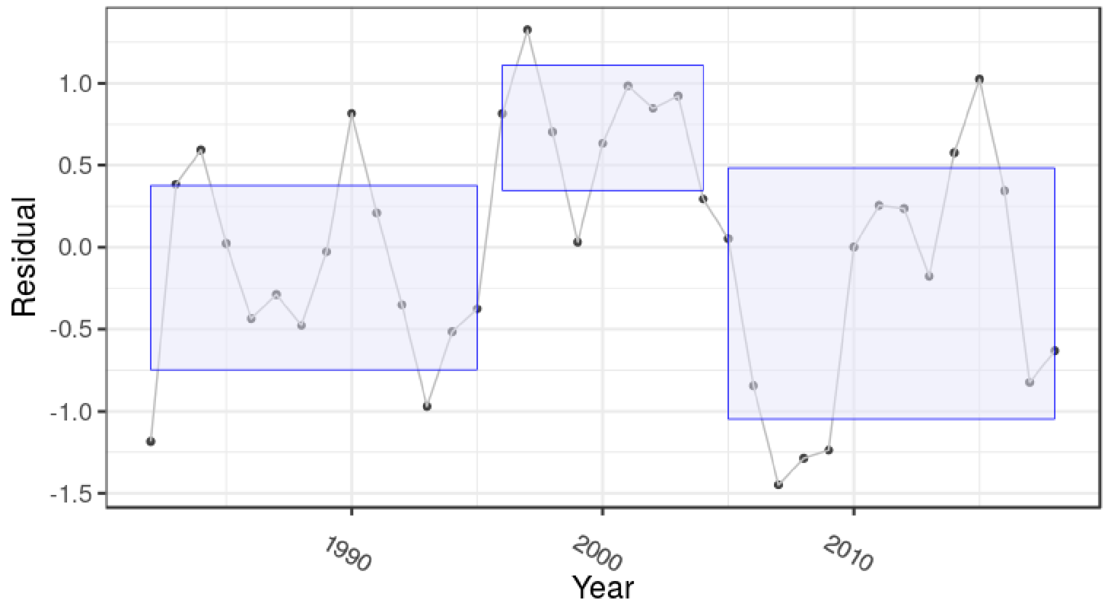

Figure 16 Recruitment deviates for segmented regression stock recruitment relationship, with regimes estimated by STARS algorithm showing changes in mean and variance.

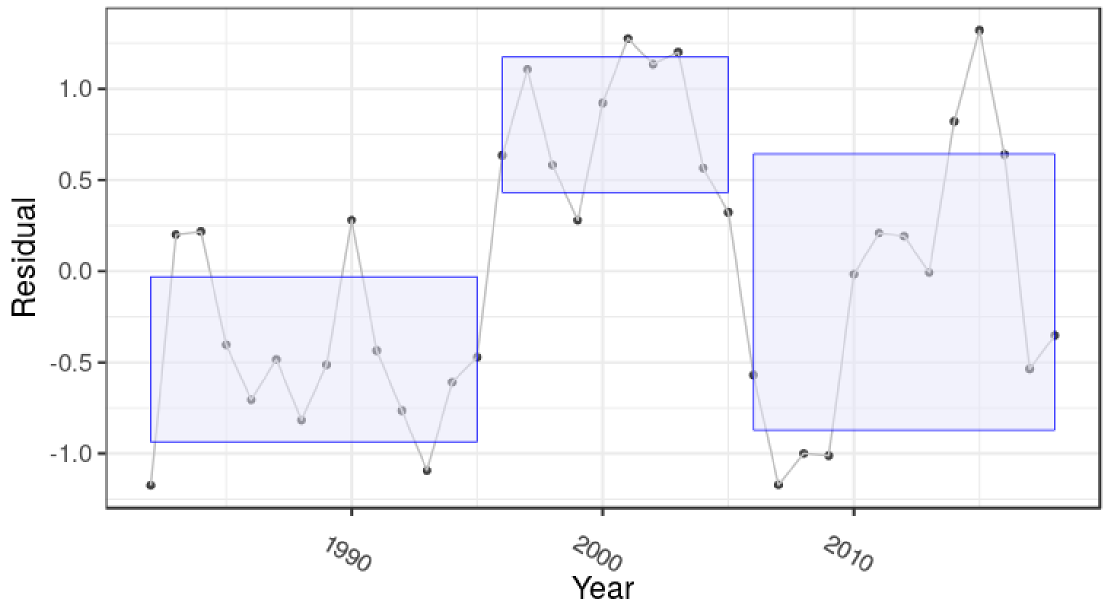

Figure 17 Recruitment deviates for Beverton and Holt stock recruitment relationship with steepness fixed at 0.9, with regimes estimated by STARS algorithm showing changes in mean and variance.

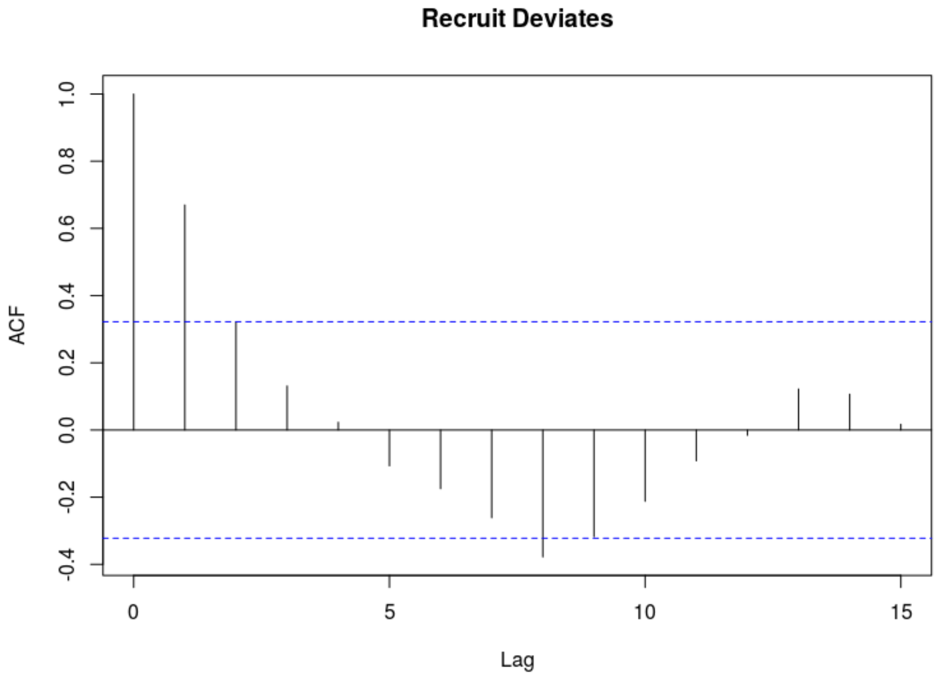

Figure 18 Autocorrelation in recruitment deviates.

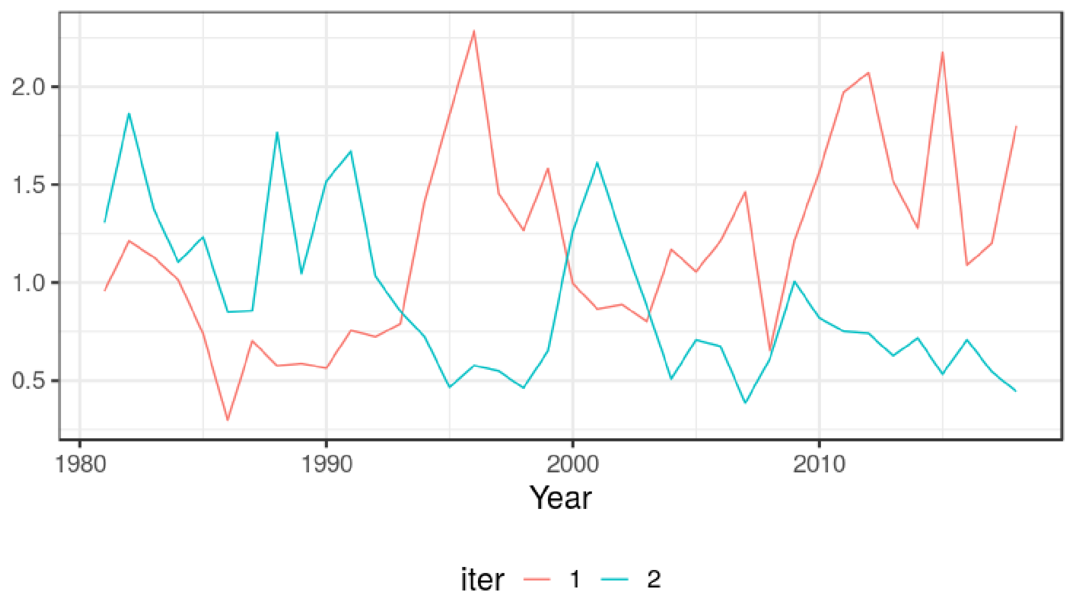

Figure 19 An example of simulated recruitment deviates with autocorrelation.

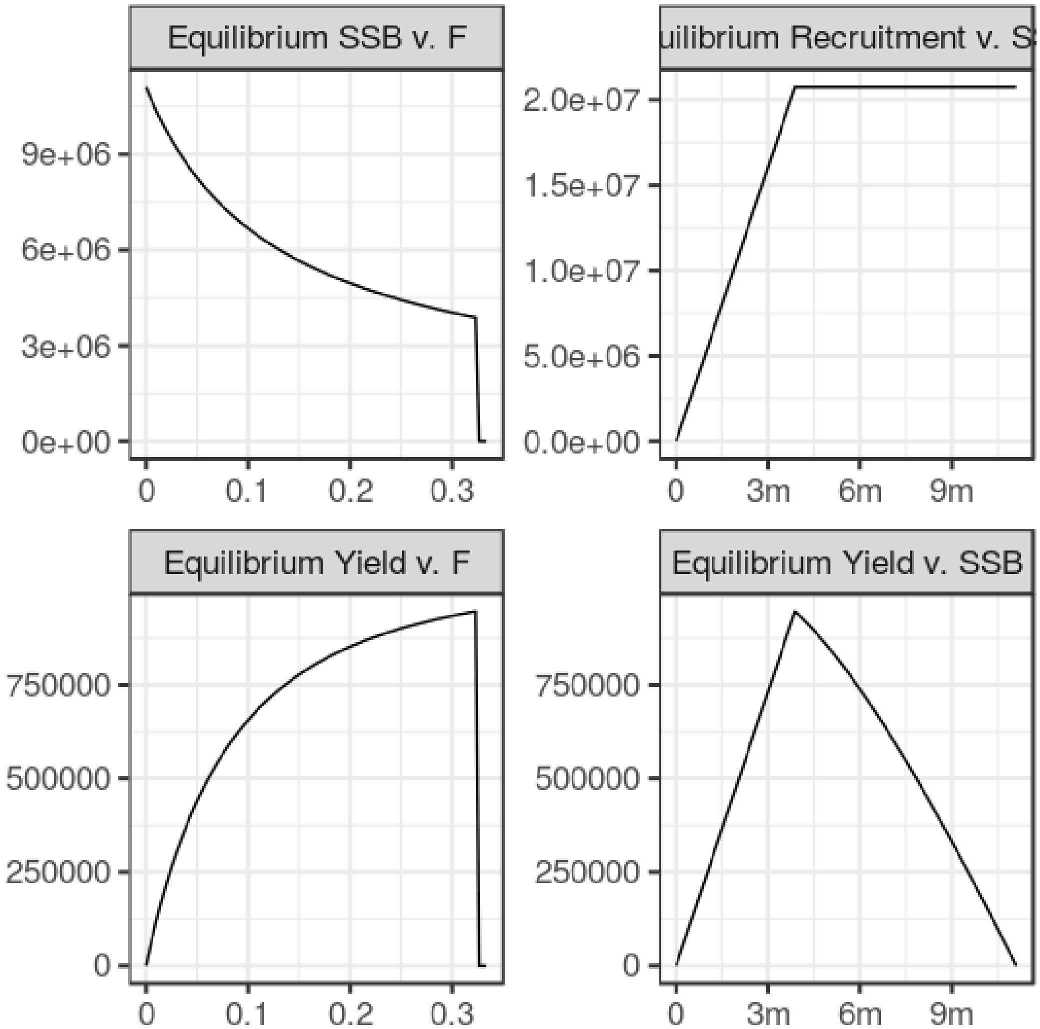

Figure 20 Biological reference points based on the Beverton and Holt stock recruitment relationship.

