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An Evaluation of Reference Points and Risk of the Scotian Shelf and Southern Grand Banks Atlantic Halibut Stock

Évaluation des points de référence et des risques relativement aux stocks de flétan de l'Atlantique du plateau néo-écossais et du sud des Grands Bancs

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ABSTRACT

Reference points were calculated at the last assessment, but projections were not made nor the risk of either exceeding a reference fishing level (F_{ref}) causing harm to the productivity of the stock, or of under exploitation leading to economic loss. Here we re-evaluate the reference points, project the population to 2014 and calculate the risk associated over a range of catch levels. Based on model projections, the 3NOPs4VWX5Zc Atlantic halibut is in a productive period due to high recruitment. In a comparison of B_{MSY} and F_{MSY} generated using a Beverton-Holt stock-recruit model versus a Ricker model, B_{MSY} and F_{MSY} differed by a factor of two, demonstrating the sensitivity to model assumptions. The 2012 population spawning stock biomass is projected to be above B_{MSY} regardless of which stock-recruit model is used.

RÉSUMÉ

Les points de référence ont été calculés lors de la dernière évaluation, mais aucune projection ni aucune mesure des risques n'ont été effectuées quant au dépassement d'un niveau de référence de la pêche (valeur $F_{réf}$), ce qui endommagerait la productivité des stocks, ou à une sous-exploitation, laquelle entraînerait des pertes économiques. Dans le cas présent, nous réévaluons les points de référence, projetons la population jusqu'en 2014 et calculons le risque en fonction des taux de capture. Les projections de modèle révèlent que le flétan de l'Atlantique de 3NOPs4VWX5Zc traverse une période productive en raison du fort recrutement. Dans une comparaison de la biomasse au rendement maximal soutenu (B_{rms}) et de la mortalité par pêche au rendement maximal soutenu (F_{rms}) générée selon un modèle du stock-recrutement de Beverton-Holt et un modèle de Ricker, B_{rms} et F_{rms} révélaient une différence de deux, démontrant la sensibilité aux hypothèses de modélisation. On prévoit que la biomasse du stock de reproducteurs de la population de 2011 sera supérieure à la B_{rms}, quel que soit le modèle de stock-recrutement utilisé.

INTRODUCTION

Atlantic halibut was assessed using a new framework in fall of 2010 (Trzcinski et al. 2011). The assessment model takes halibut catch at length data, converts lengths to ages using growth information and incorporates the associated uncertainty. Processes, such as recruitment, gear selectivity, fishing mortality vary with age. The model then converts the catch-at-age to length and minimizes the difference between the observed and predicted survey catch rates and the survey and commercial catch at length. The model runs on a calendar year and the stock was last assessed with 1970-2009 data.

Several trial reference points were calculated at the last assessment and F0.1 was calculated in Trzcinski et al. (2009), but projections were not made nor the risk of either exceeding a reference fishing level (F_{ref}) causing harm to the productivity of the stock, or of under exploitation leading to economic loss. Here we re-evaluate the reference points, project the population to 2014 and calculate the risk associated over a range of catch levels.

METHODS AND RESULTS

INPUT PARAMETERS

The trial reference points presented in Trzcinski et al. (2011) were generated using an average weight at age, maturity at age, and selectivity across males and females. Since approximately 90% of the landings are by longline gear, only the selectivity to this gear was used. Recruitment was projected using a Ricker stock recruitment curve. The same approach was used here, but the reference points generated from the Ricker stock recruitment curve were contrasted with those produced by a Beverton-Holt (BH) curve so that uncertainty in the stock-recruit model could be estimated. A yield per recruit (YPR) was also calculated for comparison and F0.1 calculated.

The 2009 numbers at age from the last assessment were used to start the projections. The Markov chain Monte Carlo (MCMC) method was used to estimate the uncertainty (observation and uncertainty in processes such as selectivity and catchability) in the numbers at age and the output (1,000 samples from 10^6 steps) used in projections.

REFERENCE POINTS

A modified Sissenwine-Shepherd (1987) model was used to estimate the Maximum Sustainable Yield (MSY) and related reference points using output from the assessment model. Forty percent and 80% of B_{MSY} were chosen as the upper and lower references. The biomass metric used was spawning stock biomass (SSB; as opposed to total or fishable biomass). Similarly, F_{MSY} was chosen for the fully recruited fishing mortality.

