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Report of the Workshop for Revision of the North Sea Herring Long Term Management Plan

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Executive summary

WKHELP evaluated the current Long term Management Plan for North Sea autumn spawning herring given the recent benchmark assessment (ICES 2012/ACOM:47) following the joint request from EC and Norway. Given the revised perception of the stock, the group allocated much effort to the evaluation of the Reference Points.

The group considered two periods of time-series data of SSB and recruitment to extract information that would support the choice of B_{lim} (SSB below which recruitment was impaired). The analysis of both time-series periods, one including phases of higher and lower productivity (1985 – 2011 data) and the other with lower productivity only (from 2003 onwards), indicated that B_{lim} = 0.8 million t would be appropriate (i.e. no change from the pre-benchmark value).

The upper 95% confidence limit around log(B_{lim}) from the recent time-series, assuming no bias and lognormal error of the assessment year SSB, was chosen for calculating B_{pa}. B_{pa} is subsequently estimated at 1 000 000 t (rounded upwards to the nearest 100 000 t).

The group explored hockey stick, Beverton and Holt and Ricker stock–recruitment functions to estimate F_{msy}. The difference between F_{msy} estimates based on Beverton and Holt and on Ricker functions is small and, given uncertainties, differences are probably not significant. In addition, the understanding about the nature of the stock and recruitment relationship is still insufficient to support either model's underlying assumptions. Therefore the range 0.24 – 0.30 resulting from both Ricker and Beverton and Holt fits was proposed.

The HRC evaluation procedure was performed using a stochastic medium term (10 years) simulation model. The model simulated the biological herring population and the behaviour of the fishing fleets and surveys, while the stock assessment was mimicked to estimate the stock status. Finally, the management advice and implementation were based on management plan scenarios. The simulations were run with 1000 Monte Carlo realisations (MCR) to obtain a broad range of possible outcomes given the variability of the input data.

Eight Harvest Control Rule (HCR) options were examined for F_{msy} targets at F=0.24 and F=0.30. The options were the following: 1)The current harvest control rule; 2) The current harvest control rule with no TAC stability mechanism; 3) The current harvest control rule with F 3years TAC stability mechanism; 4) The current harvest control rule with the 50:50 rule TAC stability mechanism; 5) The current harvest control rule with a constraint in F variability as the TAC stability mechanism; 6) The current harvest control rule with a quota flexibility of +10% (banking); 7) The current harvest control rule with a quota flexibility of ±10% (banking and borrowing) and 8) The current harvest control rule changing the target fishing mortality for 0-1 ringers over a range of values from 0.0375 to 0.05.

All eight Harvest Control Rule options tested included precautionary scenarios. WKHELP selected five HCR options for the advice based on an evaluation of the performance of the options in terms of the chosen performance indicators, but also how operational these options will be for management of North Sea autumn spawning herring (NSAS). Both FIAV (option 5) and mean TAC (option 4) are operational and have the ability to quickly adapt to changes in recruitment and stocks. LTMP (option 1) is currently implemented and therefore considered operational. Banking (option 6) or Banking and Borrowing (option 7) are practical solutions to facilitate fishery operations, e.g. a full TAC utilisation without risking overshooting the TAC.

Option 1) HCR with max 15% interannual variability (IAV) in TAC. This scenario showed average performance in all the indicators; SSB in 2022, mean F2-6, mean yield and TAC stability, compared to the other HCRs.

Option 4) HCR with mean TAC. This scenario showed average performance in all the indicators; SSB in 2022, mean F2-6, mean yield and TAC stability compared to the other HCRs. However, it gives the highest yield of the options with high stability over the 10 year period.

Option 5) HCR with max 15% IAV in TAC and FIAV. This scenario results in the highest mean yield (and mean F2-6), but at the cost of highest interannual TAC variability.

Option 6) HCR with max 15% IAV in TAC and banking and borrowing. This scenario showed average performance in the performance indicators mean F2-6, mean yield, and TAC stability compared to the other HCRs. This scenario performed best with regards to the SSB in 2022.

Option 7) HCR with max 15% IAV in TAC and banking. This scenario showed average performance in the performance indicators SSB in 2022, mean F2-6, and mean yield compared to the other HCRs. This scenario performed best with regards to the TAC stability.

WKHELP does not recommend implementation of an HCR without a TAC stabilising mechanism (option 2) or the 3 year rule (option 3). The HCR without a TAC stabilising mechanism was only included for comparison and the 3 year rule is based on projections dependent on the last year where uncertainty on stock development is highest. The juvenile bycatch option (option 8) was only used to explore the trade-off between the juvenile and adult herring fisheries.

The current evidence and knowledge of density-dependence processes in the biology of NSAS is not strong enough to justify an increase in the target F at high stock sizes. Density-dependent mechanisms cannot be ruled out at the early larval stages of herring. It may be that the decline in recruitment is purely environmentally driven and the apparent synchrony with spawning biomass is a coincidence. Clearly more evidence is necessary in order to identify the regulatory mechanisms underlying the low productivity regime currently observed in North Sea herring.

1 Terms of reference

2011/2/ACOM64 The **Workshop for revision of the North Sea Herring Long-term management Plan** (WKHELP), chaired by: Lotte Worsøe Clausen* (Denmark) and Niels Hintzen* (NL), will have two 2-day meetings in ICES HQ in September/October 2012 to:

a) re-evaluate the precautionary reference points (B_{lim}, B_{pa}, F_{lim} and F_{pa}) and management reference points ($B_{trigger}$, F_{msy}) for the stock and to conduct an evaluation of the harvest control rule under the following conditions

i) Using target F values above $B_{trigger}$ of 0.2, 0.25, 0.3 and any revised estimate of F_{msy}, which are reduced linearly to 0.1 at B_{lim}.

ii) Applying the harvest control rule with no TAC stability mechanism.

iii) Applying the HCR with the following stability mechanisms when the SSB is above B_{lim}:

1) Setting a TAC in the TAC year based on the average of the projected TACs at target F over three years starting with the TAC year.
2) Setting the TAC to be the average of the current TAC and the TAC that would result from the application of the HCR for the TAC year.
3) Applying a TAC constraint of +/- 15% but where the resulting fishing mortality is not allowed to deviate by more than 15%, 20% or 25% from the target F

iv) Applying the HCR with the above mentioned stability mechanisms, but applying them only when the stock is above $B_{trigger}$.

v) Allowing an interannual quota flexibility of +/-10%

vi) Changing the target fishing mortality for 0-1 ringers over a range of values from 0.00 to 0.12

b) suggest alternative values for the constraints and ranges where appropriate.

c) consider if it is possible to advise on whether or not there is evidence of density-dependent effects or increases in predation mortality that could justify an increase in the target fishing mortality at high stock sizes.

The group will report to ACOM by the 12th October 2012.

2 Agenda and participation

The workshops were set up by ICES to help ACOM answer a request from the EU and Norway as described in the ToRs of the workshop. There were 12 participants of the workshops (Annex 2) that took place on the 3-4th of September and 1-2nd of October 2012. Prior to the first workshop, a WebEx was held as a preparation for the meeting in order to give feedback on suggested settings for the management plan evaluation and decide on the performance indicators.

Based on the outcomes from the WebEx, all simulations and evaluations of the Reference Points were run prior to the first workshop, facilitating a full and thorough discussion of results, decisions, and final runs to be performed prior to the final workshop in October, where the advice was formulated. The agenda for the workshop followed the outline of the report.

The list of participants can be found in Annex 2.

3 Brief introduction of the LTMP for NSAS and previous evaluations of this

The current management plan is the result of a process that began in the mid-1990s. Any consideration of the plan needs to be made within the context of this process and the ongoing developments in the ICES advice. Thus this section puts the new request into the context of the last 15 years of development and the recent approaches used by ICES.

The origin of the present management plan stemmed from negotiations between the EU and Norway in 1997. The background for this development was the imminent stock collapse that was recognised in 1996 and led, following the advice from ICES, to a drastic reduction in the catches in the middle of 1996. The key elements in this plan were a fishing mortality set separately for adult and juvenile herring (at 0.25 and 0.12 respectively) and a trigger biomass (1.3 million tonnes) below which the fishing mortalities should be reduced. The target fishing mortalities were decided based on extensive simulations (Patterson et al., 1997) to find the level of sustainable exploitation of adults and juveniles that resulted in a low risk of bringing SSB below 800 000 tonnes, which was the MBAL at the time (Minimum Biological Acceptable Levels). The trigger biomass (1.3 Mt) was decided mainly on political grounds, but it was also thought to give some protection against falling below the MBAL.

When the rule was decided the SSB was well below 1.3 million tonnes. The rule did not specify mortalities for that situation, but in practice the TACs set corresponded to an adult F of about 0.2. The industrial fishery on juvenile herring and sprat became heavily regulated and controlled, resulting in a fishing mortality around 0.05, well below the agreed level.

When ICES introduced precautionary reference points in its advisory practice, the MBAL level was adopted as B_{lim} and the trigger biomass of 1.3 million tonnes as B_{pa}. The target fishing mortalities in the harvest rule were adopted as F_{pa}.

The harvest rule was amended in 2004. The amendments included specific rules to apply when SSB is below 1.3 million tonnes and a constraint on TAC change from year to year.

ICES examined the performance of this revised harvest control rule in 2005 and considered the target F to be consistent with the precautionary approach (ACFM, 2005). However, ICES considered that the strict application of the TAC change limit of 15% (rule number 5) may not be consistent with the precautionary approach. Assuming that paragraph 6 (reducing the TAC more than 15%) would be invoked when TAC constraints would lead to SSB falling below B_{pa}, the HCR (harvest control rule) was considered to be in accordance with the precautionary approach.

Previous evaluations of the rule were done assuming recruitment at the historical average. Since 2001, the recruitment has been at about half the long-term average. There are no indications that this is just a temporary change in stock dynamics. Hence, ICES advised that management should adapt to a regime with reduced recruitment, and noted that the performance of the existing rule at the time was at best marginal in this situation, as it may break down if the assessment and/or implementation and compliance were sufficiently biased.

The current plan has a trigger biomass of 1.5 million tonnes, thus reducing the target fishing mortality of the human consumption fishery when the SSB is between 0.8 and 1.5 million tonnes. The target fishing mortality on the juveniles is reduced to 0.05 and 0.04 when below 0.8 million tonnes SSB. The 15% interannual variability (IAV) on TAC is viewed as precautionary, as long as paragraph 6 also remains in the plan. The current plan (from 1 January 2009 to 31 December 2011) has thus been the basis for advice for North Sea autumn spawning herring.

3.1 WKHMP (2008)

The WKHMP was set up to evaluate the management plan of North Sea herring and continue the development of a management plan for western Baltic spring-spawning herring. For North Sea herring, the approach applied was of a framework of simulation tools to explore a range of settings for management simulations.

The simulations confirmed the conclusion by ACFM in 2005 that the performance of the current harvest rule was suboptimal in the present situation of reduced recruitment. The key issue was that even the relatively low fishing mortalities prescribed in the rule led to an equilibrium biomass that was close to the B_{lim}. A further reduction in recruitment, a higher overfishing or less reliable assessments all led to a risk of falling below B_{lim} that was incompatible with the precautionary approach. A better protection required a reduction in the realised fishing mortality, which can be achieved by a reduction in target Fs or (less effectively) by a higher trigger biomass in the harvest rule. Neither of these would lead to substantial loss of catch for the A-fleet in the longer term, while the catch of the B-C-D fleet would change according to the target fishing mortality for that fleet. A reduction in the F for the B-C-D fleet would lead to substantial increase in the catch for the A-fleet. Stability of TACs was thought to potentially improve with lower fishing mortalities.

The key criteria employed for judging the efficacy of a management plan were: the long-term yields from the stock; conformity with the precautionary approach (specifically the risk of falling below B_{lim}) and the stability of the yields.

The rule to constrain the interannual variation in TACs appeared to work well, and 15% permitted change was concluded to be within the acceptable range after testing a range between 10-20 % IAV. The rule in paragraph 6 (see above) in these simulations was only used as an additional protection below the B_{lim}. Lifting the trigger biomass for the paragraph 6 rule was not explored in depth, but would offer a further protection if the conditions deviated from what had been assumed here. For the first time, alternative SSB trigger points (different from B_{pa}) for the HCR were examined where stakeholders were consulted to express their preference of either a scenario with lower SSB trigger point and lower target F value or a scenario with higher SSB trigger point and higher target F value. The latter combination was put forward as a final result and resulted in the definition of $B_{trigger}$ at 1.5 million tonnes.

3.2 WKHERMP (2011)

The workshop on the evaluation of the long-term management plan for North Sea herring was set up by ICES to answer a request from the EU and Norway on the future of the management plan for North Sea autumn spawning herring. The approach was a qualitative assessment of the questions from EU/Norway within the framework of the herring assessment working group and the previous investigations of the North Sea herring management plan (e.g. HMP described above). No substantial changes to the biology or ecology of North Sea autumn spawning herring (NSAS) were found, thus the simulations performed in HMP were concluded to be still applicable.

The management plan was evaluated to be operating well in relation to the objectives of consistency with PA and a rational exploitation pattern, but not in relation to achieving stable and high yield. The main weakness appeared to be the 15% IAV limit on TAC change which leads to unnecessarily restrictive TACs when the stock is improving. Thus, although the management plan was considered to be consistent with the MSY approach, the trade-off between stability and high yield was viewed as limiting the maximising of yield in some circumstances.

The current $F_{2\text{-}6}$ of 0.25 was concluded to be consistent with the MSY approach under the current low recruitment regime and no basis was found to further adjust the harvest control rule to account for recruitment variability or trends.

In view of the exceptional increase in the estimated SSB in 2010, HERMP noted that it was better to have a management plan that is able to be responsive to large changes in the biology of the stock, or assessment uncertainty, than mechanisms for within-year revisions within the management plan.

3.3 HIAMP (2011)

The HIAMP evaluated whether the existing management plan was precautionary under various settings for a TAC constraint, as variations to the then current Long-term Management Plan (LTMP), provided that expected recruitment was low. All the variations to the LTMP were tested in the short term forecast where TACs were proposed for the A- and B-fleet given the harvest control rule and possible inter annual variation on TAC constraint.

The five HCR options that were examined were: 1) Current HCR; 2) Current HCR without constraint; 3) 0.2 – 0.3 HCR; 4) 50-50 HCR and 5) Current HCR without constraint in 2012.

All options were found to be in conformity with the precautionary approach, as the risk of SSB falling below B_{lim} was always low under the assumed conditions. The current HCR rule, with the 15% constraint, allowed only a slow increase in TAC from the low in 2011. It gave a similar or better stability than the other options, but it did so at the expense of a lower average yield, even in the medium term. Average F is 0.18.

EU and Norway requested ICES to comment on whether an in-year revision of the TAC in similar circumstances is consistent with the objectives of the long-term management plan for herring in the North Sea. In its response, ICES stated that it is better to have a management plan that can respond to large changes in the biology of the stock or assessment uncertainty rather than within-year revisions of the TAC. In order to address this issue, ICES indicated that it would favour a collaborative iterative process between scientists, managers, and stakeholders if the management plan was revisited.

3.4 Conclusions

The stochastic simulation model has been designed to explicitly incorporate the natural and stock assessment variability as observed over the recent years which have led to considerable revisions in recruitment and spawning-stock biomass. The evaluations performed hitherto have given indications and conclusions to the robustness of the evaluated harvest control rules against this variability. However, the rules have not been evaluated against exceptional variations in biology which are beyond the variation observed in history, nor have the rules been tested for robustness under varying starting conditions in population size. These analyses, therefore, can be viewed as appropriate given the uncertainty in the current population size and they answer the requests fully.

HELP set out to evaluate the current LTMP for NSAS given the recent benchmarked assessment of NSAS (PELA 2012, ICES 2012) following the joint request from EC and Norway. Given the revised perception of the stock, the group allocated much effort to the evaluation of the Reference Points, these being the background for any evaluation of the HCR. The evaluation procedure was performed using a stochastic medium-term simulation model. The model simulates the biological herring population and the behaviour of the fishing fleets and surveys, while the stock assessment is mimicked to estimate the stock status. Finally, the management advice and implementation are based on the adjusted management plan scenarios. In turn, management feeds back into the biological population and the fishery the year after. The simulations are run with 1000 Monte Carlo realisations (MCR) to obtain a broad range of possible outcomes given the variability of the input data. Stochasticity (randomness) was added to variables and parameters to ensure that biological variation, and the uncertainty in the historic perception of the stock was thus reflected.

4 Evaluation of the Reference Points

One of the the ToRs for HELP requests a re-evaluation of the precautionary reference points (B_{lim}, B_{pa}, F_{lim} and F_{pa}) and management reference points ($B_{trigger}$, F_{msy}) for the stock.

4.1 Precautionary Reference Points

4.1.1 Limit spawning-stock biomass (B_{lim})

The group considered two periods out of the entire time-series of SSB and recruitment to extract information that would support the choice of an SSB below which recruitment was impaired. The fit of a segmented regression stock–recruitment relationship to the 1985 – 2011 pairs as estimated by the most recent assessment, which would exclude the period of high productivity of the stock, gave an estimated breakpoint at about 0.8 million tonnes. When only pairs from 2003 onwards were considered, the lowest R observed corresponded to SSB = 0.8 million tonnes. On this basis B_{lim} was agreed at 0.8 million, unchanged from the pre-benchmark value.

4.1.2 Precautionary spawning-stock biomass (B_{pa})

ICES approach to defining PA reference points has been developed through a number of workshops and expert meetings. The study group on the Precautionary Approach to Fisheries Management (ICES 2003) and later REF (ICES 2007) presented the following concept:

a) a revised framework for estimating reference points, starting with B_{lim}, and leading on to the estimation of F_{lim}, F_{pa}, and B_{pa}.

b) the methodology for estimating B_{lim}, using segmented regression

c) a methodology for estimating F_{lim} from B_{lim} deterministically

d) a proposed new methodology for estimating F_{pa} and B_{pa} in order to take into account assessment uncertainty

e) clarification of the risks to be accounted for in this framework

Based on this framework the B_{pa} should be set at a sufficient high level so that the risk of being below B_{lim} due to assessment uncertainty is small (<5%).

The risk is determined by the uncertainty of the estimated SSB in the assessment year (most often the least certain estimate). Provided the assessment model performs without bias, an average CV could be estimated from an appropriate time-series of assessment years CVs.

It is, however, more unclear how to deal with assessment bias. From a theoretical point of view, one cannot trust the model if, at the same time, one believes that it has a bias. On the other hand, if considerable effort has been put into identifying and eliminating sources of bias and they still persist, one should find a pragmatic solution. The observed variation includes both the assessment variance and the assessment bias. However, the setting of a B_{pa} is a one tailed probability problem where the sign of the bias has an important influence.

In the case of running the present SAM based assessment model for North Sea herring for the last 20 years there is what appears to be a consistent bias of underestimating the SSB in the assessment year. However, there are two considerations that can be made concerning this bias. The first consideration is that the observed bias only converges slowly with the number of subsequent assessments and no obvious model can be applied to estimate the bias in the assessment year. The second consideration is that the bias underestimates SSB in the recent time-series and thus acts in a conservative way and reduces the risk to B_{lim}. An attempt was made to estimate the variation pattern taking into account both the assessment error and the retrospective bias. This gave a much wider band of the lower 95% fractile, e.g. estimating a SSB of about 0.75 of the true SSB. The question is if the bias pattern of underestimating SSB is immediately reversible in a single or a couple of years which would potentially drastically increase the risk to B_{lim}. If this was a frequent pattern then it would not be considered a bias and the variation should anyhow be picked up by the variance estimated by the assessment. All in all the mechanizms behind, and the dynamics of change in, bias are not sufficiently understood, and although the time-series does not indicate any drastic changes in bias pattern from one year to the next, attention should be paid to indications of shifting selection pattern that could be a sign of overestimating SSB.

Given that the estimated bias generally results in underestimation of SSB a pragmatic approach was chosen to calculate B_{pa} based on the estimated assessment variance alone. The upper 95% confidence limit (cl) around log(B_{lim}) from the recent time-series, assuming no bias and lognormal error of the assessment year SSB, was chosen for calculating B_{pa}.

$\log(B_{lim}) = \log(B_{pa})$ - ucl*cv =>

$B_{pa} = \exp(\log(B_{lim})$ + cv*ucl)

where B_{lim} is set at 800 000 t;

the maximum CV in the assessment year over a 10 years' time-series is 0.1 and,

the upper confidence limits of the standardised Normal distribution (ucl) is approximately 1.64.

B_{pa} is subsequently estimated at 1 000 000 t (rounded upwards to the nearest 100 000 t).

4.2 MSY reference points

4.2.1 Methods

Yield-per-recruit and MSY reference points and, their associated uncertainties were estimated by means of the "plotMSY" software (FRAME 2010). Derivations of yield- and SSB-per-recruit follow from equilibrium considerations. $F_{0.1}$ and F_{max} are derived calculating the derivative with respect to F of the YPR function. MSY quantities are also derived from the YPR equation, but they also incorporate the stock–recruit relationship. In order to do this, the stock–recruit functions are reformulated in terms of spawning biomass per recruit and multiplied by the YPR equation. Following appropriate substitutions an expression of yield in terms of F is obtained.

The software "plotMSY" uses Markov Chain Monte Carlo (MCMC) methods to infer the distribution of stock and recruitment and yield-per-recruit parameters. In general terms MCMC is an attempt to simulate direct draws from a given complex distribution. MCMC approaches are so named because they use the previous sample values to randomly generate the next sample value, generating a Markov chain (as the transition probabilities between sample values are only a function of the most recent sample value, in a similar way to a random walk). MCMC provides a good tool for exploring the posterior and hence for drawing inferences about models and parameters. The book by Gilks et al. (1996) provides an accessible introduction to MCMC. An application to fisheries modelling can be found in Ibaibarriaga et al. (2008).

Estimates of F_{msy} based on the three common stock recruit relationships: Ricker, Beverton and Holt and Hockey stick (approximated by a continuous function as suggested by Mesnil and Rochet (2010)) were compared. A thousand iterations of the MCMC were performed.

4.2.2 Data

Reference points were estimated based on historic data from 1948 to 2011 and estimates from the 2012 SAM assessment. Input data were:

- Mean weights at age (1960 – 2011), maturity (1948 – 2011) and natural mortality (1963 – 2010) and their corresponding CVs;
- Numbers-at-age in the most recent year and associated CVs as in 2012 assessment output;
- Selection of fishery 2009-2011 ;
- Stock and recruitment pairs for the whole time-series (1948-2011) as estimated in the 2012 SAM assessment.

The selection pattern was obtained by scaling Fs-at-age to the F_{bar} in the final year of the SAM assessment, over three years, then calculating the mean of the Fs-at-age. By standardising to the current F_{bar} before calculating the mean, changes in the overall F between years were removed. The CVs correspond to the CVs of F in the last year of the SAM assessment.

4.2.3 Stock and Recruitment data

The choice of stock and recruitment pairs influence the estimates of MSY reference points. Whether they correspond to a low productivity regime, a mixed productivity regime (and even a high productivity regime) would be critical. We are currently in a phase where the recruit-per-spawner is low compared to the rest of the time-series:

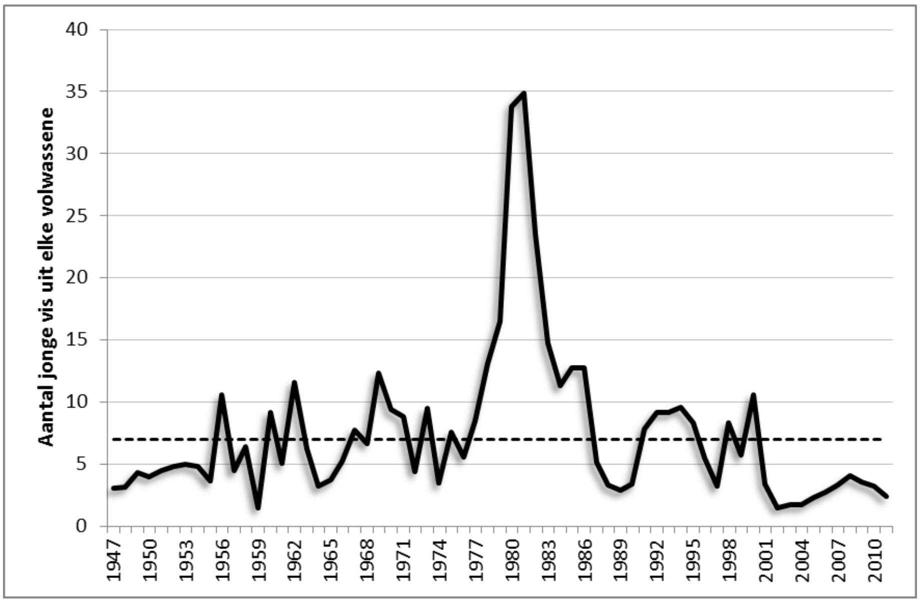

Figure 4.2.3.. The number of young fish (recruits) from each spawning adult per year (1947 to 2011). The dotted line shows the average for the time-series. Note the increase in productivity around 1980, which helped the recovery of the stock after the 1970s collapse, and the extremely low productivity since 2002 (Figure from Dickey-Collas 2012).

Based on productivity criteria, stock and recruitment data for the MSY analysis were selected for three periods: 1) the recent period of low productivity; 2) the entire series excluding the period subsequent to the collapse and 3) the entire time-series 1948 – to date.

The first selection, only including the recent period of low productivity, resulted in few data points and too little contrast in the data to estimate stock and recruitment parameters reliably.

It was therefore considered to be inappropriate. Thus the choice was between using all data and excluding the rebuilding phase. Removing the rebuilding period would take away some real signal coming from a period of high productivity when the spawning-stock biomass was low. Therefore, for the purpose of fitting stock and recruitment functions the group agreed to use the entire time-series of stock and recruitment pairs. This approach mirrored the procedure used for the Norwegian spring-spawning herring stock where such analysis includes all stock and recruitment pairs despite very large fluctuations in stock size (ICES 2007, ACFM:05). If reliably estimating reference points based on the first (short) time period would have been possible, F_{msy} estimates would be estimated considerably higher. High natural mortality is the main driver of this process which suggest that fish must be exploited before they (rapidly) die of natural causes. A fitted stock–recruitment curve on this first time period would suggest that highest productivity occurs at lower SSBs, contrary to what can be observed in the entire time-series. Under these conditions, estimated F_{msy} and F_{crash} are close to each other. The current approach taken can therefore be seen as a precautionary approach.

4.2.4 Results

Estimates of the reference points and associated uncertainties are shown in Table 4.2.4. Yield-per-recruit reference points are also shown and so is the AICc (Akaike's Information Criteria) for small sample sizes. Stock and recruitment parameters alpha and beta (scaled and unscaled), as estimated by ADMB (A-D model builder), are shown. The transformation is used to increase orthogonality and reduce the correlation between the parameters allowing an improved estimate for both the Ricker and Beverton–Holt curve parameters.

Figure 4.2.4.1 illustrates the uncertainty inherent in the estimation of the stock and recruitment curves. The steepness of the curves at the origin is fairly similar for the three models although the Beverton and Holt model result curve appears slightly steeper which results in a lower τ (inverse to slope at the origin) and a lower F_{msy} and F_{crash}.

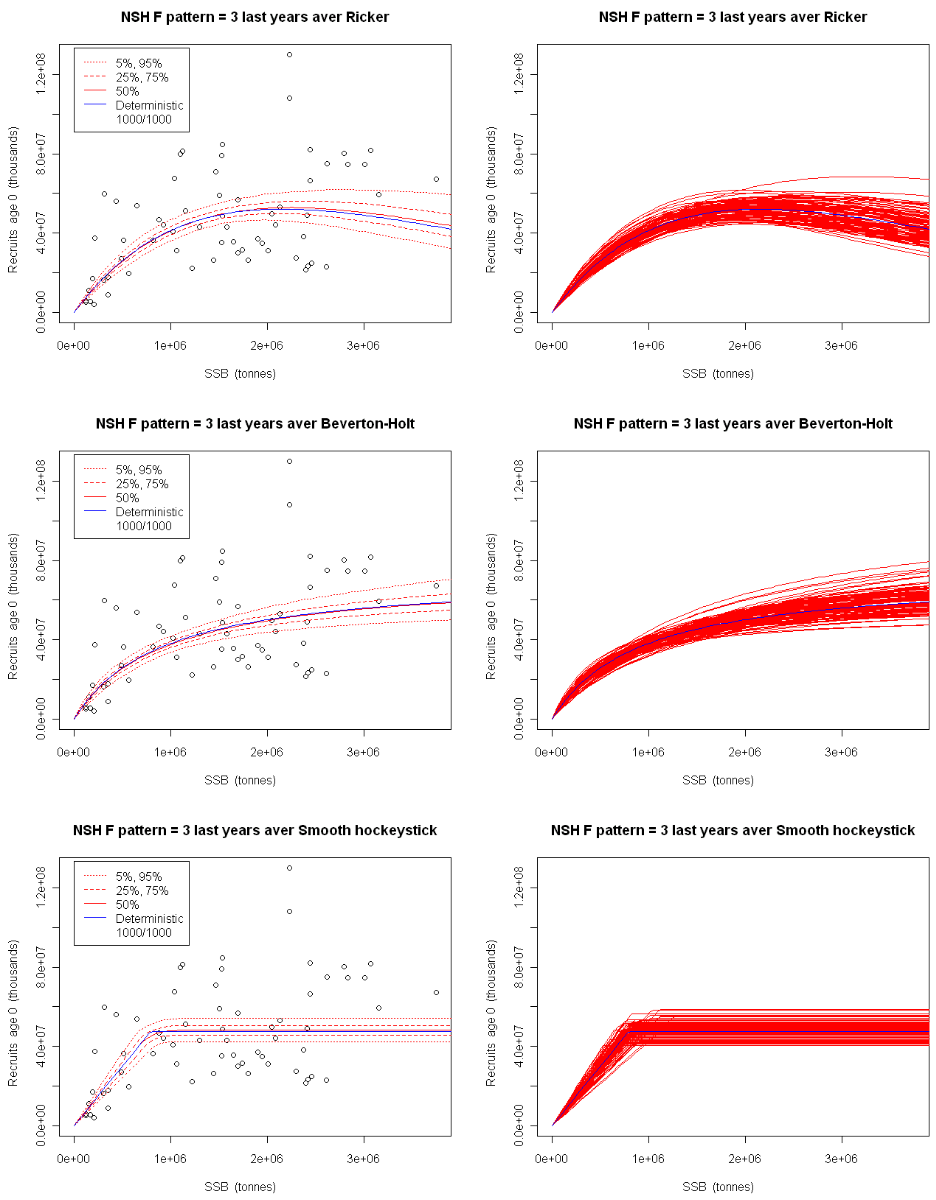

Figure 4.2.4.1. Stock and recruitment curves for the Ricker, Beverton and Holt and smooth hockey stick models. The left hand curves in each figure illustrate the confidence intervals. Curves plotted from the 1st hundred re-samples are shown on the figures to the right. The blue line indicates a deterministic estimate, separate from the MCMC chain.

Figure 4.2.4.2 presents the fit of the Beverton and Holt curve:

a) box plots of the estimated F_{msy} fishing mortality with proxies for F_{msy}, based on the yield-per-recruit definitions of F_{max}, $F_{0.1}$, F35% and F40%, and F in the final year, for comparison(F_{lim}, F_{pa} not shown). Both left- and right-hand plots are the same in this particular case.

b) the equilibrium landings versus fishing mortality plot based on the fitted stock and recruit plot and the selection, maturity and weight at age data. The left hand figure illustrates the percentiles from re-sampling the MCMC chain with the assessment data points, the right hand figure the first hundred re-samples of the estimated relationship;

c) the equilibrium SSB versus fishing mortality relationship for the fitted stock and recruit plot, selection, weight and maturity-at-age data, with the assessment data points.

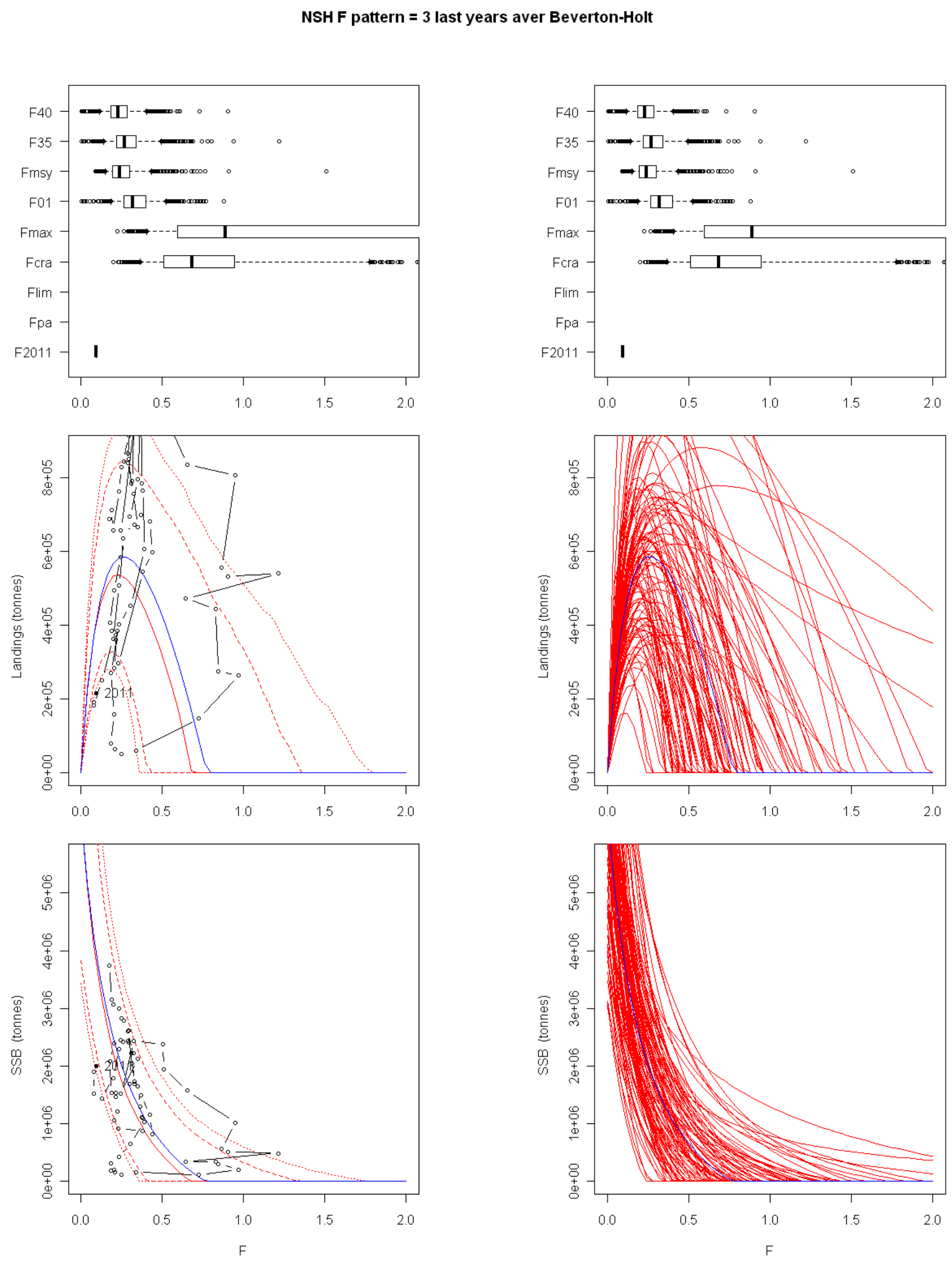

Figure 4.2.4.2: Beverton and Holt stock and recruitment function: reference points (top), equilibrium landingvs.fishing mortality (F, centre) and equilibrium SSBvs.F (bottom).

