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Evaluation of an alternative harvest control rule for 3LNO American plaice

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Abstract

Preliminary evaluation of a harvest control rule proposed by Fisheries Commission as an alternative to the Conservation Plan and Rebuilding Strategy for Div. 3LNO American plaice is carried out using stochastic forward simulation. The performance of this fairly simple harvest control rule is compared to the desired performance statistics found within the more complex Conservation Plan and Rebuilding Strategy. The alternative harvest control rule is found to meet most of the desired performance statistics specified in the Conservation Plan and Rebuilding Strategy, however rebuilding the Div. 3LNO American plaice stock will be a slow process which has been retarded thus far by significant bycatch mortality. This bycatch mortality is not reduced under either the alternative harvest control rule or the Conservation Plan and Rebuilding Strategy. Although the objective is to rebuild the stock to the NAFO safe zone, no time horizon is specified over which this should take place. The alternative harvest control rule is not the most aggressive that could be proposed to rebuild the stock to the Safe Zone. A more aggressive rule would implement an initial reduction in fishing mortality while the stock remains below Blim to facilitate recovery.

Key words: American plaice, rebuilding strategy, management strategy, harvest control rules, Precautionary Approach, reference points, stochastic simulation

Introduction

In 2010 FC adopted an "Interim 3LNO American Plaice Conservation Plan and Rebuilding Strategy" (CPRS; NAFO/FC Doc. 10/13). The CPRS is complex requiring evaluation of a number of probabilities and risks at each time step within the procedure in order to set the annual TAC. The procedure has not been scientifically evaluated or reviewed by SC to determine whether or not it conforms to the NAFO PA framework and associated risk tolerance criteria, and whether or not it is likely to rebuild the stock to the NAFO Precautionary Approach (PA) "Safe Zone" in a reasonable period of time. Such an evaluation would be difficult to do because of the complexity of the CPRS.

Updated PA reference points for 3LNO American plaice and 3NO cod were provided in Shelton and Morgan (2011) as well as preliminary evaluation of an aggressive MSY-based HCR in which F is initially reduced to a low level but is allowed to increase to 3/4Fmsy as the stock rebuilds towards an assumed target of Bmsy.

FC's request for advice from SC in 2012 included a request for review of the CPRS for 3LNO American plaice and 3NO cod through risk based projections (NAFO/FC Doc. 11/4, Annex 4; NAFO/FC Doc. 11/4, Annex 5). In addition FC requested SC to evaluate an alternative simpler F0.1 based strategy, called here the "Alt HCR" in contrast to the CPRS (NAFO/FC Doc. 11/4, Annex 4, item 4; NAFO/FC Doc. 11/4, Annex 5, item 4). It was requested that this be done through stochastic projections in a risk based approach which would allow the evaluation of performance in terms of probabilities associated with maintaining biomass above Blim and ensuring continuous SSB growth, as well as showing SSB and associated catch trajectories for 5, 10 and 15 years.

This report describes the analysis carried out on the Alt HCR and the results obtained. A comparison is made with a constant F=F0.1 strategy and with the MSY-based HCR from Shelton and Morgan (2011). Although the CPRS was considered too complex for simulation testing, results from the Alt HCR are compared with the objectives and associated performance measures and statistics found in the description of the CPRS.

Methods

The stock-recruit Loess smoother described in Shelton and Morgan (2011) was updated with data for a further year from the 2011 stock assessment (Rideout et al. 2011). The resulting best smoothing parameter is 0.53 and the bias correction factor is 1.096, similar to the values previously obtained by Shelton and Morgan (2011). As in Shelton and Morgan (2011), it is assumed that beyond the highest SSB value, recruitment is constant at the Loess smoother predicted value for the highest SSB (i.e. the S-R relationship has a flat-top). Similarly, below the lowest SSB value recruitment is assumed constant at the predicted value from the smoother for the lowest SSB.

The Alt HCR is described in NAFO/FC Doc. 11/4, Annex 4, item 4:

a) When SSB is below Blim:

i. no directed fishing, and
ii. by-catch should be restricted to unavoidable by-catch in fisheries directing for other species
b) When SSB is above Blim:
If P y+1 > 0.9 Then Fy+1 = F0.1 * Py+1
Else
Fy+1 = 0
TACy+1 = B y+1 * Fy+1
Where:
Fy+1 = Fishing mortality to project catches for the following year,
Py+1 = Probability of projected Spawning Stock Biomass to be above Blim,
B y+1 = Exploitable biomass projected for the following year.