The methods used to investigate biological reference points and trial harvest control rules follow Mohn et al. (2010). The basic Sissenwine-Shepherd model fits a stock-recruit relationship and then infers the production curve (MSY, B_{MSY}, etc.) from it using growth and survivorship. The stock-recruit relationship is quite noisy and could potentially change over time. Figure 1 shows that the 1990s were a period of low recruitment at low SSB and that the 1970s and 2000s are periods of high recruitment at average SSB. The Ricker model fit the data better than the BH model (R^2 = 0.17 versus 0.04). Yield for the BH and Ricker models and YPR are shown as a function of F in Figure 2. One can see in this case that although calculations of MSY are similar, B_{MSY} and F_{MSY} are quite different, with the BH model estimating a B_{MSY} of nearly twice and an F_{MSY} at nearly half that of the Ricker model. It is well known that the BH model is more precautionary, and this comparison serves to demonstrate how model uncertainty in addition to observation and process error influences references points and our perception of risk. The underlying inputs and equilibrium fits are shown in Figure 3. The lines are the equilibrium yields (black: BH, red: Ricker) from the stock-recruit data and are those developed by Sissenwine and Shepherd.

If the upper and lower biomass limits were defined as 40% and 80% B_{MSY} from the production based estimates, a trial harvest control rule can be produced. These limits may be compared to the history of the SSB in Figure 4. Notice how the lower limit from the BH model is similar to the upper limit for the Ricker; thus, there is considerable uncertainty in what could be defined as the ‘cautious’ and ‘healthy’ zones. Figure 3 combines these references into a simple harvest control rule using the trial limits and the F_{MSY}.

PROJECTIONS

Projections were made using the BH model of stock-recruitment, without error, for five years assuming removals of 2,000 mt per year (Figure 4, upper) and 4,000 mt per year (Figure 4, lower). The grey area represents uncertainty in F and SSB. Removals of 2,000 mt a year leaves the stock expanding due to high recruitment and well within the healthy region. Removals of 4,000 mt per year will probably keep the population in the healthy region, but the population will decline and there is some risk of entering the cautious region.

Given the uncertainty in the data, risk relative to the productivity of the stock and economic gains or losses can be evaluated several ways. Specifically, the following scenarios and risk were evaluated:

- For a range of total catch values in 2012/2013 and 2013/2014, estimate the risk that fishing mortality rate (F) would exceed F_{ref}=0.2 and F_{lim}=0.36 in each year (Tables 1 and 2). Include a table showing the 2012/2013 and 2013/2014 catches corresponding to low (25%), neutral (50%) and high (75%) probability that the F would exceed F_{ref}=0.2 and F_{lim}=0.36 (Tables 3a and 3b).

- For a range of total catch values in 2012/2013 and 2013/2014, estimate the risk that the biomass (SSB) would decline by 10% (Table 4), remain stable (ΔSSB<80%, Table 5) or increase by 10% (Table 6) from 2009.

- Estimate the risk that the fishing mortality would exceed F_{ref}=0.2 and F_{lim}=0.36 in 2012/2013, and the risk that biomass would decline by 10%, remain stable or increase by 10% at a catch of 2,127.5 mt or 1,572.5 mt (plus or minus 15% of the 2011/2012 Total Allowable Catch [TAC]).

Figure 5 shows the probability of exceeding F (0.2 or 0.36) in 2012, 2013 and 2014 for yield ranging from 1,500 to 3,500 mt per year. The same information is provided in Tables 1 and 2. Given the amount of uncertainty incorporated into this analysis, there is no risk of exceeding F_{ref} =0.2 at a yield below 2,200 mt in 2012, 2013 and 2014. A yield of 2,600 mt would exceed F_{ref} =0.2 in all years. Figures 3 and 4 show that the population would continue to increase at a yield of 2,000 mt per year. A catch of 1,850 mt in 2012 (2012/2013 TAC) is expected to result in an F of 0.15 and a 9.5% percent increase in biomass in 2013. A catch of 2,127.5 mt in 2012 (15% increase to the TAC) is expected to result in an F of 0.17 and a 7% percent increase in biomass.