Figure 4.2.4.3 shows the basis for the estimation of F_{msy} resulting from a Ricker stock and recruitment function fit to the data. This results in a higher F_{msy} compared to the Beverton and Holt fit. The Akaike's information criteria are fairly similar for both models (Table 4.2.4). The estimate of F_{msy} based on the hockey stick shows wide confidence intervals (Figure 4.2.4.5) and it is close to F_{crash} (not shown) which makes it inadvisable from a conservation perspective.

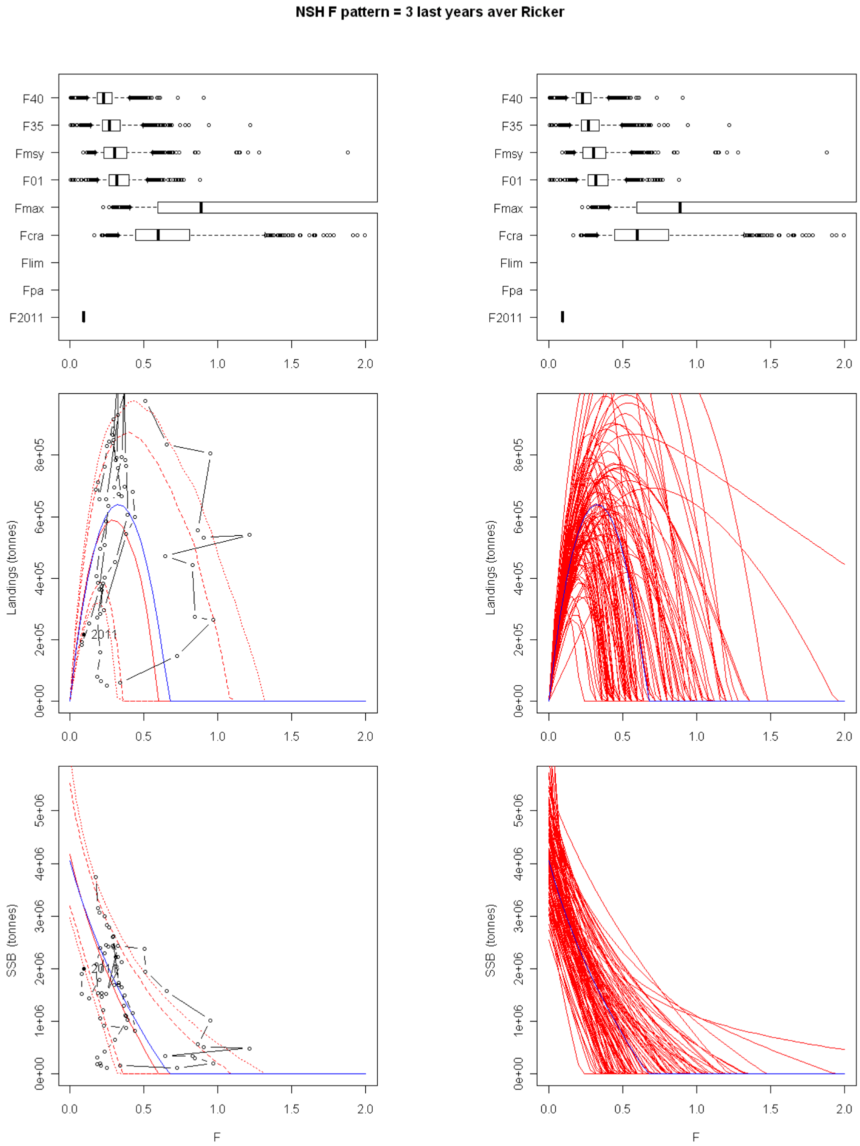

Figure 4.2.4.3. Ricker stock and recruitment function: reference points (top), equilibrium landingvs.fishing mortality (F, centre) and equilibrium SSBvs.F (bottom).

Figure 4.2.4.4 presents the yield-per-recruit output from the model:

a) The estimates of F_{max}, $F_{0.1}$, F35% and F40% SPR with F_{lim}, F_{pa} and the final year F.

b) The human consumption yield-per-recruit at specified levels of fishing mortality.

c) The spawner biomass per recruit at the specified level of fishing mortality.

The uncertainty associated with the stock and recruit function is based on the uncertainties in natural mortality, weight-at-age, maturity and selection which are model input.

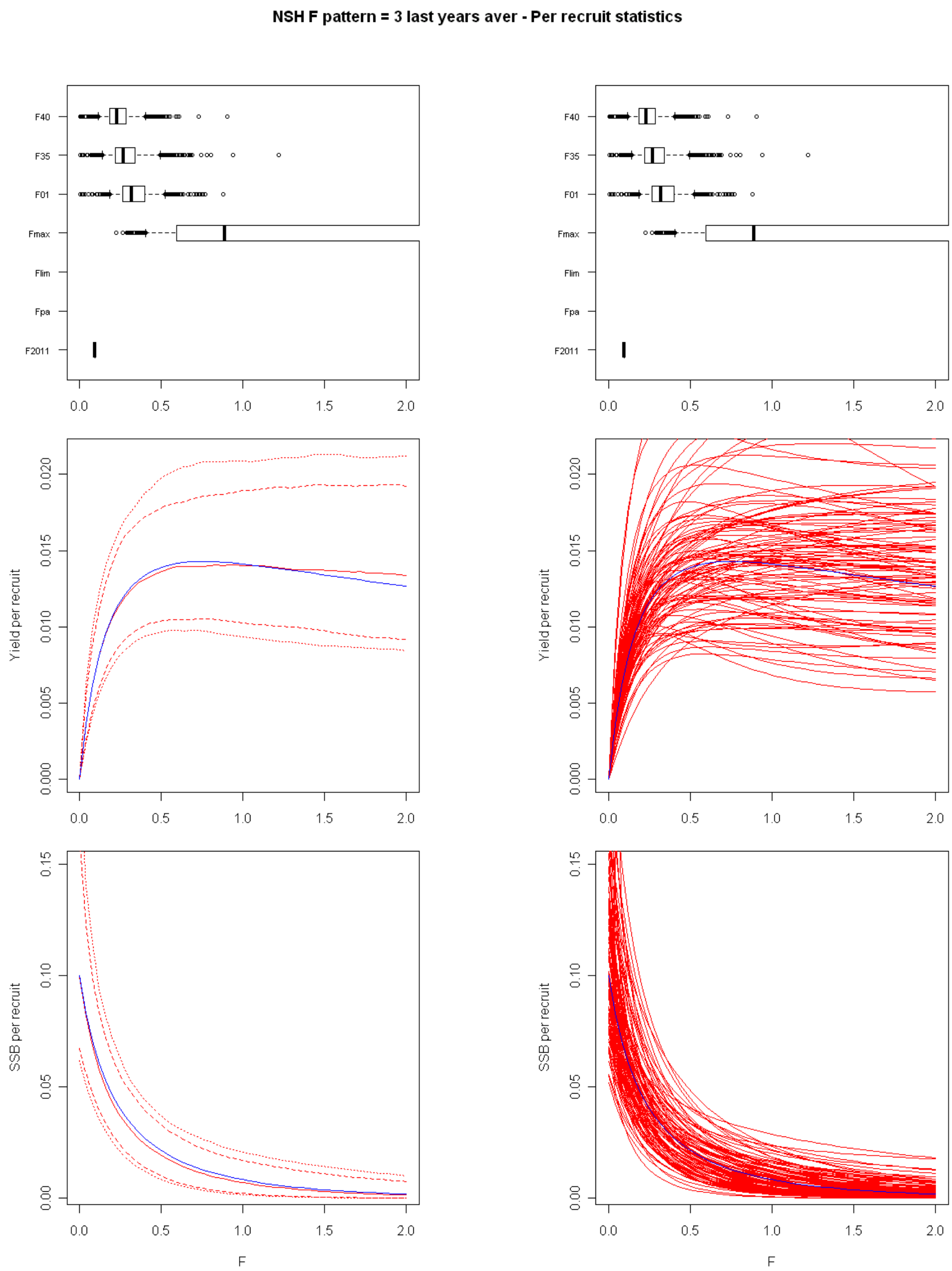

Figure 4.2.4.4. Yield-per-recruit output from the model.

$F_{0.1}$ corresponds to the fishing mortality at which the slope of the YPR curve is 10% of its slope at the origin. $F_{0.1}$ has been widely adopted as a conservation goal and is apparently sustainable for all parameter combinations with τ < than 0.4 (Mace, 1994). In the case of North Sea herring $F_{0.1}$ is very similar to F_{msy} based on the Ricker relationship, which suggests a τ value close to 0.1. For the Beverton and Holt relationship, with a less steep curve at the origin comparatively, $F_{0.1}$ is greater than F_{msy} (see Figure 4.2.4.5).

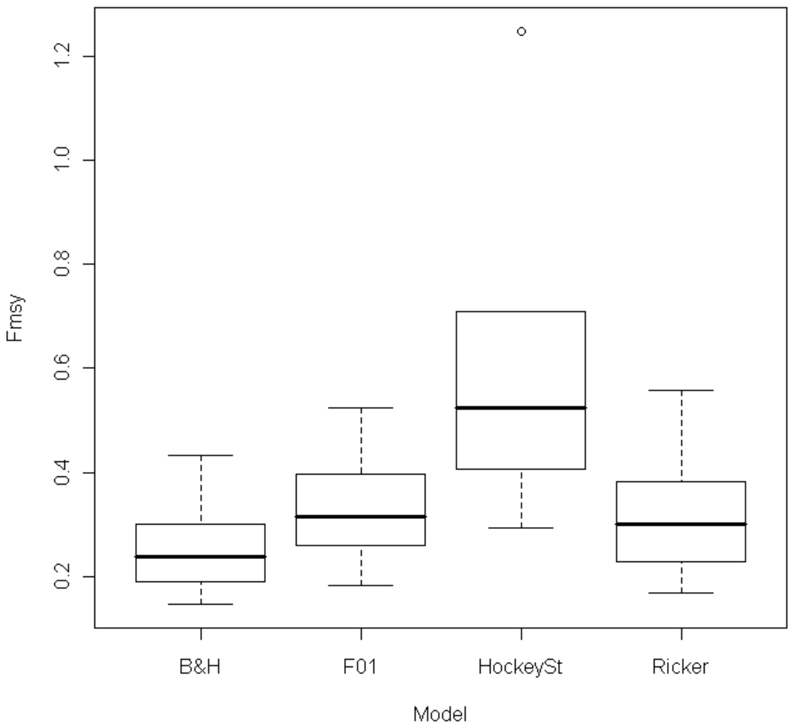

Figure 4.2.4.5. F_{msy} median, 5th, 25th, 75th and 95th percentiles of the distributions as obtained by MCMC for the Beverton and Holt, Smooth Hockey stick and Ricker stock and recruit relationships and for $F_{0.1}$.

4.2.5 Conclusions

The difference between the point estimates for F_{msy} based on Beverton and Holt and on Ricker functions is small and, if uncertainties are taken into account the differences are probably not significant (see Figure 4.2.4.5). In addition, the understanding about the nature of the stock and recruitment relationship is still insufficient to support either model's underlying assumptions. Therefore a range of values were proposed for F_{msy}. Those correspond to the median of the estimates resulting from the Ricker and the Beverton and Holt fits which are 0.24 and 0.30 (see Table 4.2.4.).

Table 4.2.4. Reference point estimates and associated percentiles based on Ricker, Beverton and Holt and Smooth hockey stick functions. Yield-per-recruit reference points are also shown, as is is the AICc for small sample sizes. Estimates of stock and recruitment parameters alpha and beta (scaled and unscaled) are shown for each function.

Ricker									
1000/1000 Iterations resulted in feasible parameter estimates									
	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta	AICc
Determini	0.670395	0.32943	1622410	641098	0.384716	1.74097	65.8193	4.65E-07	104.144
Mean	0.698327	0.324626	1665709	652832.7	0.405309	1.684885	65.07901	4.50E-07	106.2583
5%ile	0.322119	0.167868	1219097	354777.3	0.29937	1.218582	52.05351	3.25E-07	104.25
25%ile	0.440764	0.229014	1442548	507988	0.35377	1.50012	59.2747	4.01E-07	104.7285
50%ile	0.599231	0.30006	1631620	629142	0.399853	1.69089	64.863	4.51E-07	105.66
75%ile	0.808073	0.381176	1840680	761753	0.44901	1.86557	70.08133	4.98E-07	107.0783
95%ile	1.319167	0.55834	2224817	1037124	0.533983	2.140363	79.82759	5.71E-07	110.4147
CV	0.660451	0.445607	0.196832	0.324377	0.180597	0.16517	0.130918	0.16517	0.019554
N	996	1000	1000	1000	1000	1000	1000	1000	1000
Beverton-Holt									
1000/1000 Iterations resulted in feasible parameter estimates									
	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta	AICc
Determini	0.77453	0.263652	1902330	586498	1.54072	1.91537	72925100	910717	103.646
Mean	0.827909	0.257693	1996773	593792.9	1.542213	1.930622	74884314	993054.7	105.6945
5%ile	0.36092	0.145564	1096683	299242.2	1.135349	1.612264	57774190	565090.8	103.7359
25%ile	0.507298	0.190323	1464873	433746.8	1.368993	1.796795	65792800	746562.5	104.2165
50%ile	0.681582	0.237086	1867225	563564	1.5446	1.92947	72741850	934191.5	105.012
75%ile	0.941735	0.299185	2343838	715821	1.707738	2.057965	82072925	1151278	106.4508
95%ile	1.770772	0.431849	3388271	985431.5	1.944764	2.264024	98962235	1629024	110.0622
CV	0.682107	0.403753	0.39079	0.371898	0.161273	0.104286	0.174208	0.354691	0.020307
N	995	1000	1000	1000	1000	1000	1000	1000	1000
Smooth hockeystick									
1000/1000 Iterations resulted in feasible parameter estimates									
	Fcrash	Fmsy	Bmsy	MSY	ADMB Alpha	ADMB Beta	Unscaled Alpha	Unscaled Beta	AICc
Determini	0.622539	0.621478	795649	675745	0.998408	0.523765	29.9521	794049	100.795
Mean	0.661112	0.613635	881445.7	693305.3	1.004454	0.536996	30.13348	814107.5	102.8181
5%ile	0.29705	0.293453	643280	440074.1	0.808593	0.411073	24.25766	623202.9	100.927
25%ile	0.42482	0.405835	751230.3	564325.3	0.907744	0.476875	27.2322	722962	101.3948
50%ile	0.553441	0.524103	839957.5	668212	0.996541	0.531405	29.8961	805630.5	102.196
75%ile	0.751467	0.70834	954909.3	797213.3	1.084255	0.588067	32.52758	891533.5	103.669
95%ile	1.306666	1.249372	1300705	1020400	1.230992	0.689078	36.92955	1044670	106.7784
CV	0.707226	0.568049	0.241769	0.266318	0.131945	0.156115	0.131945	0.156115	0.019286
N	995	995	995	995	1000	1000	1000	1000	1000
Per recruit									
	F35	F40	F01	Fmax	Bmsypr	MSYpr			
Determini	0.299193	0.251091	0.330274	0.760657	0.016729	0.014208			
Mean	0.285855	0.238227	0.32988	1.39049	0.018295	0.014377			
5%ile	0.136709	0.114581	0.182575	0.402463	0.013783	0.009443			
25%ile	0.215739	0.182373	0.260323	0.590233	0.01577	0.01182			
50%ile	0.267184	0.225064	0.315087	0.886965	0.017541	0.013926			
75%ile	0.339418	0.28342	0.396631	3	0.019398	0.016489			
95%ile	0.490976	0.403521	0.524546	3	0.026773	0.021155			
CV	0.404337	0.386537	0.343986	0.729091	0.231353	0.251351			
N	1000	1000	1000	748	1000	1000			

5 Evaluation of the LTMP

The HELP evaluated if the proposed management plan options are precautionary provided that expected recruitment remains within its current low productivity phase. The evaluated management plan options are variations to the current Long-term Management Plan (LTMP) with various constraints in TAC or fishing mortality. All these variations to the LTMP come into play in the short term forecast (10 years) where TACs are proposed for the A- and B-fleet given the harvest control rule and possible interannual variation constraints.

5.1 Evaluation procedure

A stochastic medium-term simulation model is used to carry out evaluations of the harvest control rules proposed in the ToRs. In this model, a multifleet fishery on, and the population dynamics of, North Sea herring are coherently simulated. The model simulates the biological herring population (closely related to the current assessment perception of the stock), the behaviour of the fishing fleets, and surveys. The stock assessment is mimicked to estimate the stock status and provide input to the management decision model. Finally, the management advice and implementation are based on the adjusted management plan scenarios. In turn, management feeds back into the biological population and the fishery the year after. The simulations are run with 1000 Monte Carlo realisations (MCR) to obtain a broad range of possible outcomes given the variability of the input data. Stochasticity is added to variables and parameters to ensure that biological variation and our uncertainty in the historic perception of the stock are reflected. Scenarios are evaluated for a 10 year period to appropriately deal with the definition of risk to fall below B_{lim} following the recommendations of MAS (ICES, 2008b). Graphical representations of the input data are given in Annex 3.

5.1.1 Model description

[1] Biological Operating Model

The biological operating model consists of the age-structured population dynamics of the North Sea herring stock as assessed in 2012 (ICES, 2012/ACOM: 06). The simulation was initiated in 2012 and each year onwards recruits are added to the simulated population. The number of zero year old recruits of the next year is produced in autumn each year by the spawning-stock biomass (SSB). Under the scenarios it is assumed that recruitment survival is poor, similar to the years 2003-2011. It is assumed that recruitment is lognormally distributed where mean and variance of this distribution follow from fitting a lognormal to the recruits in 2003-2011 as estimated by the most recent stock assessment. The number of recruits added to the population each year is drawn from this lognormal distribution.

The biological numbers-at-age are formed by the different cohorts, each affected by fishing mortality and natural mortality. In the simulations these cohorts are followed from ages 0 to 8 (plus group). Natural mortality, that historically varies year by year, is assumed to be similar to the 2012 stock assessment time-series and hence no uncertainty estimate is applied here. The same assumption applies for maturity and weight-at-age. In the projected period, however, all these processes are simulated with variation. To maintain a certain level of autocorrelation, previously observed natural mortality vectors (all ages at once) are sampled in blocks up to 9 years (2003-2011 period, similar to poor-recruitment survival regime) and glued together until the entire projection period is filled, hereby, the selected blocks of years can be reversed in order too. Additionally, to maintain a degree of correlation between maturity-at-age, natural mortality-at-age and weight-at-age (both in the population and in the fishery), year ranges are shared among these processes. Catches and survivors in the forecasted years of the population are calculated using the (natural and fishing) mortality rates.

Within the simulations, the state-space stock assessment model used to yearly assess North Sea herring is not embedded but rather mimicked. This is because including the assessment model in the simulations would result in practical problems with the amount of time available to do the evaluations. As we embed the stock assessment model including uncertainty estimates, we perform Monte-Carlo simulations to represent the stochasticity / uncertainty of the biological population and its behaviour. Over the years 1947-2011 we consider that in the 2012 assessment, the estimated numbers-at-age and fishing mortality-at-age are not without error. Hence, to generate an appropriate starting condition for each of the 1000 MCR, new numbers-at-age, fishing mortality-at-age and total catches are drawn from a multivariate normal distribution using the variance/covariance matrix which is estimated in the 2012 assessment. In the same run, a new set of survey catchabilities are generated. These new values allow us to recalculate survey indices and catches-at-age in a coherent manner. Additionally, survey and catch residuals are calculated and randomly applied to the new catch-at-age and index-at-age time-series to represent observation error. For each of these new sets of catch and survey time-series a new assessment is run, where the assessment result serves as the starting condition of the simulation.

[2] Fleet characteristics and the fishery

The North Sea herring stock is exploited by four fleet types. The stock is primarily targeted by Fleet A, catching herring for human consumption in the North Sea and to a lesser degree by Fleet B, an industrial fishery in the North Sea with bycatches of herring. North Sea herring is also caught in a mixture with western Baltic spring-spawning herring in the Kattegat and Skagerrak area by Fleets C and D (human consumption and industrial fishery respectively). The projected combined selection pattern is assumed to follow an age-correlated random walk where each step follows a normal distribution with mean 0 and variance estimated based on the covariance of log-transformed F-at-age change (from year y to year y+1) over the years 1997-2011. To prevent extreme changes, steps outside the 95% CI of the distribution were excluded.

Selection by fleet is derived by multiplying the combined selection pattern with the catch numbers-at-age proportion of each fleet (average 2009-2011, a period assumed to represent accurately the current exploitation by the fisheries). Landing weights-at-age (for the combined fishery but split by fleet afterwards) are varied in an identical manner as described for maturity- and natural mortality-at-age above.

The long-term management plan model suggests a quota (TAC) that meets the management target. The fleet operating model estimates the annual effort applied by the fleets, given the allocated quotas. To this end, the fishing mortality (F) that corresponds to the TAC or bycatch ceiling for the four fleets is estimated. The fleets consequently generate fishing mortality, calculated by age group as the product of fishing effort, catchability (q), and selectivity-at-age. Fishing mortality affects the numbers-at-age in the biological operating model. Using the Baranov catch equation we can calculate the 'true' catches.

[3] Surveys

Within the simulation framework, four index series are designed, similar to the index series as currently used in the North Sea herring stock assessment, i.e. the SCAI index, a larvae survey index representing SSB at spawning time; IBTS0, an index for the recruits at age 0; IBTS-Q1, an index for age 1 and HERAS, an acoustic survey for ages 1-8+. Survey catchability (q) is assumed to be fixed within a realisation. Re-calculation of the survey indices and their role in determining the starting condition of the simulation is described under [1].

As the stock assessment is mimicked in the projected period, and therefore does not include index values, survey indices are only calculated and used in the historic period.

[4] Assessment and forecast

The perception of the stock status in the period before 2012 is generated through explicit inclusion of a stock assessment in the simulation, which is based on fishery-independent (surveys) and -dependent (catch) data.

From 2012 onwards the assessment is simulated by introducing error in the "true" numbers-at-age and "true" exploitation pattern. This noise is estimated by running 10 year retrospective analyses for each realisation. Within a realisation, the error is measured by the log-ratio of the true numbers-at-age and retrospective numbers-at-age. The final result is an error time-series per retrospective year per realisation. These error time-series are re-sampled and used to generate future retrospective error for the forecasted period. The same procedure as used to sample natural mortality- and maturity-at-age is applied to sample numbers-at-age and F-at-age error. Correlation among N-at-age and F-at-age is maintained here as well.

The stock assessment process results in fishing mortality estimates until year y-2, and survivor and SSB estimates for year y-1 (where year y is the year that the TAC applies). The assessment output data may deviate from the true population characteristics as modelled in the biological operating model because of the variability of the data sources that go into the assessment.

A short-term forecast is used within the MSE to set annual TACs as described below. The short-term forecast is similar to the multifleet forecast as currently used within the North Sea herring assessment. A fixed TAC for the C- and D-fleet is assumed (9600 and 2100 respectively) while the TAC for the A- and B-fleet proposed by the short-term forecast depends on the management scenario. Selectivity by fleet in the TAC and forecast year follow the exploitation pattern as estimated within the stock assessment multiplied with the proportional catch numbers by fleet. Recruitment in the forecast year is fixed to the geometric mean of the period 2003 – the assessment year, while recruitment in the TAC year is taken from the assessment prediction. Stock weight-at-age and time of spawning is similar to the assessment year settings while maturity in the TAC and forecast year equals the average maturity estimate over the past three years and natural mortality is averaged over the most recent five years. The exploitation pattern by fleet is scaled up or down to ensure that the catch equals the TAC in the TAC year. In the forecast year, the LTMP determines the increase or decrease in fleet effort and proposes a TAC for the A- and B-fleet.

However, the proposed TAC is calculated based on numbers, landings selectivity and fleet selectivity obtained from the assessment results which differ from the numbers, landings selectivity and fleet selectivity in the 'true' population. Hence, the fishing mortality needed to realise catch equalling the TAC is not identical to the target fishing mortality as set within the LTMP. As there is no analytical solution to this equation, an optimisation method is used (based on a combination of golden section search and successive parabolic interpolation (Brent, 1973)) to calculate 'true' fishing mortality.

Within this study, alternative long-term management plan (LTMP) scenarios are evaluated to determine if under these changed conditions the LTMP is still precautionary.

5.2 Harvest Control Rule options examined

Eight harvest control rule (HCR) options, with 99 different scenarios in total, were examined. These options were based on the questions posed in the request by EU and Norway (see Section 1). The following assumptions were used:

For all options, catches for the C- and D-fleets were set at fixed values (9 600 and 2 100 tonnes respectively), based on recent catches (2009-2011) of NSAS herring by these fleets. No flexibility from area IIIa into area IV for the C-fleet was assumed. The catches for the A- and B-fleets were determined in two steps as described below. In the implementation step it was assumed that the agreed TACs for all fleets were fully utilised, except for some of the runs of option (vi) where the bycatch TAC for the B-fleet was set to be lower than the maximum allowed by the current LTMP.

In the simulations the basic rule is to first calculate the **preliminary TAC** for the A-fleet in accordance with fishing mortalities derived from the agreed HCR, using the expected SSB in the TAC year as follows:

SSB > $B_{trigger}$: $\mathbf{F_{2\text{-}6}}$ = F_{adults}; $F_{0\text{-}1}$ = 0.05

B_{lim} < SSB < $B_{trigger}$: $\mathbf{F_{2\text{-}6}}$ = F_{adults} -((F_{adults}-0.10)*($B_{trigger}$-SSB)/($B_{trigger}$-B_{lim})); $F_{0\text{-}1}$ = 0.05

SSB < B_{lim}: $\mathbf{F_{2\text{-}6}}$ = 0.10; $F_{0\text{-}1}$ = 0.04

The TACs calculated in this first step are referred to as preliminary TACs in the following text. In a second step, the preliminary TACs are modified in accordance with the specifics of a particular HCR option (e.g. applying or relaxing the 15% TAC constraint or by averaging it with the TAC of the previous year) as described below. The eight HCR options examined (notation relates to the listing in the ToRs in Section 1) were:

ToR i. The current harvest control rule but with the new candidate F_{MSY} values

ToR ii. The current harvest control rule with the new candidate F_{MSY} values and no TAC stability mechanism

ToR iii.1. The current harvest control rule with the new candidate F_{MSY} values and F 3years TAC stability mechanism

ToR iii.2. The current harvest control rule with the new candidate F_{MSY} values and the 50:50 rule TAC stability mechanism

ToR iii.3. The current harvest control rule with the new candidate F_{MSY} values and the FIAV TAC stability mechanism

ToR v. The current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of +10% (banking)

ToR v. The current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of ±10% (banking and borrowing)

ToR vi. The current harvest control rule with the new candidate F_{MSY} values and changing the target fishing mortality for 0-1 ringers over a range of values from 0.0375 to 0.05

ToR i. The current harvest control rule but with the new candidate F_{MSY} values (LTMP)

The run with the current reference points is included as a baseline for general comparison. The values of $F_{2\text{-}6}$ (0.20, 0.24, 0.25 (i.e. current value), 0.30) and $B_{trigger}$ (1.3-2.0 Mt, in steps of 100 kt) were varied in these scenarios. If the preliminary TAC deviates less than 15% from the TAC in the year before, the preliminary TAC is kept. If not, a constrained TAC is set that deviates 15%

from the TAC the year before. If the constrained TAC leads to an SSB < B_{lim}, the preliminary TAC is kept. Applying the stability mechanism above both B_{lim} and $B_{trigger}$ were tested.

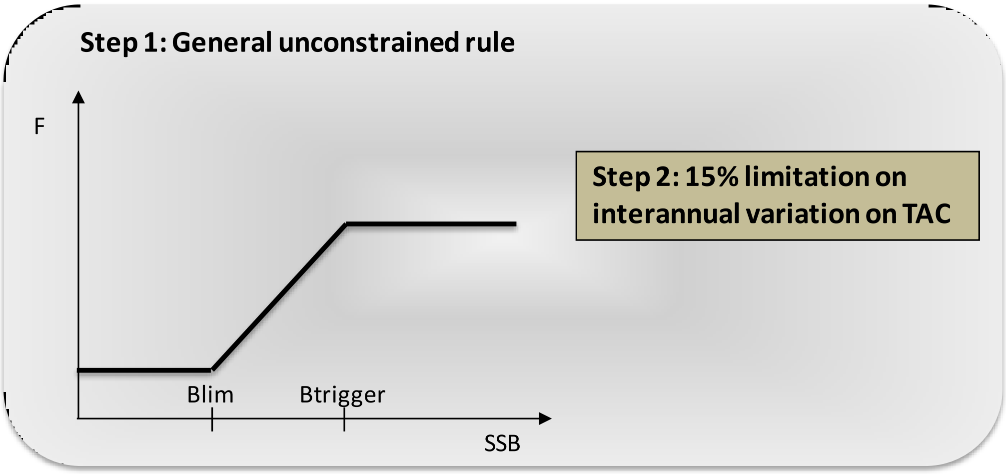

Figure 5.2.1. The current harvest control rule but with the new candidate F_{MSY} values (option i). Note that these two steps were carried out also in the options iii. 3, v, and vi, whereas only step 1 was implemented in options ii and iii.2.

ToR ii. The current harvest control rule with the new candidate F_{MSY} values and no TAC stability mechanism (noIAV)

This option is included as a baseline for comparison, especially in relation to performance indicators for stability in the TAC. Without exception, the TAC is set based on the F resulting from the currently agreed HCR without applying the TAC constraint. In other words, the preliminary TAC becomes the final TAC without any modifications. Two values of $F_{2\text{-}6}$ (0.24, 0.30) were implemented in this option.

ToR iii. 1. The current harvest control rule with the new candidate F_{MSY} values and F3years TAC stability mechanism (F3years)

Forecasting was done 3 years ahead with the same $F_{2\text{-}6}$ (current management plan with updated F_{MSY} values gives $F_{2\text{-}6}$ from SSB in TAC year) and the mean catch from those 3 years calculated with the $F_{2\text{-}6}$ value from the TAC year was applied as final TAC advice. Two values of $F_{2\text{-}6}$ (0.24, 0.30) were tested in this option, and the stability mechanism was applied either above B_{lim} or $B_{trigger}$.

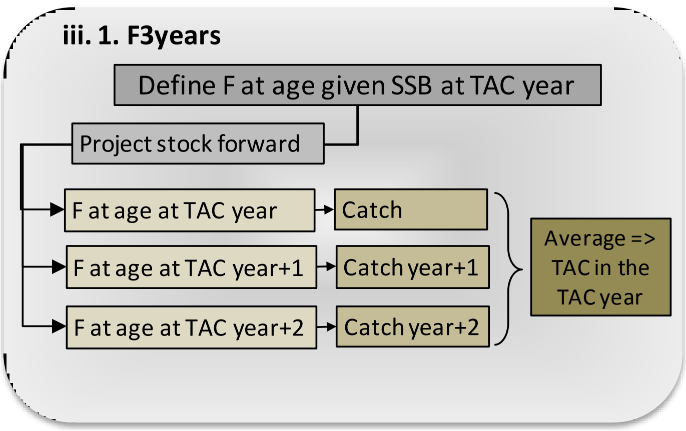

Figure 5.2.2. The current harvest control rule with the new candidate F_{MSY} values and F 3years TAC stability mechanism (option iii.1).

ToR iii. 2. The current harvest control rule with the new candidate FMSY values and the 50:50 rule TAC stability mechanism (meanTAC)

Option ii with a stability mechanism setting the TAC at the average of the preliminary TAC and the agreed TAC for the current year using equal weights (50:50%) for both years. The values of F2-6 (0.24, 0.30) and Btrigger (1.3-2.0 Mt, in steps of 100 kt) were varied in this option. The stability mechanism was applied either above Blim or Btrigger.

ToR iii. 3. The current harvest control rule with the new candidate FMSY values and limiting variability of F as the TAC stability mechanism (FIAV)

Option i is applied, but the resulting fishing mortality is not allowed to deviate by more than 15% from the target F (limiting variability of target F2-6, FIAV). The values of F2-6 (0.24, 0.30) and Btrigger (1.3-2.0 Mt, in steps of 100 kt) were varied in this option. Both TAC and FIAV stability mechanisms were applied either above Blim or Btrigger.