Stochastic simulations of the Alt HCR were carried out in an initial determination of the robustness of the strategy following the same general approach described in Shelton and Morgan (2011). This can be considered a prelude to a full management strategy evaluation (MSE). Simulations were run forward for 50 years, repeated 1000 times. The HCR was applied in each year to generate the F to be applied to the stock and hence the TAC.

Four sources of random error were introduced: error in recruitment, error in natural mortality (both are process error), error in the one year projected SSB to trigger the rule to get the intended F (assessment error) and error around the intended F to get the actual F that is applied (assessment and implementation error). Putting an error on the intended F to get the actual applied F is a short cut to a more comprehensive MSE approach in which both the simulated “true” population (with process error) and the simulated “perceived” population (assessment errors) are tracked over time with the rule applied (with implementation error) to the perceived population and the performance measured against the true population.

Recruitment in the simulation is obtained from the Loess smoother fit to log recruitment with random error introduced by resampling the residuals with replacement and adding them to the Loess smoother predicted recruitment in each year. Natural mortality (M) is modeled by drawing a random value from a beta distribution with a range of 0.15:0.53 and parameters a = 0.15 and b = a/0.2-a. This distribution has mean = 0.2, median = 0.173 and variance = 0.019. Neither sources of process error currently include autocorrelation.

Random error on the one year projections of SSB which trigger the harvest control rule to obtain the intended F was drawn from a lognormal distribution with CV=10% to match the confidence intervals given in Rideout et al. (2011) for the one year projected SSB. Additional runs were carried out with CV’s of 20% and 30% in case 10% is an underestimate. Random error was applied to the intended F to determine the realized value of the actual F applied to the simulated population. This error was lognormally distributed with CV=30% to account for combined assessment and implementation errors.

Values for catch weights, stock weights, maturity and partial recruitment (selectivity) were based on recent average (last three years) values given in the 2011 stock assessment (Rideout et al. 2011).

In addition to testing of the Alt HCR, comparative runs were carried out with a constant F0.1 strategy and the MSY HCR as proposed in Shelton and Morgan (2011), the latter assuming lognormal error in the annual estimate of SSB (lognormal with CV=10%).

Results and Discussion

The results are shown in Table 1 based on 1000 runs. In addition SSB trajectories and F vs SSB scatter plots are illustrated for 100 runs of the Alt HCR with projection CV=10%, the constant F = F0.1 strategy and the MSY-based HCR in Figs. 1 to 3. The rows in Table 1 correspond to a list of performance statistics based in part on the stated requirements for stock rebuilding probabilities and risks given in the CPRS.

With regard to rebuilding, the Alt HCR and F0.1 have a high risk of not allowing the stock to reach Blim by 2020 (Table 1, stat 1). In comparison, the more aggressive (in terms of rebuilding) MSY-based HCR has a relatively low risk of the stock failing to reach Blim by 2020. This illustrates the importance of reducing the fishing mortality from the current level by reducing bycatch of Div. 3LNO American plaice in other fisheries. As has been pointed out before (Shelton and Morgan 2005), by-catch mortality is essentially preventing, or excessively prolonging, the recovery of this stock. An initial reduction in F is not built into the Alt HCR or the CPRS.

The risk of not reaching Bmsy by 2030 is 1.0 for all HCRs, (stat 2), indicating the need to manage fishing mortality to a low level for a protracted period of time to achieve stock rebuilding. The median time to recover to Blim (stat 3) is earliest for the MSY HCR and latest for F0.1. The Alt HCR is intermediate, taking until 2022 irrespective of the level of uncertainty in the one year projection carried out to determine the intended F under the HCR. Median time to reach Bisr (2 times Blim) is 2036 for the Alt HCR (stat 4). While this is earlier than under the F0.1 strategy, it is later than under the MSY HCR. The median time to reach Bmsy (stat 5) is beyond the simulation time horizon of 2060 in all cases other than MSY HCR for which it is 2057. For comparison, under F=0 the median year to reach Blim is 2016, to reach Bisr is 2024 and to reach Bmsy is 2032.