CONCLUSIONS

Based on model projections, the 3NOPs4VWX5Zc Atlantic halibut is in a productive period due to high recruitment. The spawning stock biomass is expected to increase and there is little risk in harming the productivity of the stock at harvest levels <4,000 t. The probability of exceeding F_{ref}=0.2 is low (<0.1%) at current catch levels and the probability decreases as the population grows. Projections to 2014 show that the probability of exceeding F_{lim}=0.36 is also low (<10%) at a catch of 3,400 mt per year. A catch of 1,850 mt in 2012 (2012/2013 TAC) is expected to result in an F of 0.15 and a 9.5% percent increase in biomass in 2013. A catch of 2,127.5 mt in 2012 (15% increase to the TAC) is expected to result in an F of 0.17 and a 7% percent increase in biomass. In a comparison of B_{MSY} and F_{MSY} generated using a Beverton-Holt stock-recruit model versus a Ricker model, B_{MSY} and F_{MSY} differed by a factor of 2, demonstrating the sensitivity to model assumptions. The 2012 population spawning stock biomass is projected to be above B_{MSY} regardless of which stock-recruit model is used.

UNCERTAINTY

The assessment model of Trzcinski et al. (2011) incorporates much observation error and some process error (selectivity, catchability). This uncertainty is carried forward to the 2009 numbers at age, which is used for projections. However, there are many sources of error which are not incorporated. Unfortunately, the assessment model became unstable if more uncertainty in selectivity or uncertainty in natural mortality was incorporated, but an educated guess about the uncertainty in the input (e.g. M, weight at age) parameters could be incorporated in the projections.

Halibut are a sexually dimorphic species, and the assessment model treats the sexes separately, that is, males and females have different growth, age at maturity and selectivity to longline gear. Consequently, they have different fishing mortalities. However, since most exploited fish populations are not managed with specific reference to the male and female components, the fishing mortality was averaged and the SSB summed across the sexes for the calculation of reference points and the provision of management advice. A better understanding of the effect of a dimorphic species on reference points could be an avenue for future research.

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Table 1. The probability of exceeding F_{ref}=0.2 for a given catch (t).

	Year		
Catch	2012	2013	2014
<2200	0	0	0
2300	0.011	0	0
2400	0.160	0.022	0.003
2500	0.702	0.355	0.132
2600	0.970	0.887	0.719
2700	0.999	0.996	0.982
>2800	0.999	0.999	0.999

Table 2. The probability of exceeding F_{lim}=0.36 for a given catch (t).

	Year		
Catch	2012	2013	2014
<3300	0	0	0
3400	0	0	0.009
3500	0	0	0.111
3600	0	0.017	0.497
3700	0	0.133	0.877
3800	0.001	0.486	0.988
3900	0.020	0.842	0.998
4000	0.132	0.975	0.999
4100	0.398	0.997	0.999
4200	0.747	0.999	0.999
4300	0.936	0.999	0.999
4400	0.992	0.999	0.999
>4500	0.999	0.999	0.999

Table 3a. Catches corresponding to low (25%), neutral (50%) and high (75%) probability that fishing mortality (F) would exceed F_{ref}=0.2.

	Quantile		
Year	0.25	0.5	0.75
2012	2417	2463	2518
2013	2468	2527	2574
2014	2520	2563	2612

Table 3b. Catches corresponding to low (25%), neutral (50%) and high (75%) probability that fishing mortality (F) would exceed F_{lim}=0.36.

	Quantile		
Year	0.25	0.5	0.75
2012	4044	4129	4202
2013	3733	3804	3874
2014	3536	3601	3667

Table 4. The probability that the SSB would decline by 10% or greater for a given catch (t).

	Year		
Catch	2012	2013	2014
<5200	0.001	0.001	0.010
5300	0.001	0.001	0.027
5400	0.001	0.001	0.067
5500	0.001	0.001	0.159
5600	0.001	0.001	0.289
5700	0.001	0.001	0.469
5800	0.001	0.001	0.653
5900	0.001	0.001	0.795
6000	0.001	0.001	0.902
6100	0.001	0.001	0.957
6200	0.001	0.001	0.985
6300	0.001	0.001	0.996
6400	0.001	0.001	0.997
>6500	0.001	0.001	1

Table 5. The probability that the SSB would remain stable (ΔSSB<80%) for a given catch (t).