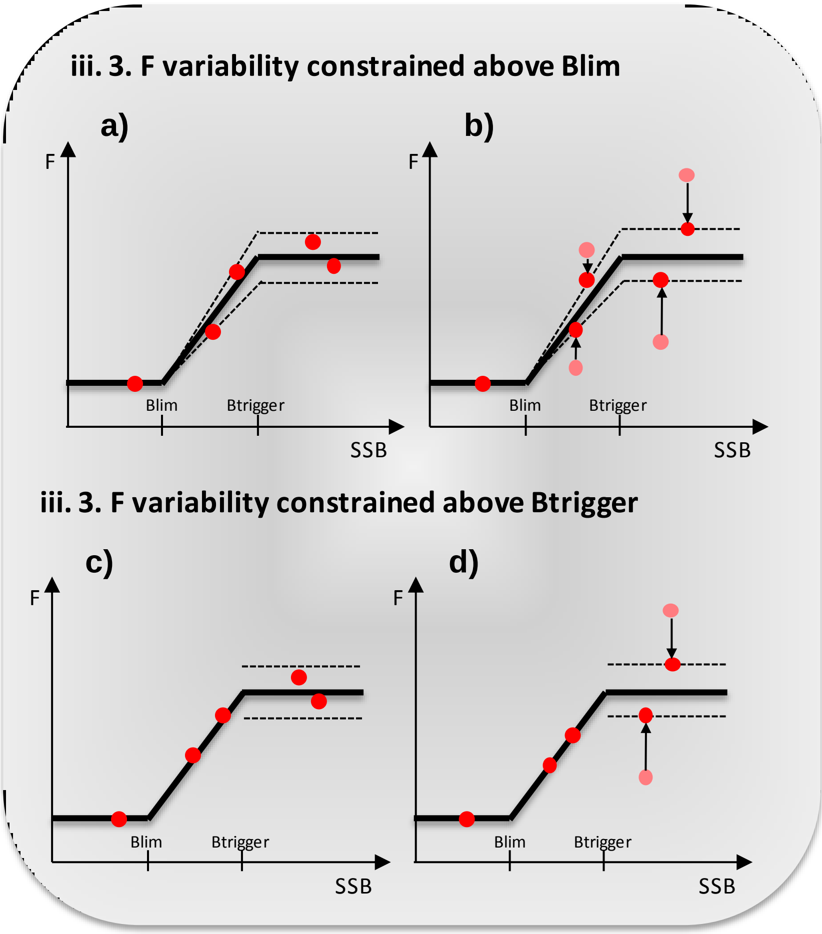

Figure 5.2.3. The current harvest control rule with the new candidate F_{MSY} values and the FIAV and TAC stability mechanisms (option iii.3). Both stability mechanisms (15% constraint on TAC interannual variability and 15% constraint in F variability) were applied either above B_{lim} (a and b) or above $B_{trigger}$ (c and d). If the preliminary F value was inside the 15% limits from the F_{HCR} (panels a and c) it was directly applied. However, if the preliminary F value was outside the 15% limits (pink dots in panels b and d), they were constrained to be within 15% from the F_{HCR}. Below B_{lim} no stability mechanisms were used in any case (resulting always in F_{HCR}).

ToR v. The current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of +10% (Banking)

Option i was applied, and in addition 10 % banking was practised by Fleet A. Banked quota is reclaimed the year after, and no borrowing is allowed. Banking was carried out each year (considered as a worst case scenario). The values of F2-6 (0.24, 0.30) and $B_{trigger}$ (1.3-2.0 Mt, in steps of 100 kt) were varied in this option.

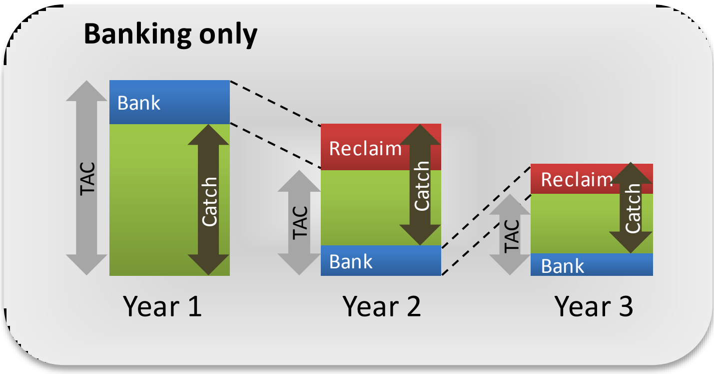

Figure 5.2.4. The current harvest control rule with the new candidate FMSY values and a quota flexibility of +10% (banking, option v). Option i with a TAC constraint of +/- 15% was applied, and in addition 10 % banking each year. Banked quota was reclaimed the year after, and no borrowing was allowed.

ToR v. The current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of ±10% (Banking and Borrowing)

Option i was applied, and in addition both banking (10%) and borrowing (10%) was allowed, with repayment and reclaim fixed to the year after. In the simulated worst case scenario, fleet A banked 10% of a large TAC the first year, and the amount banked was reclaimed the year after. In addition, from the second year onwards a 10% TAC borrowing was implemented. The amount borrowed was 10% of the TAC at current year. This option could result in a large catch allowance in the second year. From year 3 onwards, only borrowing and repayment was carried out (no further banking after first year). The values of $F_{2\text{-}6}$ (0.24, 0.30) and $B_{trigger}$ (1.3-2.0 Mt, in steps of 100 kt) were varied in this option.

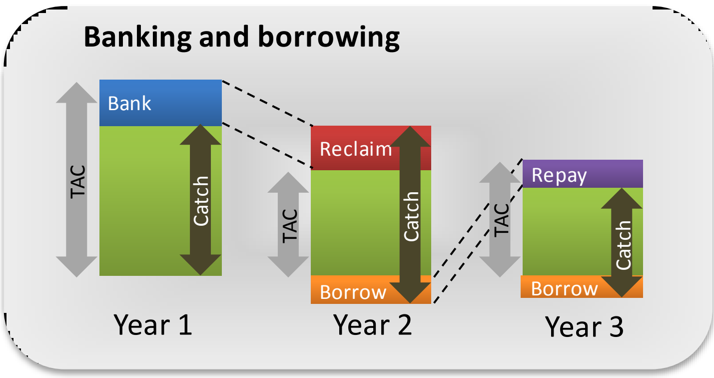

Figure 5.2.5. The current harvest control rule with the new candidate FMSY values and a quota flexibility of ±10% (banking and borrowing, option vi). Option i with a TAC constraint of +/- 15% was applied, and in addition both banking (10%) and borrowing (10%) were allowed, with repayment and reclaim fixed to the year after. In the simulated scenario 10% was banked in the first year, and the 10% quota was reclaimed the year after. In addition, from the second year onwards a 10% quota borrowing was implemented. From year 3 onwards, only borrowing and repayment was carried out (no further banking after first year).

ToR vi. The current harvest control rule with the new candidate F_{MSY} values and changing the target fishing mortality for 0-1 ringers over a range of values from 0.0375 to 0.05 (juv)

Option i with a TAC constraint of +/- 15% was applied, and in addition the $F_{juveniles}$ (0-1 ringers) was varied from 0.0375 / 0.03 to 0.05 / 0.04 (above / below B_{lim}, respectively). The value of $F_{2\text{-}6}$ was varied (0.20, 0.24, 0.30).

5.3 Choice of performance indicators

In the request from EU and Norway, ICES is requested to re-evaluate the precautionary reference points (B_{lim}, B_{pa}, F_{lim} and F_{pa}) and management reference points ($B_{trigger}$, F_{msy}) for the stock and to conduct an evaluation of the harvest control rule under a number of conditions, specified in the ToRs of HELP. ICES is also invited to suggest alternative values for the constraints and ranges where appropriate.

HELP identified the list of indicators below to provide a broad overview of the performance of the different options. The indicators in bold were selected as the five best indicators to be included in the advice.

1. Risk: percentage of iterations in which SSB falls below B_{lim} at least once during the simulation period, in accordance with the criteria laid down by OMSE (2009) (PA)

2. Stock performance:

- **SSB in 2022 (median of all iterations) (2022SSB)**
- Mean SSB over the simulation period (meanSSB)

3. Fishing mortality:

- **Mean fishing mortality of year classes 2-6 over the simulation period (mean F2-6)**
- Mean fishing mortality of year classes 0-1 over the simulation period (meanF01)
- Fishing mortality of year classes 2-6 in 2022 (median of all iterations) (2022F)

4. Yield:

- **Mean catch of A-fleet over the simulation period (Mean Yield A)**
- Mean catch of B-fleet over the simulation period (Mean Yield B)
- Catch in 2013 of A-fleet (median of all iterations) (2013 Yield A)
- Catch in 2013 of B-fleet (median of all iterations) (2013 Yield B)

5. Stability in TAC:

- **Mean % absolute TAC change of fleet A between consecutive years over the simulation period [abs(TAC year2 – TAC year1)]*100/TAC year2 (meanrelTACIAV A)**
- Mean absolute TAC change in tonnes of fleet A between consecutive years over the simulation period [abs(TAC year2– TAC year1)] (meanTACIAV A)
- Number of times (%) the TAC change was restricted upwards by the 15% IAV rule (IAVrestrict up#)
- Number of times (%) the TAC change was restricted downwards by the 15% IAV rule (IAVrestrict down#)
- Mean TAC change for all A-fleet TAC increases (TACup)
- Mean TAC change for all A-fleet TAC decreases (TACdown)

The performance of each of the HCRs according to the above mentioned indicators is given in Annex 3. Note that as a general rule, unless specified otherwise, when an indicator is provided as a mean, first the mean is calculated over time for each iteration, after which the median is taken over these means. All numbers (SSB, F) refer to the true values in the simulated populations.

5.4 Results

In the following section, results from selected scenarios of the harvest control rules proposed (described above) are examined. These scenarios represent outcomes of the evaluations requested in the terms of reference for the group. In total, 99 scenarios were evaluated but only 16 were selected for a close examination in this section. The criteria for selection were: i). considered to be precautionary; ii). result in highest mean yield and iii). most stable (i.e. showing the minimum relative annual variability of TAC). In each case, the results are presented as double panel plots, representing simulated trajectories of landings, $F_{2\text{-}6}$ and SSB, with $F_{2\text{-}6}$ at F=0.24 and F=0.30. These candidate F_{MSY} values are the medians of the estimates resulting from the Ricker and Beverton and Holt fits respectively (see Section 4). Trends in SSB, true $F_{2\text{-}6}$ and landings are discussed. Each of these trends corresponds to the median result of 1000 Monte Carlo simulations. A 90% confidence interval is provided to help judge the precautionary approach criteria from the graphs. Trends described below refer to median results only.

5.4.1. ToR a.i. The current harvest control rule but with the new candidate F_{MSY} values (LTMP).

Twenty two scenarios were tested in total, applying the stability mechanism either above B_{lim} or above $B_{trigger}$. Four scenarios were tested applying the stability mechanism above $B_{trigger}$ and eighteen above B_{lim}. Four of the scenarios tested $F_{2\text{-}6}$ at F=0.20 and F=0.25; the rest used the candidate F_{MSY} values. The majority of the scenarios (16) were tested with $F_{2\text{-}6}$ at F=0.24 and F=0.30, candidate $B_{trigger}$ values ranging from 1.3 to 2.0 million tonnes and applying the stability mechanism above B_{lim}. Each of the eight scenarios tested with F=0.24 was evaluated to be in accordance with the precautionary approach. In contrast, for F=0.30 only two of the eight scenarios, with candidate $B_{trigger}$ values of 1.9 and 2 million tonnes, were precautionary.

The plot below compares the selected two scenarios for LTMP, with$F_{2\text{-}6}$ at F=0.24 and F=0.30, with the candidate $B_{trigger}$ value at 1.3 million tonnes and applying the stability mechanism above B_{lim}.

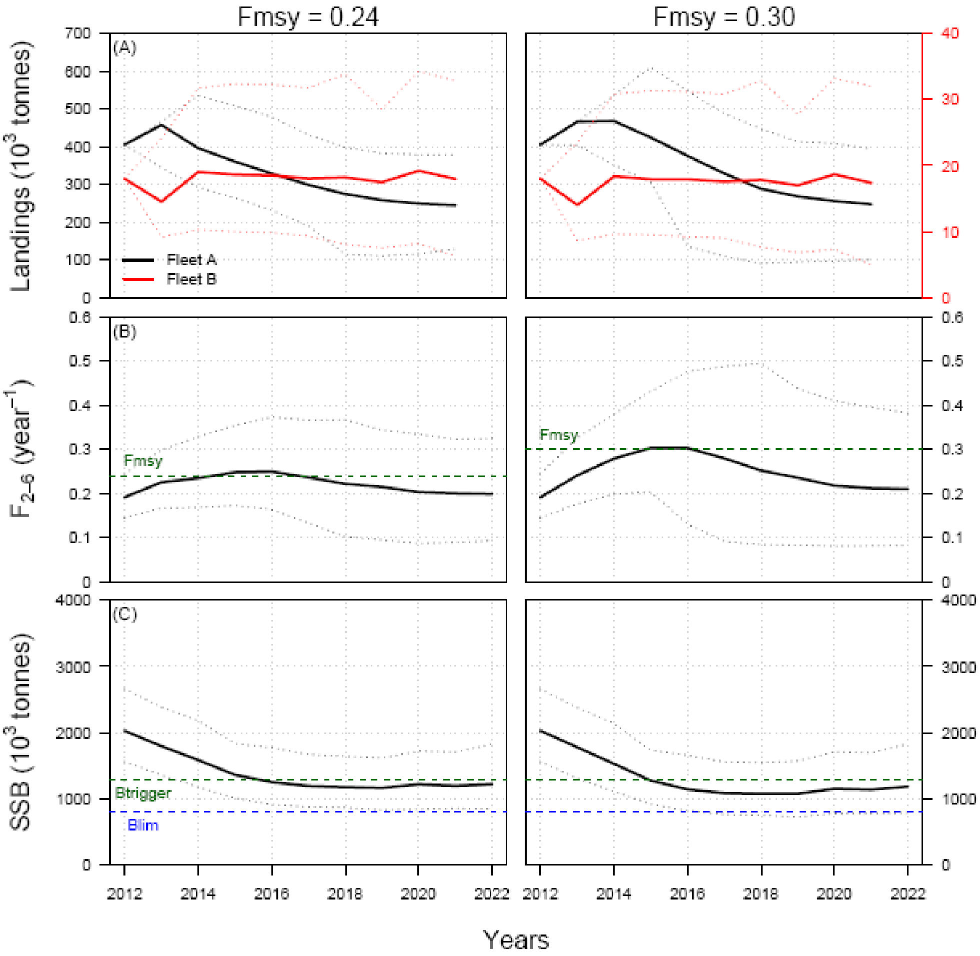

Figure 5.4.1. Current harvest control rule but with the new candidate F_{MSY} values. Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.1.A left panel) increase to their peak in 2013 (~450 000t); then they decrease gradually to around 250 000 t in the last couple of years. $F_{2\text{-}6}$ increases gradually to around F=0.25 in 2016, i.e. slightly above the candidate F_{MSY} (Figure 5.4.1.B left panel) and then declines gradually to around F=0.20. The SSB trajectory (Figure 5.4.1.C left panel) declines steadily until 2017, after which it stabilises to around 1.2 million tonnes. SSB is above $B_{trigger}$ until 2016. From 2017 onwards, SSB is below $B_{trigger}$ but closer to $B_{trigger}$ than B_{lim}. The right panel plots, where F=0.30, show trajectories with considerably higher values for landings and $F_{2\text{-}6}$ until around 2020, when they are similar to the F=0.24 scenario. From 2014 onwards, SSB is slightly lower than for the F=0.24 scenario.

The scenarios with the stability mechanism applied above B_{lim} are more stable than those with the stability mechanism applied above $B_{trigger}$.

The F = 0.24 scenario presented gives the highest average yield within precautionary limits and is the most stable of the scenarios tested for stability applied above B_{lim}. The F=0.30 scenarios are not precautionary (see Table 5.4, scenario numbers 63 and 72).

5.4.2. ToR a.ii. The current harvest control rule with the new candidate F_{MSY} values and no TAC stability mechanism (noIAV).

Two scenarios were tested, with $F_{2\text{-}6}$ at F=0.24 and F=0.30 and a candidate $B_{trigger}$ value of 1.5 million tonnes. Both were evaluated to be in accordance with the precautionary approach. The plot below compares these two scenarios.

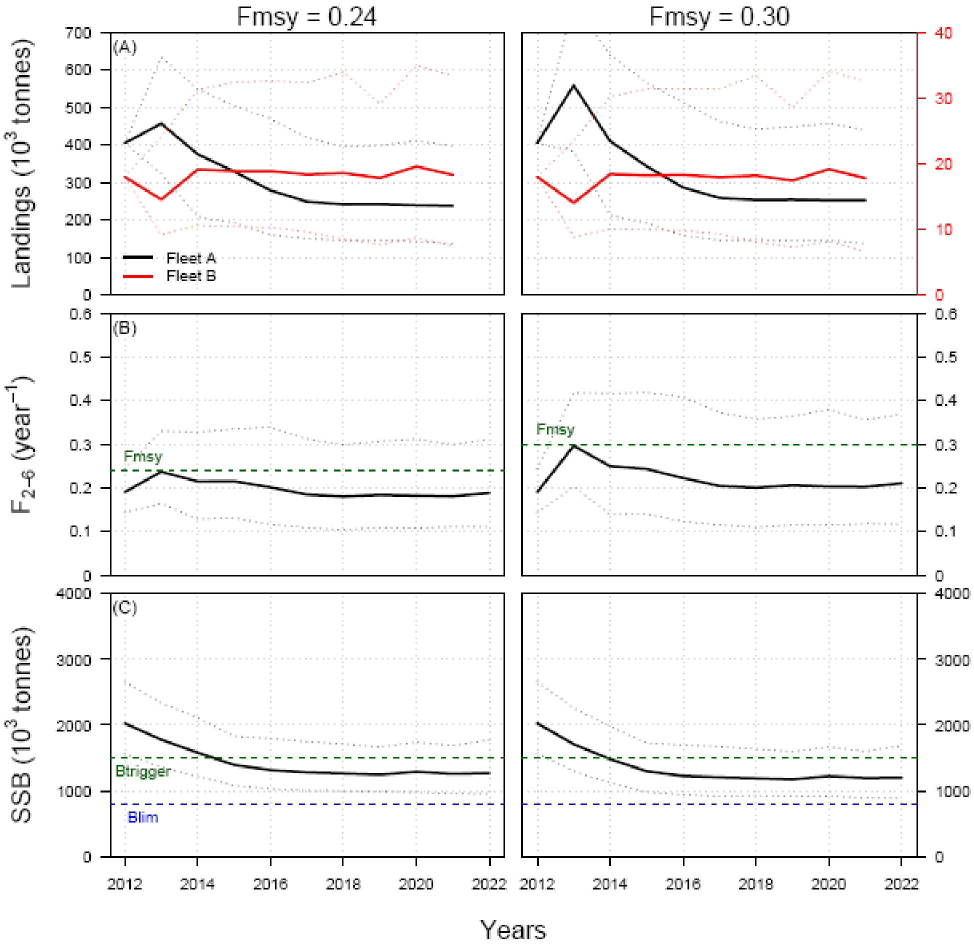

Figure 5.4.2. Current harvest control rule with the new candidate F_{MSY} values and no TAC stability mechanism. Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.2.A left panel) increase to their peak in 2013 (~460 000 t); then they decline quite sharply to 2017 after which they stabilise at around 240 000 t. $F_{2\text{-}6}$ increases in 2013 to around F=0.24, the candidate F_{MSY} (Figure 5.4.2.B left panel) and then declines slowly to 2017 after which it stabilises at around F=0.18. The SSB trajectory (Figure 5.4.2.C left panel) declines gradually until 2016, after which it stabilises around 1.3 million tonnes. SSB is above $B_{trigger}$ until 2014. From 2015 onwards, SSB remains between $B_{trigger}$ and B_{lim}. The right panel plots, where F=0.30, show similar trajectories. Landings and $F_{2\text{-}6}$ are higher in all cases and the trajectories more exaggerated; SSB is slightly lower than for the F=0.24 scenarios.

The F=0.30 scenario results in the higher average yield within precautionary limits. However, the F=0.24 scenario is more stable (see Table 5.4, scenario numbers 98 and 99).

5.4.3. ToR a.iii.1. The current harvest control rule with the new candidate F_{MSY} values and F 3years TAC stability mechanism (F3years).

Four scenarios were tested, with $F_{2\text{-}6}$ at F=0.24 and F=0.30, a candidate $B_{trigger}$ value of 1.5 million tonnes and applying the stability mechanism either above B_{lim} or above $B_{trigger}$. All were evaluated to be in accordance with the precautionary approach.

The plot below compares the two F scenarios with the stability mechanism applied above B_{lim}.

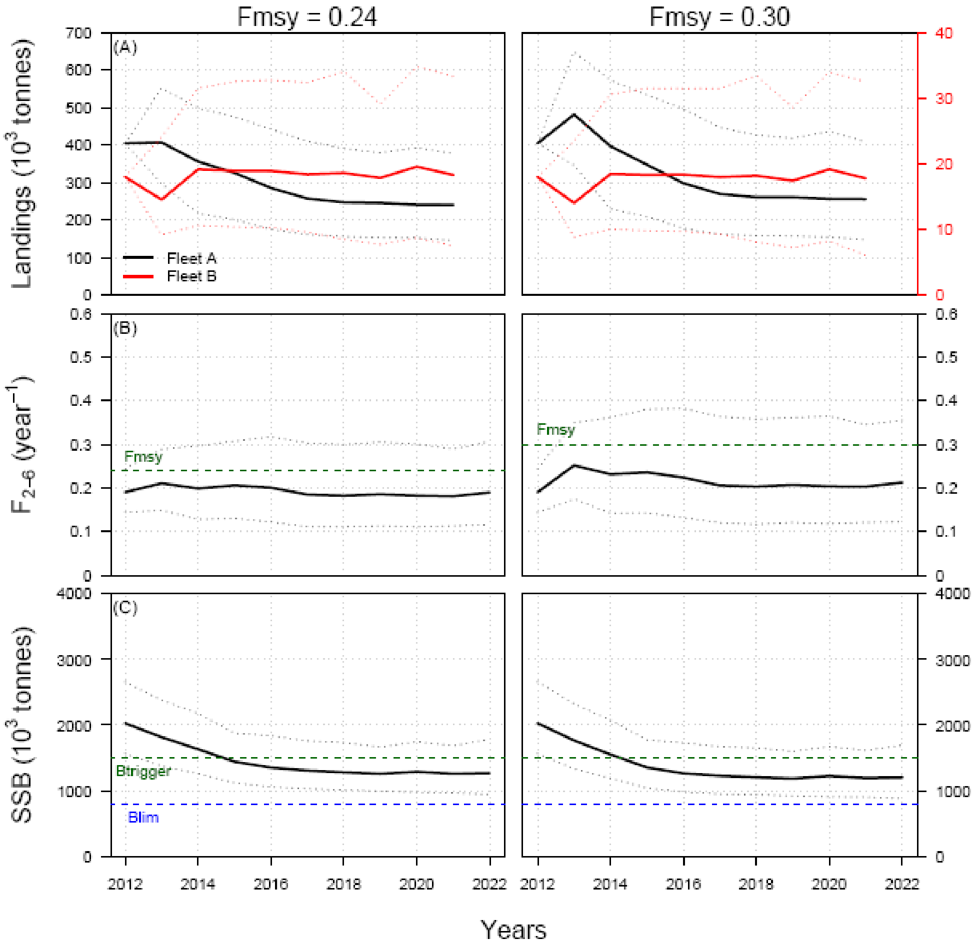

Figure 5.4.3. Current harvest control rule with the new candidate F_{MSY} values and F 3years TAC stability mechanism. Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.3.A left panel) increase to their peak in 2013 (407 000 t); then they decline to 2017 after which they stabilise at around 240 000 t. F is relatively stable, with slightly higher estimates until 2016 and slightly lower for the remaining years thereafter. $F_{2\text{-}6}$ is always below the candidate F_{MSY} (Figure 5.4.3.B left panel). The SSB trajectory (Figure 5.4.3.C left panel) declines gradually until 2016, after which it stabilises around 1.3 million tonnes. SSB is above $B_{trigger}$ until 2014. From 2015 onwards, SSB remains between $B_{trigger}$ and B_{lim}. The right panel plots, where F=0.30, show similar trajectories. Landings are higher from 2013-2015; $F_{2\text{-}6}$ and SSB are comparable to those of the F=0.24 scenarios.

The scenarios with the stability mechanism applied above B_{lim} are more stable than those with the stability mechanism applied above $B_{trigger}$. The scenarios with F=0.30 result in the higher average yield within precautionary limits. However, the scenarios with F=0.24 are more stable. Therefore the scenario with F=0.24 and the stability mechanism applied above B_{lim} is the scenario of choice for this option (see Table 5.4, scenario numbers 33 and 34).

5.4.4. ToR a.iii.2. The current harvest control rule with the new candidate F_{MSY} values and the 50:50 rule TAC stability mechanizm (meanTAC).

Eighteen scenarios were tested, applying the stability mechanism either above B_{lim} or above $B_{trigger}$. Sixteen of these were tested with $F_{2\text{-}6}$ at F=0.24 and F=0.30, candidate $B_{trigger}$ values ranging from 1.3- to 2.0 million tonnes and applying the stability mechanism above B_{lim}. Of these sixteen scenarios, each of the eight F=0.24 scenarios was evaluated to be in accordance with the precautionary approach. In contrast, for the F=0.30 scenarios applying the stability mechanism above B_{lim}, only those with $B_{trigger}$ values >1.5 million tonnes were considered to be precautionary.

The plot below compares the two F scenarios where the candidate $B_{trigger}$ value is 1.3 million tonnes with the stability mechanism applied above B_{lim}.

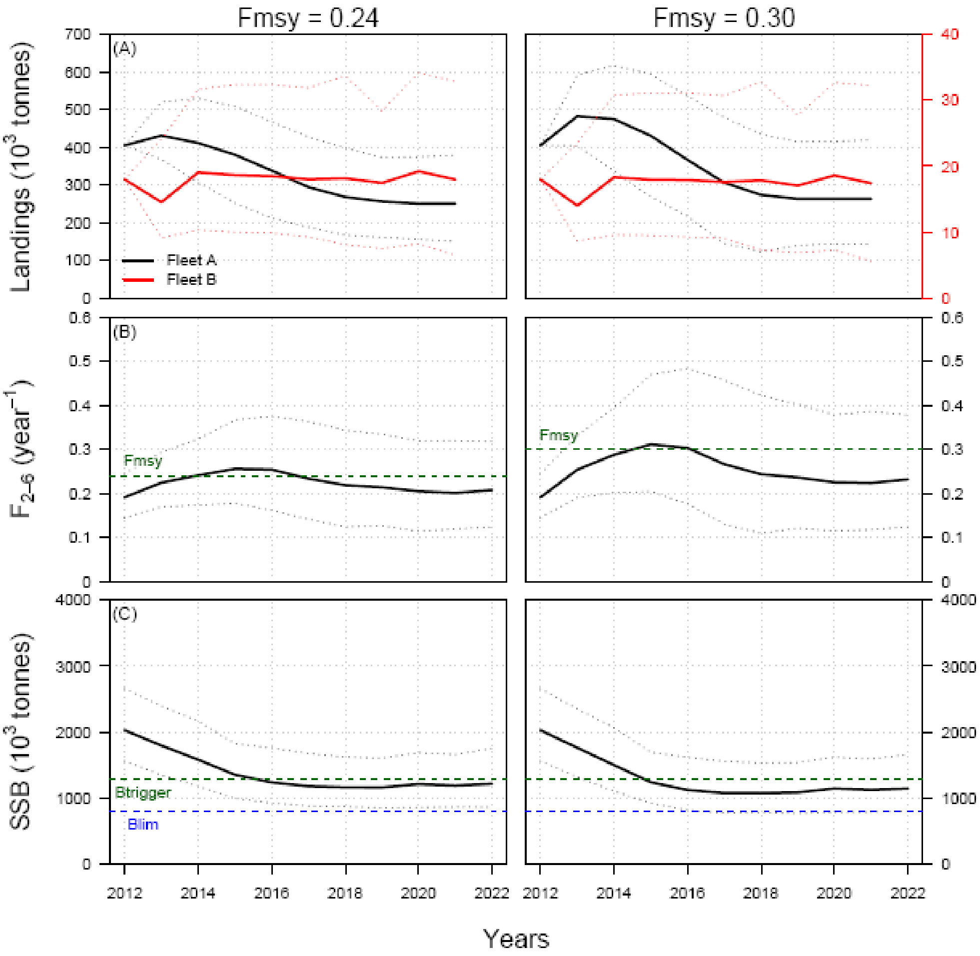

Figure 5.4.4. Current harvest control rule with the new candidate F_{MSY} values and the 50:50 rule TAC stability mechanizm. Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), F_{2-6} (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.4.A left panel) increase to their peak in 2013 (~430 000 t); they then decline quite sharply to 2017 after which they stabilise at around 250 000 t. F_{2-6} increases to a peak around F=0.25 in 2015 (Figure 5.4.2.B left panel) and then declines slowly to 2020 after which it stabilises at around F=0.20. The SSB trajectory (Figure 5.4.4.C left panel) declines gradually until 2016, after which it stabilises around 1.2 million tonnes. SSB is above $B_{trigger}$ until 2015. From 2016 onwards, SSB remains below, but close to, $B_{trigger}$. The right panel plots, where F=0.30, show trajectories with considerably higher values for landings and F_{2-6} until around 2017, when they are similar to the F=0.24 scenario. From 2015 onwards, SSB is slightly lower than for the F=0.24 scenario.

The scenario presented for F=0.24, where the candidate $B_{trigger}$ value is 1.3 million tonnes, is the most stable scenario within precautionary limits of the scenarios tested applying the stability mechanism above B_{lim}. For F=0.30, the scenario presented is not precautionary (see Table 5.4, scenario numbers 82 and 90).

5.4.5. ToR a.iii.3. The current harvest control rule with the new candidate F_{MSY} values and constraining variability of F as the TAC stability mechanism (FIAV).

Eighteen scenarios were tested, applying the stability mechanism either above B_{lim} or above $B_{trigger}$. Sixteen of these were tested with $F_{2\text{-}6}$ at F=0.24 and F=0.30, candidate $B_{trigger}$ values ranging from 1.3 to 2.0 million tonnes and applying the stability mechanism above B_{lim}. All scenarios were evaluated to be in accordance with the precautionary approach.

The plot below compares the two F scenarios where the candidate $B_{trigger}$ value is 1.3 million tonnes and the stability mechanism is applied above B_{lim}.

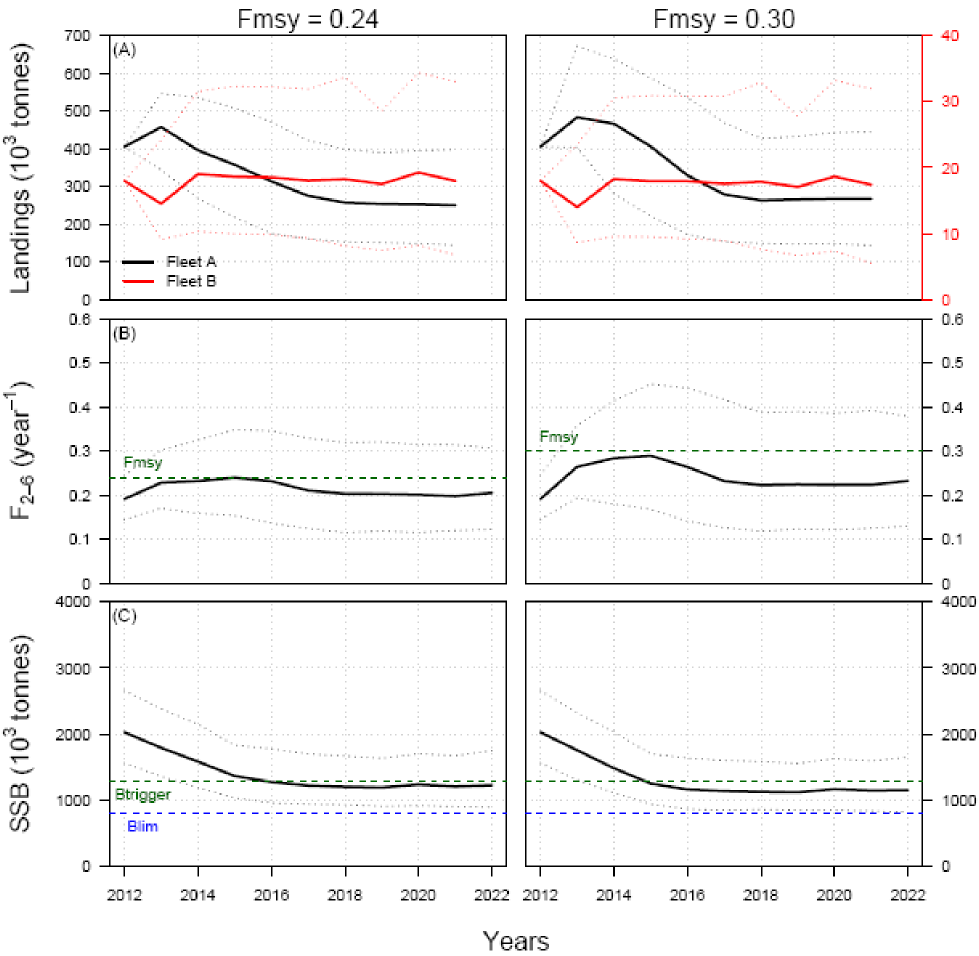

Figure 5.4.5. Current harvest control rule with the new candidate F_{MSY} values and the FIAV TAC stability mechanism. Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.5.A left panel) increase to their peak in 2013 (~460 000 t); then they decline quite sharply to 2017 after which they stabilise at around 250 000 t. $F_{2\text{-}6}$ increases to 0.24 (the candidate F_{MSY}) in 2015 (Figure 5.4.5.B left panel) and then declines slowly to 2018 after which it stabilises at around F=0.20. F is below F_{MSY} from 2015 onwards. The SSB trajectory (Figure 5.4.5.C left panel) declines gradually until 2015, after which it stabilises around 1.2 million tonnes. SSB is above $B_{trigger}$ until 2015. From 2016 onwards, SSB remains just below $B_{trigger}$. The right panel plots, where F=0.30, show trajectories with considerably higher values for landings and $F_{2\text{-}6}$ until around 2017, when they are similar to the F=0.24 scenario. From 2015 onwards, SSB is slightly lower than for the F=0.24 scenario.

The scenarios with the stability mechanism applied above B_{lim} are more stable than their counterparts with the stability mechanism applied above $B_{trigger}$. The scenarios with F=0.30 result in higher yields than their counterparts at F=0.24. However, the F=0.24 scenarios are more stable.

The scenario presented for F=0.24, where the candidate $B_{trigger}$ value is 1.3 million tonnes and the stability mechanism is applied above B_{lim}, is the most stable scenario within precautionary limits of the eighteen scenarios tested (see Table 5.4, scenario number 37).

5.4.6. ToR a.v. The current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of +10% (Banking).

Sixteen scenarios were tested, with $F_{2\text{-}6}$ at F=0.24 and F=0.30, candidate $B_{trigger}$ values ranging from 1.3 to 2.0 million tonnes and applying the stability mechanism above B_{lim}. For the F=0.24 scenarios, only those with $B_{trigger}$ values ≥1.6 million tonnes were considered to be precautionary. None of the F=0.30 scenarios were precautionary.