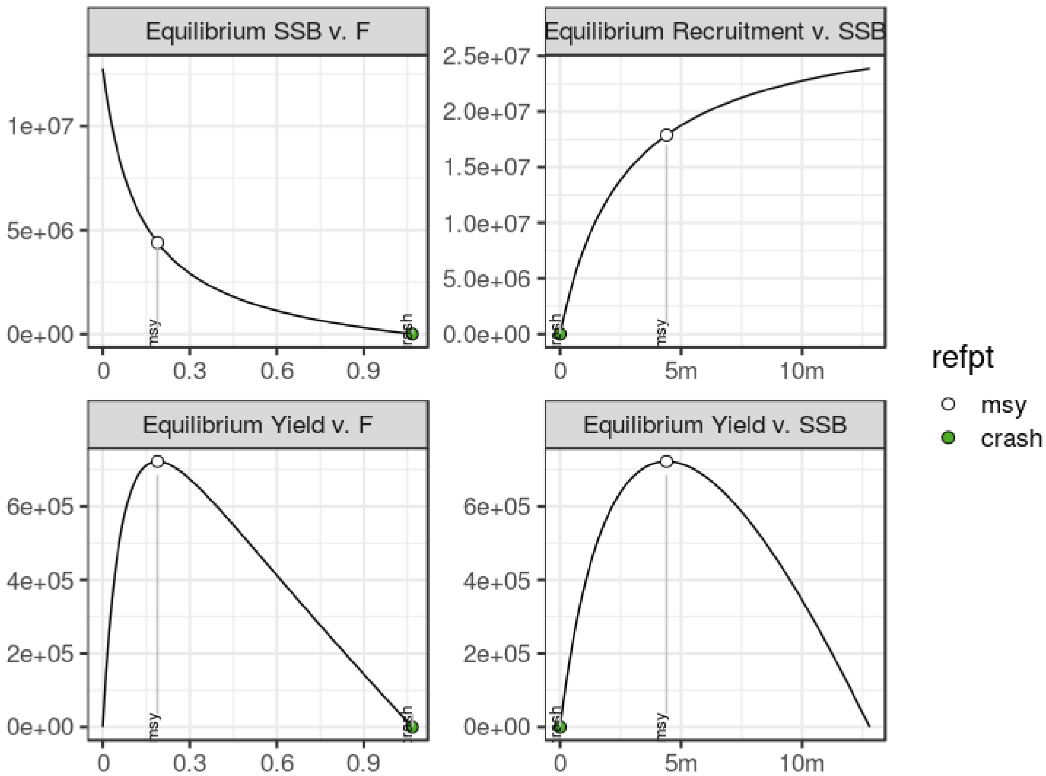

Figure 21 Biological reference points based on the fitted segmented regression stock recruitment relationship.

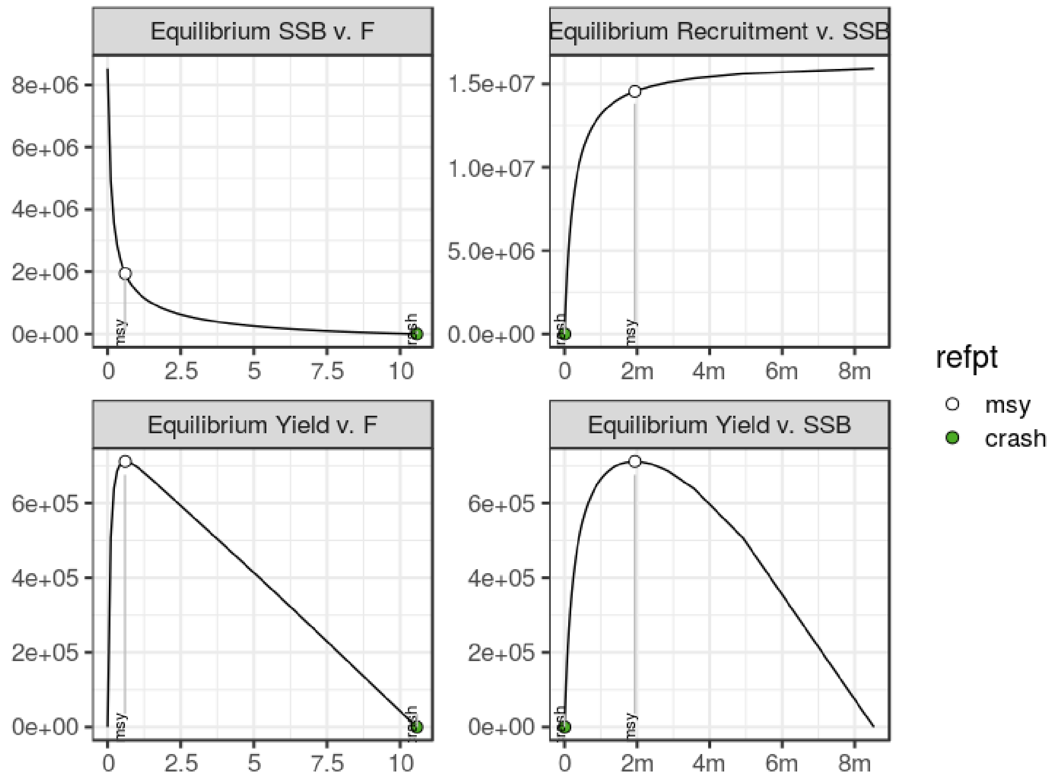

Figure 22 Biological reference points based on the Beverton and Holt stock recruitment relationship with steepness fixed at 0.9.

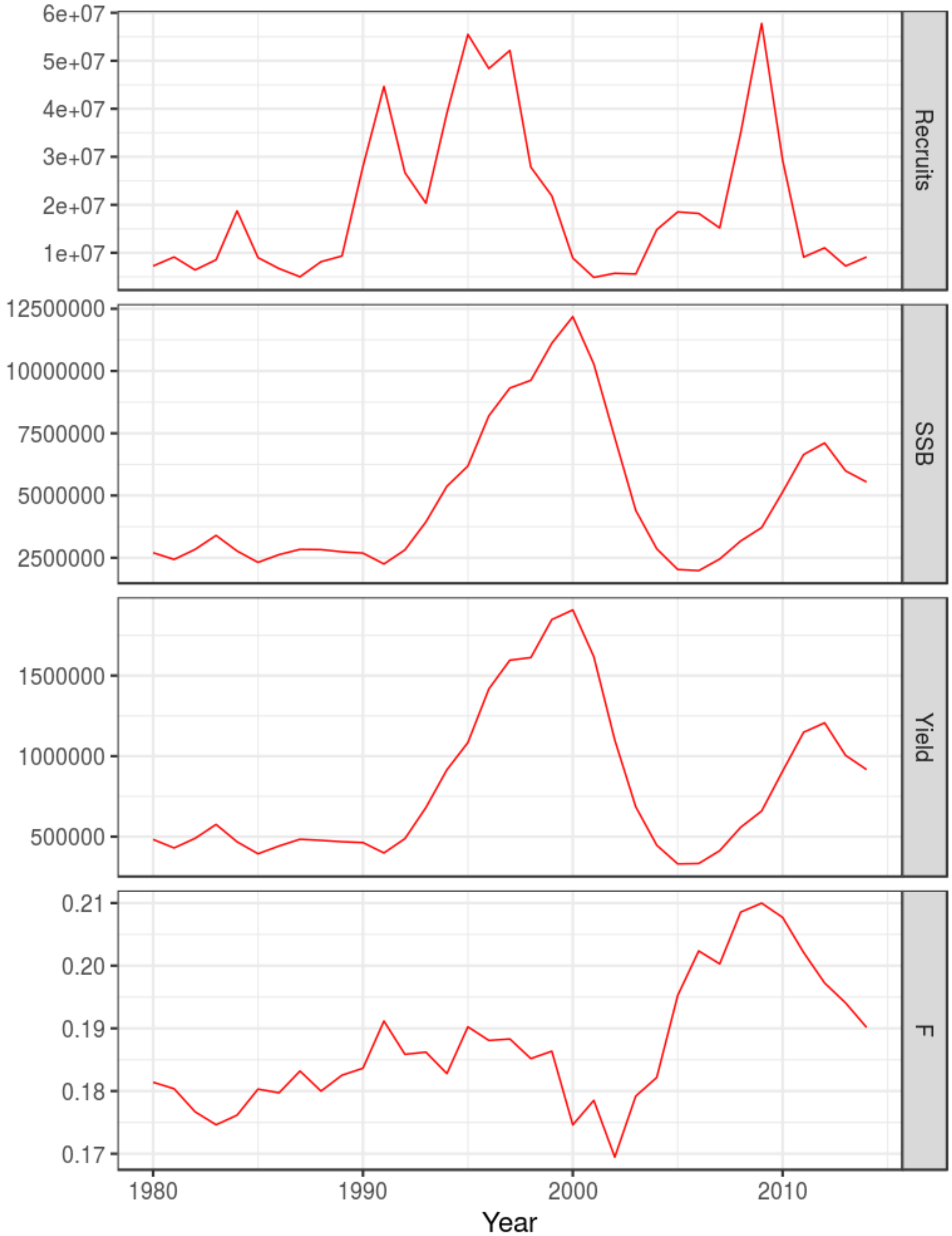

Figure 23 F0.1 proxy for Fmsy reference point calculated with a three year moving window

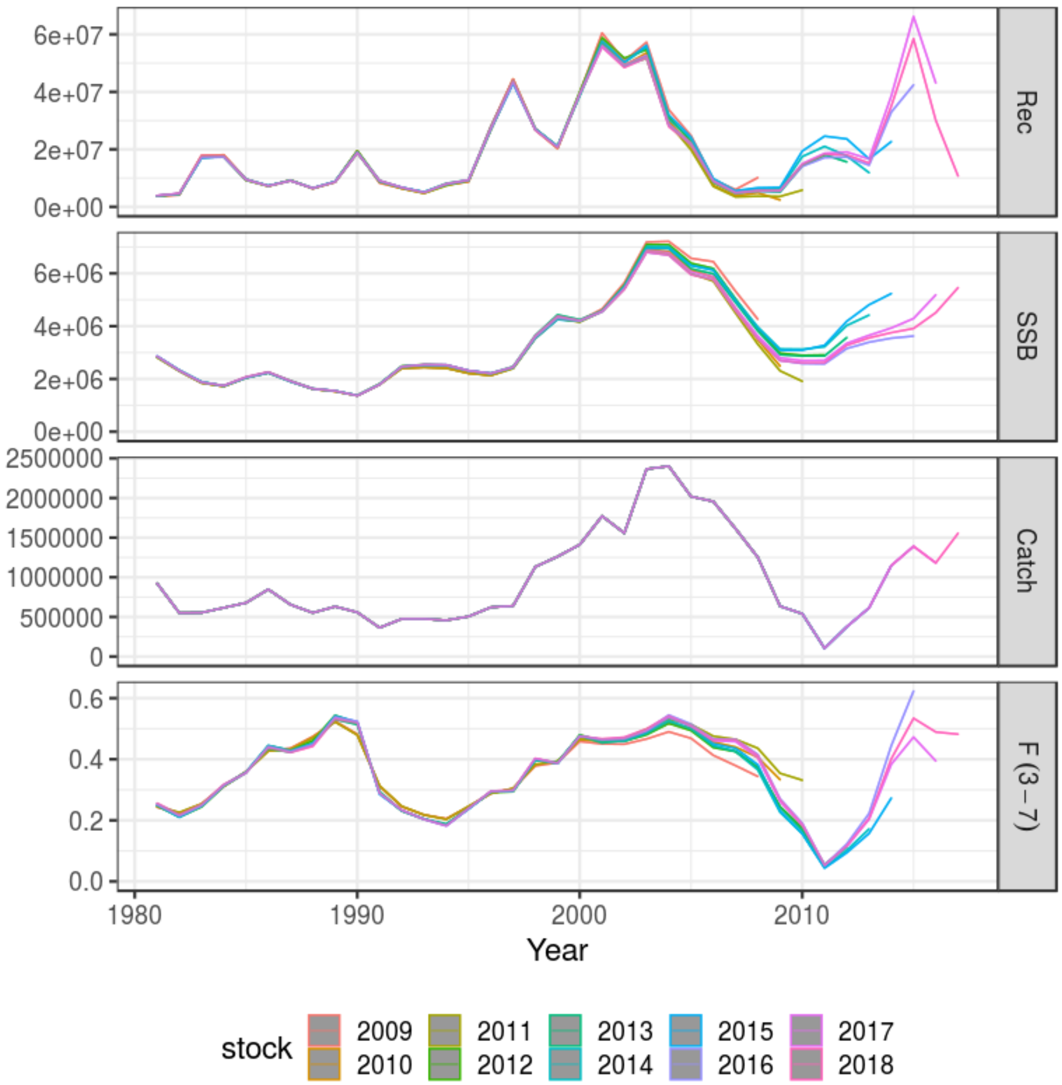

Figure 24 Retrospective estimates of time series of catch, recruitment, spawning stock biomass and fishing mortality from the 2018 stock assessment.