	Year		
Catch	2012	2013	2014
<4500	0	0	0.014
4600	0	0	0.035
4700	0	0	0.082
4800	0	0	0.196
4900	0	0	0.335
5000	0	0	0.524
5100	0	0	0.694
5200	0	0	0.831
5300	0	0	0.895
5400	0	0	0.902
5500	0	0	0.832
5600	0	0	0.707
5700	0	0	0.530
5800	0	0	0.347
5900	0	0	0.205
6000	0	0	0.098
6100	0	0.001	0.043
6200	0	0.002	0.015
6300	0	0.008	0.004
6400	0	0.012	0.003
6500	0	0.019	0
6600	0	0.033	0
6700	0	0.058	0
6800	0	0.100	0
6900	0	0.153	0
7000	0	0.228	0
7100	0	0.304	0
7200	0	0.392	0
7300	0	0.492	0
7400	0	0.602	0
7500	0	0.693	0
7600	0	0.762	0
7700	0	0.827	0
7800	0	0.884	0
7900	0	0.922	0
8000	0	0.938	0

Table 6. The probability that the SSB would increase by 10% or greater for a given catch (t).

	Year		
Catch	2012	2013	2014
<4500	0.999	0.999	0.985
4600	0.999	0.999	0.964
4700	0.999	0.999	0.917
4800	0.999	0.999	0.803
4900	0.999	0.999	0.664
5000	0.999	0.999	0.475
5100	0.999	0.999	0.303
5200	0.999	0.999	0.159
5300	0.999	0.999	0.078
5400	0.999	0.999	0.031
5500	0.999	0.999	0.009
5600	0.999	0.999	0.004
5700	0.999	0.999	0.001
5800	0.999	0.999	0
5900	0.999	0.999	0
6000	0.999	0.999	0
6100	0.999	0.998	0
6200	0.999	0.997	0
6300	0.999	0.991	0
6400	0.999	0.987	0
6500	0.999	0.980	0
6600	0.999	0.966	0
6700	0.999	0.941	0
6800	0.999	0.899	0
6900	0.999	0.846	0
7000	0.999	0.771	0
7100	0.999	0.695	0
7200	0.999	0.607	0
7300	0.999	0.507	0
7400	0.999	0.397	0
7500	0.999	0.306	0
7600	0.999	0.236	0
7700	0.999	0.170	0
7800	0.999	0.110	0
7900	0.999	0.067	0
>8000	0.999	0.045	0

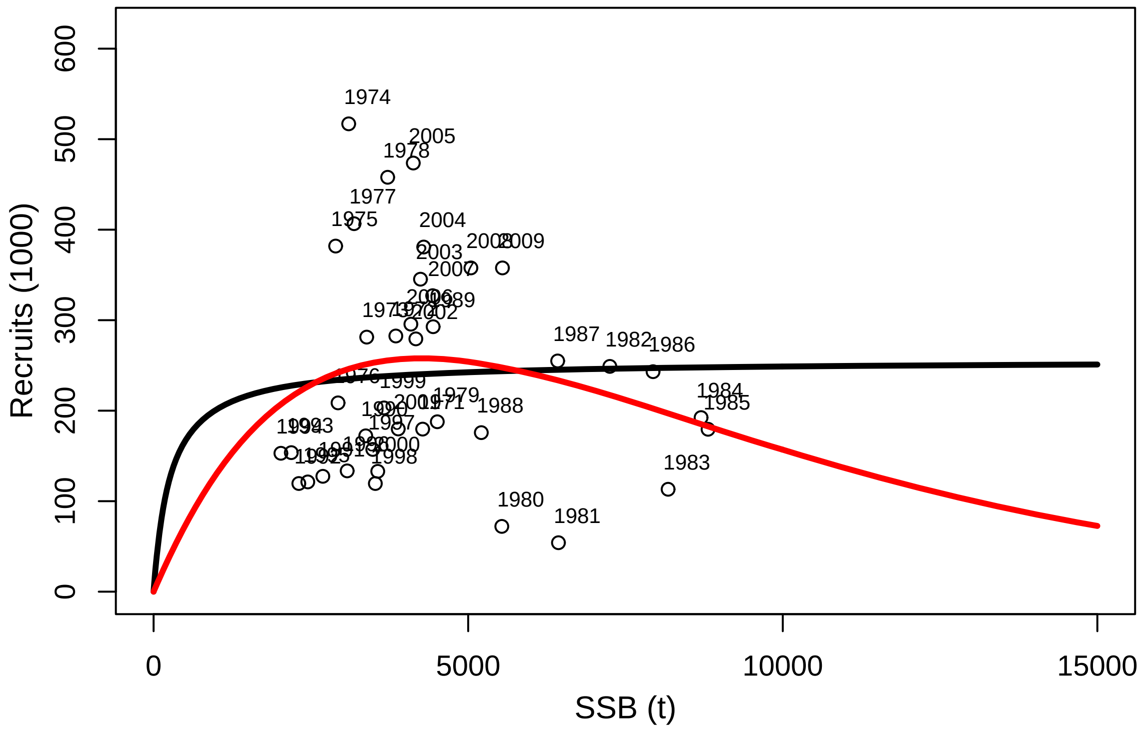

Figure 1. Stock-recruit relationship showing a Beverton-Holt (black) and Ricker (red) curve. The history of the stock is shown as labelled points.