The plot below compares the two F scenarios where the candidate $B_{trigger}$ value is 1.6 million tonnes.

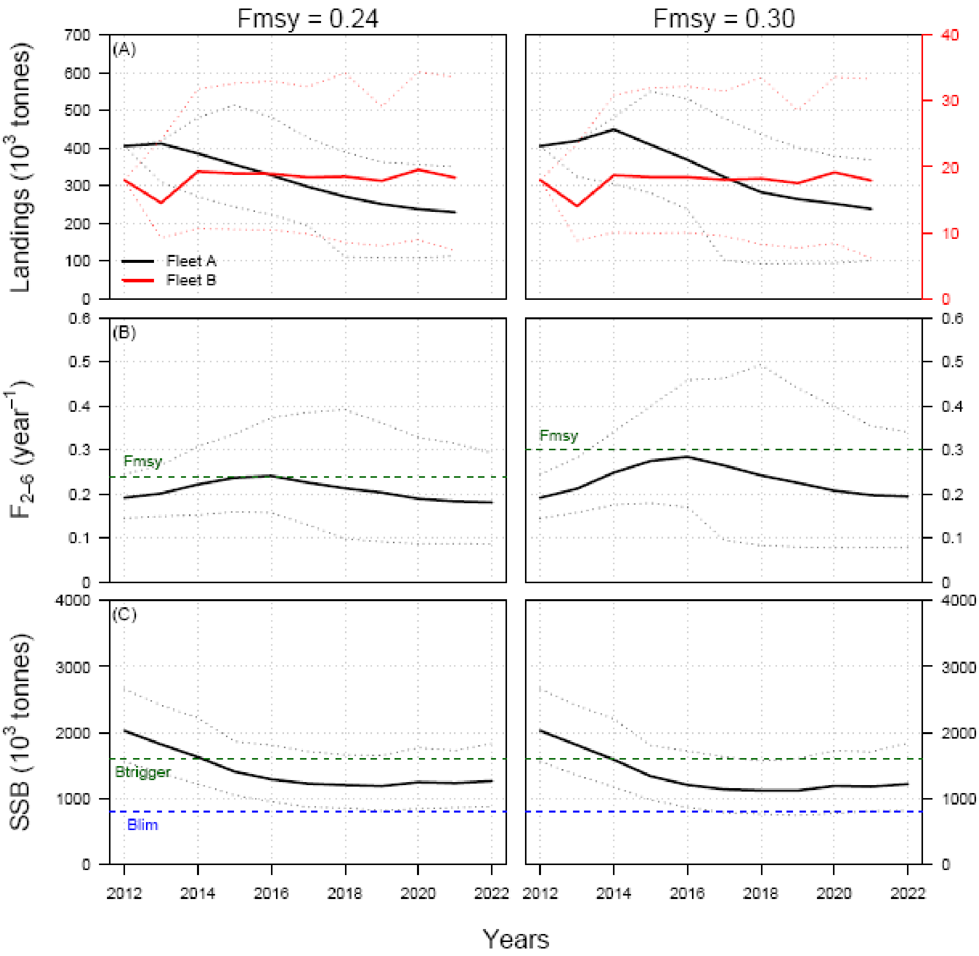

Figure 5.4.6. Current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of +10% (banking). Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.6.A left panel) decrease gradually from 2013 (~410 000 t) to a minimum of ~230 000 t in 2021. $F_{2\text{-}6}$ increases to 0.24 (the candidate F_{MSY}) in 2016 (Figure 5.4.6.B left panel) and then declines slowly to 2020 after which it stabilises at around F=0.18. F is below F_{MSY} from 2016 onwards. The SSB trajectory (Figure 5.4.6.C left panel) declines gradually until 2015, after which it stabilises around 1.3 million tonnes. SSB is above $B_{trigger}$ until 2014. From 2015 onwards, SSB remains between $B_{trigger}$ and B_{lim}. The right panel plots, where F=0.30, show trajectories with higher values for landings and $F_{2\text{-}6}$ until around 2017, when they are similar to the F=0.24 scenario. From 2015 onwards, SSB is slightly lower than for the F=0.24 scenario.

The scenario presented for F=0.24 results in the highest average yield within precautionary limits and is the most stable. For F=0.30, the scenario presented is not precautionary (see Table 5.4, scenario numbers 4 and 12).

5.4.7. ToR a.v. The current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of ±10% (Banking and Borrowing).

Sixteen scenarios were tested, with $F_{2\text{-}6}$ at F=0.24 and F=0.30, candidate $B_{trigger}$ values ranging from 1.3 to 2.0 million tonnes and applying the stability mechanism above B_{lim}. For the F=0.24 scenarios, only those with $B_{trigger}$ values ≥1.6 million tonnes were considered to be precautionary. None of the F=0.30 scenarios were precautionary.

The plot below compares the two F scenarios where the candidate $B_{trigger}$ value is 1.6 million tonnes.

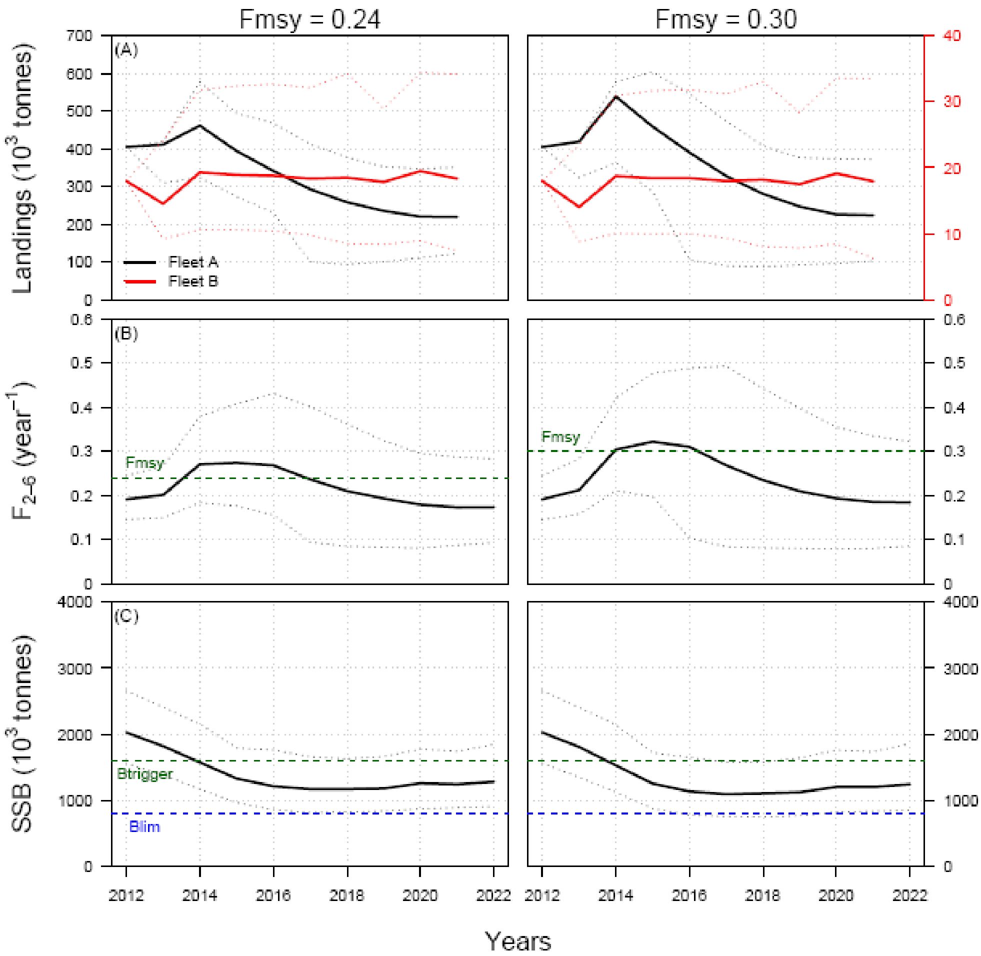

Figure 5.4.7. Current harvest control rule with the new candidate F_{MSY} values and a quota flexibility of ±10% (banking and borrowing). Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations

For F=0.24, landings (Figure 5.4.7.A left panel) increase and peak in 2014 (~ 460 000 t) and then decrease gradually to a minimum of ~210 000 t in 2021. $F_{2\text{-}6}$ increases and shows a plateau at F=0.27 (above F_{MSY}) for the period 2014-2016 (Figure 5.4.7.B left panel) and then declines slowly to 2020 after which it stabilises at around F=0.18. F is below F_{MSY} from 2016 onwards. The SSB trajectory (Figure 5.4.7.C left panel) declines gradually until 2016, after which it stabilises around 1.3 million tonnes. From 2019 onwards, SSB slightly increases again to around 1.4 million tonnes. SSB is above $B_{trigger}$ until 2014. From 2015 onwards, SSB remains between $B_{trigger}$ and B_{lim}. The right panel plots, where F=0.30, show trajectories with higher values for landings and $F_{2\text{-}6}$ until around 2017, when they are similar to the F=0.24 scenario. From 2015 onwards, SSB is slightly lower than for the F=0.24 scenario.

The scenario presented for F=0.24 results in the highest average yield within precautionary limits. For F=0.30, the scenario presented is not precautionary (see Table 5.4, scenario numbers 20 and 28).

5.4.8. ToR a.vi. The current harvest control rule with the new candidate F_{MSY} values and changing the target fishing mortality for 0-1 ringers over a range of values from 0.0375 to 0.052 (juv).

Three scenarios were tested with $F_{2\text{-}6}$ at F=0.2, F=0.24 and F=0.30, a candidate $B_{trigger}$ value of 1.5 million tonnes and applying the stability mechanism above B_{lim}. The $F_{0\text{-}1}$ was F=0.05 for $F_{2\text{-}6}$ at F=0.2 and F=0.0375 for $F_{2\text{-}6}$ at F=0.24 and F=0.30. The F=0.20 and F=0.24 scenarios were evaluated to be in accordance with the precautionary approach. The F=0.30 scenario was not precautionary.

The plot below compares the two F scenarios with $F_{2\text{-}6}$ at F=0.24 and F=0.30 and $F_{0\text{-}1}$ at F=0.0375

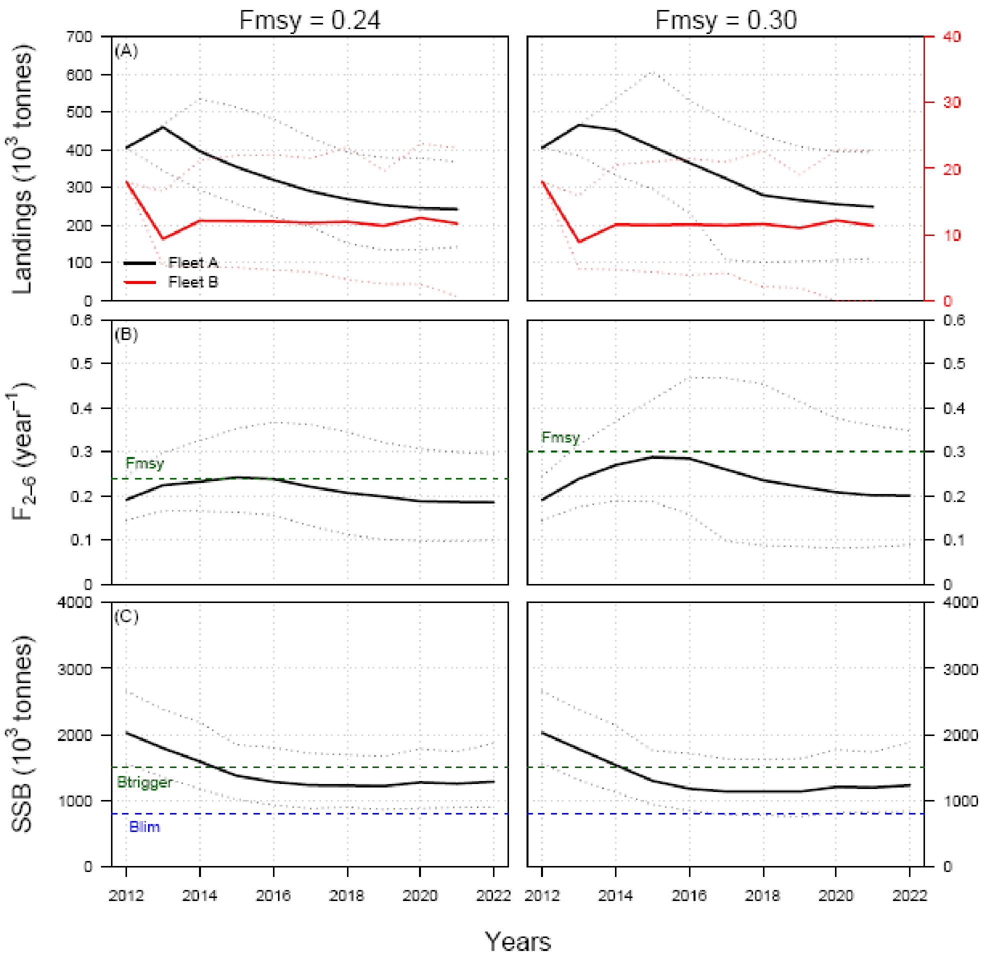

Figure 5.4.8. Current harvest control rule with the new candidate F_{MSY} values and changing the target fishing mortality for 0-1 ringers over a range of values from 0.0375 to 0.052. Left panels F=0.24; right panel F=0.30. Landings by Fleet A and B (panels A), $F_{2\text{-}6}$ (panels B) and SSB (panels C) trajectories given 1000 Monte Carlo simulations.

For F=0.24, landings (Figure 5.4.8.A left panel) show a peak in 2013 (~ 460 000t) and then decrease gradually to a minimum of ~240 000 t in 2021. $F_{2\text{-}6}$ increases slightly and reaches F_{MSY} at F=0.24 in 2015 and 2016 (Figure 5.4.8.B left panel). F then decreases to around F=0.19 in 2020 and thereafter. The SSB trajectory (Figure 5.4.8.C left panel) declines sharply to 1.4 million tonnes in 2015, after which it stabilises around 1.3 million tonnes. From 2020 onwards, SSB slightly increases again to around 1.4 million tonnes. SSB is above $B_{trigger}$ until 2014. From 2015 onwards, SSB remains between $B_{trigger}$ and B_{lim}. The trajectories of the right panel plots, where F=0.30, show almost identical patterns.

The scenario presented for F=0.24 results in the higher average yield within precautionary limits. For F=0.30, the scenario presented is not precautionary (see Table 5.4, scenario numbers 56 and 57).

Table 5.4. Selected results for the chosen scenarios and their counterparts at F=0.24 or F=0.30, with the most informative indicators. For the full list of 99 scenarios with all the performance indicators, see Annex 3. The run numbers below relate to the number within the full list of 99 scenarios.

Scenario tested	Scenario ID	Run No.	$B_{trigger}$	F_{2-6}	F_{0-1}	Stability	PA	2022 SSB	mean F2-6	Mean Yield	meanrelTACIAV A
ToR a.i.	LTMP	63	1.3	0.24	0.05	B_{lim}	4.6	1 220 486	0.224	326 727	13.002
ToR a.i.	LTMP	72	1.3	0.30	0.05	B_{lim}	15.7	1 185 980	0.219	322 511	13.313
ToR a.ii	noIAV	98	1.5	0.24	0.05	B_{lim}	0.1	1 267 549	0.202	308 955	22.3
ToR a.ii	noIAV	99	1.5	0.30	0.05	B_{lim}	1.2	1 198 524	0.229	333 158	28.456
ToR a.iii.1.	F3years	33	1.5	0.24	0.05	B_{lim}	0	1 265 708	0.195	303 715	17.427
ToR a.iii.1.	F3years	34	1.5	0.30	0.05	B_{lim}	1.1	1 201 675	0.221	326 168	20.693
ToR a.iii.2	meanTAC	82	1.3	0.24	0.05	B_{lim}	2.7	1 218 871	0.226	329 062	11.856
ToR a.iii.2	meanTAC	90	1.3	0.30	0.05	B_{lim}	12.6	1 146 803	0.219	323 045	12.289
ToR a.iii.3	FIAV	37	1.3	0.24	0.05	B_{lim}	0.9	1 225 590	0.216	321 891	16.011
ToR a.iii.3	FIAV	46	1.3	0.30	0.05	B_{lim}	4.5	1 153 097	0.21	316 217	16.643
ToR a.v	Bank	4	1.6	0.24	0.05	B_{lim}	4.3	1 266 038	0.212	314 796	11.247
ToR a.v	Bank	12	1.6	0.30	0.05	B_{lim}	11.8	1 220 281	0.205	310 011	11.366
ToR a.v	Bank&Borrow	20	1.6	0.24	0.05	B_{lim}	4.3	1 284 021	0.22	321 870	14.942
ToR a.v	Bank&Borrow	28	1.6	0.30	0.05	B_{lim}	13.3	1 245 688	0.215	316 520	14.847
ToR a.vi	Juv	56	1.5	0.24	0.0375	B_{lim}	2.4	1 289 745	0.215	323 050	13.334
ToR a.vi	Juv	57	1.6	0.30	0.0375	B_{lim}	10.3	1 234 223	0.242	345 796	14.056

6 Evidence of density-dependent mortality in NSAS

The North Sea herring stock is currently strong and healthy, with over two million tonnes of mature herring estimated to be swimming in the North Sea. However, in relation to the size of the adult population, the catch is still relatively small because the stock is not producing as many new young fish each year as it has in the past. Over the last 65 years, on average, each spawning herring produced approximately seven new young fish every year. Since 2002, however, the number of new fish for each spawning herring has been three or less (Figure 4.2.3). This change in productivity has resulted in lower recruitment of young fish to the population.

Large population size can restrict productivity but there is little evidence that the current stock size is too big; even the much larger population in the late 1940s produced 4 to 5 recruits per spawning adults. However, the reason for this recruitment impairment remains unresolved.

The international herring larvae surveys in the North Sea (IHLS) show the production of newly hatched larvae, monitored at the main spawning grounds in autumn and winter. Larval abundance and spatial distribution varies somewhat between areas and time periods, but the resulting annual abundance indices are larger for the recent decade than for those in the past. The last three year's estimates are historic high records (ICES 2012/ACOM: 06), and the number of offspring is enormous. Larvae abundance is often affected by patchiness, but the increase in numbers is not driven by single station measurements alone. Newly hatched herring larvae appear relatively widely distributed over the spawning areas, especially in the Orkney/Shetland and the Downs regions. This may or may not reduce the impact of intraspecific food competition of first-feeding and foraging larvae already at the hatching sites. However, the late-stage larvae surveys in February show a reduction in abundance of these larvae from 2002 onwards (ICES 2012/ACOM: 06). This indicates that processes resulting in poor recruitment must occur between the newly hatched larvae and late larval stages.

Environmentally induced change appears to be impacting the recruitment of North Sea herring. Despite simultaneously having a large adult population, historically low exploitation, and Marine Stewardship Council accreditation (implying sustainability), there has been an unprecedented nine year period of low juvenile production (recruitment). Analysis suggests that the poor recruitment arises during the larval overwintering phase, with recent survival rates greatly reduced. Contemporary warming of the North Sea has caused significant changes in the plankton community, and a recently identified regime shift around 2000 shows close temporal agreement with the reduced larval survival (Payne et al., 2009). It is therefore possible that the first consequences of this planktonic change for higher trophic levels are now being experienced. At large herring population sizes density-dependent effects could intuitively be expected. Several examples of this are to be found in the literature, e.g. Fuiman and Gamble (1988), Cushing and Horwood (1994), Fox (2001), Heath (2007) and Pitois and Fox (2008), and as a concept it is widely accepted by fisheries scientists. Thus we might expect the adults and juveniles to grow more slowly and each adult to produce fewer recruits. Fässler at al. (2011) showed that the larvae are currently dying at a quicker rate than before 2002, and this rate varies in the same way as the increase in population numbers. However, this work also showed that the death rate of the larvae varies with the change in temperature on the spawning grounds as well. Temperature alone will not affect the death rate of the larvae, as it only varied by a couple of degrees, but this temperature rise will increase the metabolic needs of the larvae, i.e. they will need more food.

Herring larvae are well known for being able to survive winter months, when there is less food around (Werner and Blaxter, 1980), however, they need food to get through the initial feeding stage and any increase in temperature will increase their food requirements. The increase in sea temperature in the Shetland/Orkney, Buchan and Banks spawning grounds was about 1°C from 1999 to 2002 (Fässler et al., 2011). Concurrently the North Sea plankton community has changed, with a big change occurring in 2000 to 2002 (Alvarez et al., 2011). This change can be categorised as a shift from species that prefer colder regimes to ones that prefer warmer conditions. The plankton has also shifted its size distribution from small zooplankton to larger zooplankton, while the first-feeding herring larvae need smaller prey. So the herring larvae require more food due to increased temperature and, simultaneously, the food environment has changed in the wrong direction. This suggests that the combination of higher temperatures and changes in plankton can influence the death rate of herring larvae.

Evidence (either through single species dynamics or through ecosystem considerations) to justify reducing the biomass of North Sea herring because the biomass is the sole cause of the changes in productivity of the stock is not available. Various hypotheses have been put forward and it appears that interlinking factors like environmental factors, biomass of spawners, changes in the zooplankton community, etc. may affect the recruitment strength. A negative impact of high spawner biomass to recruitment could be through cannibalism, the attraction of other predators, competition for spawning space, or competition for food by larvae. This biomass effect could be compounded by the failure to recolonize all traditional spawning grounds, after the stock's collapse in the late 1970s. However, the North Sea herring stock was much bigger in the late 19th and early 20th centuries, with over 4-5 million tonnes of herring in the North Sea~~.~~ This adds further weight to the argument that it is not the greater spawning-stock biomass alone that is impacting on recent recruitment, as the stock has been even bigger in the past.

North Sea herring spawn on the seabed on patches of gravel or course sand. Despite the population of adult North Sea herring recovering in biomass to over 2 million tonnes, some of the old traditional spawning sites have not been recolonized (Corten 2001, 2002). However, evidence of density-dependent regulatory mechanisms based on spatial utilisation of spawning grounds remains to be found.

6.1 Conclusions

The current evidence and knowledge of density-dependence processes in the biology of NSAS is not strong enough to justify an increase in the target F at high stock sizes. Density-dependent mechanisms cannot be ruled out at the early larval stages of herring. It may be that the decline in recruitment is purely environmentally driven, and the apparent synchrony with spawning biomass is a coincidence. Clearly more evidence is necessary in order to identify the regulatory mechanisms underlying the low productivity regime currently observed in North Sea herring.

6.2 Advice for further investigations

The reasons for the recent observed drop in recruitment at higher biomass are complex. Canibalism may play a role; however, it is not known if this potential cannibalism has a dramatic impact on the recruitment and stock productivity and, as shown above, it may just be coincidental that this high SSB co-occurs with a change in environment. The predator field has also changed over the past years; an increase in mackerel and horse mackerel may increase the predation on herring larvae.

Modelling of the spatial and temporal overlap of larvae and adult herring in combination with analysis of stomach contents (e.g. genetic probing) of adult herring encountered in areas with high larval abundance could potentially provide information on whether cannibalism is an important regulatory mechanism for the NSAS recruitment. HELP discussed how such a set-up could be done in collaboration between industry and science partners; briefly it could be done following the steps described below:

- Mapping of adult herring in the time-window between IHLS and MIK surveys; involving commercial vessels, their acoustic records and the like;
- Temporal and spatial overlap analysis of larval abundance (from scientific surveys) and the adult herring population (from the analysis described above);
- Analysis of stomach contents from adult herring caught in areas identified as potential cannibalistic hot spots. As the degradation of herring larvae in herring stomachs is very rapid (after an hour most of the degradation of the larvae is completed), application of genetic analysis of the stomach contents could potentially be applied to quantify the consumption of herring larvae by the adult herring;
- Scaling the potential consumption (if identified) of the adult herring population of herring larvae to the NSAS stock size.

7 Conclusions

Given the updated perception of the NSAS stock development following the 2012 benchmark, ICES has evaluated the biological reference points. Blim is estimated at 800 000 t; based on analyses of the stock and recruitment data and consideration of ICES procedures for setting limit reference points (ICES 2001: Report of the Study Group on the Further Development of the Precautionary Approach to Fisheries Management. ICES CM 2001/ACFM:11). Bpa is estimated at 1 000 000 t, assuming assessment model uncertainty is the core aspect to take into account when considering a buffer to Blim. FMSY is estimated within the range of F2-6= 0.24 to 0.30, following from stochastic FMSY calculations based on two different stock–recruitment relationships (Beverton and Holt and Ricker).

ICES concludes that all eight Harvest Control Rule options tested include precautionary scenarios. This is based on the assumption that the current (since 2003) low productivity regime for North Sea herring will continue. For most options, different Btrigger values were scanned, which resulted in a large number of scenarios tested. Within each of the options, those scenarios which had highest risk of falling below Blim but still complying with the Precautionary Approach were selected, as they result in highest long-term yield compared to other scenarios. The trade-offs in stability within each of the options is small and therefore scenario selection was primarily (but not exclusively) made on the basis of high long-term yields.

Only five out of the eight HCR options tested are considered to be appropriate candidates for a Long-term Management Plan. The HCR without a TAC stabilising mechanism is not included in this list as it was only included for comparison while the 3 year rule (F3years) is based on projections dependent on the last year estimates from the assessment where uncertainty about stock development is highest. Introducing more uncertainty in the TAC setting procedure is not considered to be a desired approach. The juvenile bycatch option was included to explore the trade-off between juvenile and adult herring fishery but was not considered to be operational from a wider North Sea fisheries management point of view where bycatches of North Sea herring in other fisheries play an important role.

Based on extensive literature review, density-dependent regulatory effects on the stock–recruitment relationship can neither be ruled out nor confirmed.

8 References

ACFM. 2005.

Alvarez-Fernandez, S., Lindeboom, H., and Meesters, E., 2011. Temporal changes in plankton of the North Sea: Community shifts and environmental drivers. Mar. Ecol. Prog. Ser. 462: 21-38.

Brent, R., 1973. Algorithms for Minimization without Derivatives, Prentice-Hall, Englewood Cliffs, New Jersey. 195 pp.

Corten, A., 2001. Herring and Climate – changes in the distribution of North Sea herring due to climate fluctuations. PhD thesis at Rijksuniversiteit Groningen.

Corten, A., 2002. The role of "conservatism" in herring migrations. Rev. Fish Biol. Fish. 11: 339–361.

Cushing, D.H. and Horwood, J.W., 1994 The growth and death of fish larvae. J. Plankton Res. 16: 291–300.

Dickey-Collas, M., 2012. Is it getting too hot for hungry North Sea herring larvae? Fisherijnews:

Fässler, S.M.M., Payne, M.R., Brunel, T., and Dickey-Collas, M., 2011. Does larval mortality influence population dynamics? An analysis of North Sea herring (*Clupea harengus*) time-series. Fish. Oceanogr. 20(6): 530-543.

Fox, C.J. 2001., Recent trends in stock–recruitment of Blackwater herring (*Clupea harengus* L.) in relation to larval production. ICES J. Mar. Sci. 58: 750–762.

Fuiman, L.A. and Gamble, J.C. 1988., Predation by Atlantic herring, sprat, and sandeels on herring larvae in large enclosures. Mar. Ecol. Prog. Ser. 44: 1–6.

Gilks W.R., Richardson S. and Spiegelhalter D.J. 1996., Markov Chain Monte Carlo in Practice. London: Chapman and Hall; p. 486.

Heath, M.R. 2007., The consumption of zooplankton by early life stages of fish in the North Sea. ICES J. Mar. Sci. 64: 1650–1663.

Ibaibarriaga, L., Fernández, C., Uriarte, A., and Roel, B.A. 2008., A two-stage biomass dynamic model for Bay of Biscay anchovy: a Bayesian approach. ICES J. Mar. Sci. 65: 191–205.

ICES. 2007., Report of the Workshop on Limit and Target Reference Points [REF]. ICES CM 2007/ACFM:05

ICES., 2008 (HMP)

ICES., 2008b. Report of the Study Group on Management Strategies (MAS). ICES CM 2008/ACOM:24

ICES., 2011. (HERMP)

ICES., 2012. Report of the ICES Workshop on Herring Interim Advice on the Management Plan. (HIAMP). ICES CM 2011/ACOM:62

ICES., 2012.(PELA)

ICES., 2012 Report of the Herring Assessment Working Group for the Area South of 62 N (HAWG). ICES CM 2012/ACOM:06

Mace, P.M., 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Can. J. Fish. Aquat. Sci. 51: 110-122.

Mesnil, B., and Rochet, M-J., 2010. A continuous hockey stick stock–recruit model for estimating MSY reference points. ICES J. Mar. Sci. 67: 1780–1784.

Patterson, K.R., Skagen, D, Pastoors, M and Lassen, H. 1997. Harvest control rules for North Sea herring. WD to ACFM 1997.

Payne, M.R., 2010. Mind the gaps: a state-space model for analysing the dynamics of North Sea herring spawning components. ICES J. Mar. Sci. 67: 1939–1947.

Payne, M.R., Hatfield, E.M.C., Dickey-Collas, M. et al. 2009., Recruitment in a changing environment: the 2000s North Sea herring recruitment failure. ICES J. Mar. Sci. 66: 272– 277.

Pitois, S.G. and Fox, C.J., 2008. Empirically modelling the potential effects of changes in temperature and prey availability on the growth of cod larvae in UK shelf seas. ICES J. Mar. Sci. 65: 1559–1572.

Werner, R.G., and Blaxter, J.H.S., 1980. Growth and Survival of larval herring (*Clupea harengus*) in relation to prey density. Can. J. Fish. Aquat. Sci. 37(7): 1063-1069.

OMSE., 2009. Report of the ICES-STECF Workshop on Fishery Management Plan Development and Evaluation (OMSE). 28-30 January 2009, ICES Copenhagen, Denmark. ICES CM 2009/ACOM:27. 32 p.

9 Annex 1: Recommendations

The HELP defined the following recommendations for further action based on the discussions and results from the workshop:

- …

Recommendation	For follow up by:

10 Annex 2: List of participants

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11 Annex 3: Full list of results of 99 scenarios tested.