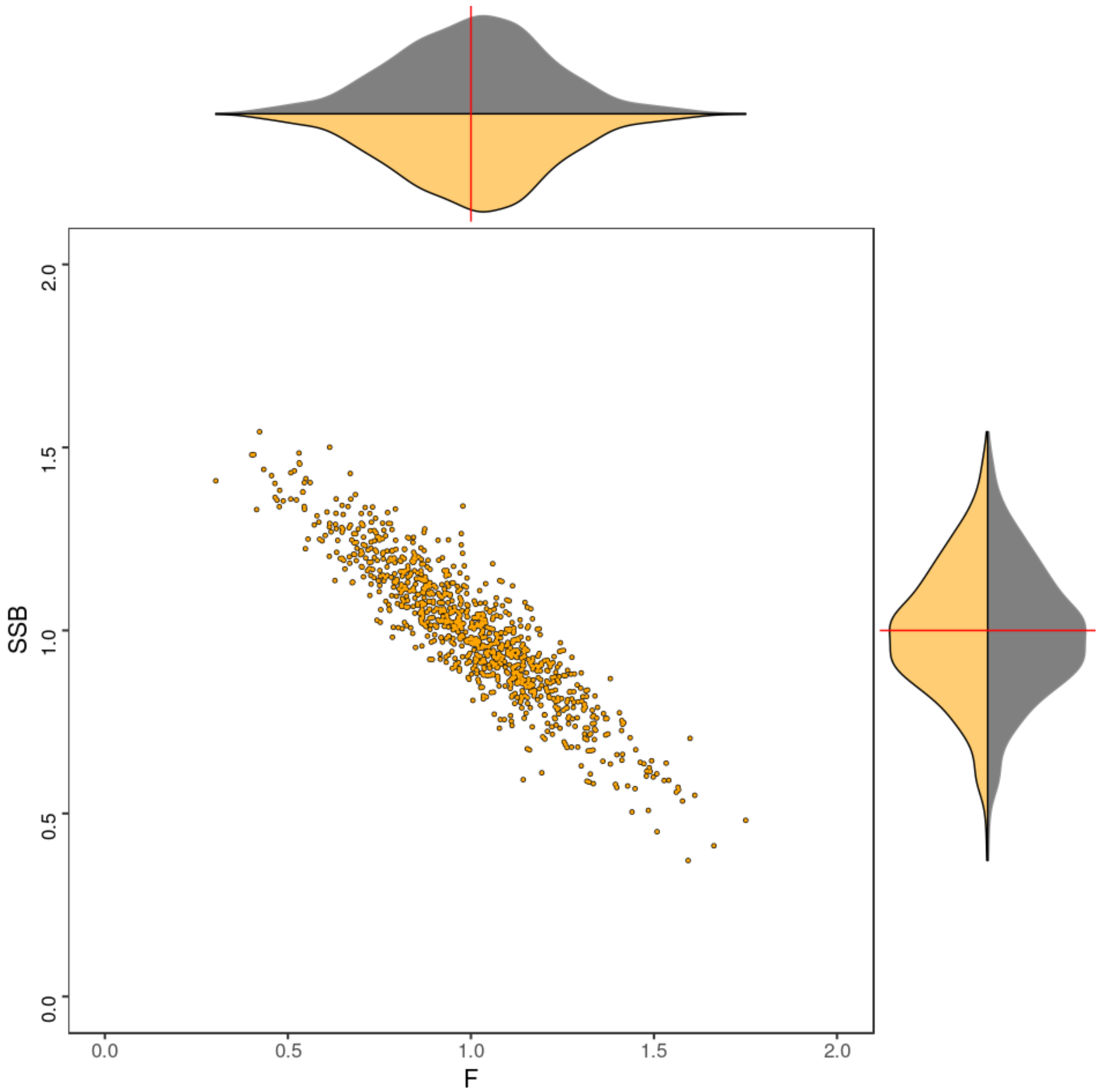

Figure 25 Assessment error in SSB and F derived from the retrospective runs.

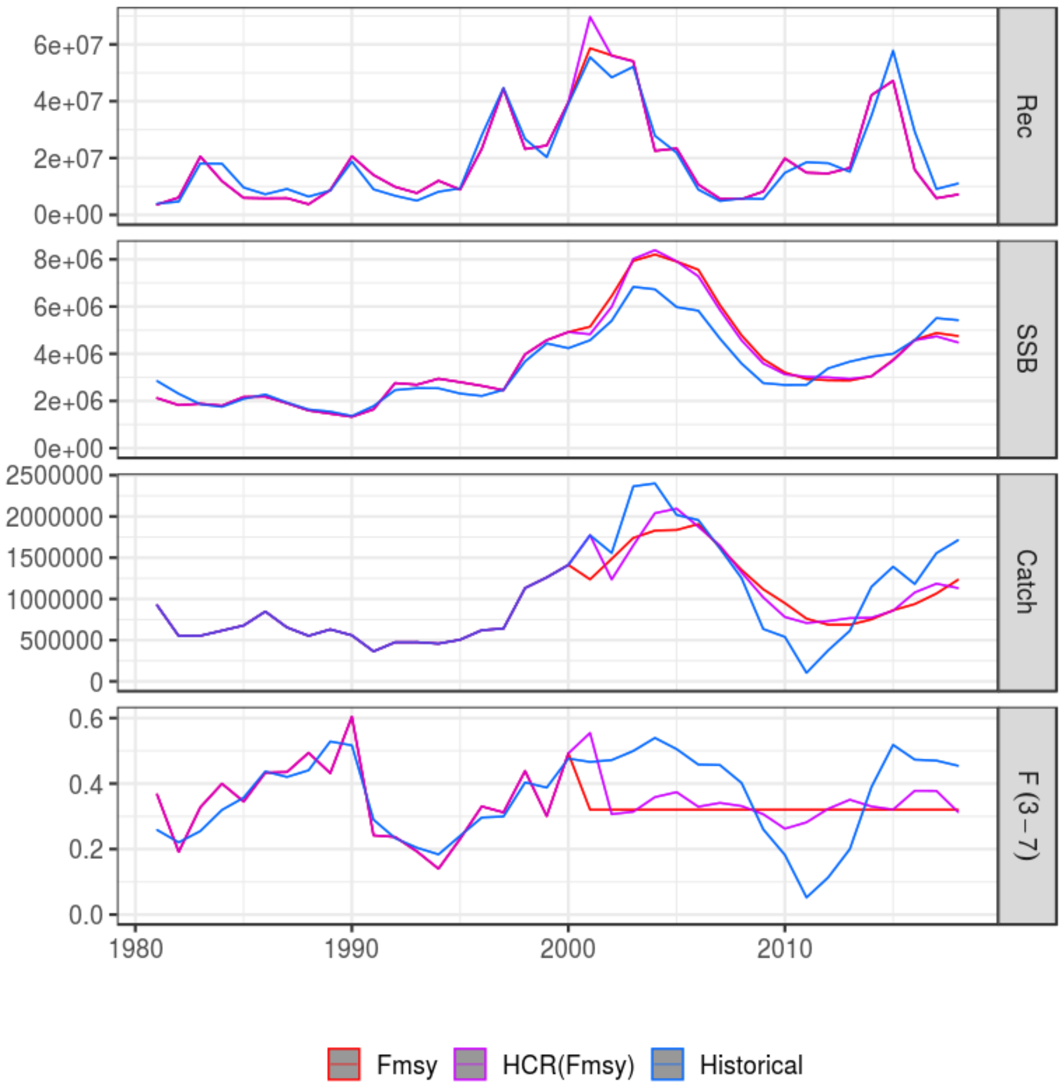

Figure 26 Comparison between historical assessment estimates, and a single Monte Carlo realisation for a projection at Fmsy, and HCR1 without assessment error.

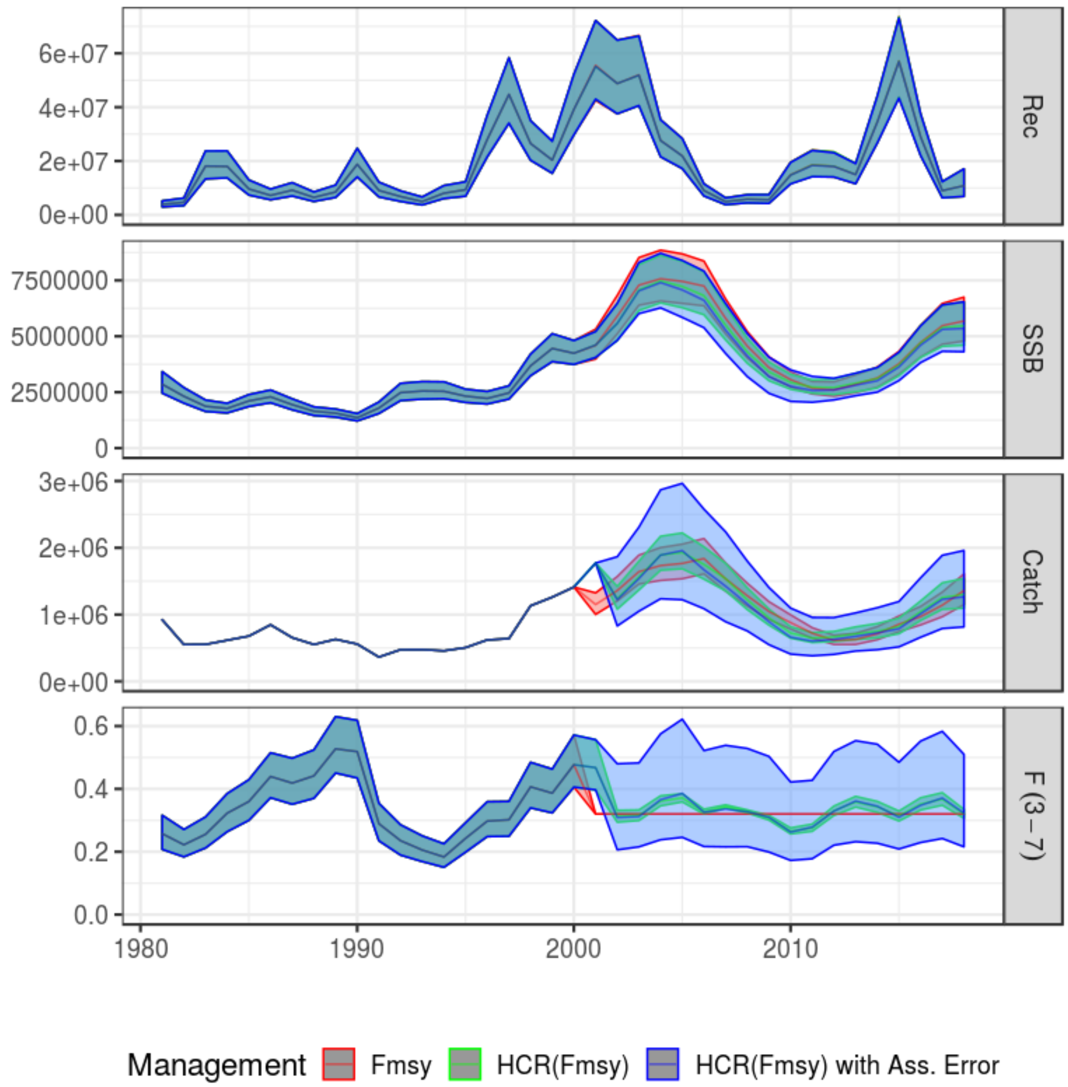

Figure 27 HCR with and without assessment error compared to historical estimates; with median and 10 and 90 percentiles, the hatched line is a single Monte Carlo realisation.