The median SSB at various time intervals (stats 6-10) demonstrates the slow rebuilding rate of the stock. Although the median SSB is above Blim (50kt) for the Alt HCR after 15 years, the median SSB is still well below Bmsy (242kt) after 30 years. After the initial 5 years, SSB tends to be higher under higher levels of projection CV. This is because the perceived smaller probability of being above Blim results in lower F values from the Alt HCR.

The Alt HCR keeps the realized F below F0.1 over the first 15 years but by the 20th year the F varies around F0.1 in accordance with HCR because there is a probability of 1.0 of perceived SSB being above Blim (stats 11-15). With increasing uncertainty in the one year projection of SSB, F remains lower for longer because the perceived probability of the SSB being above Blim is lower.

The Alt HCR would allow only limited catches (10kt or less) in the first 20 years, increasing to 20kt after 30 years (stats 16-20).

The probability of reaching Blim in 10 years under the Alt HCR is 0.25 (stat 32). This probability could be much higher if a more aggressive rebuilding strategy were adopted that restricted bycatch to lower than the current level during the initial rebuilding period (e.g. MSY HCR).

The probability of SSB growth over a range of time periods is 80% or higher for the Alt HCR (stats 36-41) demonstrating a high probability of continuous growth under this HCR. Eventually the stock would come into equilibrium at a higher biomass than Bmsy and the growth rate would fluctuate around zero.

NAFO has adopted Fmsy as a Limit Reference Point for fishing mortality (NAFO/FC Doc. 04/18). As a limit, the realized F should only exceed Fmsy with a very low probability. While the HCR generates an F, this is the intended F from which the TAC is derived, and the realized F that is applied may be higher or lower than the intended F because of assessment and implementation error. However, F0.1 (0.16) is much lower than Fmsy (0.31) for this stock, keeping the risk of exceeding Fmsy low under the Alt HCR. Even under the MSY HCR, which allows F to increase to 2/3Fmsy (0.2) as the stock recovers, the risk of exceeding Fmsy remains low.

The fishing industry finds that large variations in the TAC from year to year can be detrimental to business, so a low CV on the annual catch variation is generally desirable. The CV for the Alt HCR is around 30%. Typically there is a trade-off between average catch and the CV in catch, with higher CV's under HCRs that give higher average catch.

The plots of a sample of 100 stock projections under each the three HCR's demonstrates that all three strategies generate a recovering stock, but vary with regard to the rate that this is achieved (Figs. 1-3). The scatter plot more clearly shows the difference between the three HCRs. There is a noticeable drop off in F at and below the Blim in the scatter for the Alt HCR (Fig. 1) compared with constant F0.1 (Fig. 2). A decline in F at low biomass is even more marked in the MSY HCR (Fig. 3). The single higher F value below Blim is for 2011 which is set at the recent average value of 0.11 in all of the simulations for all the HCRs.

The results from the above simulations depend on assumptions that have been made which may not closely match reality. The VPA assessment makes assumptions about selectivity to the fishery and annual values of natural mortality. It also assumes that the catch is known without error. The measurement error of the various tuning surveys do not factor directly into the assessment. Instead the SE for numbers at age is estimated from the VPA model fit to the survey numbers at age index. In the case of the short-term stochastic projections undertaken in the stock assessment, the variances and covariances in the numbers at age are taken into account (Rideout et al., 2011) so that while the CV in the survivors are typically of the order of 15% or more, the CV on the SSB is smaller, around 10%. This may be an underestimate of the uncertainty in the SSB in any one year.

Errors introduced in the testing of the HCR's included process error in recruitment based on randomly resampling residuals with replacement ignoring any autocorrelation. Similarly, process error in M is simulated by drawing random values from a beta distribution ignoring any autocorrelation. Process errors are typically autocorrelated rather than completely random from year to year because changes tend to happen gradually in the ecosystem and the environment.

In the current simulations it is assumed that while the CV on the lognormal assessment error on the SSB is 10%, consistent with the confidence intervals give in Rideout et al. (2011). The CV on the F that is applied relative to the intended F generated by the HCR is 30%, accounting for both assessment and implementation error. These sources of uncertainty require careful consideration because they directly affect the results.