#	Scenario	Btrigger	F adults	F juveniles	Stability	PA	2022 SSB	2022 F	Mean F01	Mean F26	Mean SSB	Mean Yield A	Mean Yield B	2013 Yield A	2013 Yield B	Meanrel TACIAV A	Mean TACIAV A	IAV restrict up#	IAV restrict down#	TAC up	TAC down
1	Bank	1.3	0.24	0.05	Blim	7.1	1204950	0.206	0.05	0.227	1410181	329382	18230	411521	14540	10.737	33039	NA	NA	26225	39421
2	Bank	1.4	0.24	0.05	Blim	6.4	1224865	0.196	0.05	0.222	1418507	324538	18342	411521	14540	10.979	33150	NA	NA	26426	39085
3	Bank	1.5	0.24	0.05	Blim	5.3	1246923	0.187	0.05	0.217	1428956	319490	18435	411521	14540	11.15	33222	NA	NA	26332	38861
4	Bank	1.6	0.24	0.05	Blim	4.3	1266038	0.18	0.05	0.212	1439274	314796	18528	411521	14549	11.247	32829	NA	NA	25762	38630
5	Bank	1.7	0.24	0.05	Blim	3.4	1285130	0.174	0.05	0.205	1452521	310011	18634	411212	14554	11.366	32838	NA	NA	25385	38145
6	Bank	1.8	0.24	0.05	Blim	2.9	1304417	0.169	0.05	0.2	1464038	304698	18697	410469	14561	11.465	32438	NA	NA	24906	37530
7	Bank	1.9	0.24	0.05	Blim	2.2	1315004	0.165	0.05	0.196	1477152	299713	18777	407645	14579	11.547	32262	NA	NA	24401	37046
8	Bank	2	0.24	0.05	Blim	1.7	1329975	0.162	0.05	0.191	1490746	295015	18846	400027	14628	11.617	31913	NA	NA	23869	36708
9	Bank	1.3	0.3	0.05	Blim	18.8	1174357	0.209	0.05	0.256	1350820	351507	17744	419175	14022	11.518	40148	NA	NA	30169	53973
10	Bank	1.4	0.3	0.05	Blim	17.5	1191323	0.203	0.05	0.249	1362616	345927	17875	419175	14032	11.582	39439	NA	NA	29952	52229
11	Bank	1.5	0.3	0.05	Blim	14.3	1213067	0.197	0.05	0.242	1375853	340792	18028	419175	14036	11.619	38786	NA	NA	29315	50328
12	Bank	1.6	0.3	0.05	Blim	11.8	1220281	0.194	0.05	0.237	1388236	336458	18153	419175	14054	11.483	37641	NA	NA	28628	47037
13	Bank	1.7	0.3	0.05	Blim	9.2	1238030	0.188	0.05	0.228	1400984	331550	18246	419175	14065	11.424	36369	NA	NA	27761	44620
14	Bank	1.8	0.3	0.05	Blim	7.7	1248141	0.185	0.05	0.224	1413746	325596	18339	419175	14100	11.396	34927	NA	NA	27242	42461
15	Bank	1.9	0.3	0.05	Blim	6.4	1261231	0.181	0.05	0.217	1426182	319540	18434	419175	14175	11.415	33979	NA	NA	26809	41055

16	Bank	2	0.3	0.05	Blim	5.1	1272596	0.177	0.05	0.212	1438954	314981	18503	419175	14232	11.468	33490	NA	NA	26024	40338
17	BB	1.3	0.24	0.05	Blim	7.4	1221232	0.197	0.05	0.233	1388683	335027	18195	411521	14540	14.99	49574	NA	NA	43864	54701
18	BB	1.4	0.24	0.05	Blim	6.5	1244722	0.188	0.05	0.229	1394164	331198	18301	411521	14540	15.109	49048	NA	NA	43417	54243
19	BB	1.5	0.24	0.05	Blim	5.2	1266723	0.179	0.05	0.225	1404556	326284	18399	411521	14540	15.111	47989	NA	NA	42279	53549
20	BB	1.6	0.24	0.05	Blim	4.3	1284021	0.173	0.05	0.22	1416067	321870	18491	411521	14549	14.942	46257	NA	NA	40590	52683
21	BB	1.7	0.24	0.05	Blim	3.6	1301652	0.168	0.05	0.215	1423902	316520	18590	411212	14554	14.847	43881	NA	NA	38719	51513
22	BB	1.8	0.24	0.05	Blim	2.9	1311015	0.163	0.05	0.21	1434487	312126	18657	410469	14561	14.76	41957	NA	NA	36620	50655
23	BB	1.9	0.24	0.05	Blim	2.8	1327550	0.16	0.05	0.205	1448132	308471	18741	407645	14579	14.703	40520	NA	NA	35036	49864
24	BB	2	0.24	0.05	Blim	2.4	1336969	0.156	0.05	0.2	1458197	304670	18807	400027	14628	14.642	39889	NA	NA	34004	48922
25	BB	1.3	0.3	0.05	Blim	19.9	1198715	0.207	0.05	0.262	1335695	357053	17750	419175	14022	16.151	61586	NA	NA	48628	73770
26	BB	1.4	0.3	0.05	Blim	18.2	1224352	0.196	0.05	0.254	1347433	352272	17869	419175	14032	16.223	61108	NA	NA	47495	71875
27	BB	1.5	0.3	0.05	Blim	16	1232707	0.191	0.05	0.249	1352497	347568	17990	419175	14036	16.04	60381	NA	NA	46080	68984
28	BB	1.6	0.3	0.05	Blim	13.3	1245688	0.183	0.05	0.243	1362809	341033	18105	419175	14054	15.883	58768	NA	NA	44422	65618
29	BB	1.7	0.3	0.05	Blim	10.7	1261847	0.18	0.05	0.236	1372441	335680	18215	419175	14065	15.582	54875	NA	NA	42302	62884
30	BB	1.8	0.3	0.05	Blim	8	1271205	0.176	0.05	0.231	1383512	330245	18305	419175	14100	15.192	50589	NA	NA	41019	59590
31	BB	1.9	0.3	0.05	Blim	6.8	1281478	0.173	0.05	0.227	1394316	325629	18386	419175	14175	14.954	47012	NA	NA	39560	56823
32	BB	2	0.3	0.05	Blim	5.5	1290951	0.17	0.05	0.222	1404629	321622	18468	419175	14232	14.827	44671	NA	NA	38312	54843

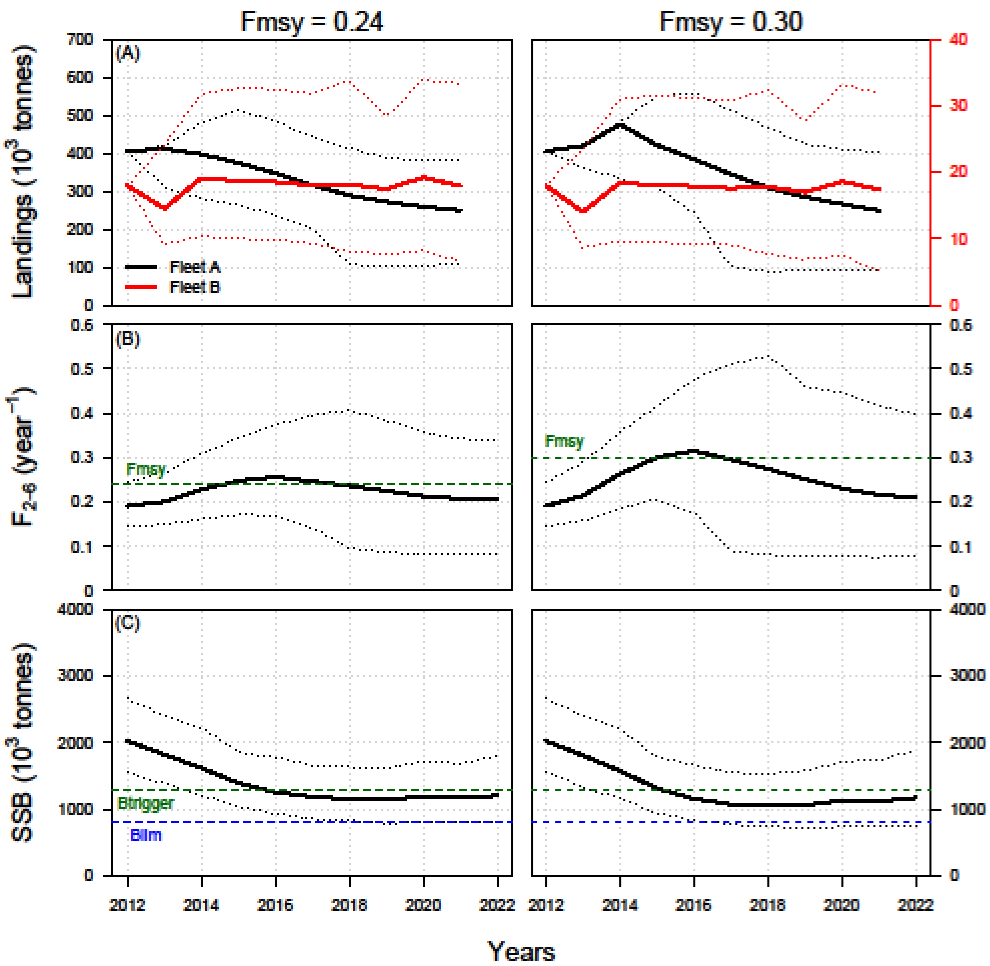
33	F3years	1.5	0.24	0.05	Blim	0	1265708	0.19	0.049	0.195	1482140	303715	18464	407301	14540	17.427	47350	NA	NA	40386	53994
34	F3years	1.5	0.3	0.05	Blim	1.1	1201675	0.213	0.049	0.221	1417153	326168	18021	481933	14037	20.693	63532	NA	NA	57680	69653
35	F3years	1.5	0.24	0.05	Btrigger	0.1	1268578	0.189	0.049	0.197	1479241	304521	18469	407301	14540	19.515	52135	NA	NA	45895	57972
36	F3years	1.5	0.3	0.05	Btrigger	1.1	1201021	0.211	0.049	0.223	1410406	328176	18021	481933	14037	23.792	70030	NA	NA	64480	77273
40	FIAV	1.5	0.24	0.05	Btrigger	0.2	1268689	0.189	0.049	0.2	1466954	307412	18457	457246	14540	20.551	55823	10	10	45934	65273
49	FIAV	1.5	0.3	0.05	Btrigger	1.2	1202747	0.211	0.049	0.226	1401437	330270	18021	483356	14036	25.13	74330	10	10	66158	84168
37	FIAV	1.3	0.24	0.05	Blim	0.9	1225590	0.205	0.049	0.216	1431024	321891	18228	457246	14540	16.011	47032	10	20	39599	53268
38	FIAV	1.4	0.24	0.05	Blim	0.4	1248230	0.195	0.049	0.21	1445510	316217	18345	457246	14540	16.643	47617	10	20	39501	54521
39	FIAV	1.5	0.24	0.05	Blim	0.2	1275211	0.185	0.049	0.203	1456846	309653	18460	457246	14540	17.01	47636	10	20	38851	55246
41	FIAV	1.6	0.24	0.05	Blim	0.1	1297439	0.178	0.049	0.197	1471236	304046	18561	457246	14549	17.144	47424	10	20	38272	55279
42	FIAV	1.7	0.24	0.05	Blim	0.1	1315664	0.173	0.049	0.191	1483519	298743	18652	456902	14554	17.183	46989	10	20	37572	54998
43	FIAV	1.8	0.24	0.05	Blim	0	1333293	0.168	0.049	0.187	1496933	293964	18737	456076	14561	17.189	46559	10	20	36915	54453
44	FIAV	1.9	0.24	0.05	Blim	0	1349892	0.163	0.049	0.182	1508170	289208	18816	452938	14579	17.105	45981	10	20	36181	53536
45	FIAV	2	0.24	0.05	Blim	0	1363750	0.159	0.049	0.178	1517552	284806	18883	444475	14628	16.983	44836	10	20	35114	52589
46	FIAV	1.3	0.3	0.05	Blim	4.5	1153097	0.232	0.049	0.246	1356586	347634	17730	483356	14022	20.481	64078	10	10	58688	71619
47	FIAV	1.4	0.3	0.05	Blim	2.9	1183558	0.217	0.049	0.237	1375441	339533	17876	483356	14032	20.711	63804	10	10	57840	71527

48	FIAV	1.5	0.3	0.05	Blim	1.8	1207915	0.208	0.049	0.228	1391706	332259	18029	483356	14036	20.573	63234	10	10	56892	70642
50	FIAV	1.6	0.3	0.05	Blim	1.1	1231417	0.199	0.049	0.22	1408090	325746	18153	483356	14055	20.379	61720	10	10	55465	69626
51	FIAV	1.7	0.3	0.05	Blim	0.7	1252762	0.192	0.049	0.213	1423789	320058	18264	482524	14065	20.253	60517	10	20	54356	68223
52	FIAV	1.8	0.3	0.05	Blim	0.4	1271081	0.185	0.049	0.207	1439049	314353	18372	480176	14100	19.921	58738	10	20	53378	66371
53	FIAV	1.9	0.3	0.05	Blim	0.3	1290933	0.18	0.049	0.202	1451929	309256	18472	471303	14175	19.673	57033	10	20	51665	64902
54	FIAV	2	0.3	0.05	Blim	0.3	1305195	0.176	0.049	0.197	1464793	304704	18553	465750	14232	19.323	55465	10	20	49647	63437
55	juv	1.5	0.2	0.05	Blim	0.5	1325399	0.166	0.05	0.188	1498461	294384	18796	385955	14851	12.965	35188	10	40	26907	39520
56	juv	1.5	0.24	0.0375	Blim	2.4	1289745	0.185	0.038	0.215	1445036	323050	12437	459260	9342	13.334	41253	20	40	34889	45016
57	juv	1.5	0.3	0.0375	Blim	10.3	1234223	0.2	0.038	0.242	1383481	345796	12070	465750	8885	14.056	46860	20	40	41264	54050
58	LTMP	1.5	0.2	0.05	Blim	0.5	1325399	0.166	0.05	0.188	1498461	294384	18796	385955	14851	12.965	35188	10	40	26907	39520
59	LTMP	1.5	0.2	0.05	Btrigger	0	1340411	0.168	0.049	0.179	1528595	286487	18830	385955	14851	17.861	44918	10	10	33690	52767
60	LTMP	1.5	0.24	0.05	Btrigger	0.2	1276266	0.187	0.049	0.199	1470652	306170	18456	457246	14540	20.146	54319	10	10	42494	64783
61	LTMP	1.5	0.25	0.05	Btrigger	0.3	1263417	0.191	0.049	0.203	1458812	310389	18390	465750	14468	20.836	56788	10	10	44457	67960
62	LTMP	1.5	0.3	0.05	Btrigger	1.1	1210874	0.21	0.049	0.222	1414801	327219	18020	465750	14036	23.257	66790	10	10	53455	80525
63	LTMP	1.3	0.24	0.05	Blim	4.6	1220486	0.198	0.05	0.224	1412627	326727	18214	457246	14540	13.002	40596	20	40	34036	45072
64	LTMP	1.4	0.24	0.05	Blim	4	1243232	0.189	0.05	0.219	1421213	322511	18331	457246	14540	13.313	40999	20	40	34226	45079

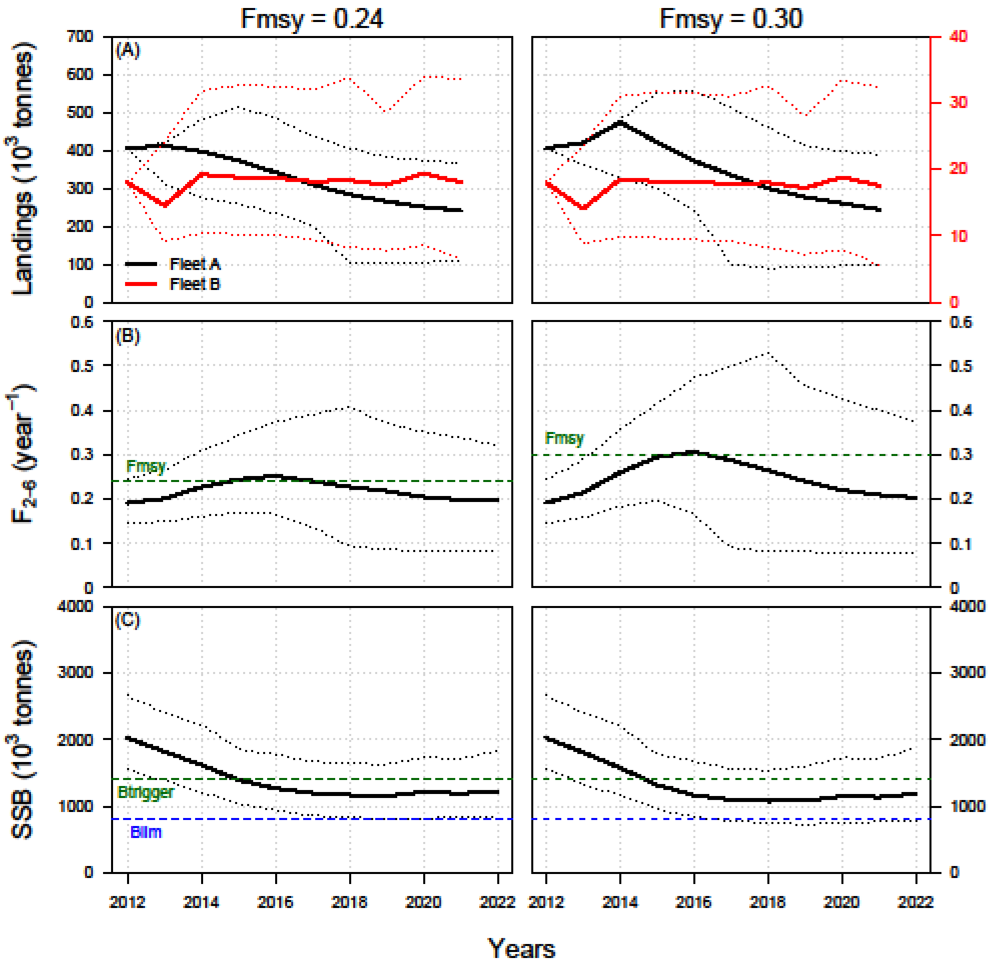
65	LTMP	1.5	0.24	0.05	Blim	3.3	1266774	0.181	0.05	0.214	1430697	316944	18426	457246	14540	13.498	41093	20	40	34042	45054
66	LTMP	1.6	0.24	0.05	Blim	2.8	1287551	0.174	0.05	0.209	1438565	311838	18534	457246	14549	13.632	40666	20	40	33959	44645
67	LTMP	1.7	0.24	0.05	Blim	2.2	1306756	0.167	0.05	0.204	1449839	307796	18619	456902	14554	13.729	40365	20	50	33762	44201
68	LTMP	1.8	0.24	0.05	Blim	1.9	1318388	0.163	0.05	0.199	1462243	303662	18693	456076	14561	13.843	40401	20	50	33319	43861
69	LTMP	1.9	0.24	0.05	Blim	1.5	1334135	0.159	0.05	0.194	1474924	299685	18769	452938	14579	13.898	40102	10	50	32754	43329
70	LTMP	2	0.24	0.05	Blim	1.3	1348621	0.155	0.05	0.19	1485619	295209	18836	444475	14628	13.922	39533	10	50	32037	42652
71	LTMP	1.5	0.25	0.05	Blim	4.7	1258131	0.184	0.05	0.219	1417732	321009	18342	465750	14468	13.633	42000	20	40	35522	46645
72	LTMP	1.3	0.3	0.05	Blim	15.7	1185980	0.209	0.05	0.256	1345342	350359	17736	465750	14022	14.144	48245	20	40	40236	57856
73	LTMP	1.4	0.3	0.05	Blim	13.8	1208875	0.199	0.05	0.247	1356931	344411	17890	465750	14032	14.197	47486	20	40	40427	56376
74	LTMP	1.5	0.3	0.05	Blim	11.5	1221583	0.193	0.05	0.242	1371203	339069	18015	465750	14036	14.29	46765	20	40	40585	54604
75	LTMP	1.6	0.3	0.05	Blim	9.5	1240209	0.187	0.05	0.233	1383402	331941	18139	465750	14054	14.354	45812	20	40	40288	52981
76	LTMP	1.7	0.3	0.05	Blim	8	1258201	0.182	0.05	0.227	1393800	325787	18235	465750	14066	14.388	45081	20	40	40179	51331
77	LTMP	1.8	0.3	0.05	Blim	6.2	1269990	0.177	0.05	0.22	1407558	321254	18340	465750	14100	14.299	44176	20	50	39251	49657
78	LTMP	1.9	0.3	0.05	Blim	4.3	1284132	0.173	0.05	0.215	1421562	316420	18428	465750	14175	14.272	43324	20	50	38245	48144
79	LTMP	2	0.3	0.05	Blim	3.6	1295398	0.17	0.05	0.211	1432862	313139	18499	465750	14232	14.164	42678	20	50	36976	46860
80	meanTAC	1.5	0.24	0.05	Btrigger	0.1	1271740	0.189	0.049	0.199	1470436	307209	18463	431123	14540	19.771	52095	NA	NA	40506	62304
81	meanTAC	1.5	0.3	0.05	Btrigger	1.1	1204513	0.211	0.049	0.225	1406565	329389	18018	482052	14036	24.116	69836	NA	NA	59423	80515

82	meanTAC	1.3	0.24	0.05	Blim	2.7	1218871	0.207	0.05	0.226	1407782	329062	18218	431123	14540	11.856	35234	NA	NA	29653	39431
83	meanTAC	1.4	0.24	0.05	Blim	1.5	1240277	0.198	0.05	0.219	1420329	323045	18325	431123	14540	12.289	35840	NA	NA	29677	40374
84	meanTAC	1.5	0.24	0.05	Blim	1	1264610	0.189	0.05	0.213	1432025	317566	18429	431123	14540	12.594	36138	NA	NA	29587	40885
85	meanTAC	1.6	0.24	0.05	Blim	0.6	1286162	0.182	0.05	0.207	1444411	311686	18525	431123	14549	12.687	36279	NA	NA	29217	41221
86	meanTAC	1.7	0.24	0.05	Blim	0.6	1305914	0.175	0.05	0.201	1455992	306493	18627	430951	14554	12.791	36086	NA	NA	28726	41228
87	meanTAC	1.8	0.24	0.05	Blim	0.3	1321585	0.17	0.05	0.196	1467012	302038	18704	430538	14561	12.869	35963	NA	NA	28449	40947
88	meanTAC	1.9	0.24	0.05	Blim	0	1333480	0.165	0.05	0.192	1479071	297266	18796	428969	14579	12.892	35564	NA	NA	27902	40587
89	meanTAC	2	0.24	0.05	Blim	0	1347012	0.161	0.05	0.188	1489600	293207	18857	424737	14628	12.833	34926	NA	NA	27367	39975
90	meanTAC	1.3	0.3	0.05	Blim	12.6	1146803	0.231	0.05	0.257	1336091	353898	17729	482052	14022	14.96	49835	NA	NA	48056	52899
91	meanTAC	1.4	0.3	0.05	Blim	9.2	1173976	0.22	0.05	0.249	1349307	346940	17882	482052	14032	15.229	49854	NA	NA	47696	53030
92	meanTAC	1.5	0.3	0.05	Blim	6.4	1199088	0.21	0.05	0.24	1366050	340414	18019	482052	14036	15.293	49072	NA	NA	47221	52504
93	meanTAC	1.6	0.3	0.05	Blim	4.4	1223648	0.202	0.05	0.232	1379625	334075	18139	482052	14054	15.288	48492	NA	NA	46731	51624
94	meanTAC	1.7	0.3	0.05	Blim	3.5	1245526	0.195	0.05	0.226	1393727	328141	18245	481906	14066	15.173	47990	NA	NA	46010	50664
95	meanTAC	1.8	0.3	0.05	Blim	2.3	1261995	0.189	0.05	0.219	1406378	322891	18340	480284	14100	14.931	47060	NA	NA	45031	49498
96	meanTAC	1.9	0.3	0.05	Blim	2.2	1277821	0.184	0.05	0.214	1419793	317920	18425	475440	14175	14.753	45655	NA	NA	43416	48397
97	meanTAC	2	0.3	0.05	Blim	1.6	1293805	0.179	0.05	0.209	1433214	313622	18506	467044	14232	14.429	44202	NA	NA	41452	47288
98	noIAV	1.5	0.24	0.05	Blim	0.1	1267549	0.189	0.049	0.202	1460681	308955	18457	457246	14540	22.3	62046	NA	NA	54627	70021

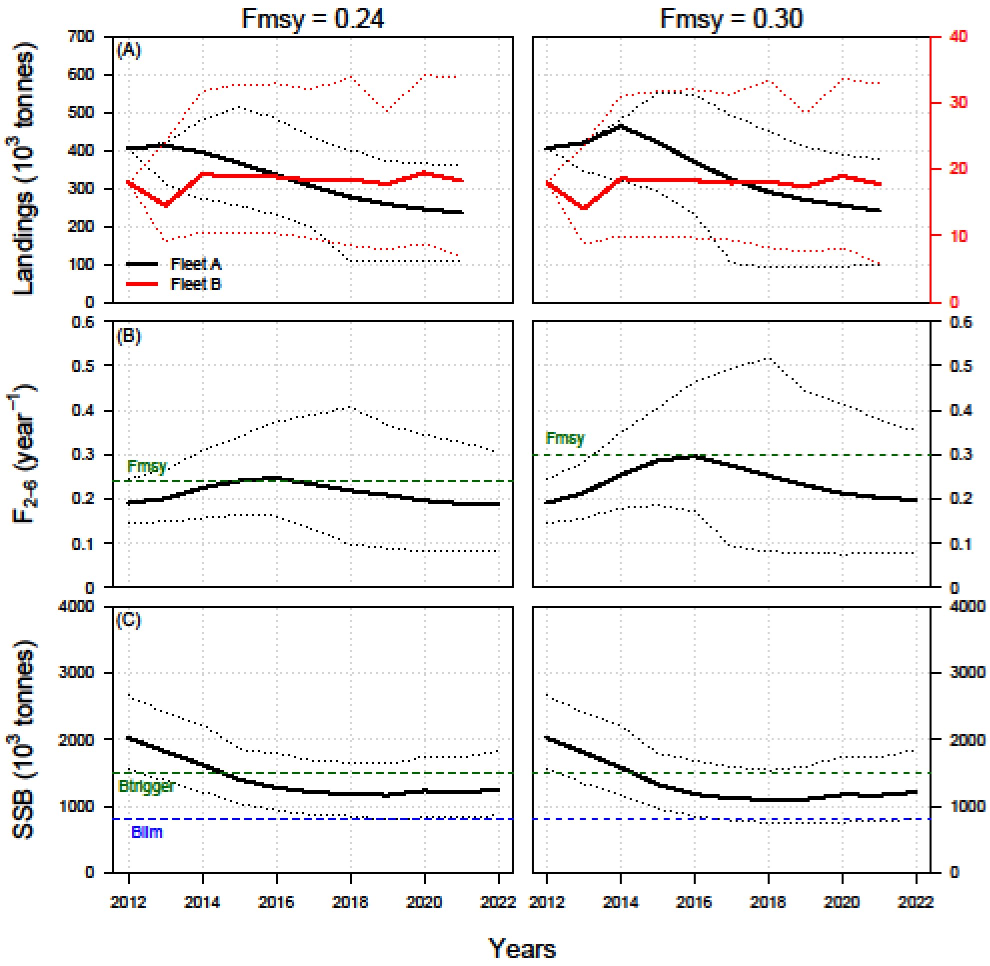
99	noIAV	1.5	0.3	0.05	Blim	1.2	1198524	0.211	0.049	0.229	1389381	333158	18027	559103	14036	28.456	89616	NA	NA	84178	95453