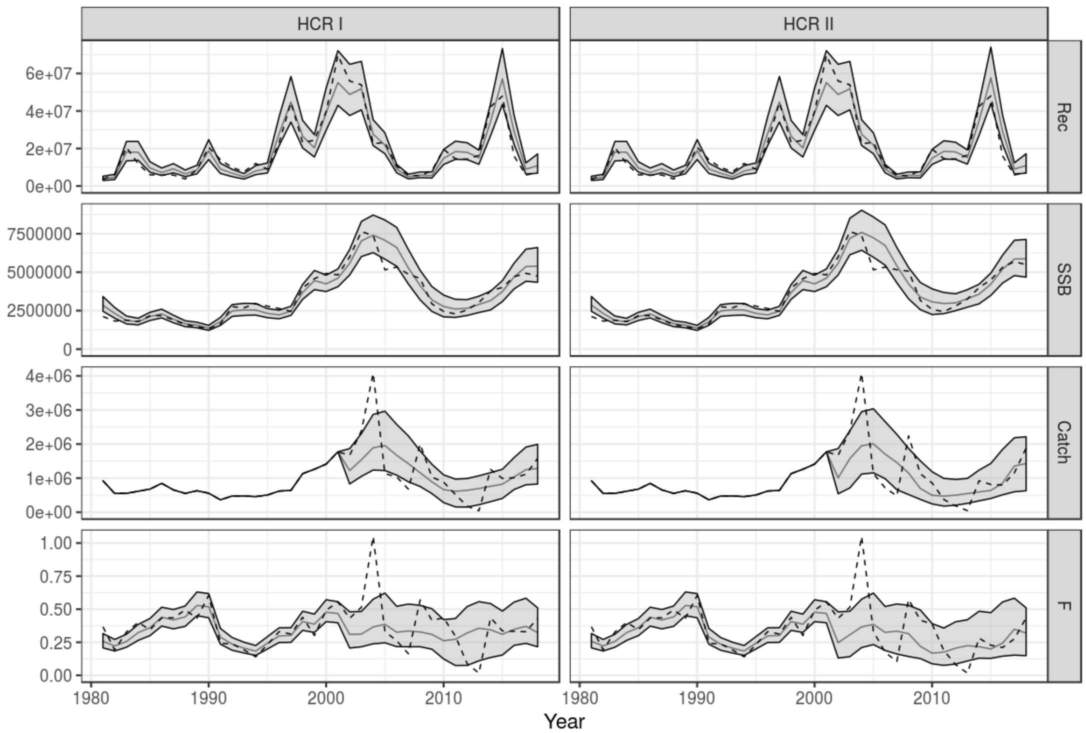

Figure 28 Comparison between HCR I & II with assessment error; shown with median and 10 and 90 percentiles, the hatched line is a single Monte Carlo realisation.

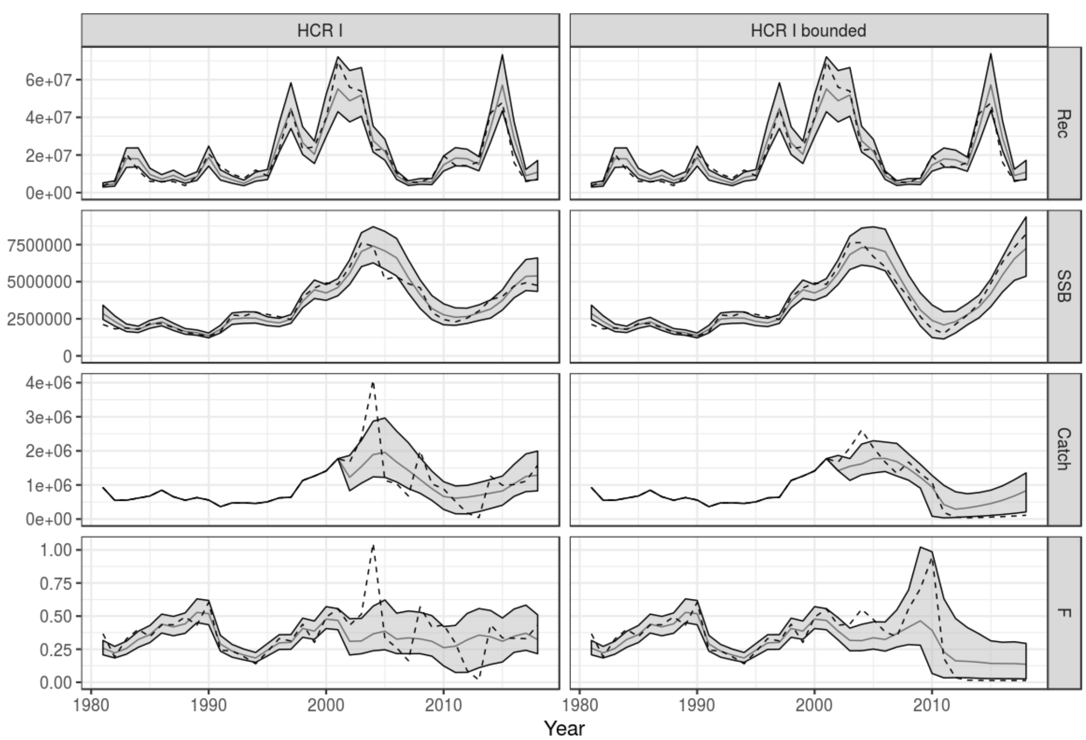

Figure 29 Comparison between HCR I without and with bounds; shown with median and 10 and 90 percentiles, the hatched line is a single Monte Carlo realisation.

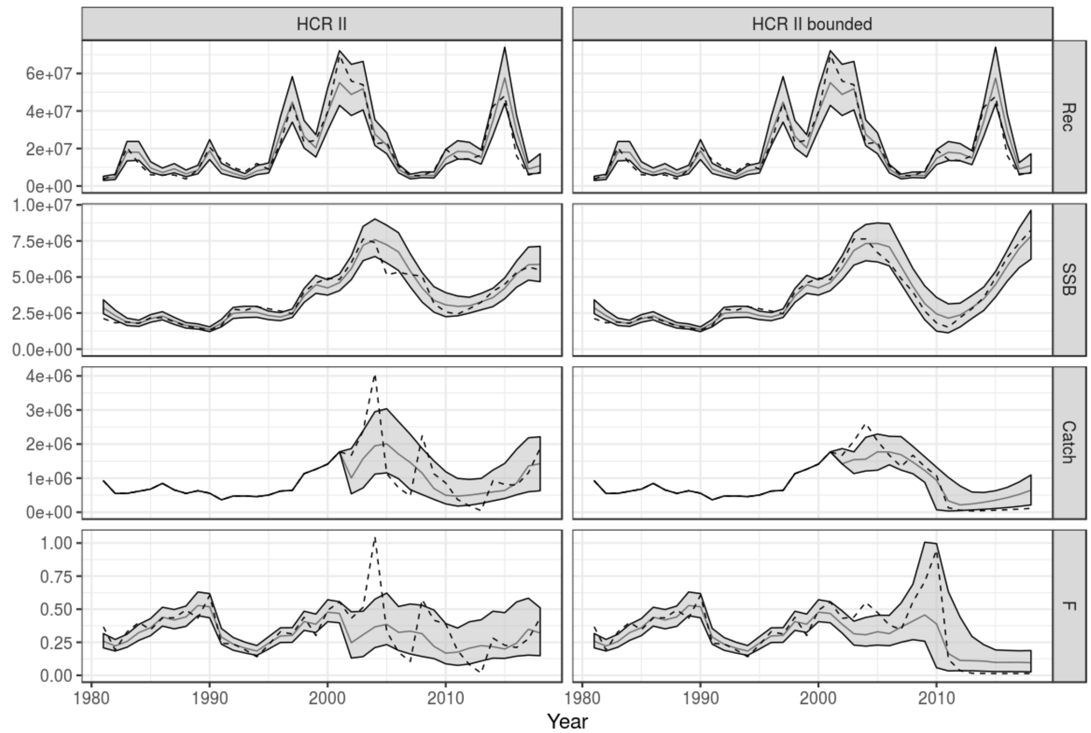

Figure 30 Comparison between HCR II without and with bounds; shown with median and 10 and 90 percentiles, the hatched line is a single Monte Carlo realisation.

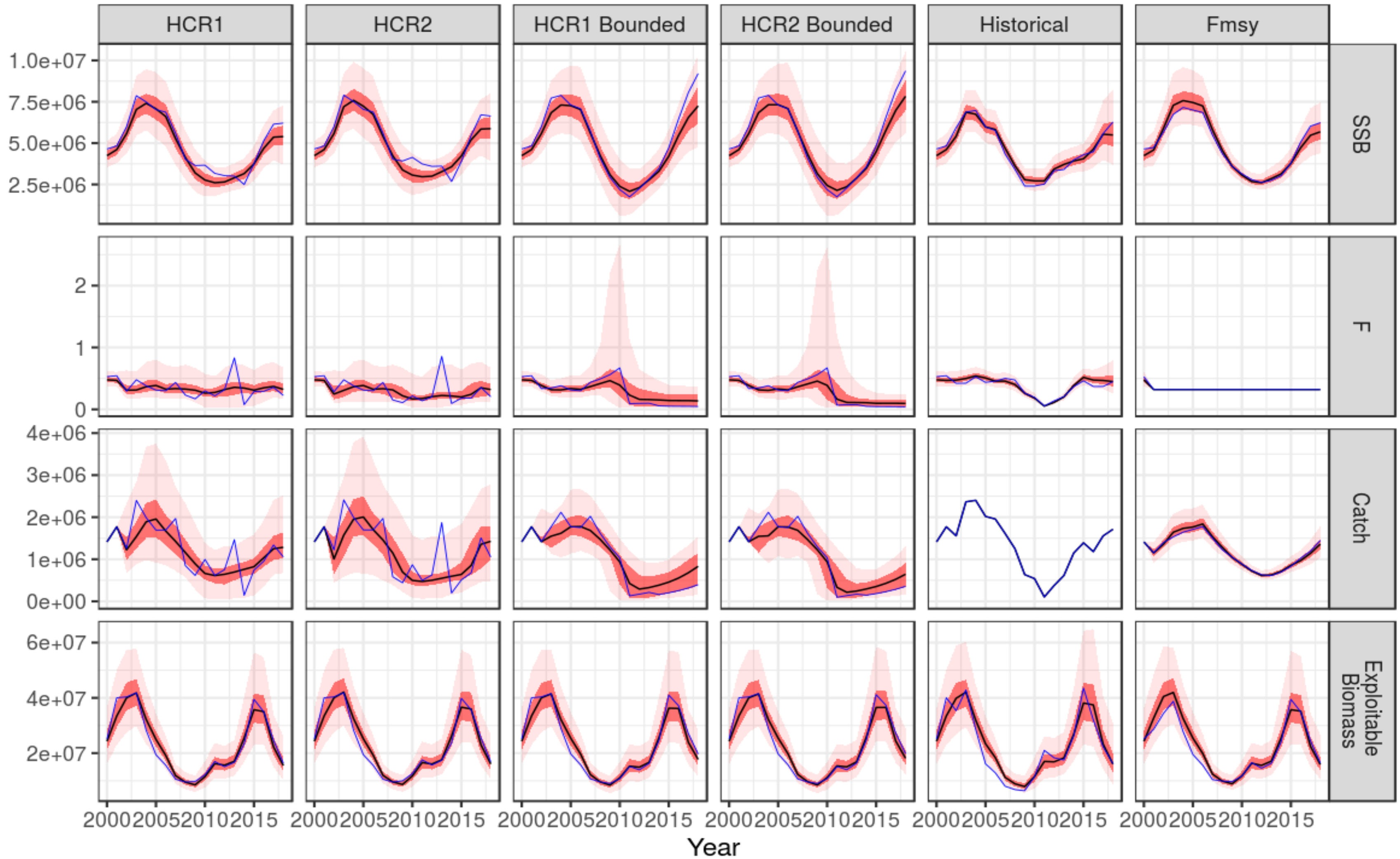

Figure 31 Summary of HCR performance.