While simulation testing of harvest control rules through stochastic simulation may be a useful prelude to full MSE, the more rigorous MSE approach is preferred. In the MSE approach a set of operating models (true population) is developed which constitute different hypotheses regarding the true underlying dynamics, consistent with the available survey and catch data. This allows the testing of robustness of the management strategy to model uncertainty. Furthermore in an MSE the assessment procedure is simulated at each time step so that both the true and perceived state of the stock is tracked over time. The HCR is applied to the perceived population while the performance is measured using data from the true population. It should be noted that the assessment procedure could be simply determining the trend in survey abundance which is then used by the HCR to adjust the TAC (see for example Shelton 2011). Under this approach the PA reference points do not factor directly into the HCR, but instead are incorporated into performance statistics.

The CPRS does not make a distinction between the harvest control rule and the performance statistics. This makes the CPRS complicated to evaluate through robustness simulation trials without a lot of simplifying assumptions. It is generally preferable to keep the HCR simple and mathematically easy to program into a simulation, and to cast the desired outcomes in terms of performance statistics. Performance statistics can be measures over specified time horizons such as average annual catch, CV in annual catch, or average SSB etc. Performance statistics can also be cast in terms of risks and probabilities over specified time horizons. Both imperative and trade-off performance statistics can be considered (Shelton and Miller 2010). Imperative performance statistics have specified risk tolerances that <u>have</u> to be met over a specified time horizon while trade-off statics represent the inevitable trade-off that occurs between fishing and conservation. HCRs that don't meet the imperative risk tolerances are eliminated as candidates. Those that meet the risk tolerances can be evaluated further with regard to trade-offs. Each HCR can be tuned to best meet the risk tolerances and achieve the desired tradeoffs by adjusting the parameters in the HCR that determine the amount of fish removed in each year based on the stock assessment. HCRs that respond directly to the survey index are called data-based HCRs, whereas those that respond to a model estimate are called model-based HCR's. Data-based HCR's may perform as well or better than model-based HCR's depending on the uncertainties.

The Alt HCR, as an alternative to the CPRS, is a step in the right direction. It is fairly simple to implement in a simulation. Unlike the CPRS, the TAC is not adjusted by the HCR in each time step to meet specified risks or probabilities. The Alt HCR does however require the probability of SSB exceeding Blim to be evaluated in each time step in order to determine the fraction of F0.1 that is to be applied and hence the TAC. Linking the TAC to the uncertainty in the assessment is a positive action. As demonstrated in the simulations, the more uncertain status of the stock, the longer it takes for F to build up to F0.1. Introducing F0.1 as the maximum allowed F is also a positive action which has been used before by NAFO in the presence of uncertainty to avoid overfishing (Shelton 2007). The negative aspect of the Alt HCR is that it does not result in an initial decrease in F from the current level of about 0.11 to allow more rapid stock rebuilding. This could be achieved by extending the range over which the probability of SSB>Blim is evaluated in the HCR from the current 0.9-1 to, for example, 0.5-1 such that if the perceived SSB has a probability of 0.5 or lower of being above Blim then the F that would be applied to determine the TAC would be 0.5xF0.1=0.08, i.e. lower than the current F. As it exists, the HCR keeps F at status quo (0.11) until the >0.9 probability threshold is met, at which time the F increases from F status quo to PxF0.1, i.e 0.14 or greater to a maximum of F0.1. Reducing the current F resulting from the bycatch fishery should be a major consideration of any rebuilding plan for Div. 3LNO American plaice.

The time to rebuild the Div. 3LNO American plaice stock to the Safe Zone is not specified in the CPRS. One approach is to base this on some multiplier of the time to rebuild under F=0. In the simulations carried out, the median year by which Bmsy would be reached in the absence of fishing is 2032. Under the Alt HCR the time to reach Bmsy exceeds the 50 year time horizon of the simulations. This suggests that, although the Alt HCR meets most of the other objectives contained in the CPRS, it is not aggressive enough to rebuild the stock within a reasonable amount of time.