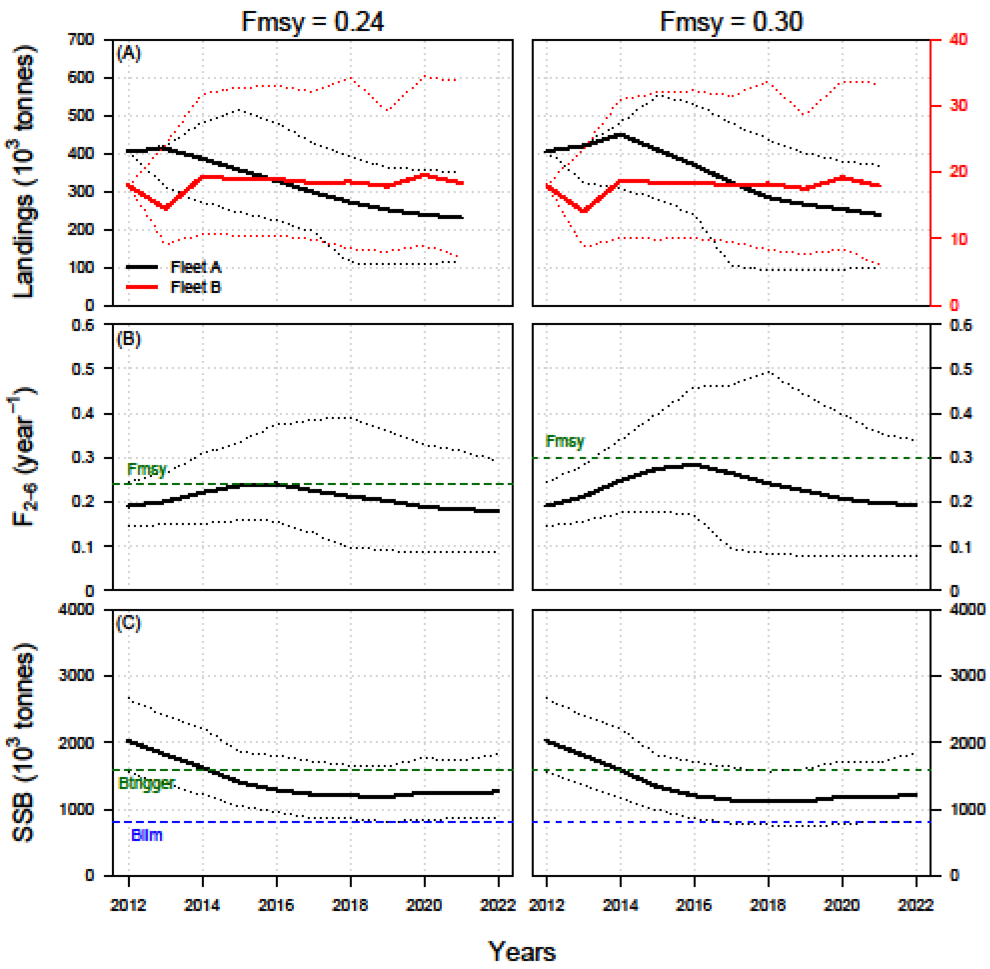
Scenario 1 and 9



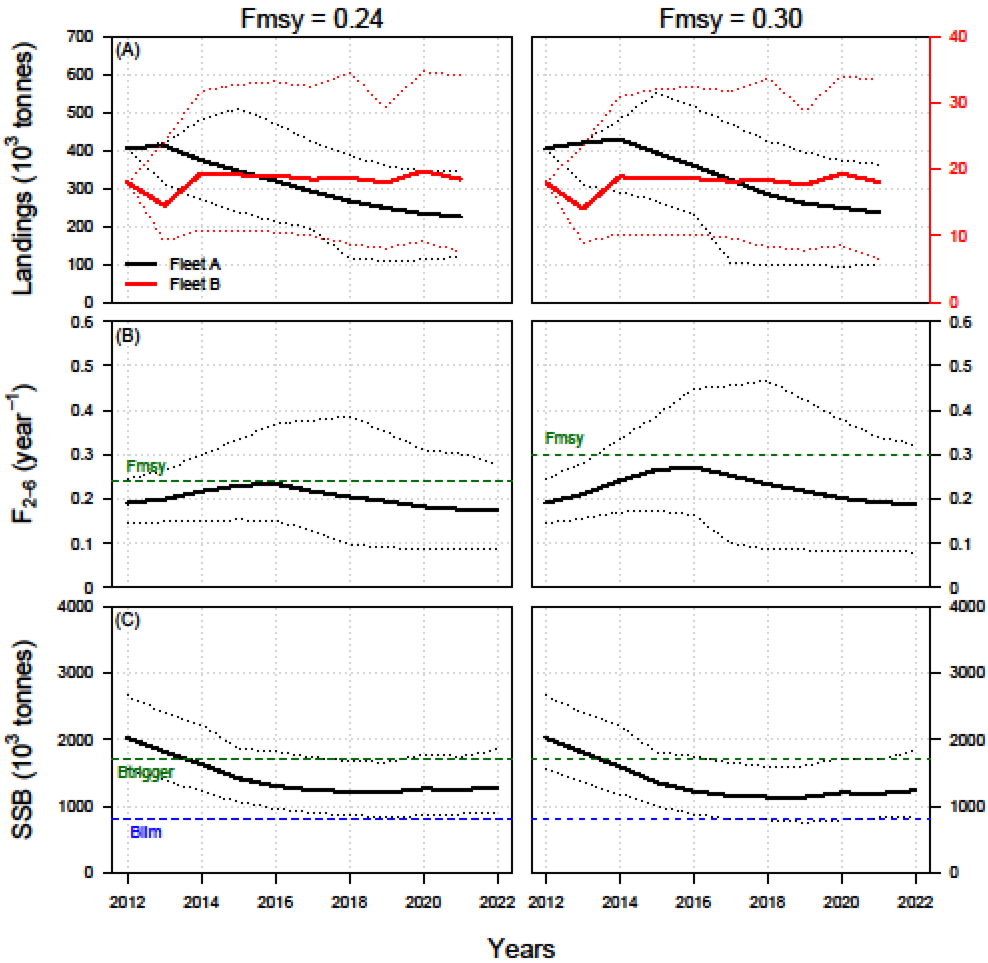
Scenario 2 and 10



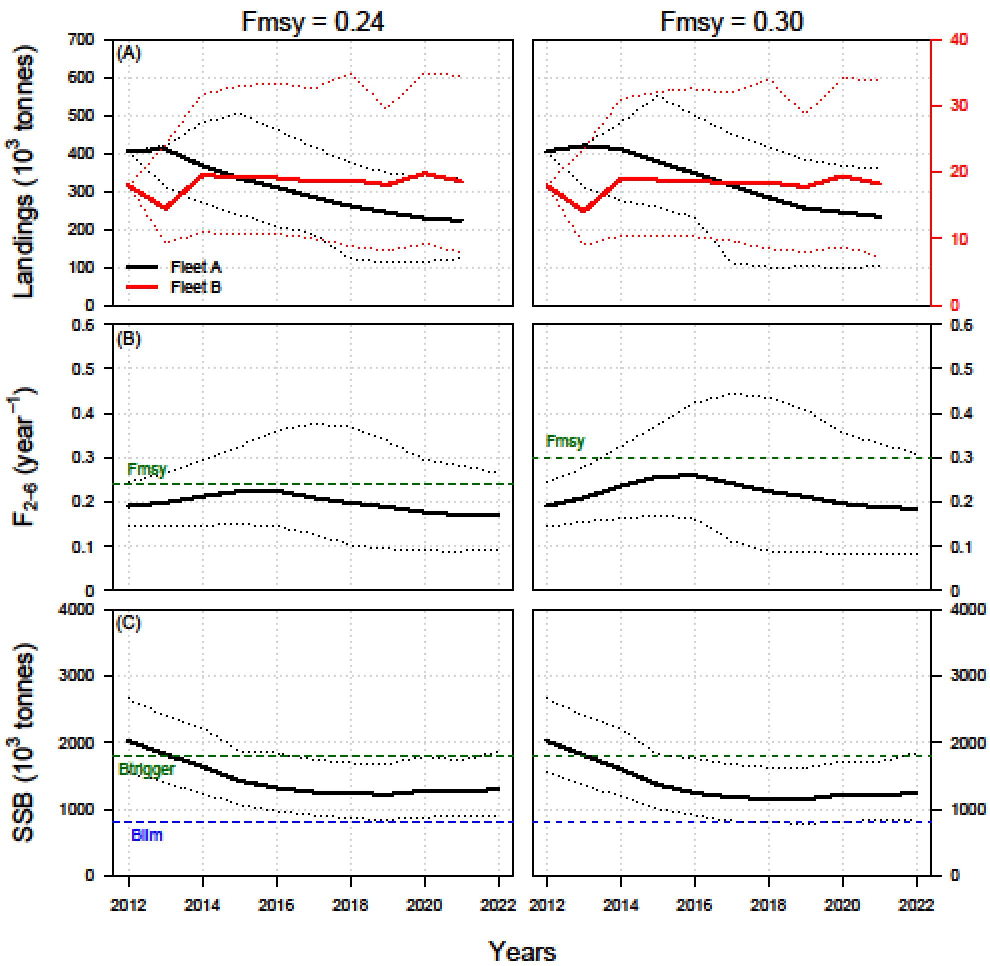
Scenario 3 and 11



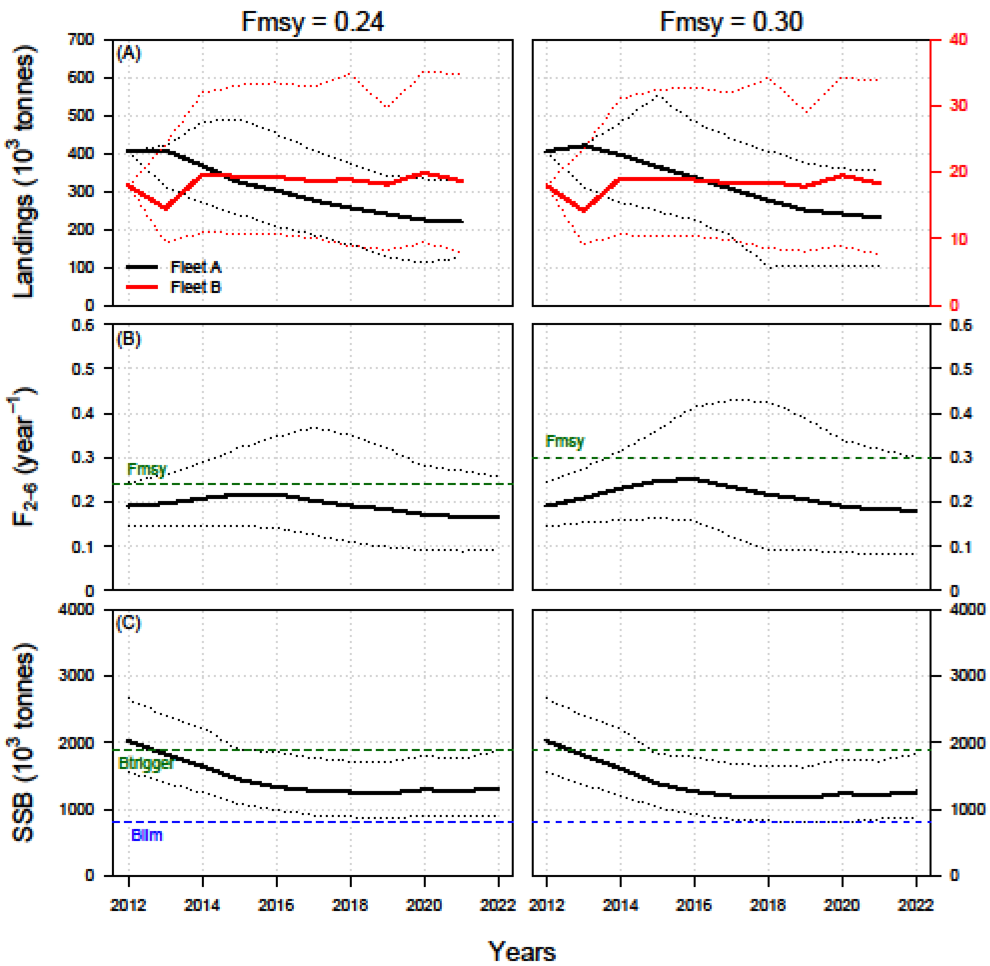
Scenario 4 and 12



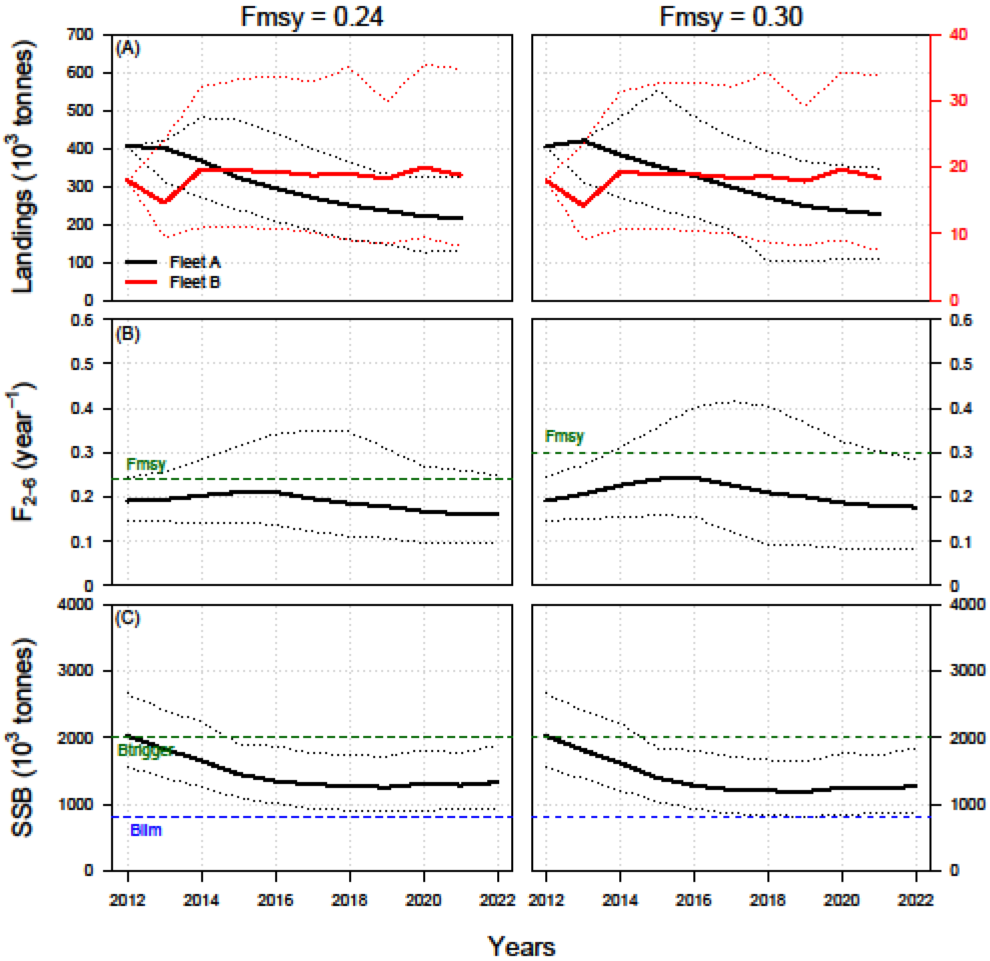
Scenario 5 and 13



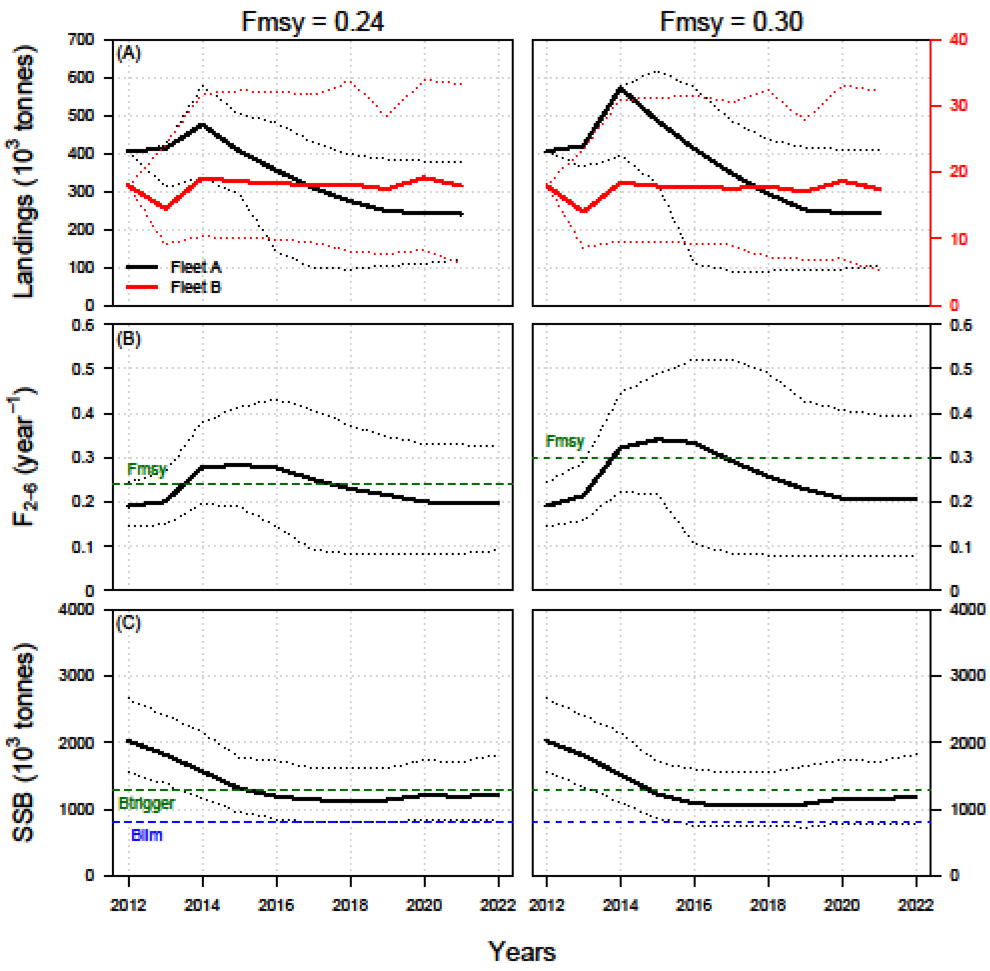
Scenario 6 and 14



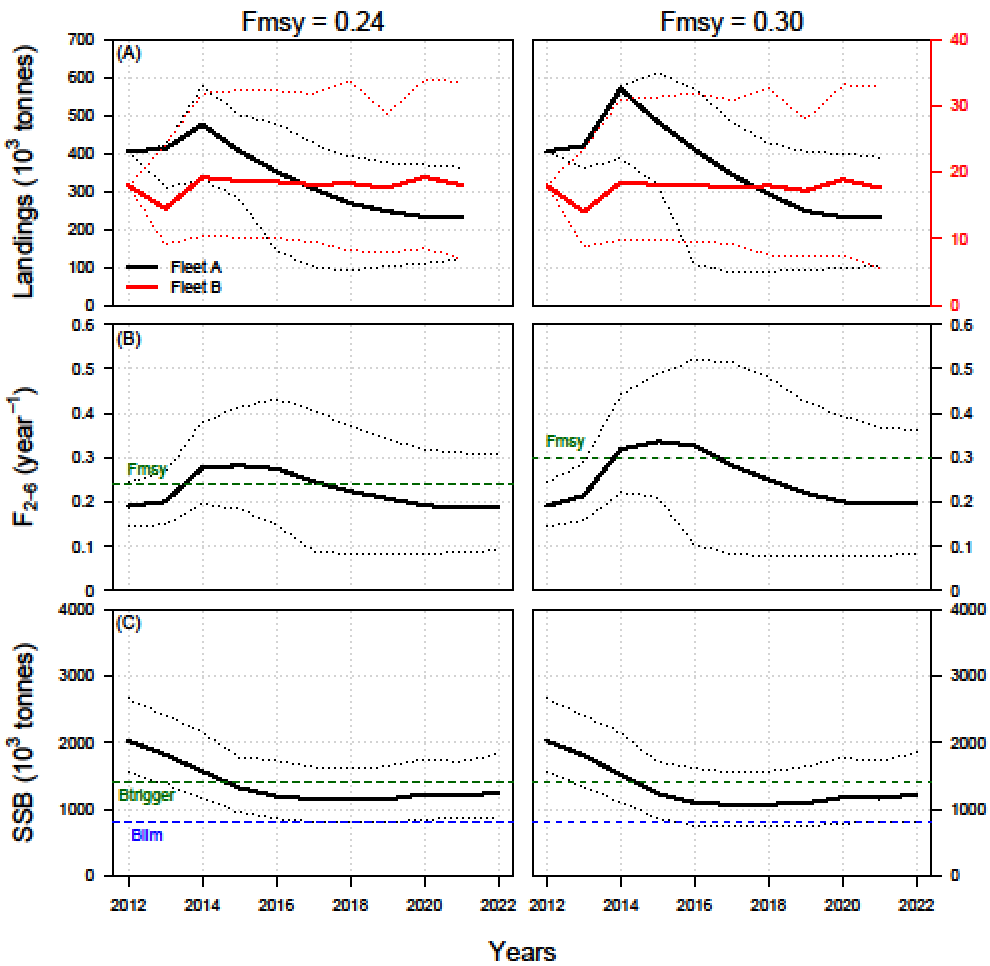
Scenario 7 and 15



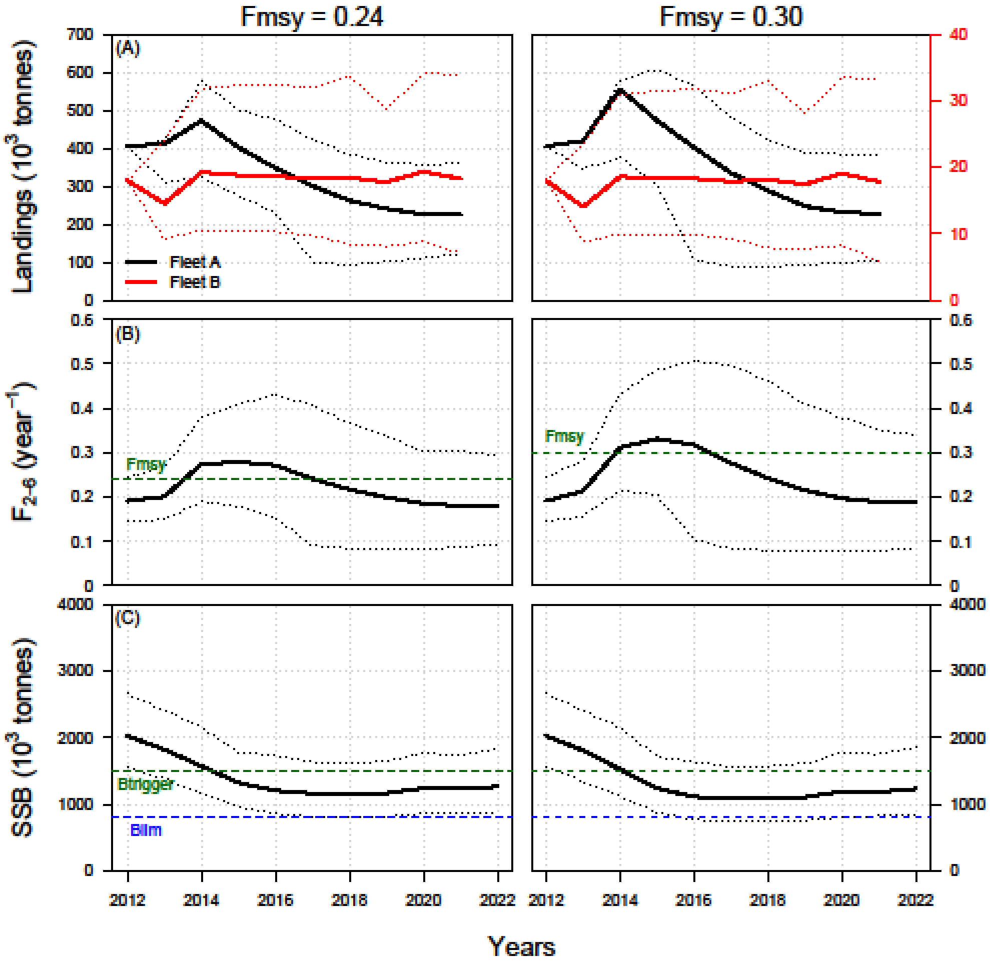
Scenario 8 and 16



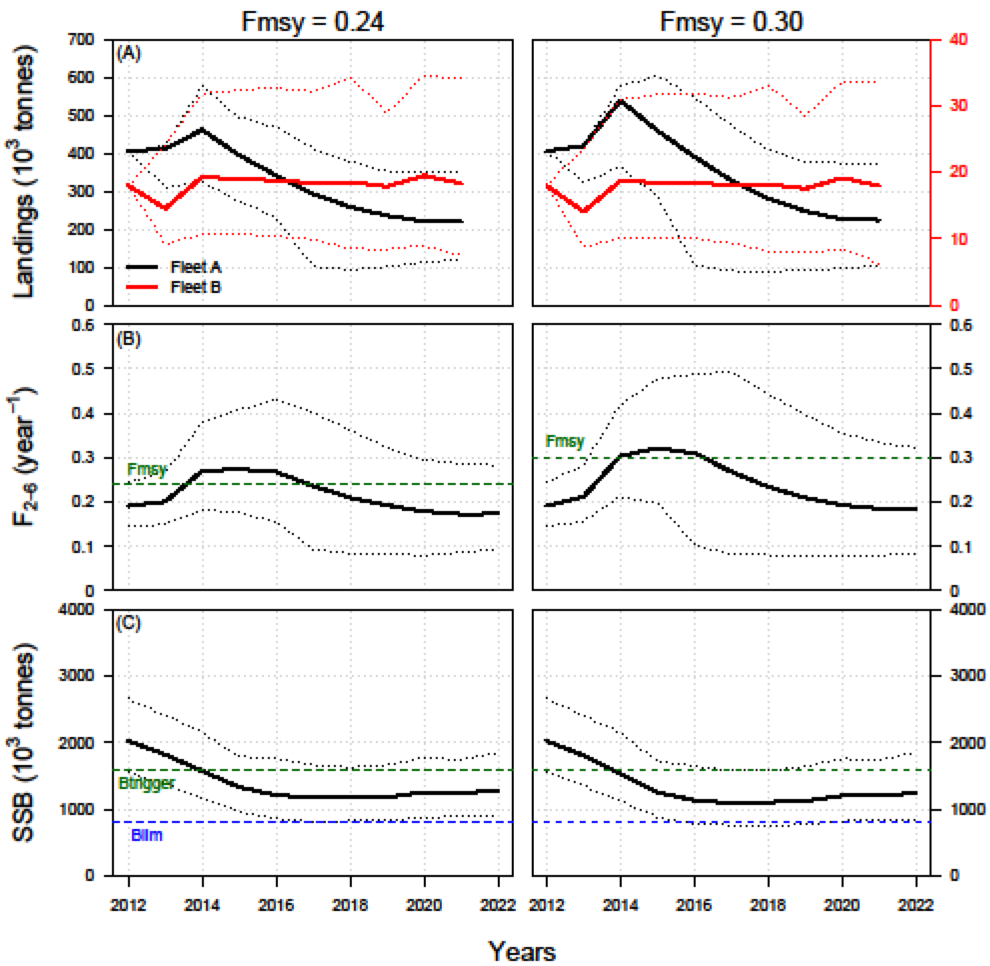
Scenario 17 and 25



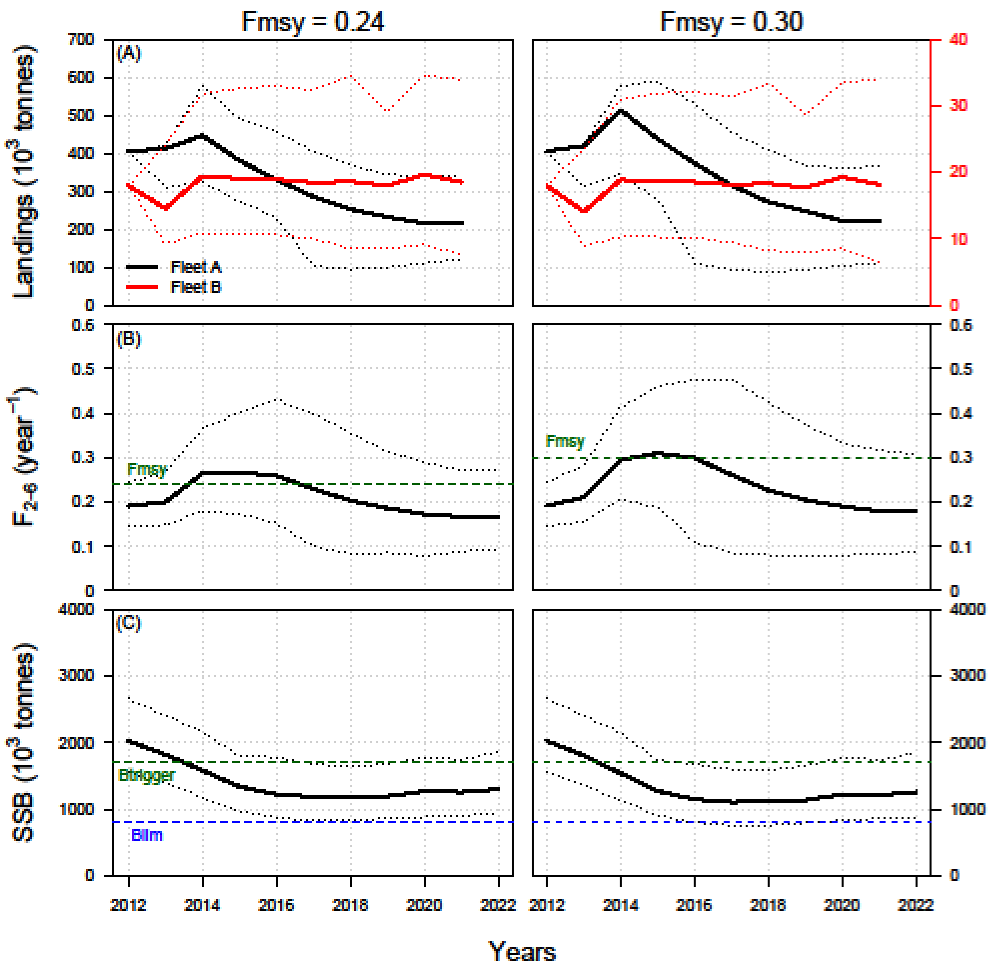
Scenario 18 and 26



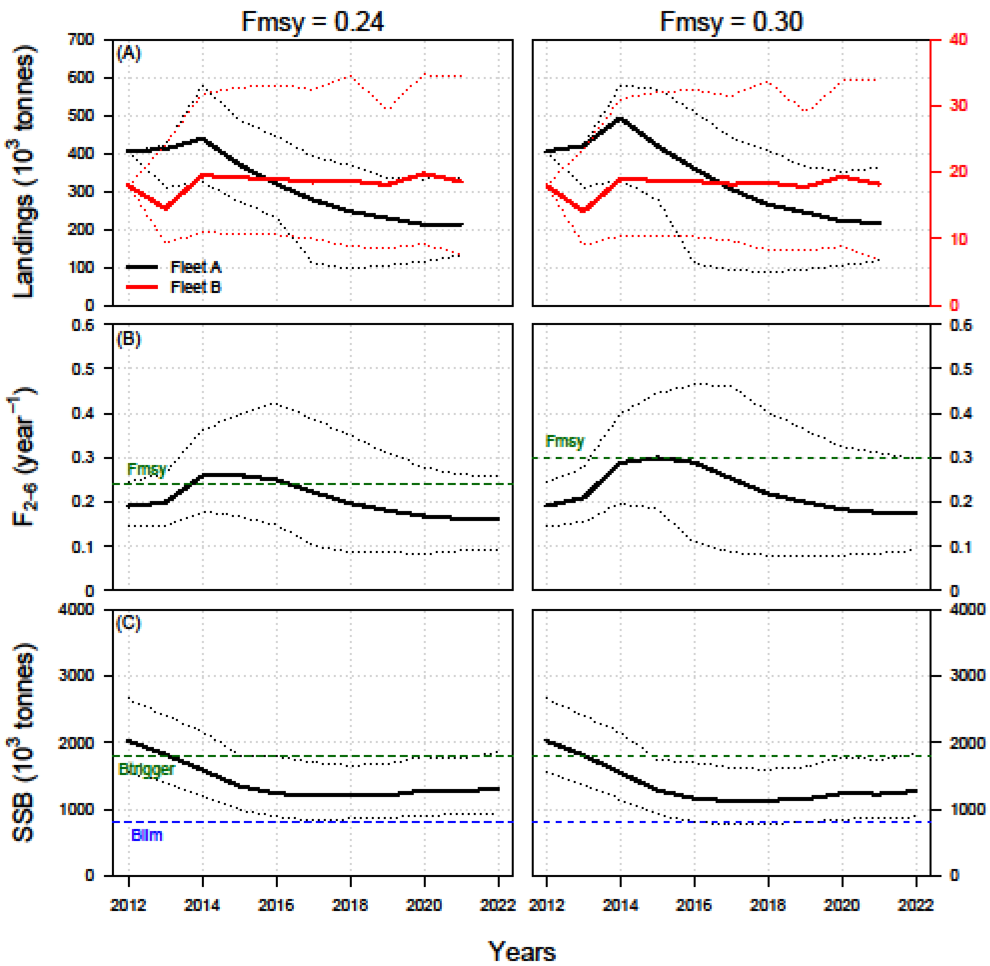
Scenario 19 and 27



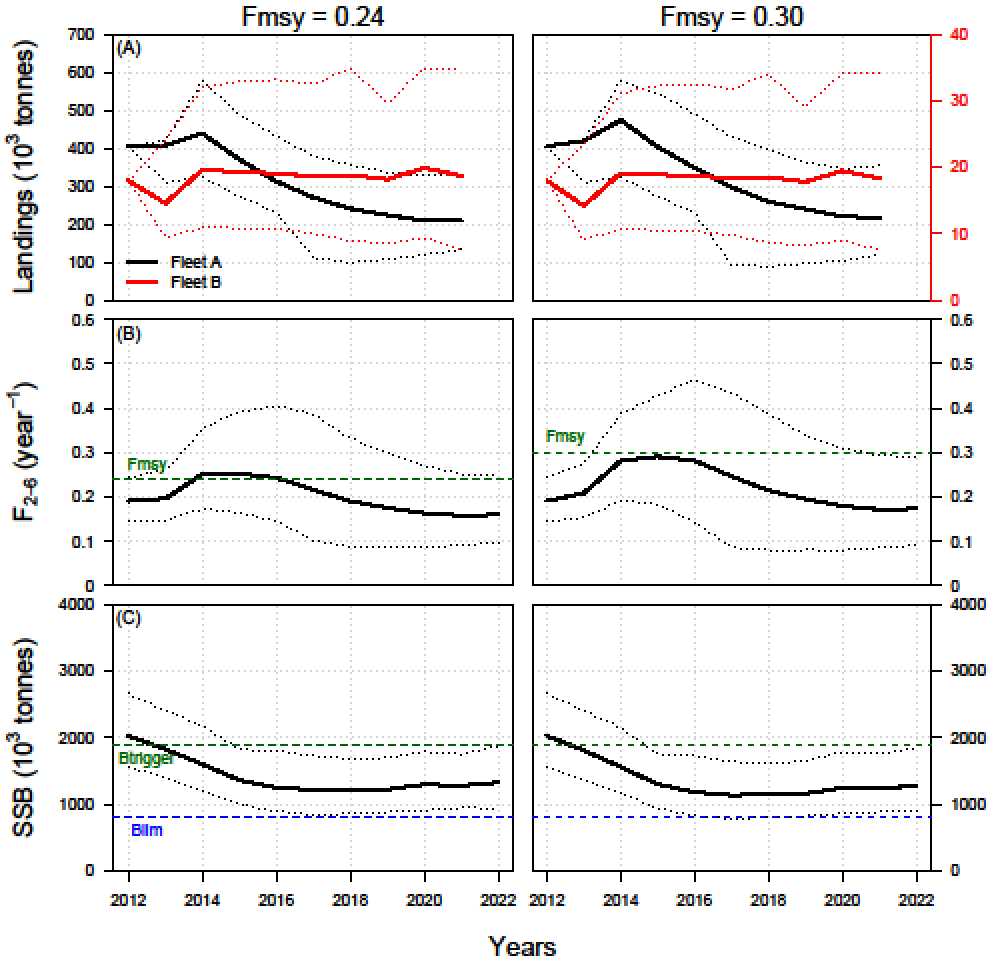
Scenario 20 and 28



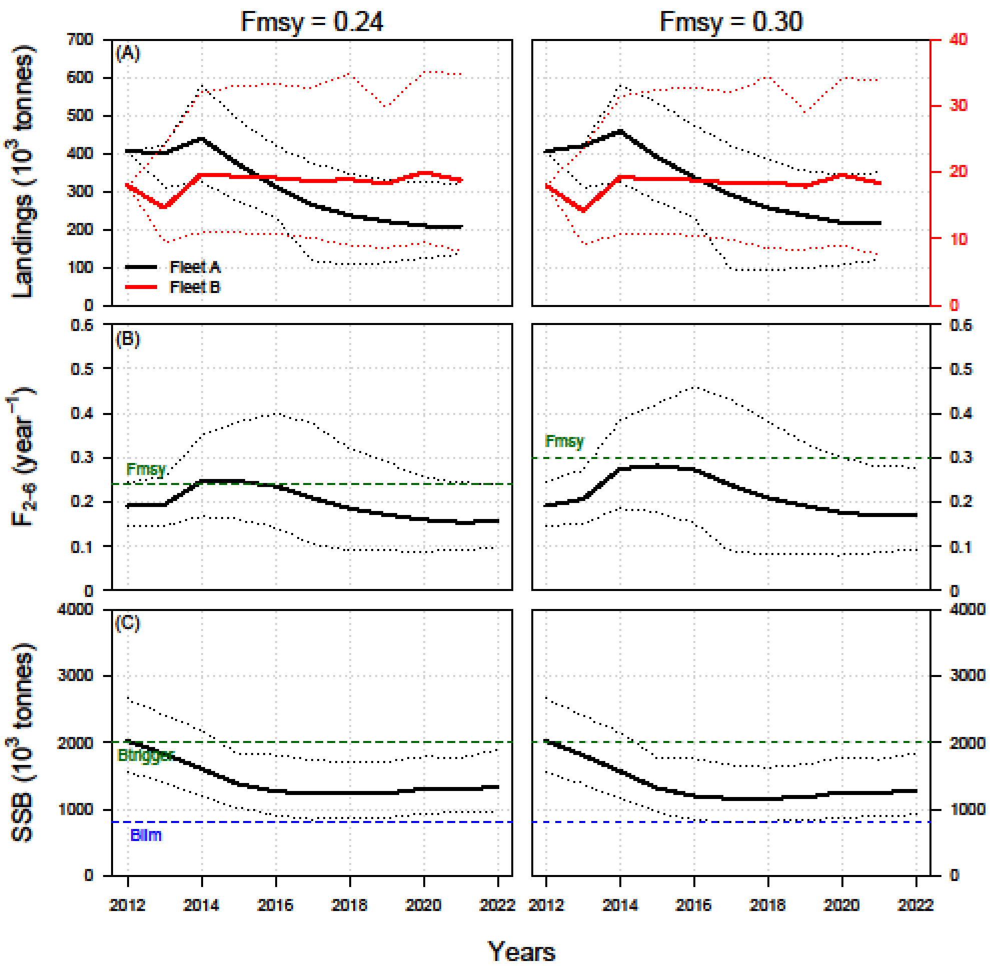
Scenario 21 and 29



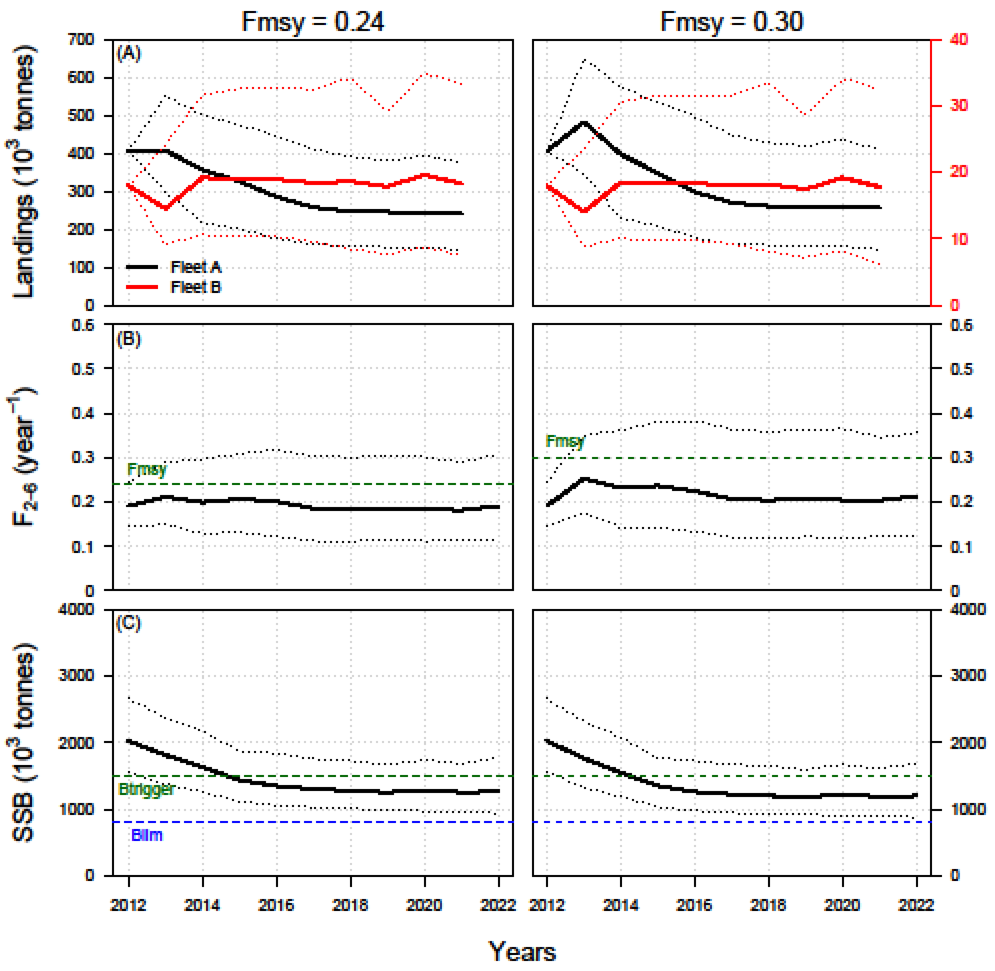
Scenario 22 and 30



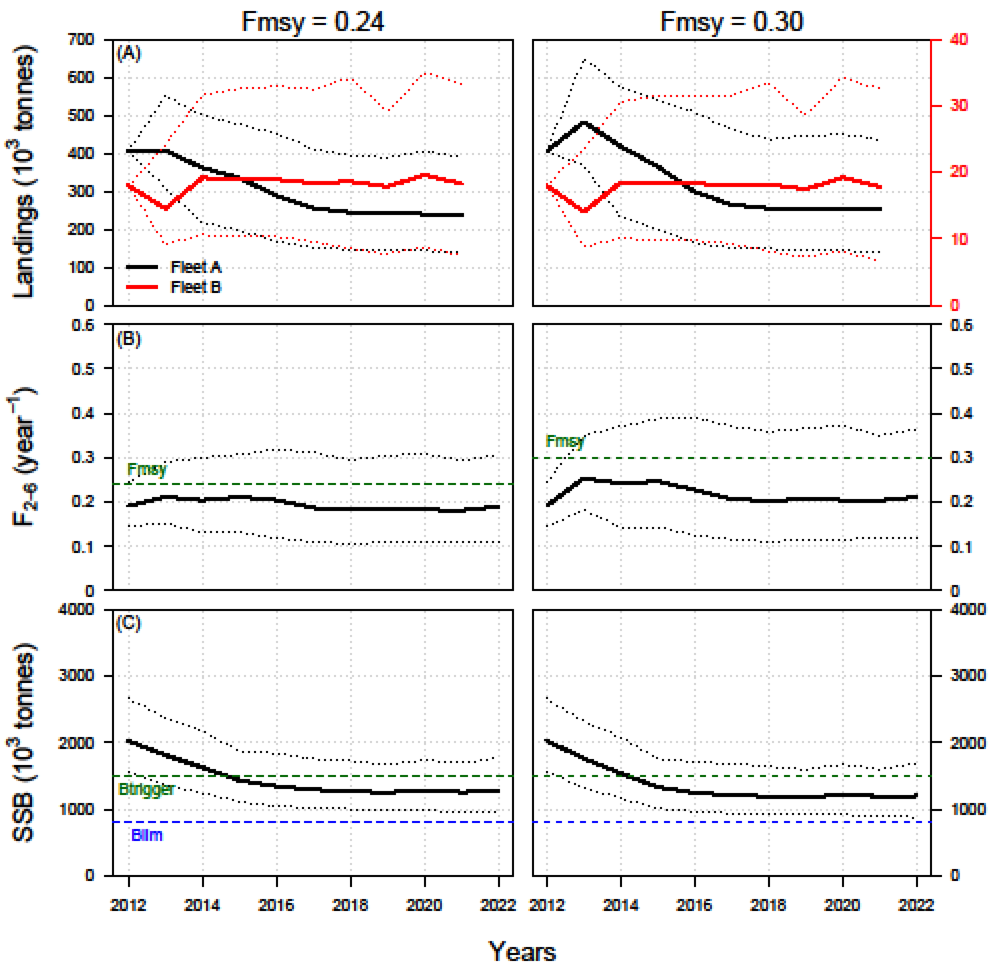
Scenario 23 and 31