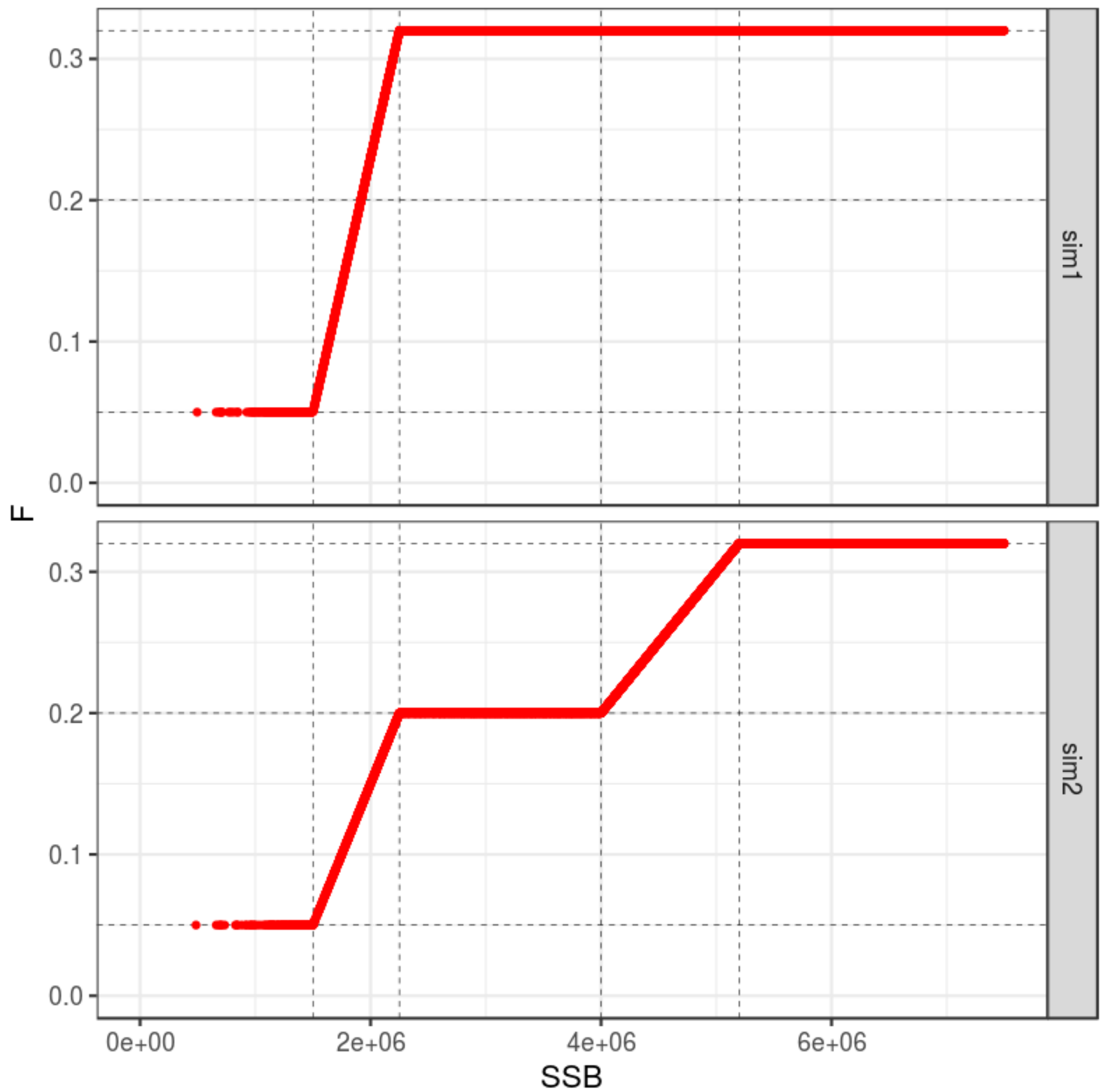

Figure 32 Values of F for assessed SSB from the HCR, as a check that the HCR is working as expected

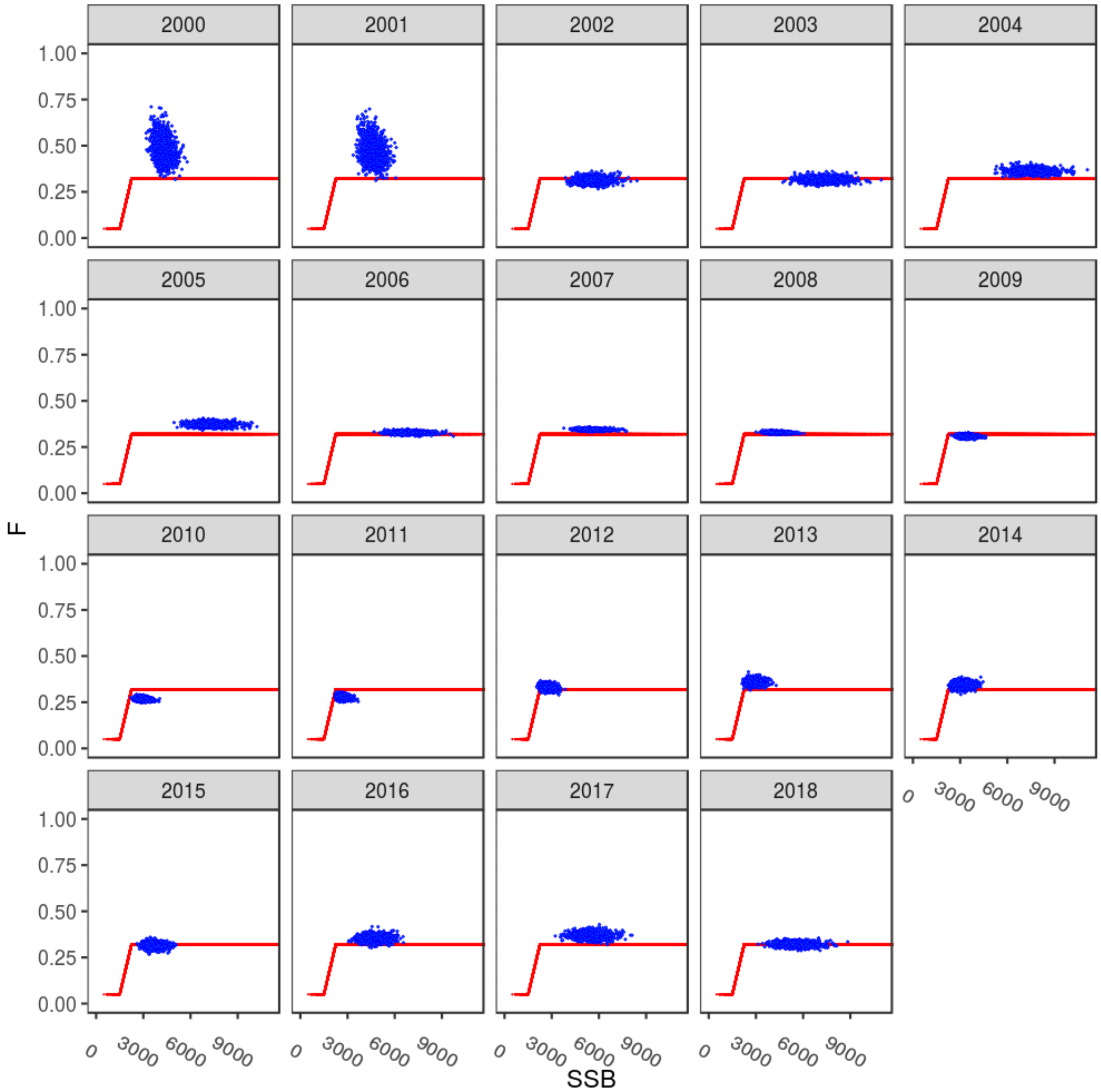

Figure 33 Plot of F v SSB for HCR I without assessment error.

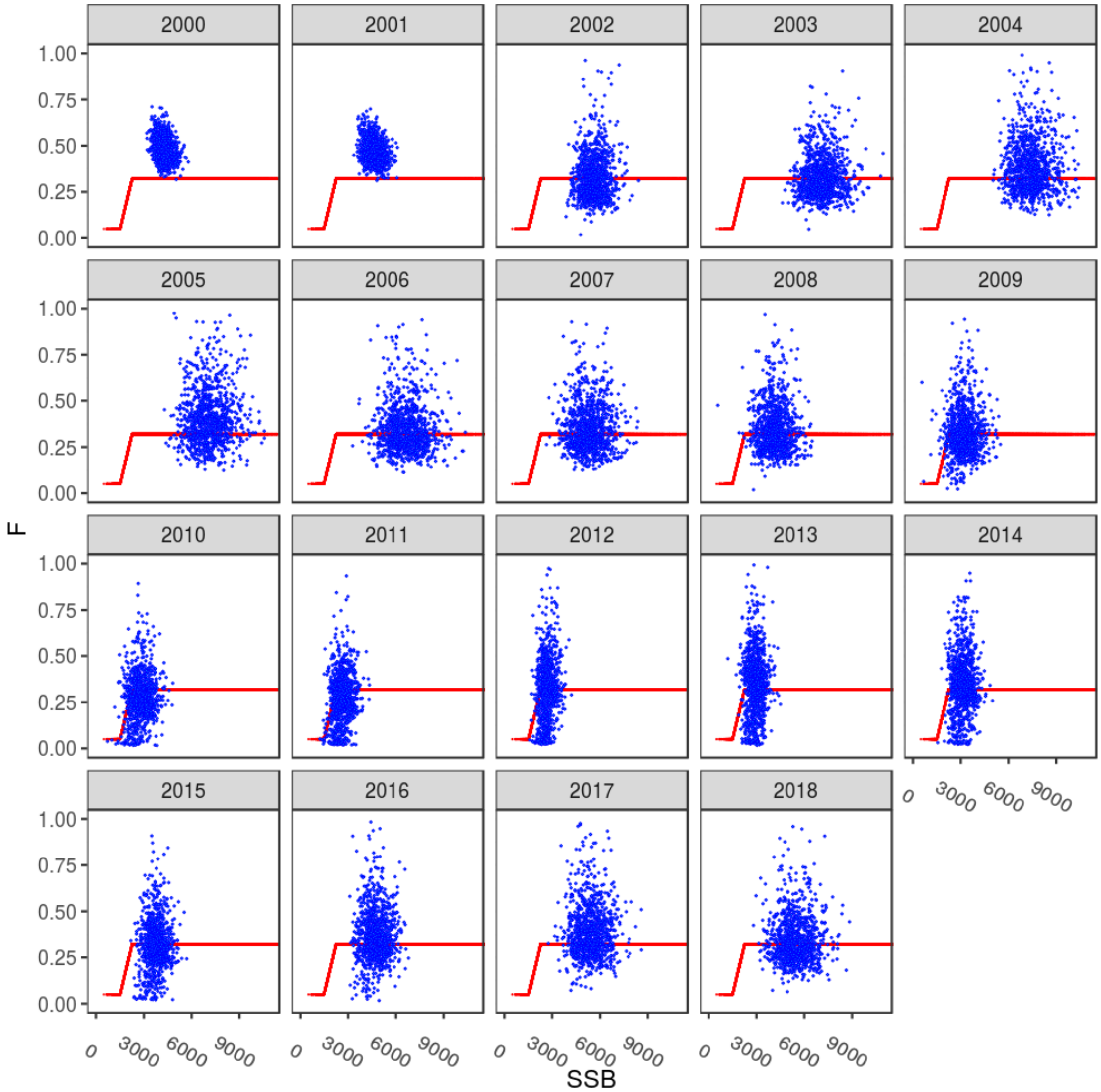

Figure 34 Plot of F v SSB for HCR I.