Conclusions

The alternative HCR (Alt HCR) proposed by FC is much simpler than the CPRS and meets most of the probabilities and risks described in the CPRS, although rebuilding to Bmsy is excessively long. This is mainly due to the level of fishing mortality that has been occurring while the stock is below Blim, a factor that would not be different under the CPRS. The CPRS is complex and does not separate out the functional elements of a harvest control rule from the desired performance of the rule. Probabilities and risks of good and bad things happening are best captured in the form of desired performance statistics in which the time horizons and acceptable risk tolerances are specified. Within these tolerances, tradeoffs between fishery related and conservation related performance statistics can be evaluated. A simplified HCR can be tuned to meet these objectives. While implementation of the Alt HCR would be a step forward, consideration should be given to a more aggressive rebuilding strategy, for example by extending the lower limit of the range of probability of the stock exceeding Blim so that F would initially decline.

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Table 1. Simulation results from testing the Alt HCR at a range of projection errors, as well as testing of a constant F strategy at F0.1 and the MSY-based HCR proposed by Shelton and Morgan (2011) for comparison.

#	Statistic	Alt HCR 10%	Alt HCR 20%	Alt HCR 30%	F0.1	MSY HCR
1	Risk of not reaching Blim by 2020	0.70	0.68	0.69	0.91	0.07
2	Risk of not reaching Bmsy by 2030	1	1	1	1	1
3	Median time to recover to Blim	2022	2022	2022	2025	2016
4	Median time to recover to Bisr	2036	2035	2035	2041	2028
5	Median time to recover to Bmsy	2060	2057	2056	2060	2057
6	Median SSB after 5 years	38,340	38,659	38,597	34,724	47,499
7	Median SSB after 10 years	43,712	45,757	45,376	38,368	57,120
8	Median SSB after 15 years	56,507	60,618	60,729	48,177	84,791
9	Median SSB after 20 years	67,957	73,194	76,950	55,136	120,794
10	Median SSB after 30 years	124,026	136,887	141,179	96,181	173,510
11	Median F after 5 years	0.112	0.109	0.109	0.162	0.012
12	Median F after 10 years	0.109	0.112	0.109	0.161	0.072
13	Median F after 15 years	0.138	0.126	0.113	0.162	0.082
14	Median F after 20 years	0.159	0.148	0.138	0.161	0.111
15	Median F after 30 years	0.161	0.162	0.159	0.162	0.174
16	Median catch after 5 years	4,446	4,371	4,323	5,616	630
17	Median catch after 10 years	4,991	5,320	5,134	6,122	4,787
18	Median catch after 15 years	8,221	7,592	6,851	7,519	7,120
19	Median catch after 20 years	10,873	11,427	10,744	8,914	14,029
20	Median catch after 30 years	20,144	21,278	22,077	15,128	39,049
21	Prob Bmsy by 5 years	0.00	0.00	0.00	0.00	0.00
22	Prob Bmsy by 10 years	0.00	0.00	0.00	0.00	0.00
23	Prob Bmsy by 15 years	0.00	0.00	0.00	0.00	0.00
24	Prob Bmsy by 20 years	0.00	0.00	0.00	0.00	0.00
25	Prob Bmsy by 30 years	0.00	0.00	0.00	0.00	0.00
26	Prob Bisr by 5 years	0.00	0.00	0.00	0.00	0.00
27	Prob Bisr by 10 years	0.00	0.00	0.00	0.00	0.00
28	Prob Bisr by 15 years	0.00	0.01	0.01	0.00	0.18
29	Prob Bist by 20 years	0.08	0.07	0.10	0.01	0.84
30	Prob Bisr by 30 years	0.85	0.89	0.90	0.47	1.00
31	Prob Blim by 5 years	0.00	0.00	0.00	0.00	0.30
32	Prob Blim by 10 years	0.25	0.29	0.29	0.09	0.84
33	Prob Blim by 15 years	0.79	0.85	0.83	0.44	1.00
34	Prob Blim by 20 years	0.96	0.96	0.97	0.64	1.00
35	Prob Blim by 30 years	1.00	1.00	1.00	0.94	1.00
36	Prob SSB after 5 years greater than after 1 year	0.80	0.85	0.83	0.57	1.00
37	Prob SSB after 10 years greater than after 1 year	0.91	0.94	0.94	0.73	1.00
38	Prob SSB after 15 years greater than after 1 year	0.99	0.97	1.00	0.92	1.00
39	Prob SSB after 10 years greater than after 5 years	0.80	0.84	0.81	0.72	0.91
40	Prob SSB after 15 years greater than after 5 years	0.98	0.99	0.98	0.92	1.00
41	Prob SSB after 15 years greater than after 10 years	0.93	0.95	0.93	0.86	1.00
42	Median catch CV over 5 years	0.29	0.28	0.28	0.32	1.15
43	Median catch CV over 10 years	0.32	0.32	0.31	0.32	0.96
44	Minium risk over 50 years of exceeding Flim	0.00	0.00	0.00	0.00	0.00
45	Median risk over 50 years of exceeding Flim	0.00	0.00	0.00	0.00	0.00
46	Maximum risk over 50 years of exceding Flim	0.02	0.02	0.00	0.01	0.01
47	Maximum risk of 3 year decline below Blim after opening	0.16	0.00	0.00	0.00	0.00
48	Median risk of 3 year decline below Blim after opening	0.00	0.00	0.00	0.00	0.00
49	Median growth rate after Bisr is reached	2.33	2.25	2.25	2.74	1.42
50	Min growth rate after Bisr is reached	1.14	1.00	1.07	1.12	0.85