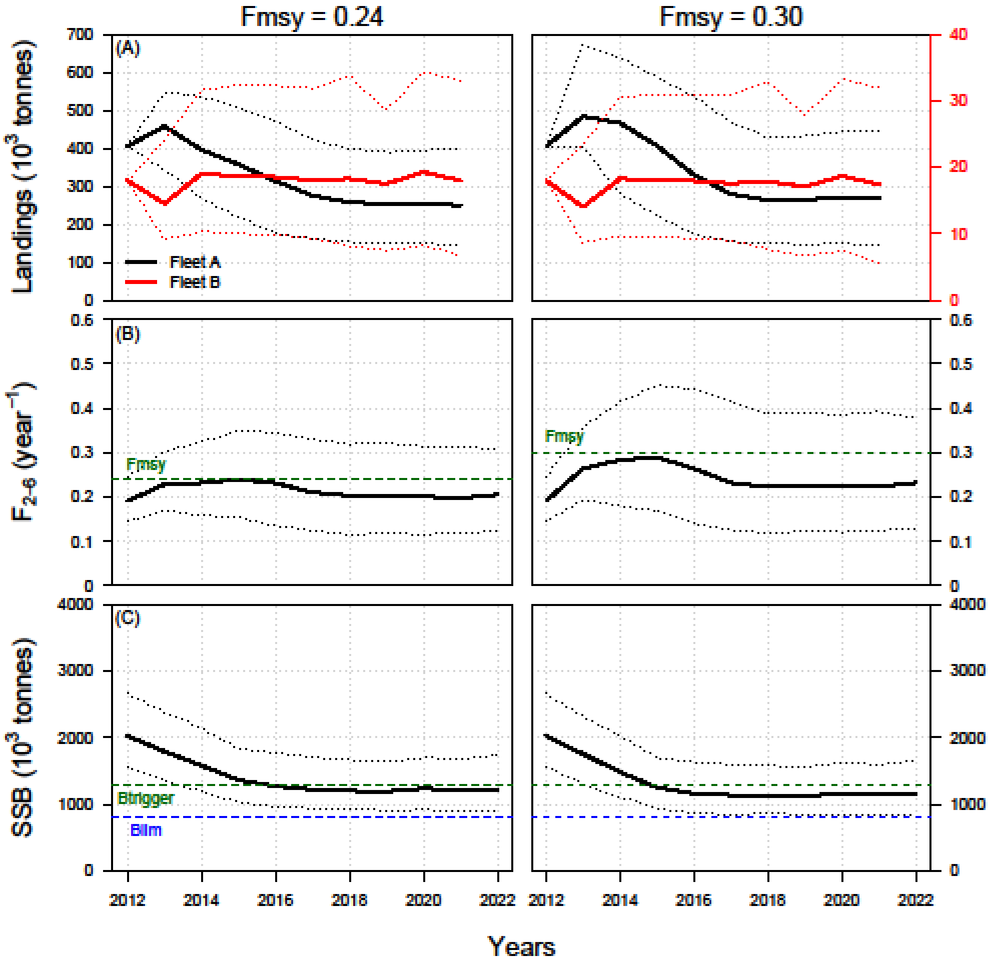
Scenario 24 and 32



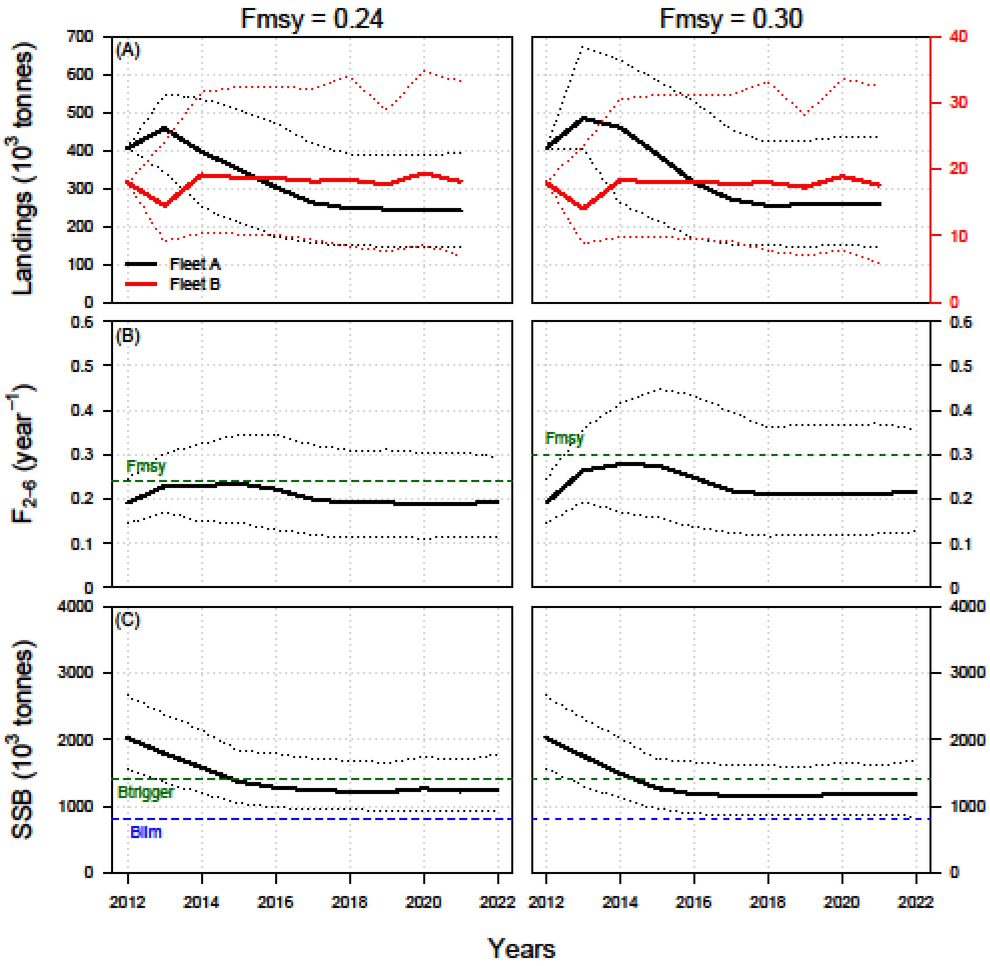
Scenario 33 and 34



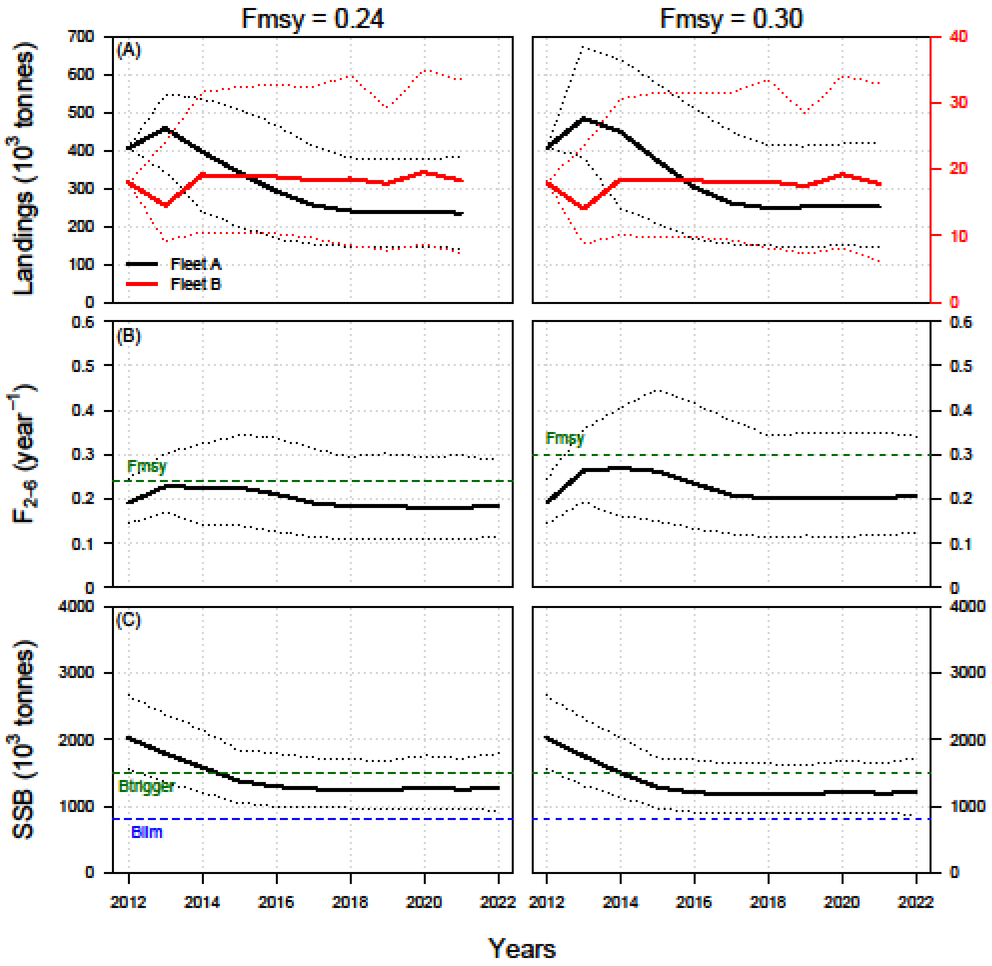
Scenario 35 and 36



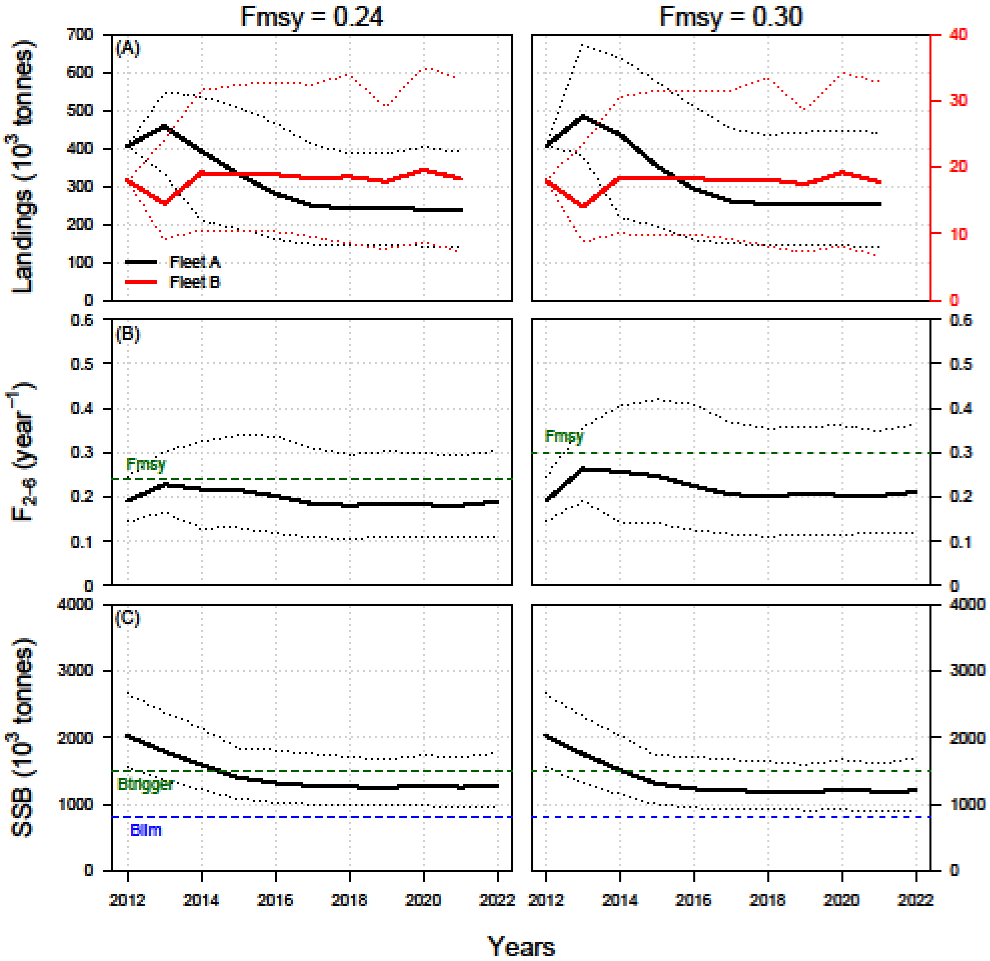
Scenario 37 and 46



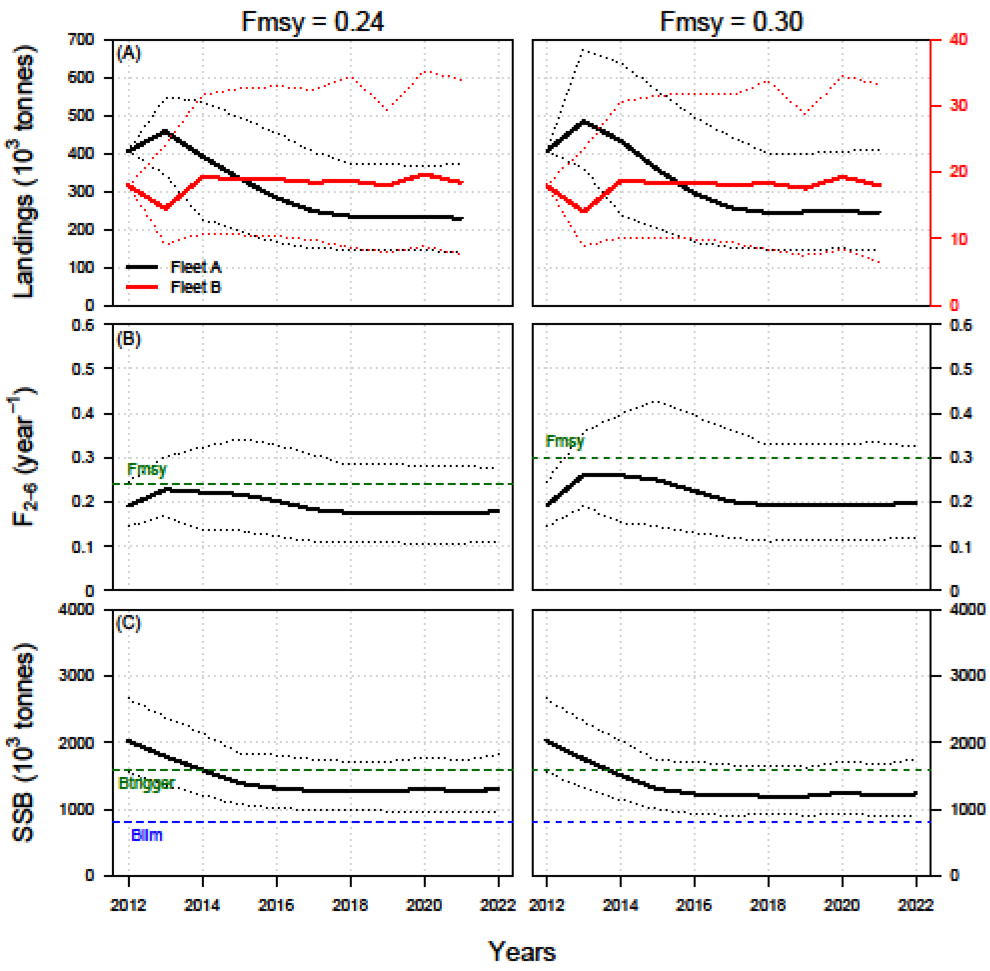
Scenario 38 and 47



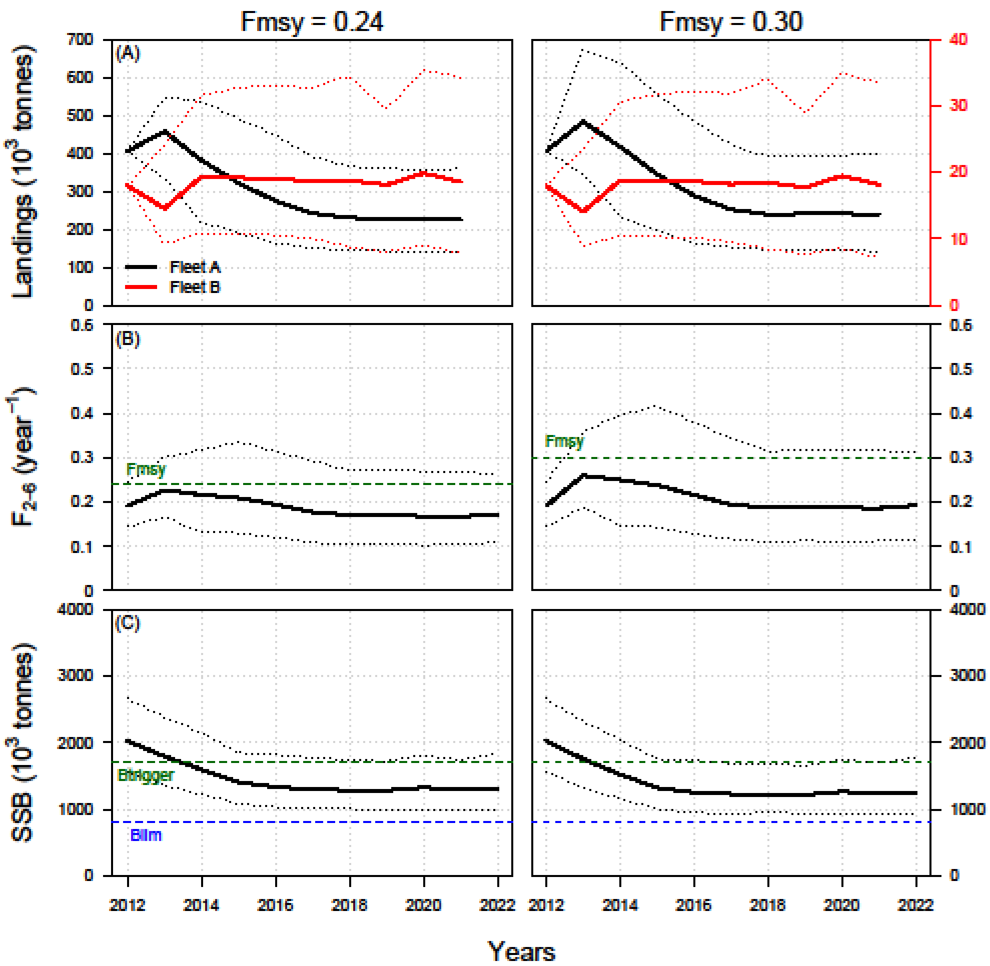
Scenario 39 and 48



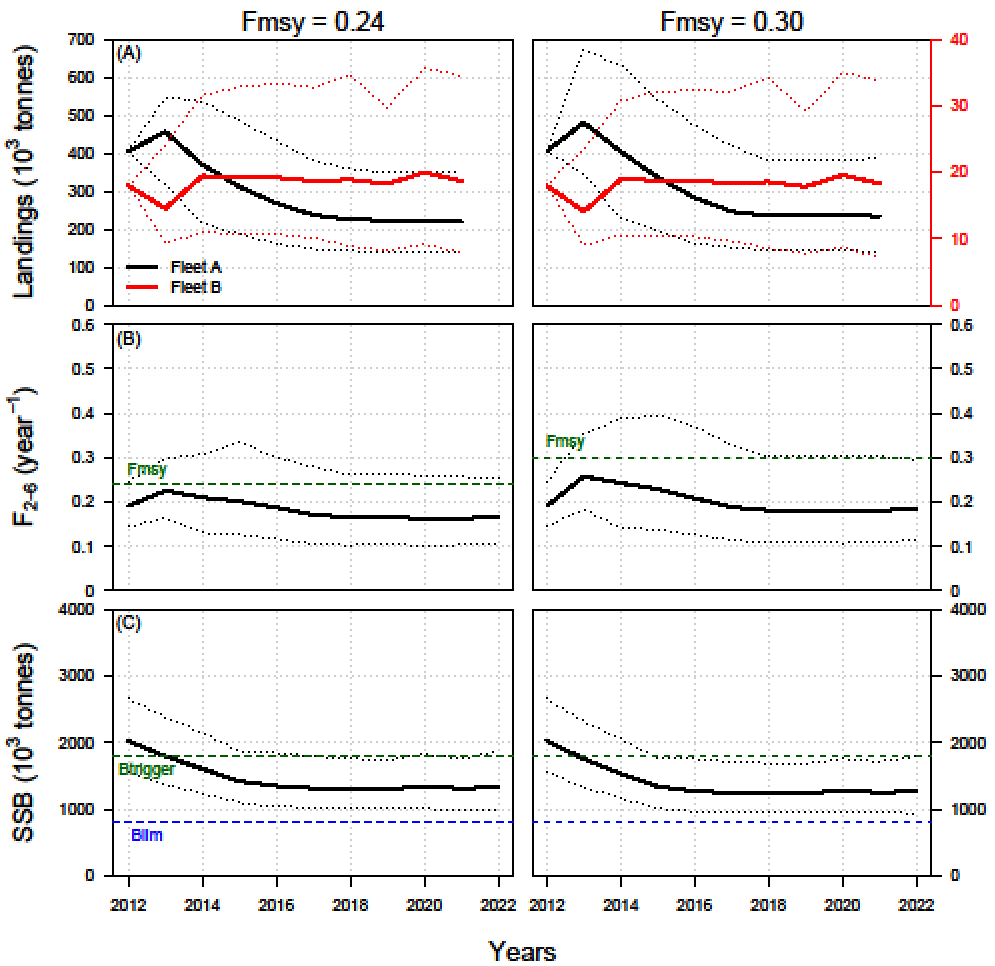
Scenario 40 and 49



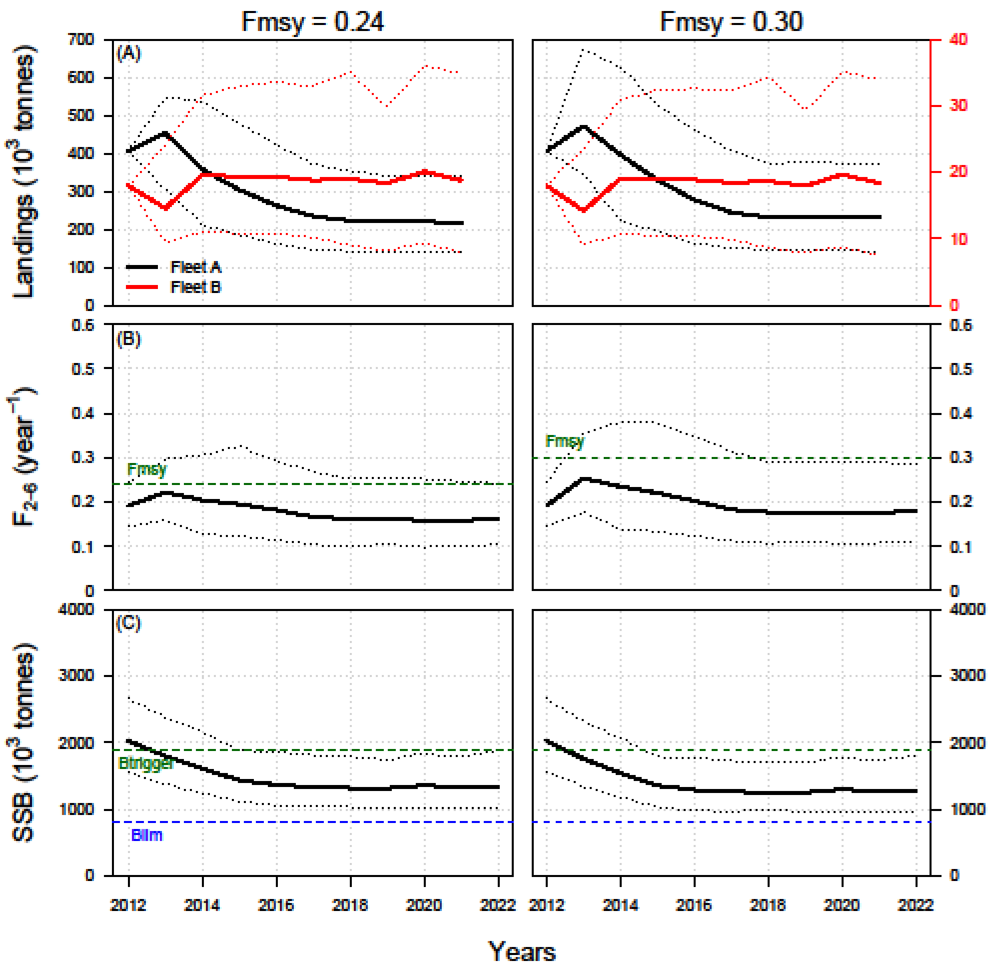
Scenario 41 and 50



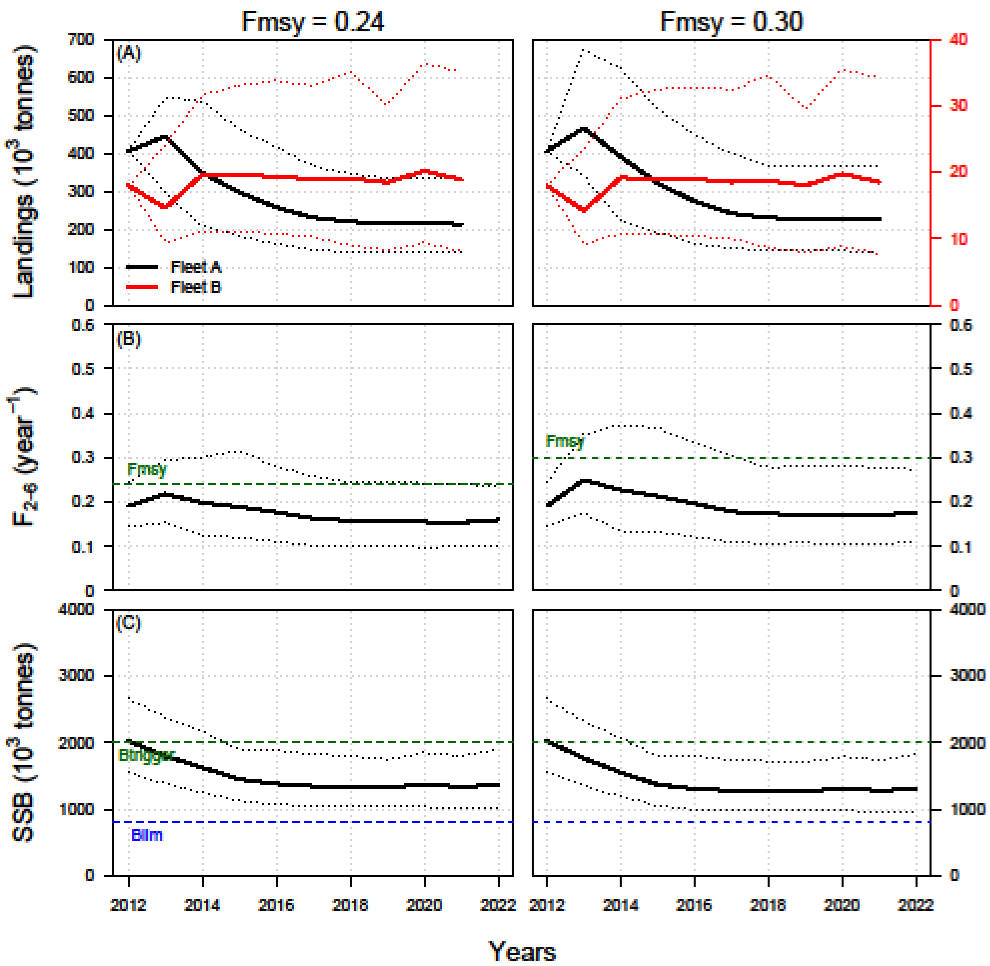
Scenario 42 and 51



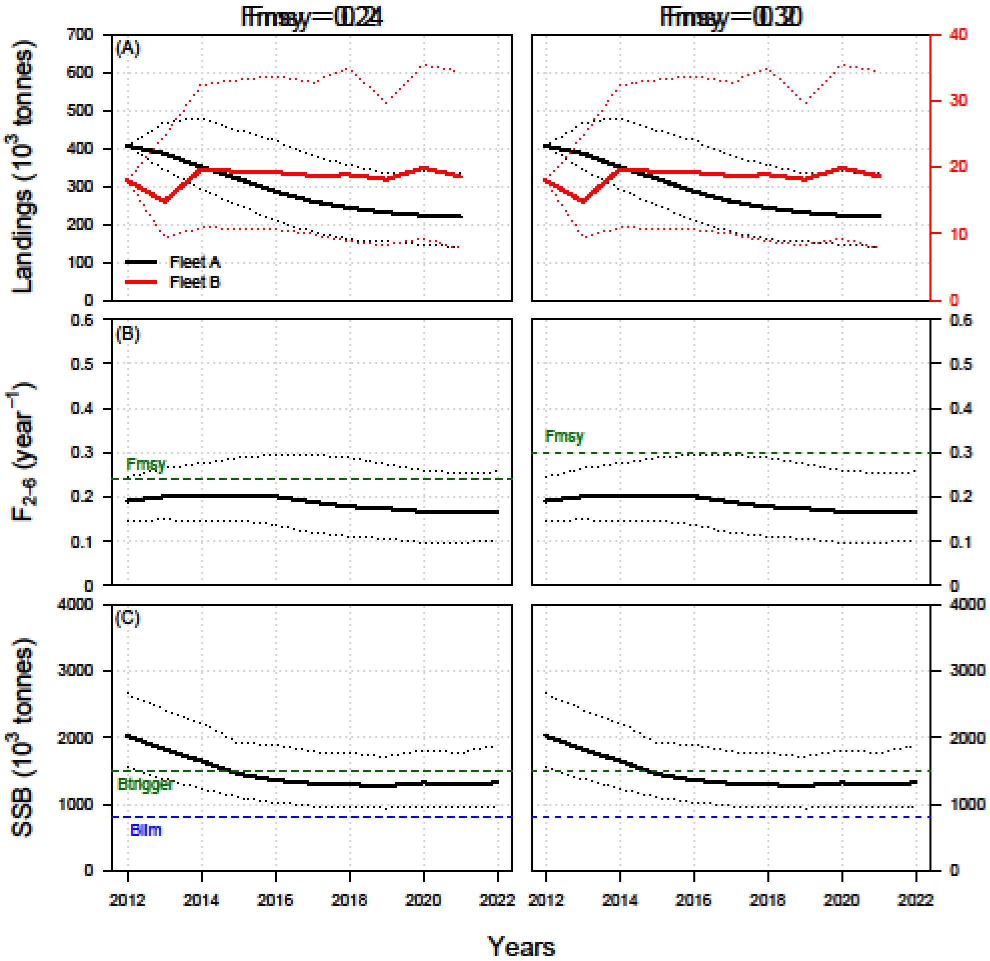
Scenario 43 and 52



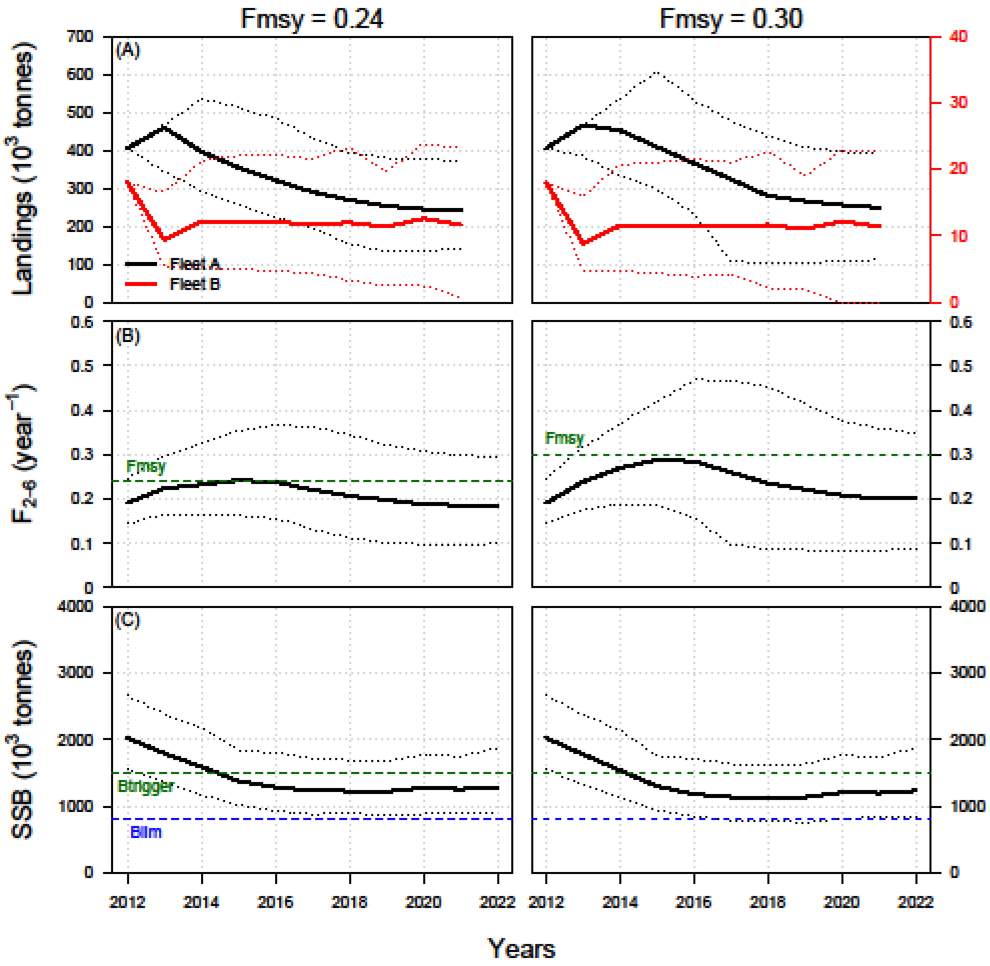
Scenario 44 and 53



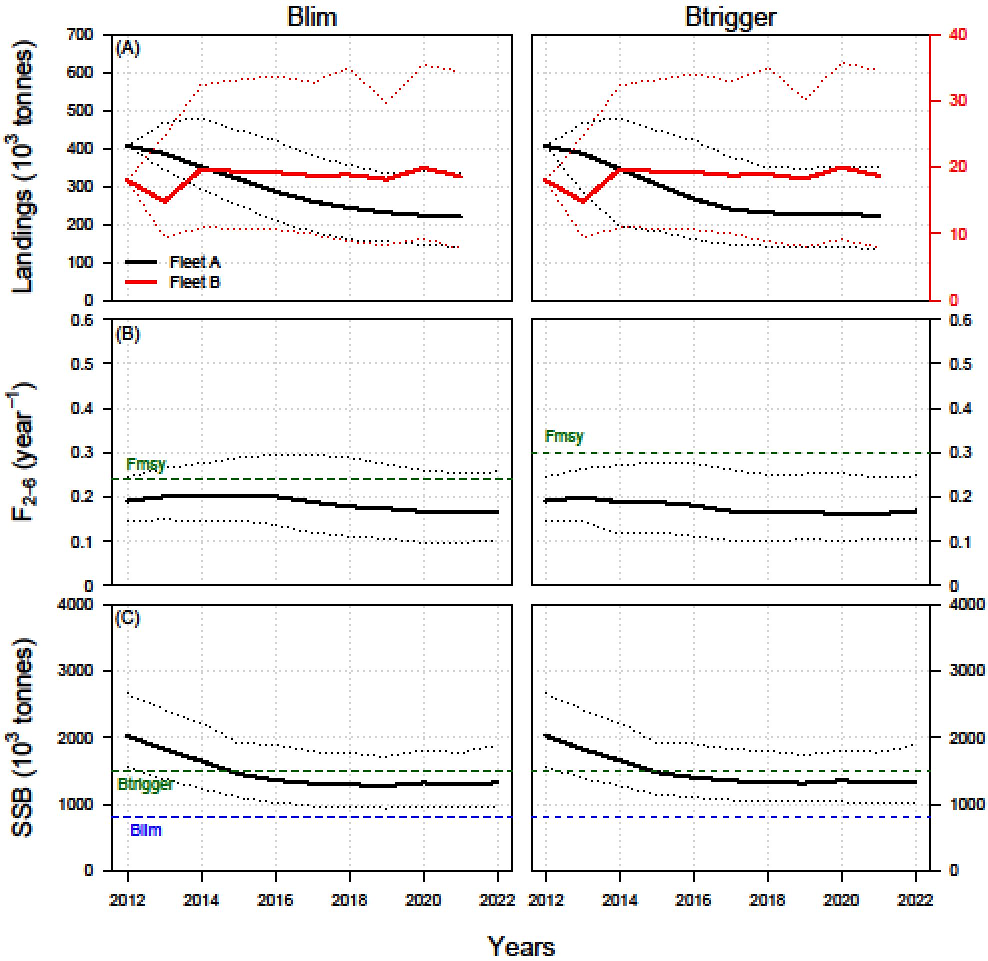
Scenario 45 and 54


Fmsy=0.24
Fmsy=0.30
(A)
(B)
(C)
Landings (10^3 tonnes)
F_{2-6} (year^{-1})
SSB (10^3 tonnes)
Fleet A
Fleet B
Fmsy
Btrigger
Blim
Years
2012
2014
2016
2018
2020
2022