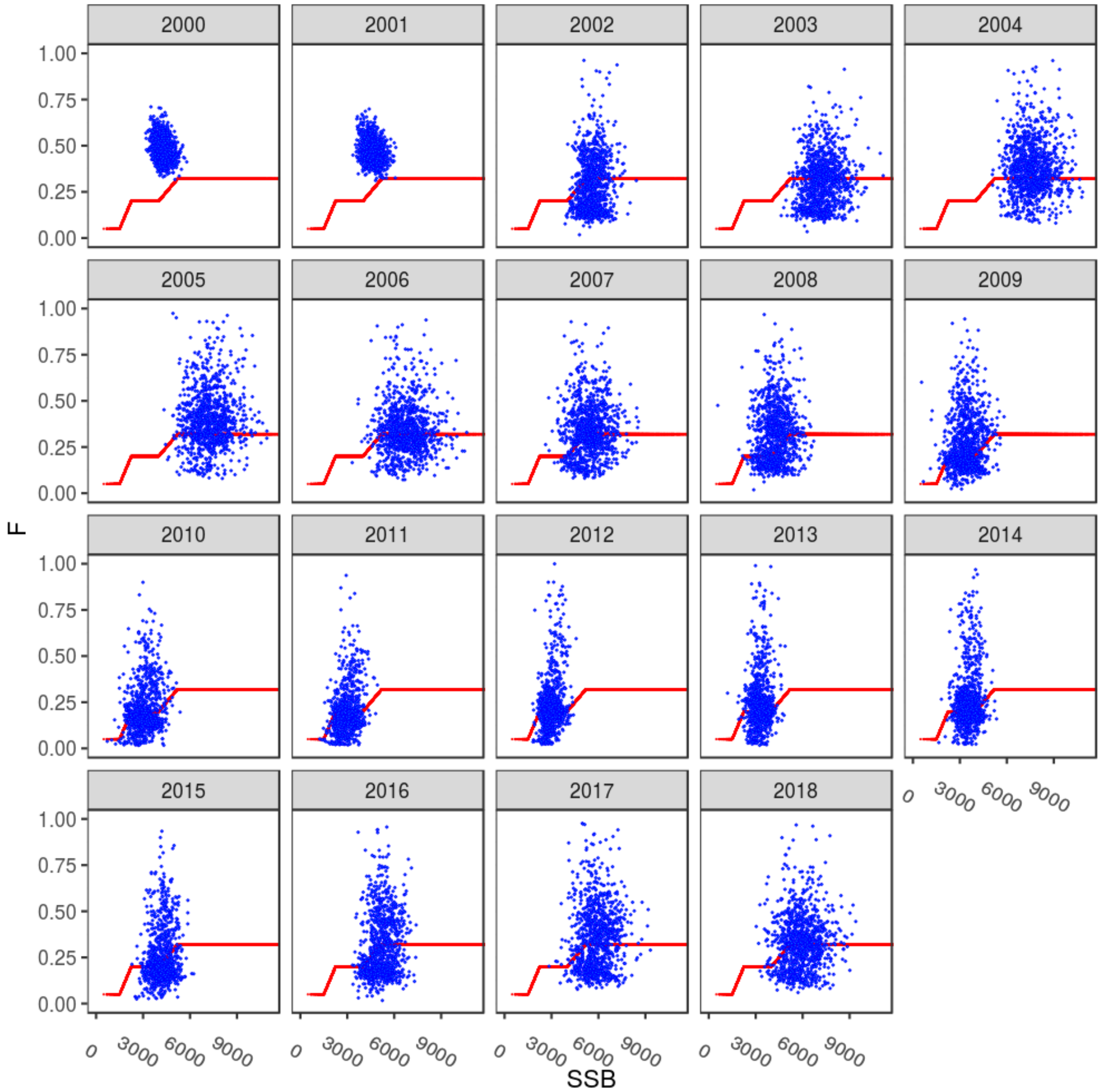

Figure 35 Plot of F v SSB for HCR II.