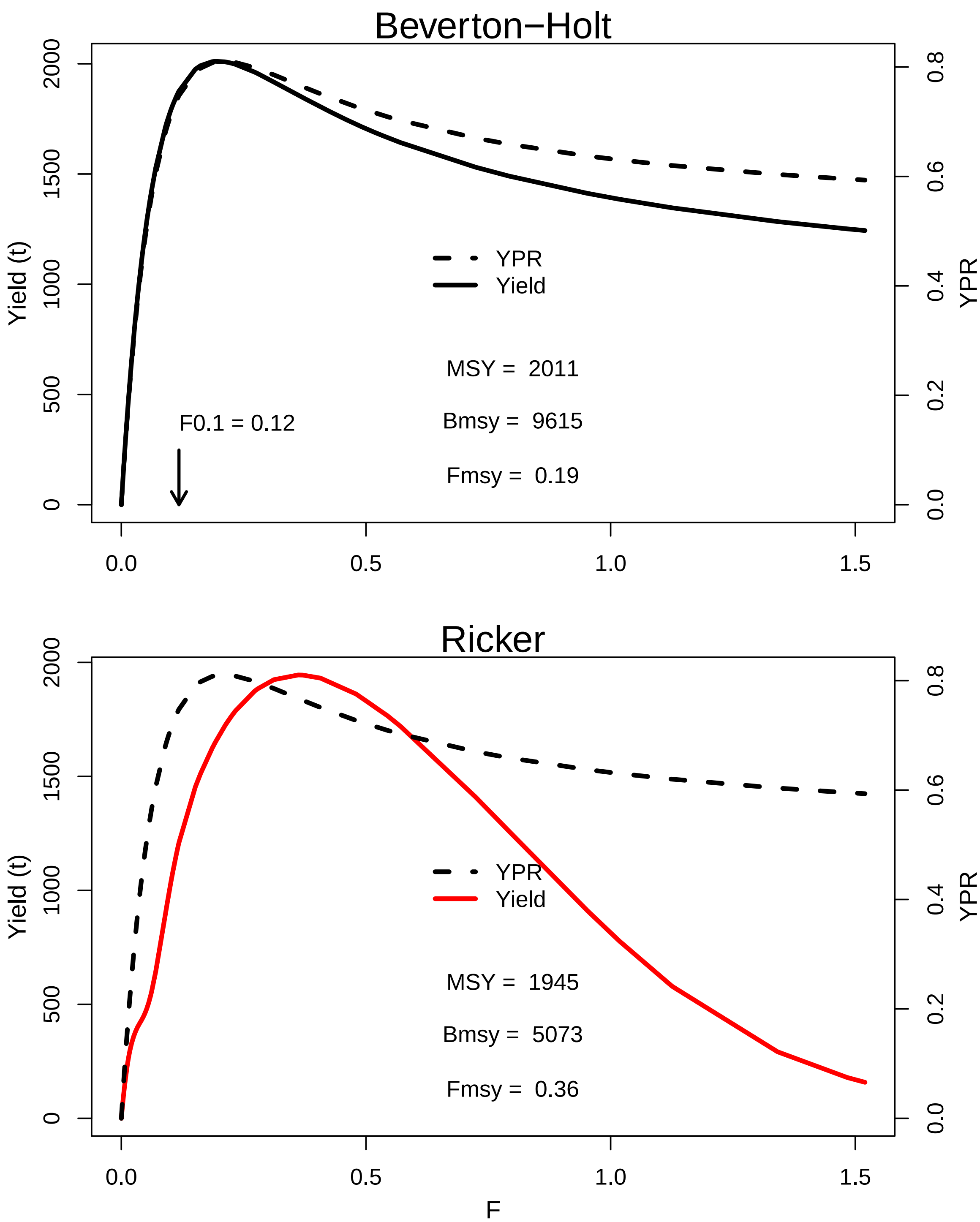

Figure 2. Atlantic halibut yield estimated from Beverton-Holt (black line) and Ricker (red line) stock recruitment models. The curves show F_{msy} at 0.19 for the Beverton-Holt and 0.36 for the Ricker models. Yield per recruit (dashed line) is plotted for comparison.