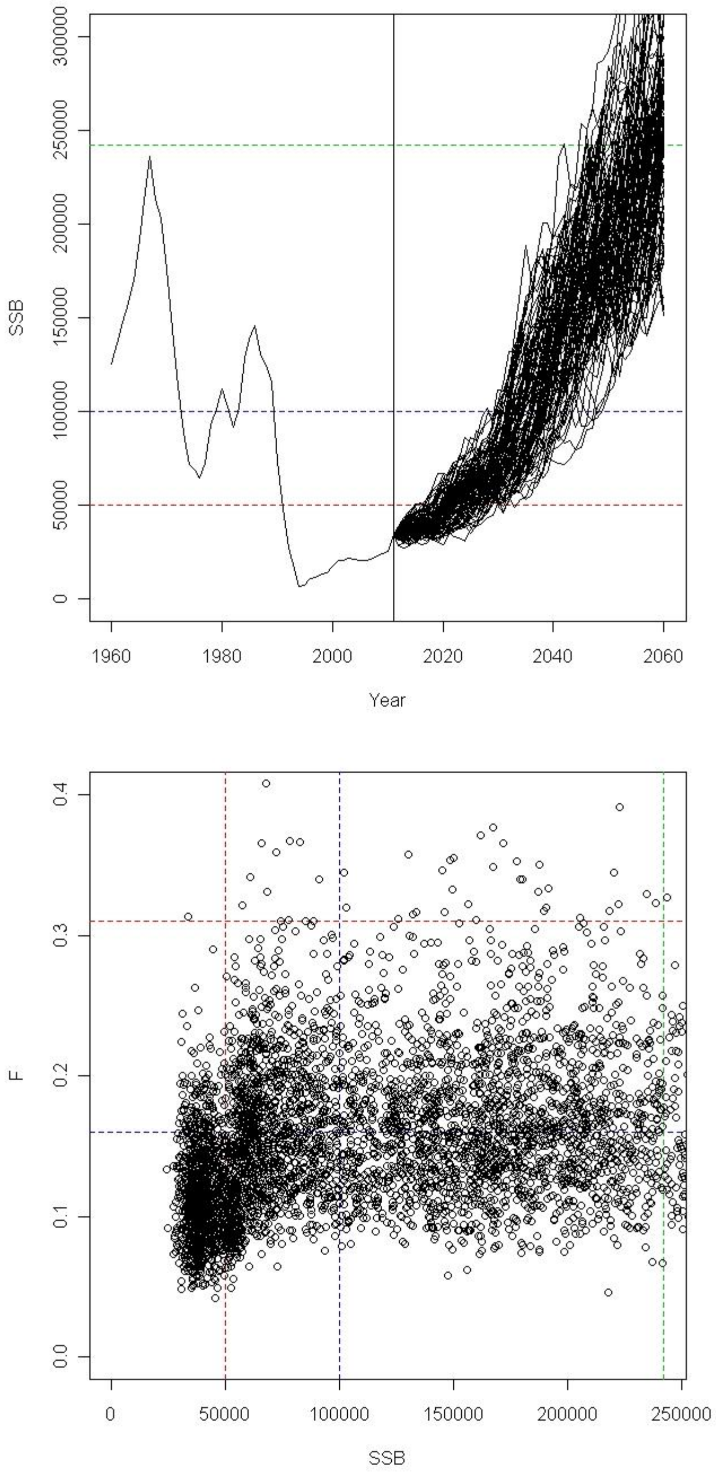

Fig. 1. Projections and scatter plot for 100 runs of the Alt HCR with a projection error CV = 10%. On the projection plot the horizontal lines denote Blim, Bisr and Bmsy. On the scatter plot the vertical lines show the same values while the horizontal lines denote F0.1 and Fmsy.