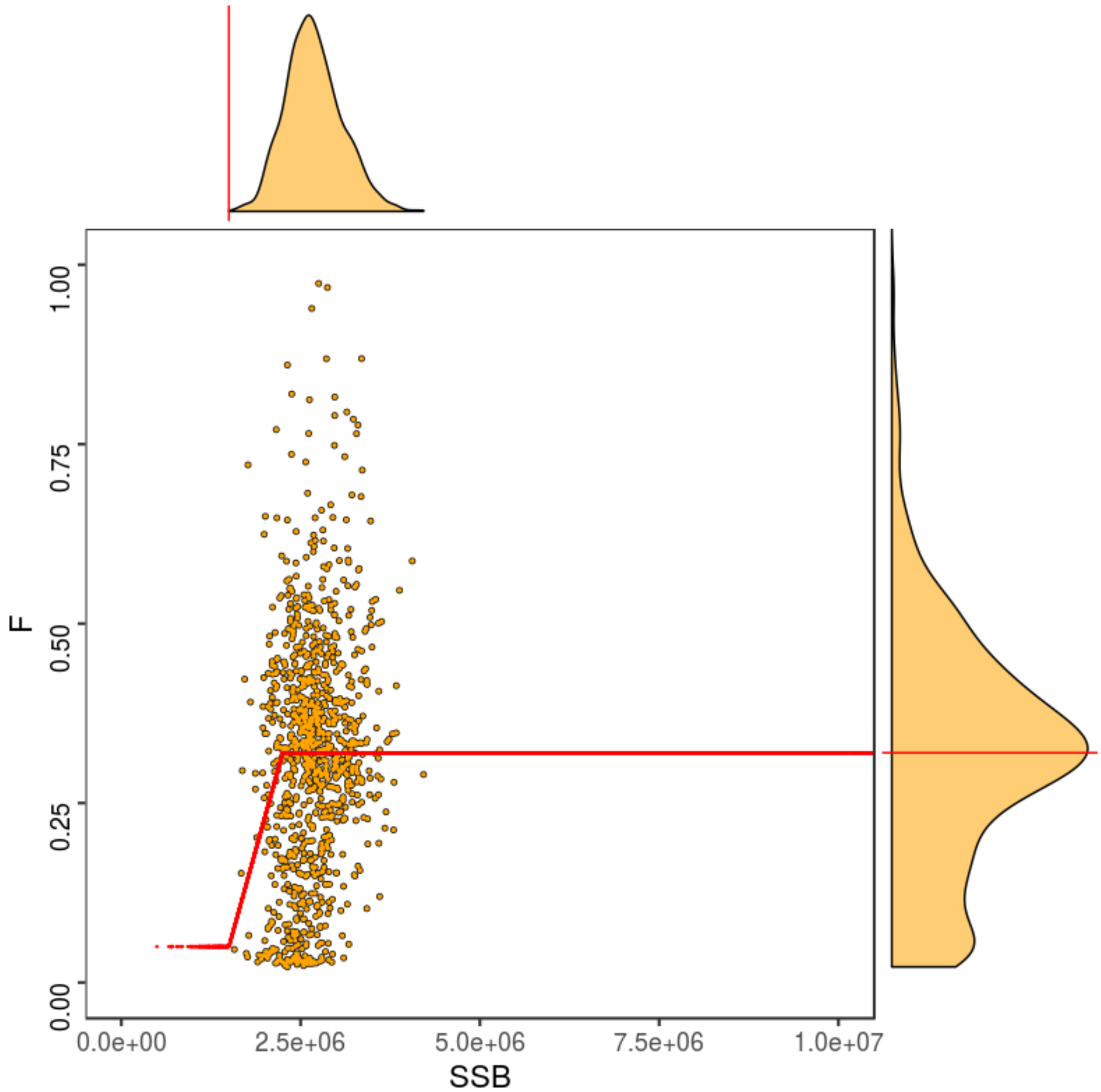

Figure 36 HCR I plot of F v SSB for 2012 with marginal densities

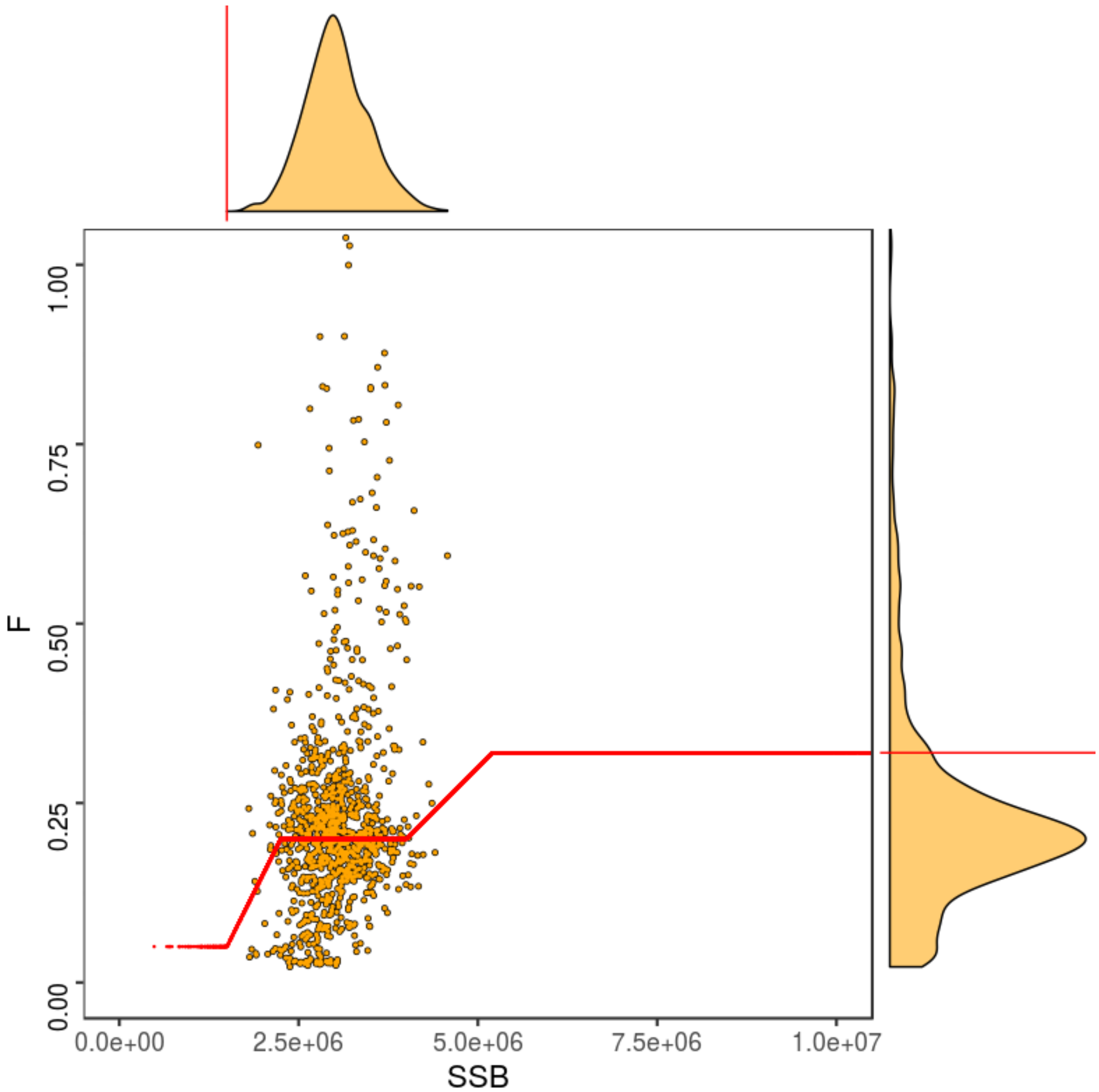

Figure 37 HCR II plot of F v SSB for 2012 with marginal densities

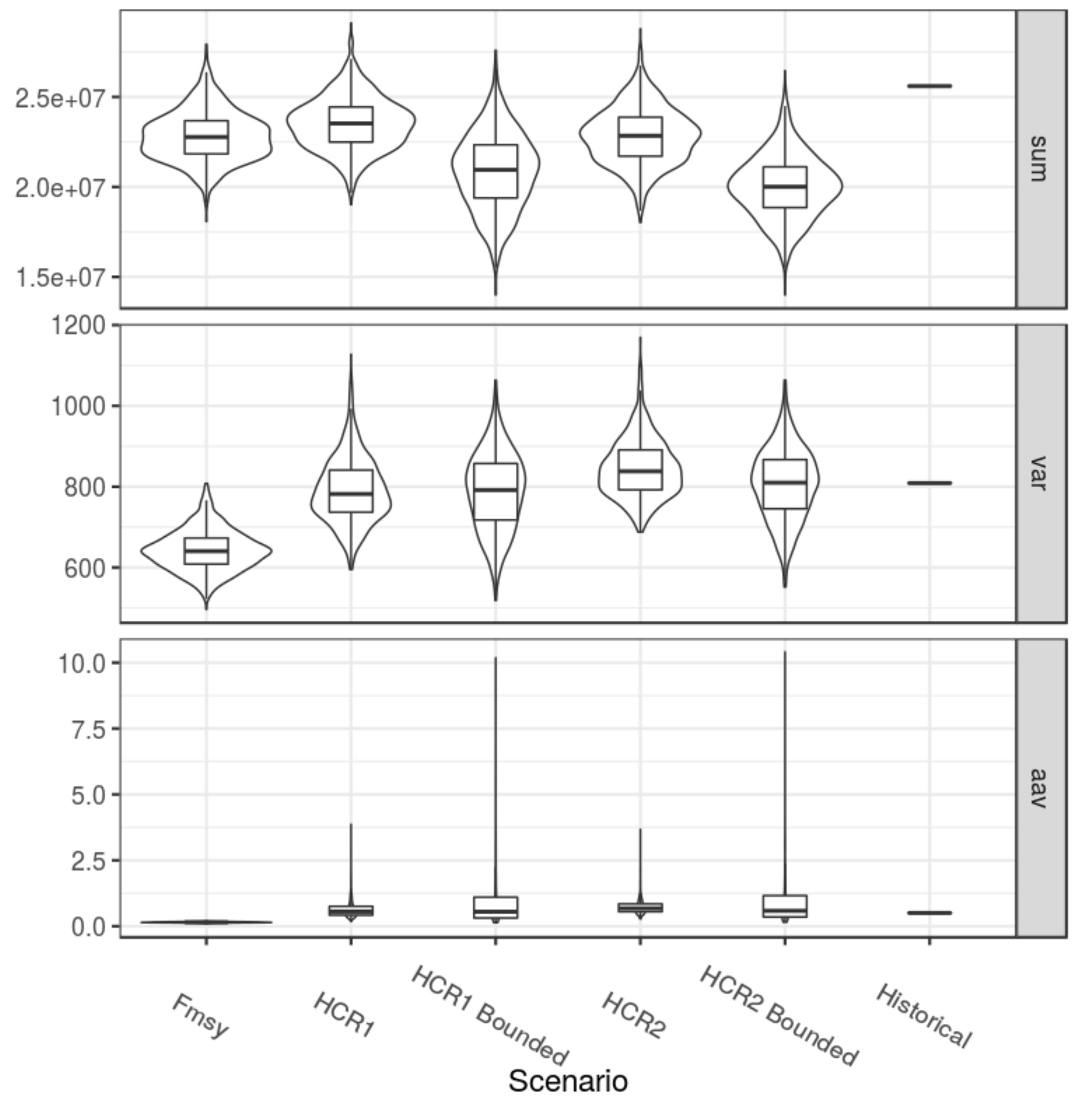

Figure 38 Catch summary, total catch and AAV by iteration over simulated period

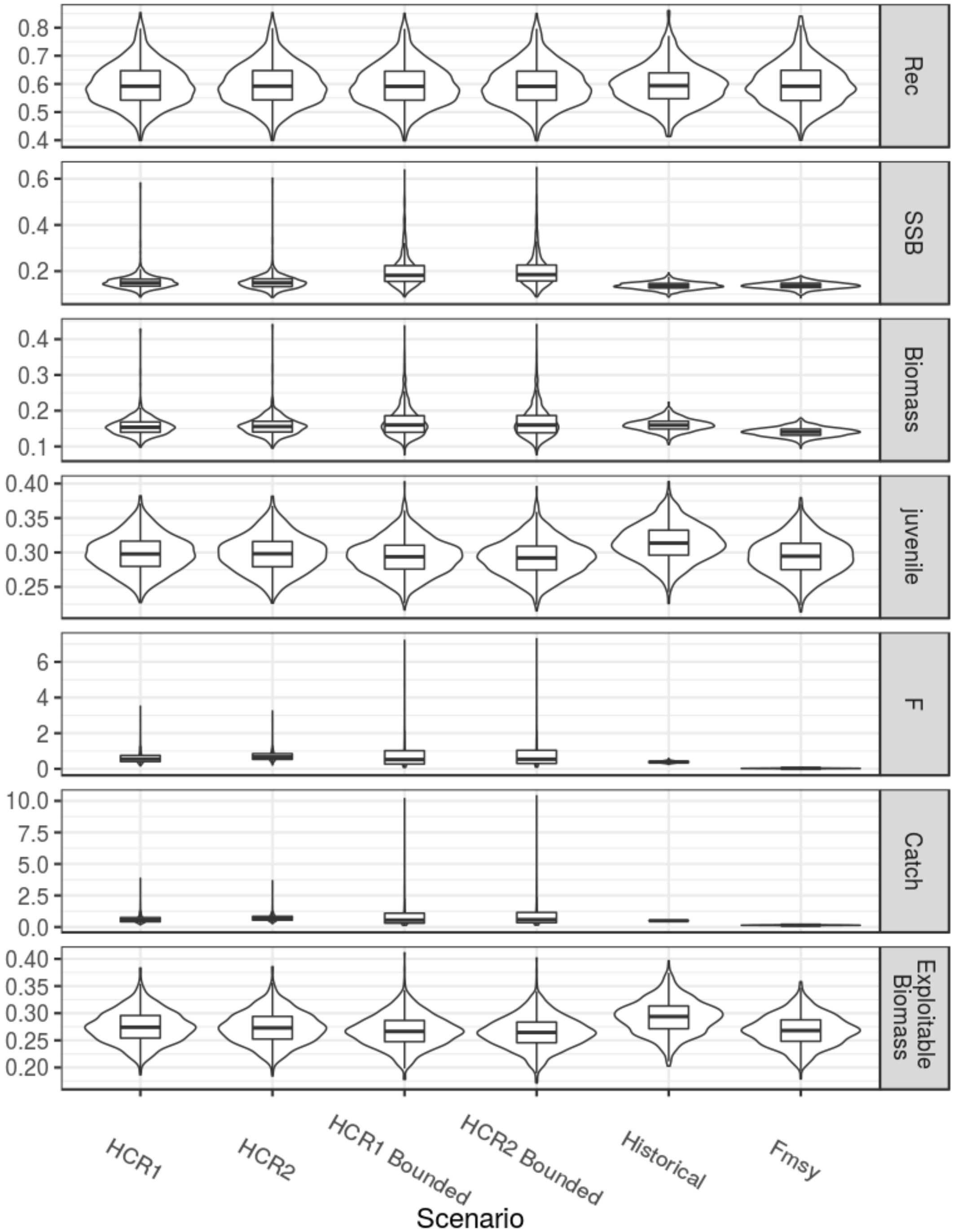

Figure 39 Mean Interannual Annual Absolute Variation over time series by iteration.

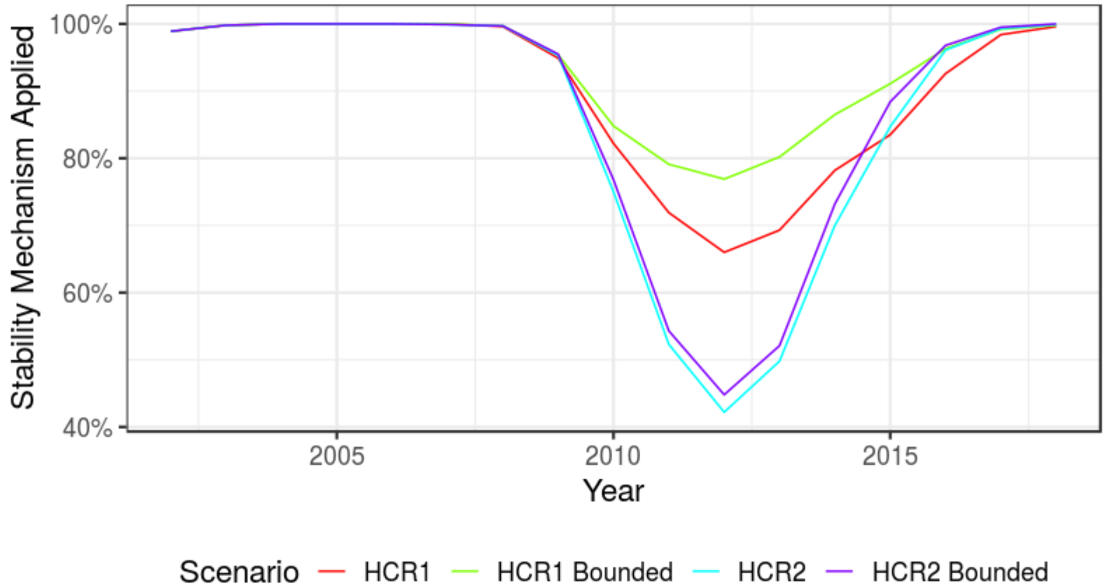

Figure 40 The percentage by year when the stability mechanism was applied.

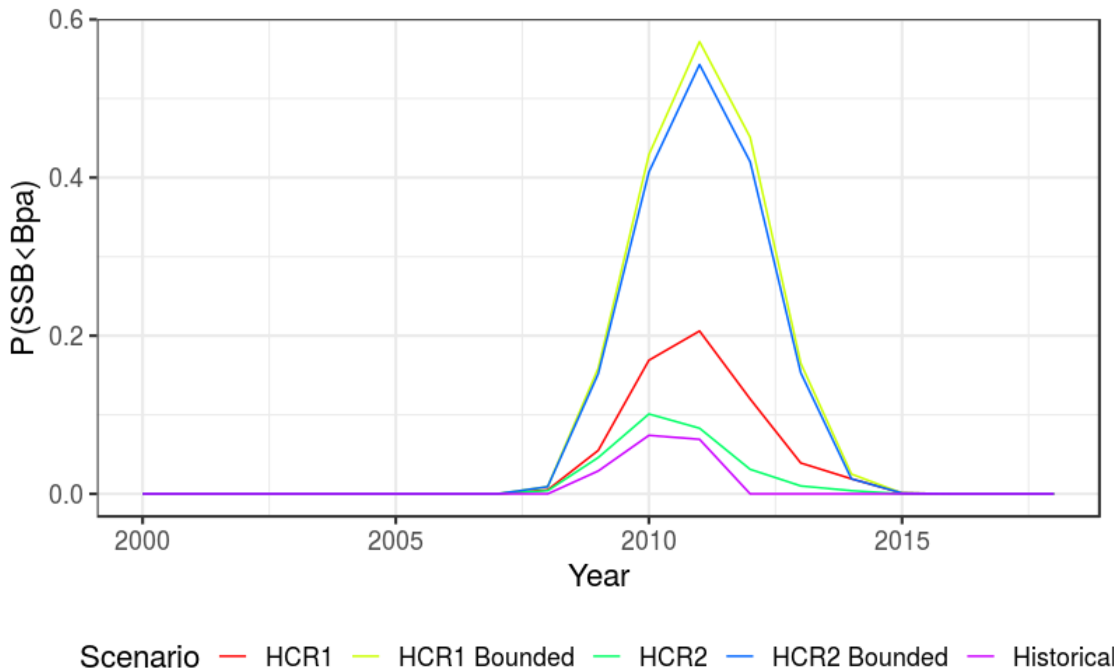

Figure 41 Probability that SSB falls below Bpa

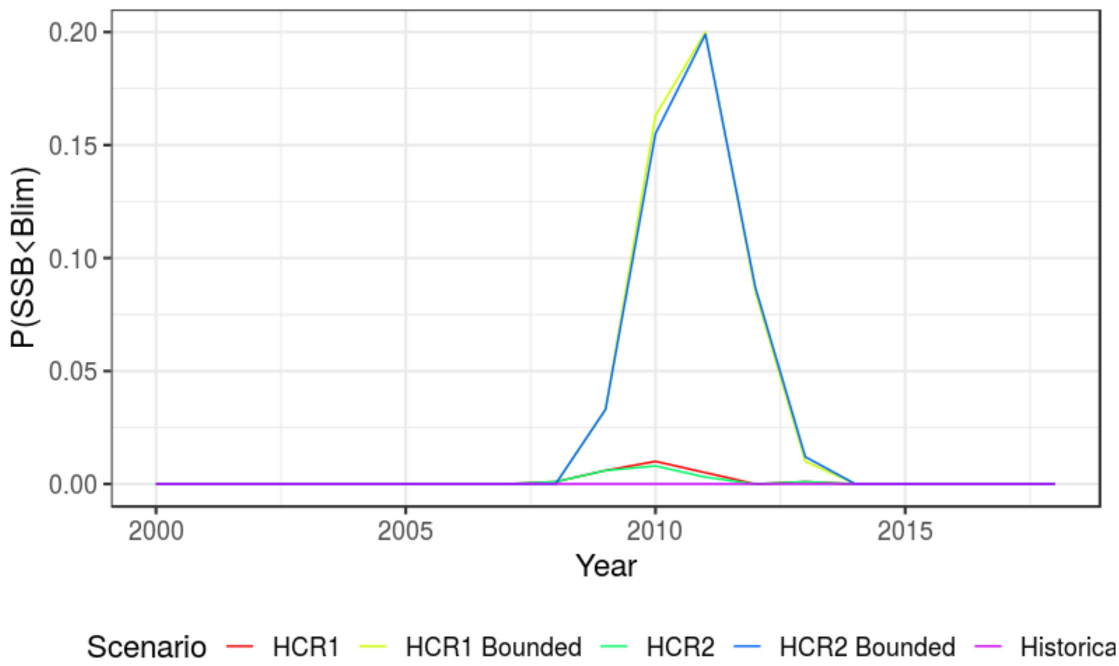

Figure 42 Probability that SSB falls below BLim.