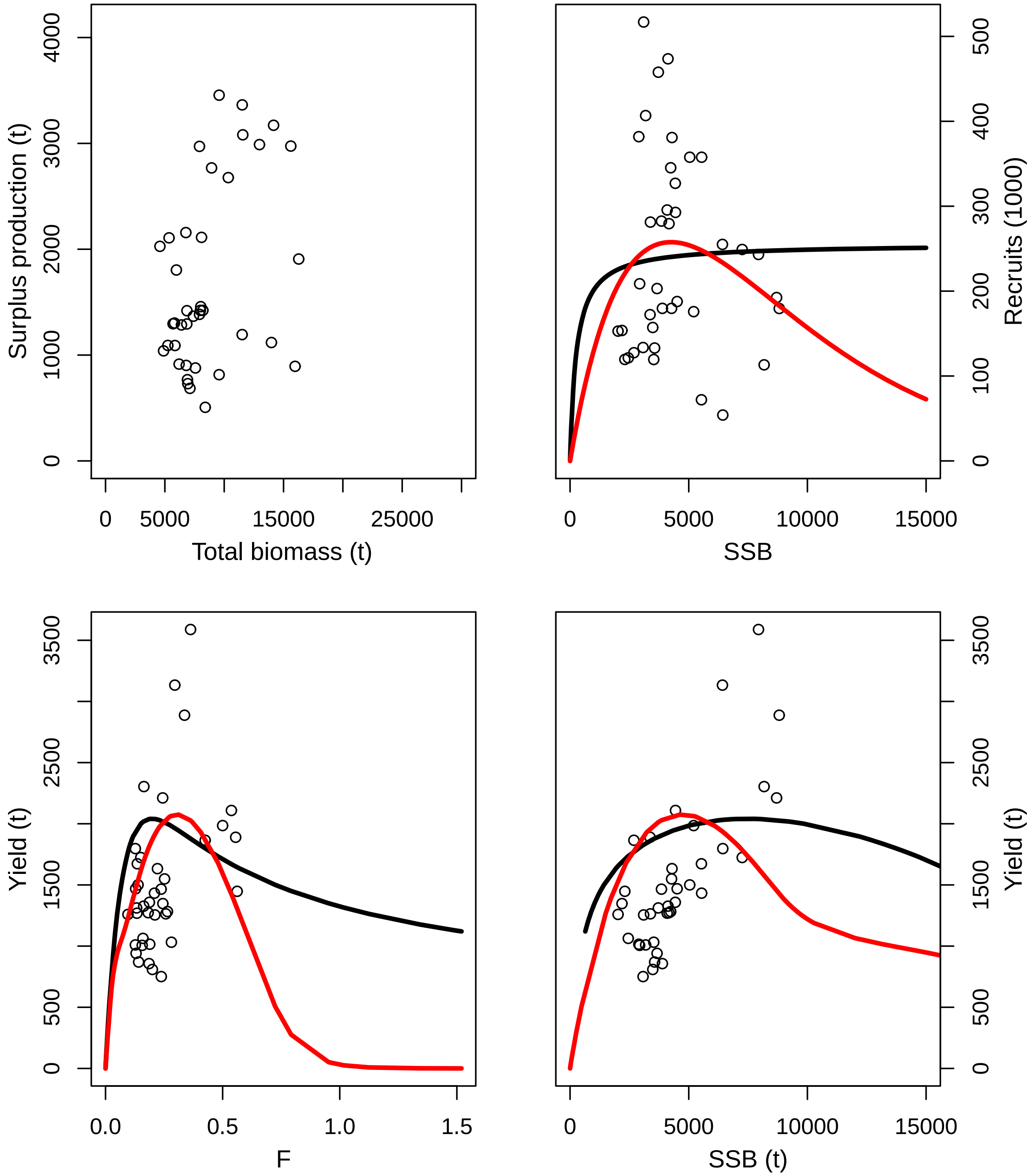

Figure 3. Sissenwine-Shepherd production model. The upper left plot is the surplus production as a function of total biomass. The upper right plot is a stock-recruit relationship showing a Beverton-Holt (black) and Ricker (red) curve. The lower left plot is yield as a function of fully recruited fishing mortality. The lower right plot is yield as a function of spawning stock biomass.