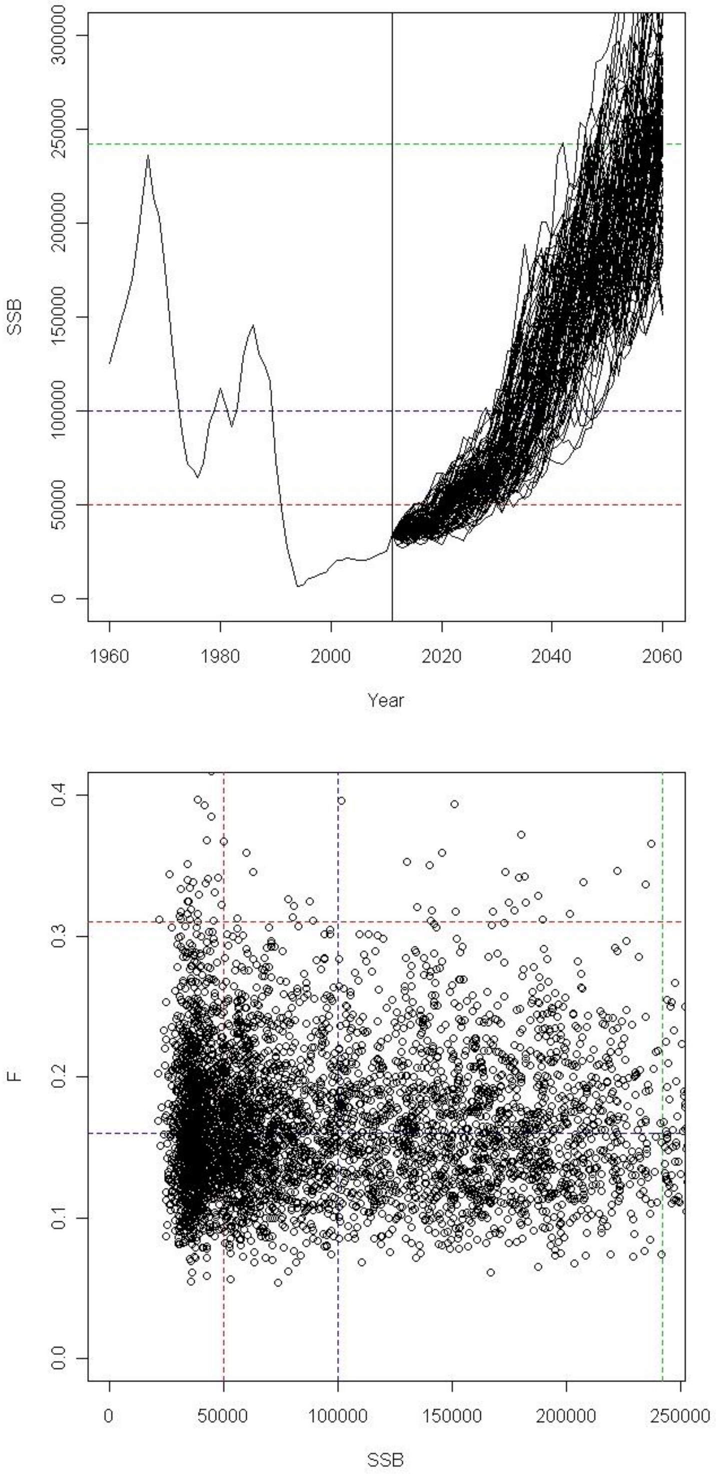

Fig. 2. Projections and scatter plot for 100 runs of an F0.1 strategy. On the projection plot the horizontal lines denote Blim, Bisr and Bmsy. On the scatter plot the vertical lines show the same values while the horizontal lines denote F0.1 and Fmsy.