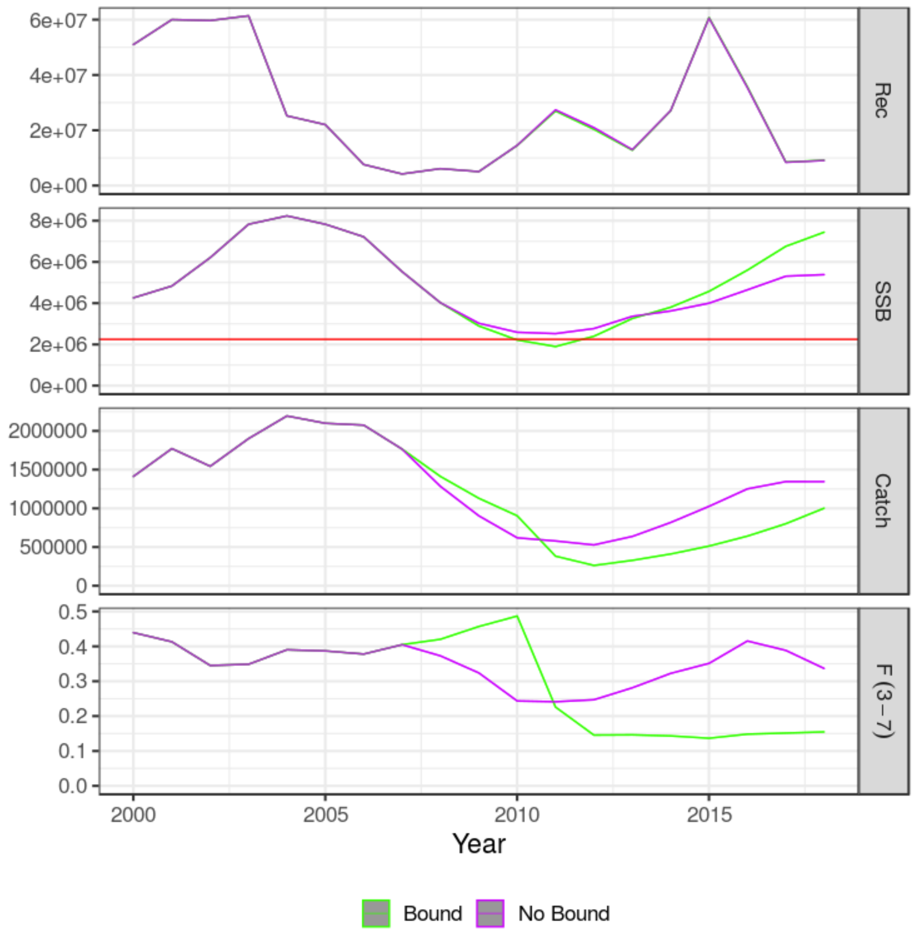

Figure 43. Simulation of HCR I for a single Monte Carlo run without assessment error and with and without bounds. The horizontal line shows the Bpa level and the verticle line the year when the bounds are turned off.

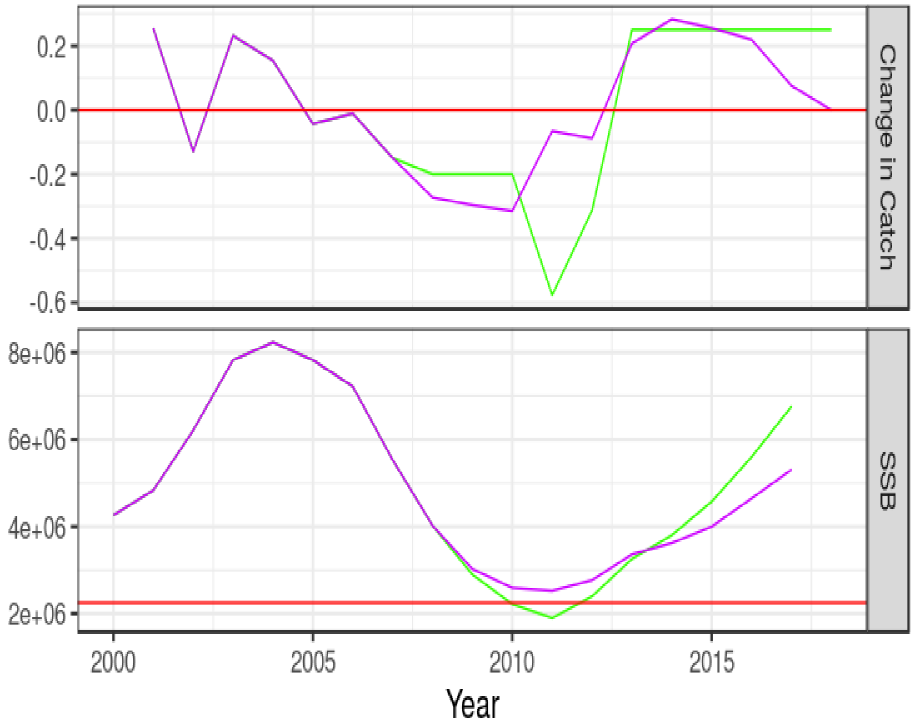

Figure 44. Simulation of HCR I for a single Monte Carlo run without assessment error and with (green) and without (purple) bounds. The horizontal line shows the Bpa level.

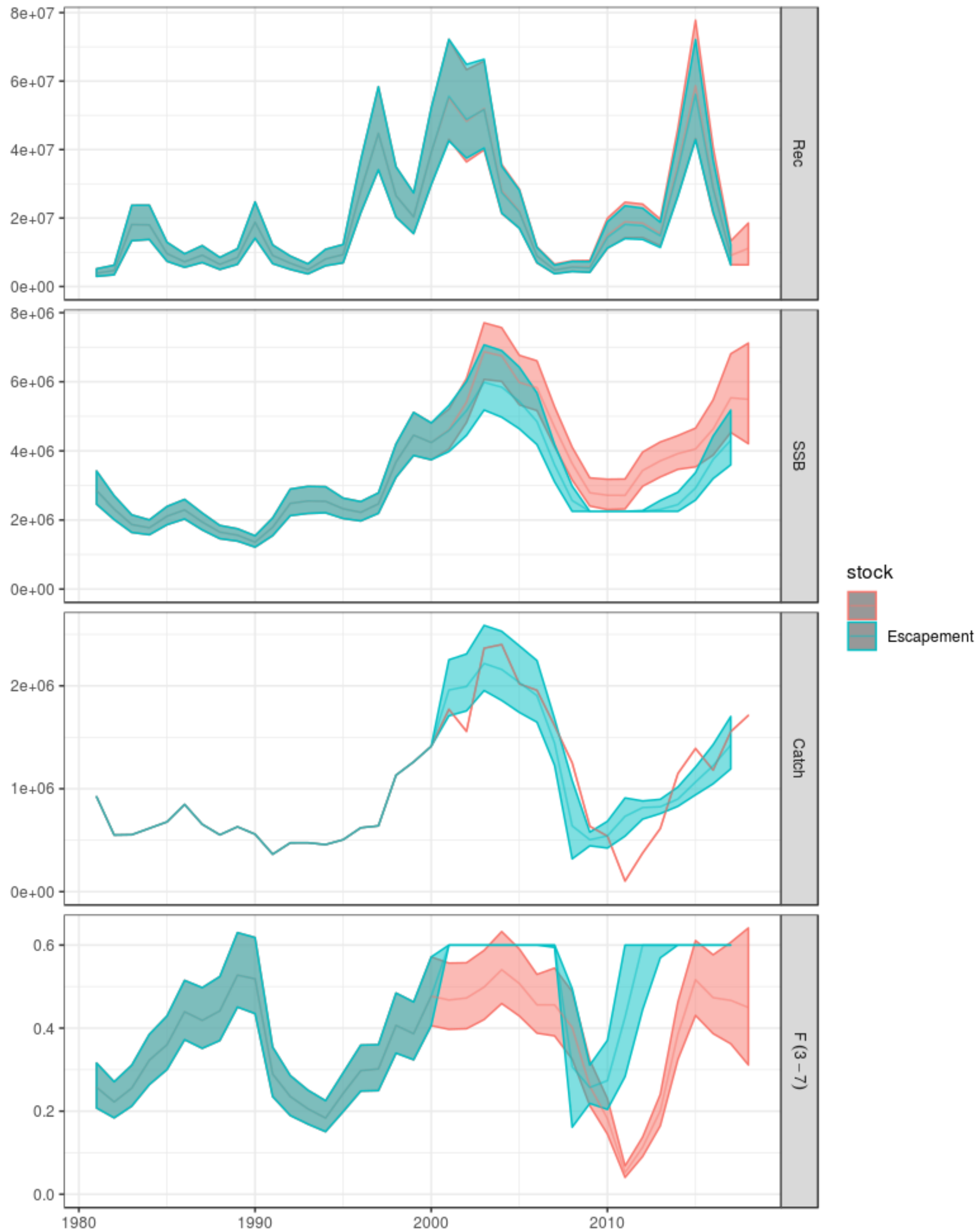

Figure 45. Comparison of historical stock trends and an escapement harvesting strategy (take all biomass>Bpa) and an F cap of 0.6

Review

Blue whiting technical meeting, 7 August 2019, WTC Schiphol

Participants: Esben Sverdrup, Gerard van Balsfoort, Laurie Kell, Polina Levontin, Martin Pastoors

The objective of the meeting was to review the preliminary results of the blue whiting hindcast evaluation, to identify whether additional work needed to be done and to prepare for the final presentation of results for the blue whiting focus group on 21 August and the ICES WGWIDE starting on the 28th of August.

Laurie Kell and Polina Levontin of Sea++ explained the results of the hindcast evaluation that they carried out for blue whiting. The basic approach has been as follows:

All coding was done in R using FLR (Kell, et al., 2007) designed to build simulation models representing alternative hypotheses about stock and fishery dynamics. Code will be made available on the GitHub repository

An Operating Model (OM) was developed to run simulations of the stock under the different HCRs. The OM was conditioned on the current ICES stock assessment (ICES. 2018)

Two HRCs were implemented and simulation tested, namely

- HCR-I: The Standard ICES MSY rule using an Fmsy= 0.32 and an MSYBtrigger of 2.25 Mt
- HCR=II: The two-tier approach with the following parameters:
    - A lower bound of Fmin= 0.05 below Blim = 1.5 Mt;
    - A linear sliding scale with slope a1 =2.0 starting at B lim and ending at B1 Trigger = 2.25 Mt;
    - A standard level between Trigger B1 and Trigger B2 at F 0.1 =0.22;
    - A linear sliding scale with slope a2 =2.0 above B2 Trigger where B2 Trigger is 4.0 Mt;
    - An upper bound at higher stock sizes at F MSY =0.32

Both scenarios were executed with and without a stability mechanism of 20% down and 25% up when the stock is assessed to be above Blim .

Simulations start in the initial year (2000) and then the stock is projected forward using either of the two alternative HCRs and with or without bounding the variability in TACs.

Uncertainty in stock assessments was taken at 0.3, derived from the retrospective analysis of the SAM assessment

Evaluation of results

Overall, the participants from PELAC were happy with the results that were presented in the sense that it was clearly outlined what had been done and that the diagnostics were well explained. Laurie and Polina were complimented for providing a comprehensive analysis for blue whiting. Because the results are based on a hindcast with a fixed recruitment pattern it was relatively easy to see the performance of different HCRs under different recruitment regimes). A remarkable (and erroneous) outcome was that when a TAC bound was applied for stocks higher than Blim, the stocks would tend to crash at some stage and finding it difficult to recover. This was thought to be caused by the lack of a 'break'-effect of a declining F in the HCR which was 'overwritten' by the stability clause, meaning that the catches would not go down quickly enough when the stock was rapidly going down.

It was suggested that possibly the best HCR rule would be an escapement rule with an Fcap of e.g. 0.5. However, this option has not been presented in the report.

There a number of issues that would need to be modified or changed prior to a final product being delivered:

[X] Add years (and colours) to the stock and recruitment plot of blue whiting

[X] In the simulation (and contract) it was specified that below Blim no bounds should be used. However, in fact this should apply below Btrigger. The results need to be redone with bounds only being applied when the stock is above Btrigger.

[X] When the stock has declined to a low level and the catches are set close to zero, the HCR does not allow for rapid increases in catch based on the bounds on TAC change. In such a situation a different element of the HCR would need to be included. It is not foreseen to carry out such an analysis prior to the 21st of August, because of timing issues. do you do when the TAC has been set to almost zero. This needs a change in the HCR approach.

[X] The results were based on almost no uncertainty in recruitment. It is recommended to use uncertainty estimates for recruitment from the 1000 replicated assessments and the estimated SRR relationships therein.

[ ] It is important to make a list of the uncertainties that have been included in the simulation.

[ ] Idea: explore the management approach for Southern bluewhiting fishery (New Zealand); MP

[ ] Idea: Make a plot of recruitment data from surveys; MP

[X] Plan a skype meeting on friday 9 August or Monday 12 August to start preparing the presentation for 21 august and WGIDE (LK, PL, CS, MP).