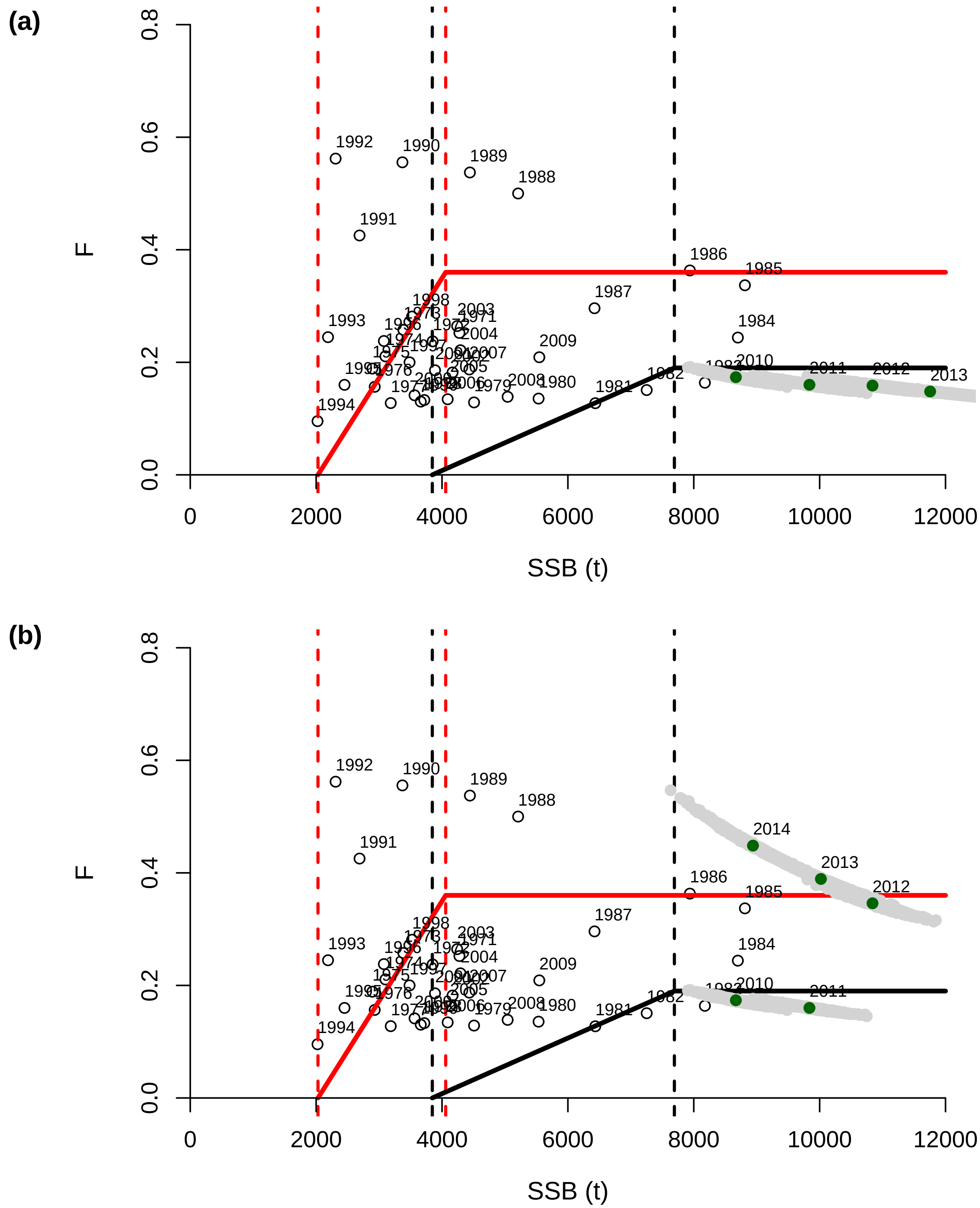

Figure 4. Harvest control rule for halibut using Beverton-Holt (black) and Ricker (red) model results. The vertical lines mark the boundaries between critical, cautious and healthy domains. The history of the stock is shown as labelled points. The stock was projected ahead for 5 years assuming removals of 1,700 t and 1,850 t for 2010 and 2011 and 2,000 t per year for 2012-2014 (upper), 4,000 t per year for 2012-2014 (lower). The grey region represents the uncertainty in the projected F and SSB.