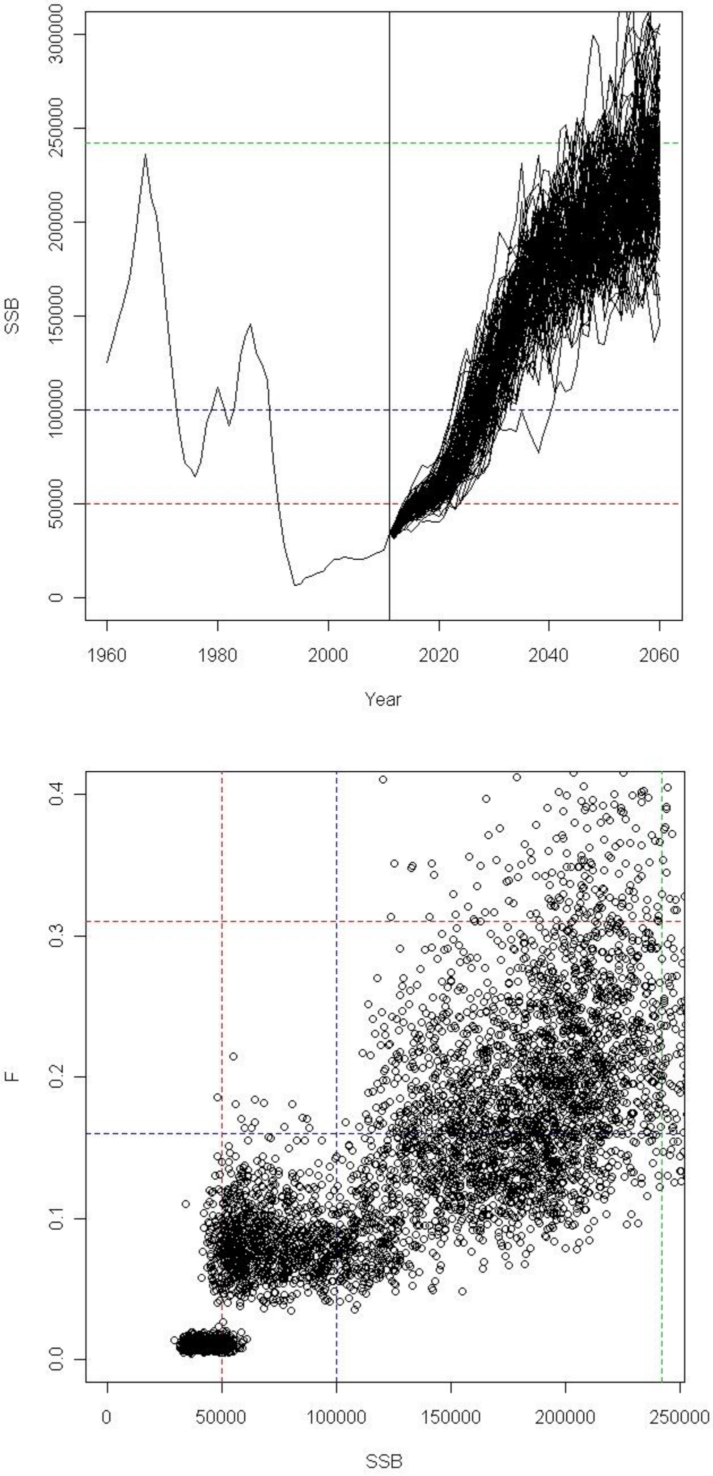

Fig. 3. Projections and scatter plot for 100 runs of the MSY-based HCR described in Shelton and Morgan (2011). On the projection plot the horizontal lines denote Blim, Bisr and Bmsy. On the scatter plot the vertical lines show the same values while the horizontal lines denote F0.1 and Fmsy.