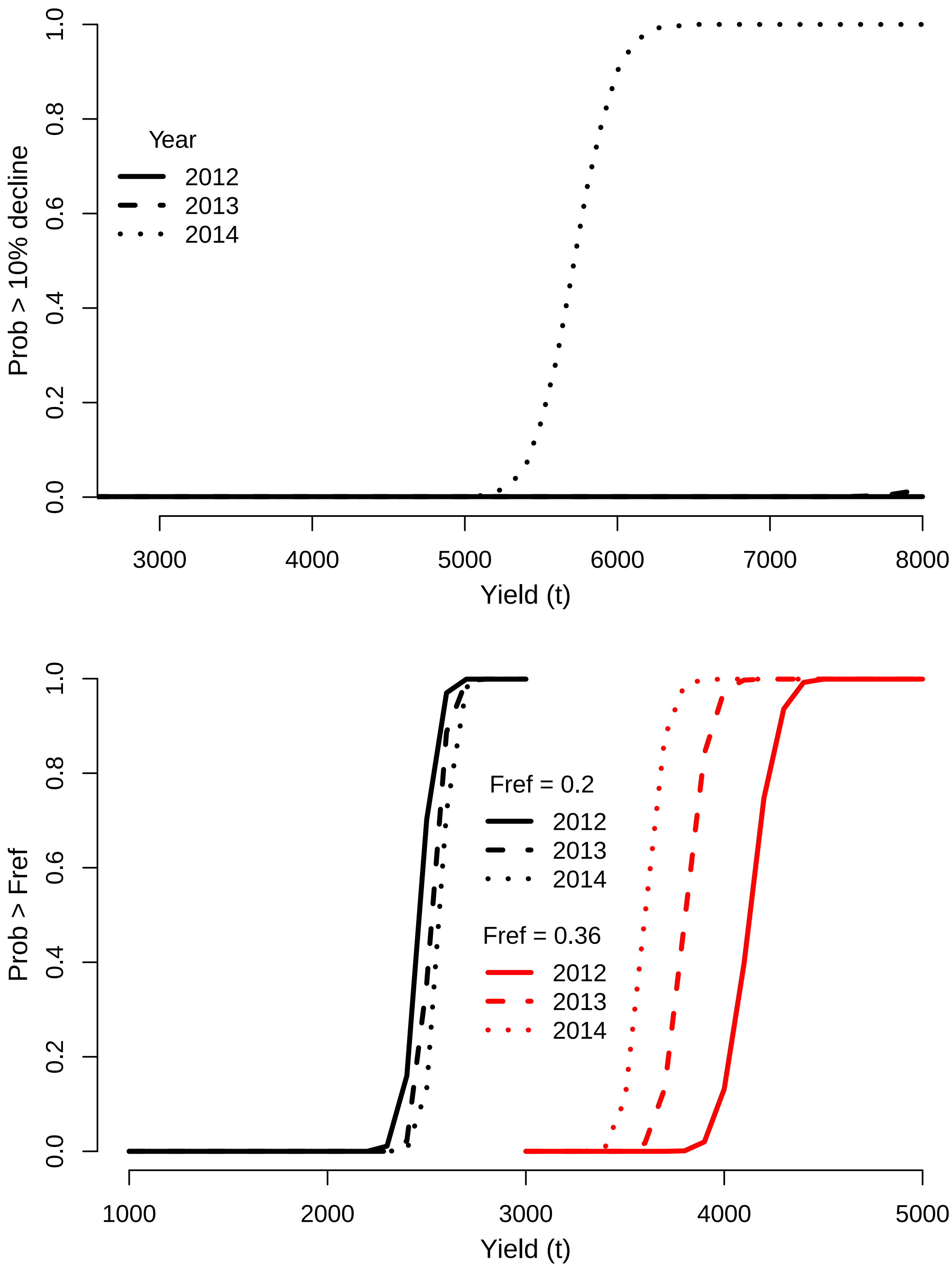

Figure 5. Probability that spawning stock biomass will decrease by 10% or greater (upper) and that F_{ref} will be exceeded (lower) at levels of yield in 2012, 2013 and 2014.