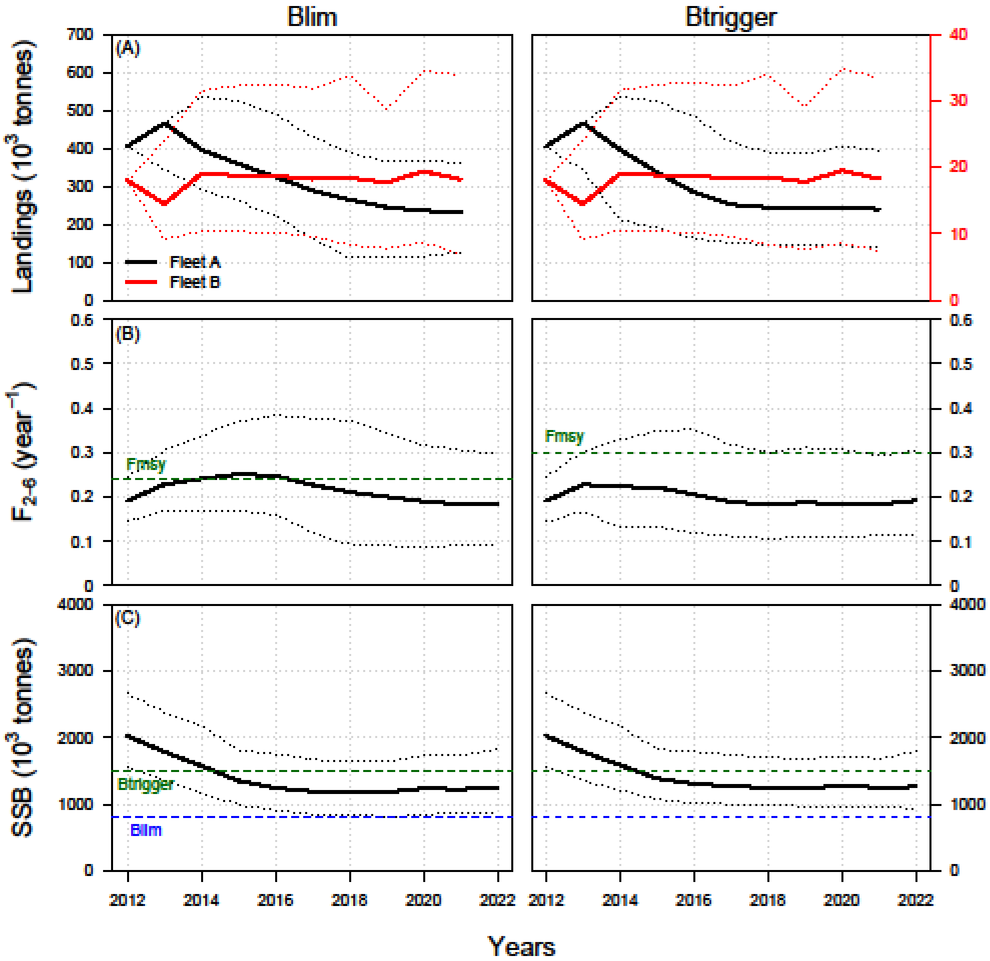
Scenario 55



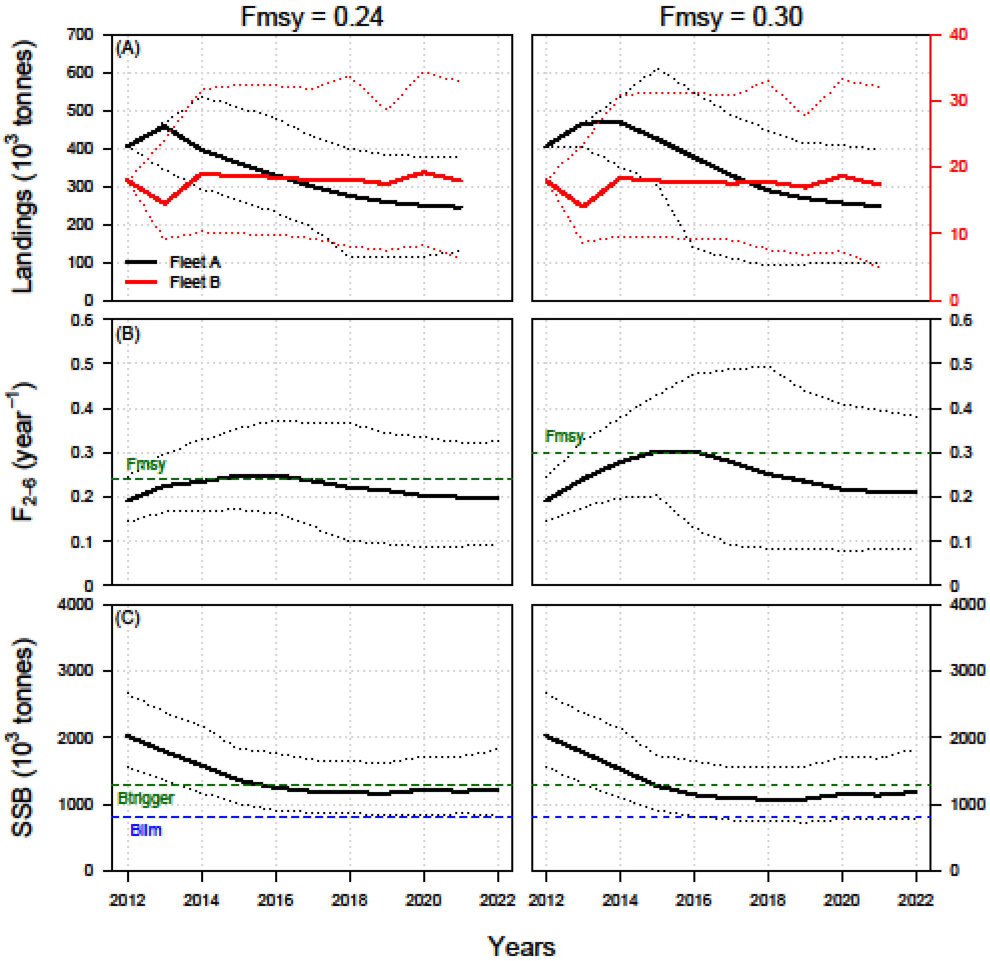
Scenario 56 and 57



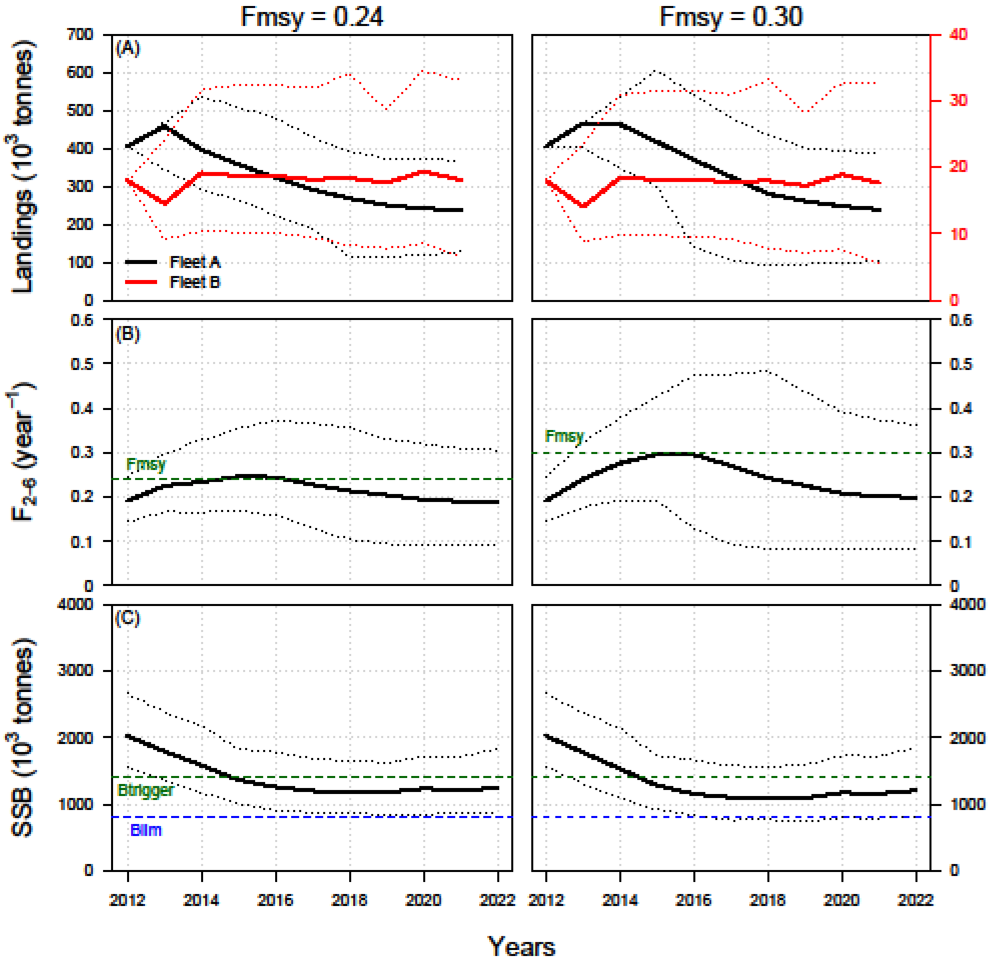
Scenario 58 and 59



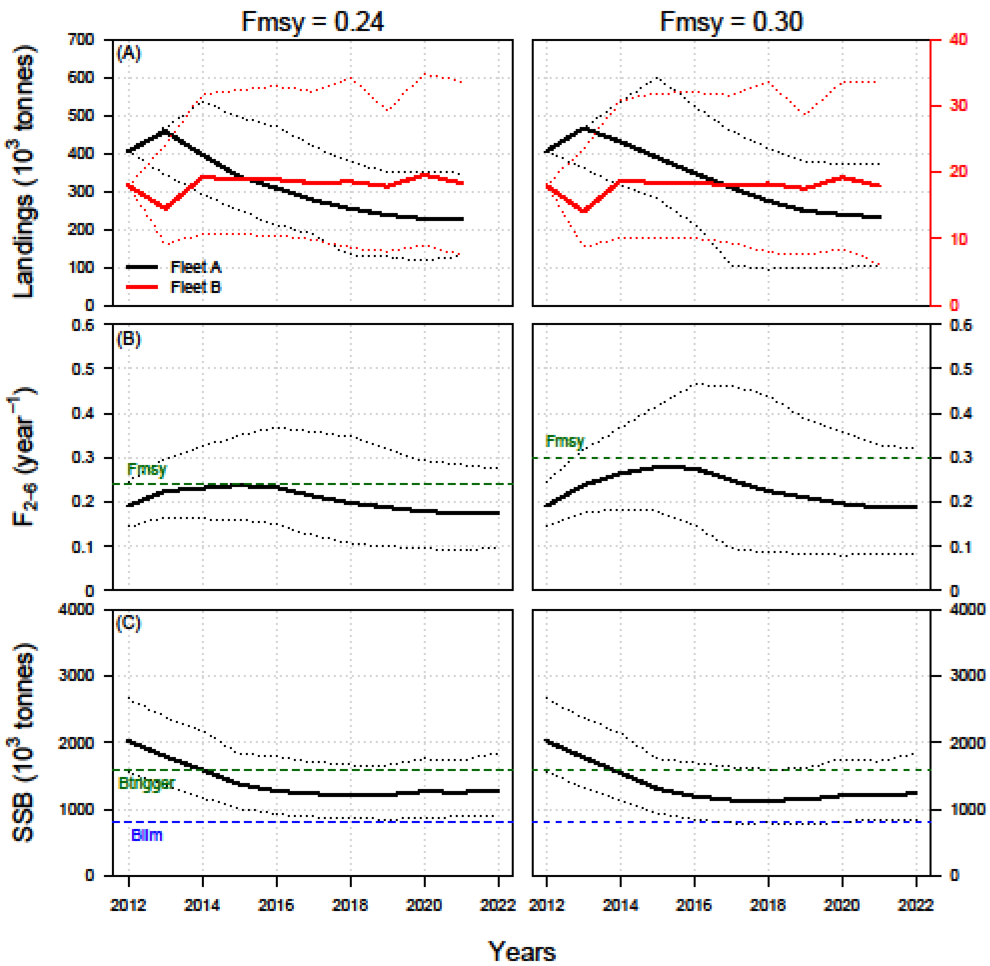
Scenario 60 and 62



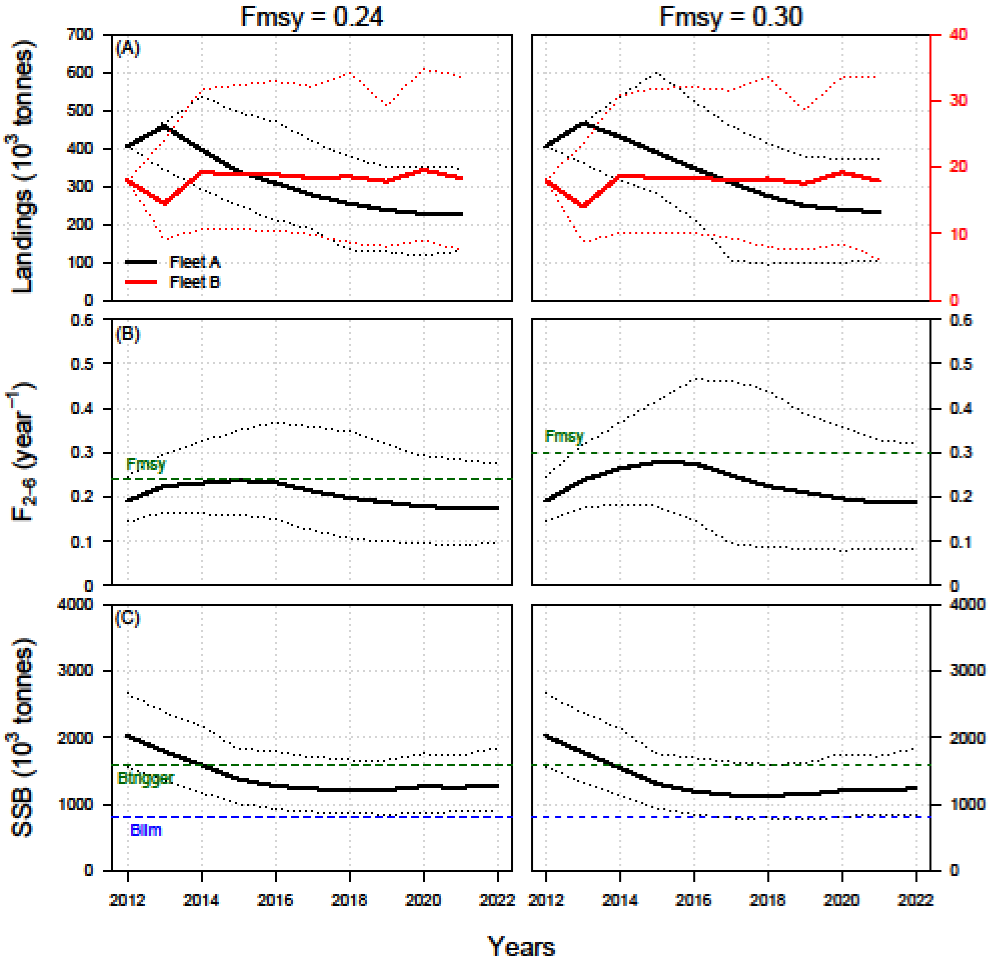
Scenario 63 and 72



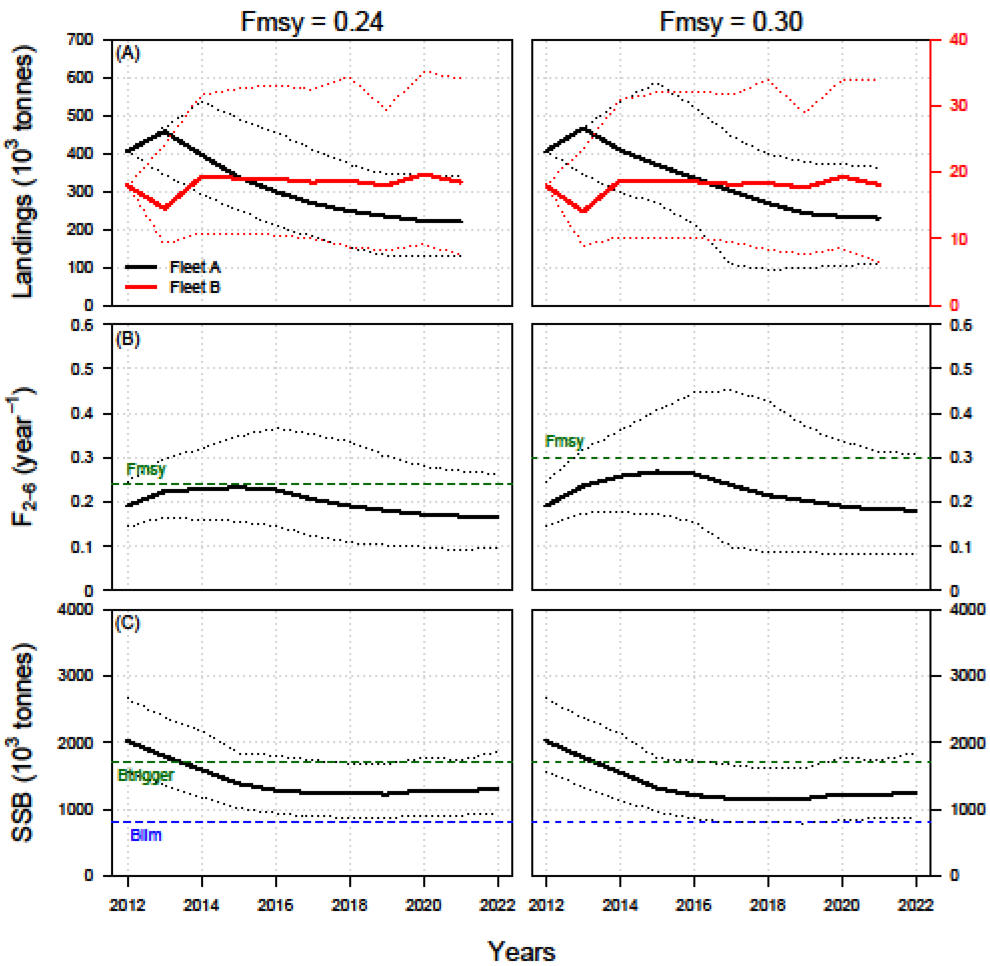
Scenario 64 and 73



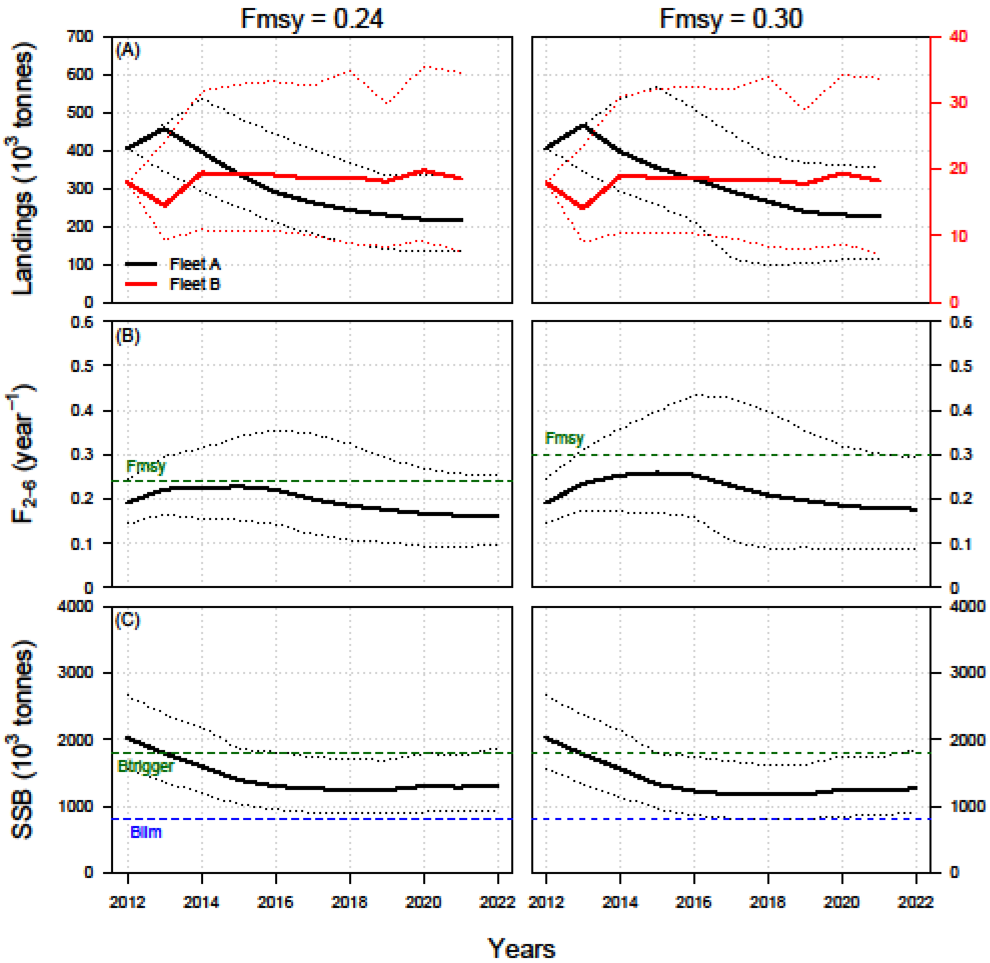
Scenario 65 and 74



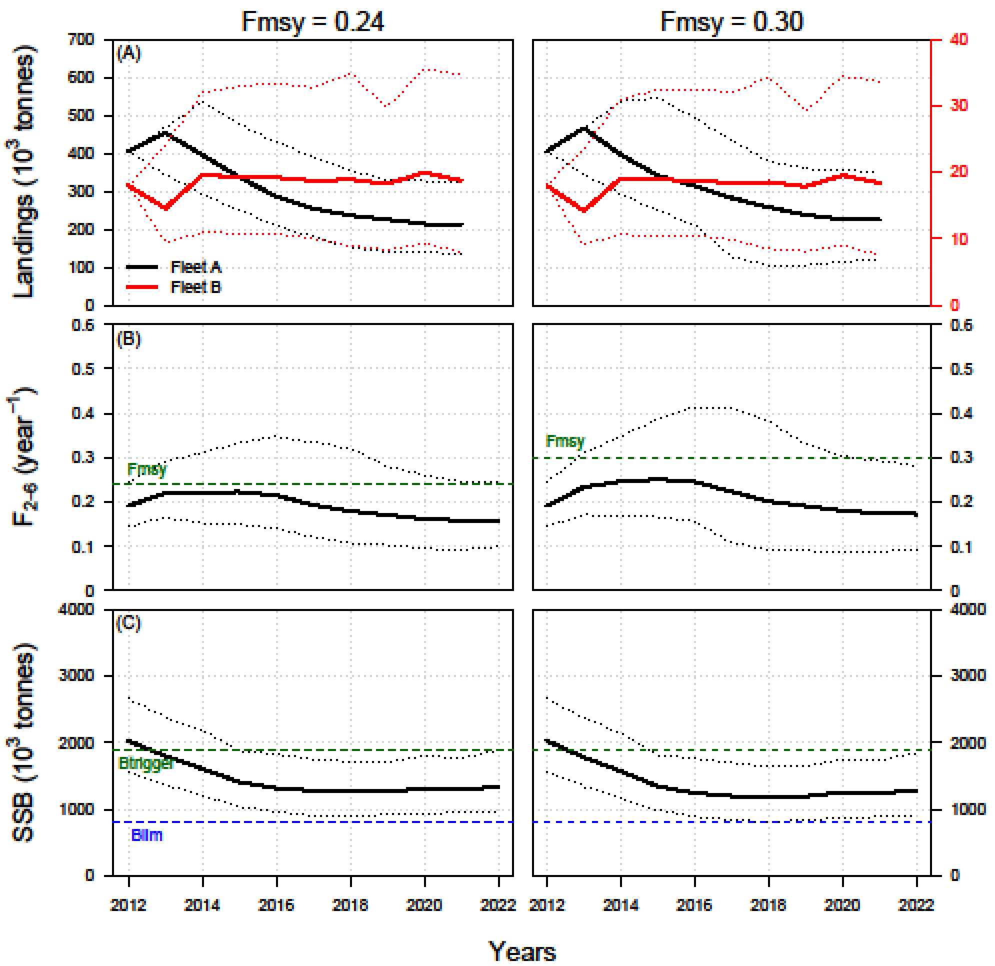
Scenario 66 and 75



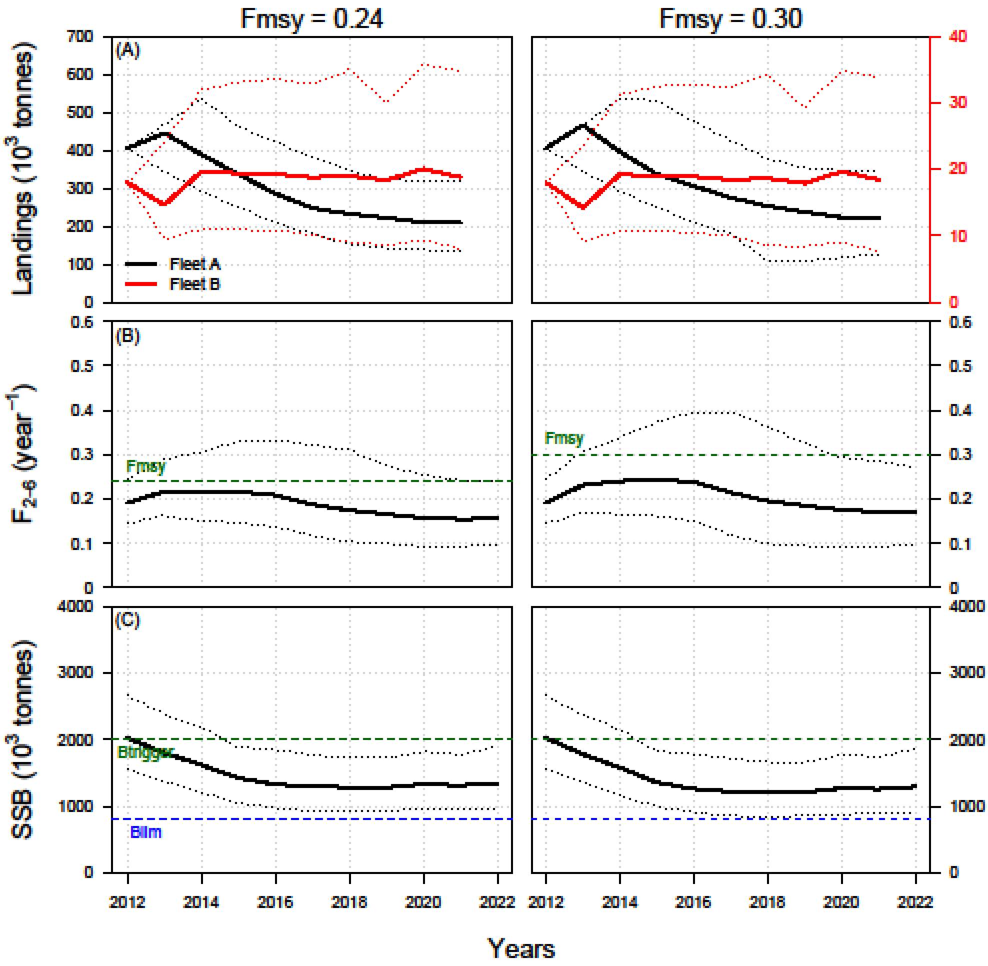
Scenario 67 and 76



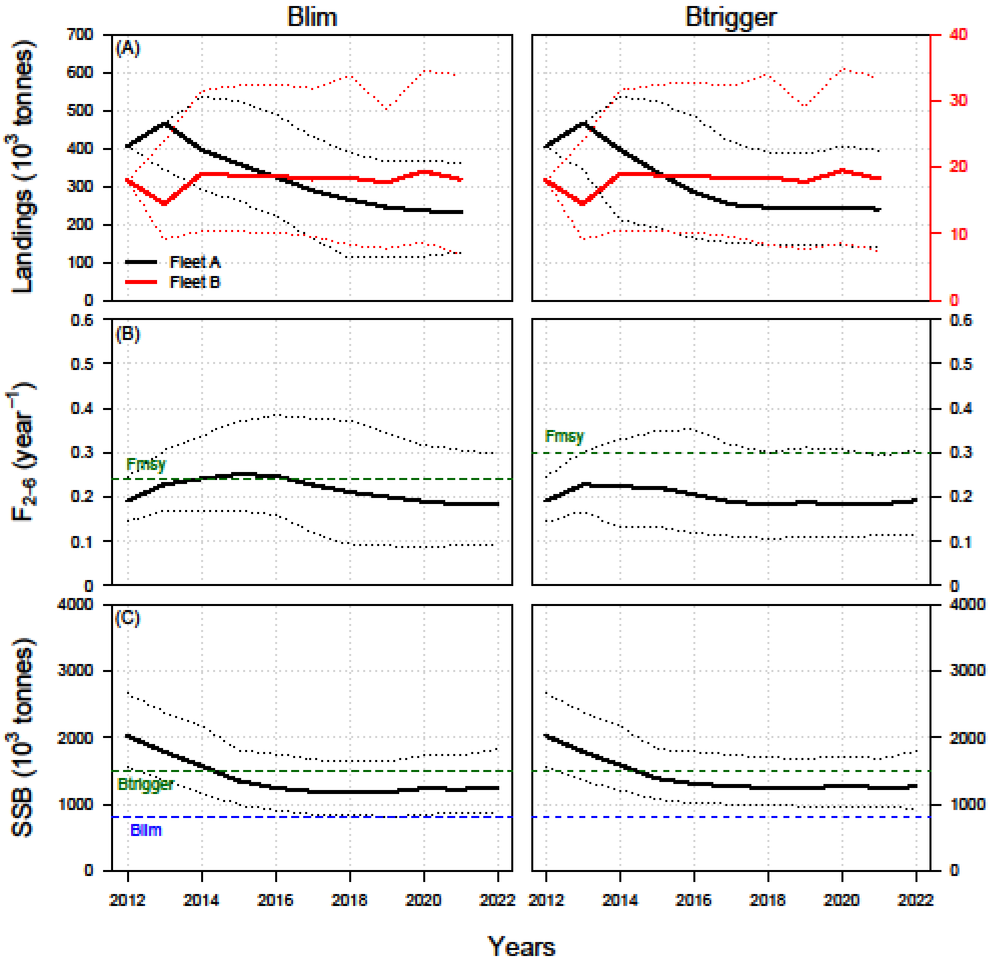
Scenario 68 and 77



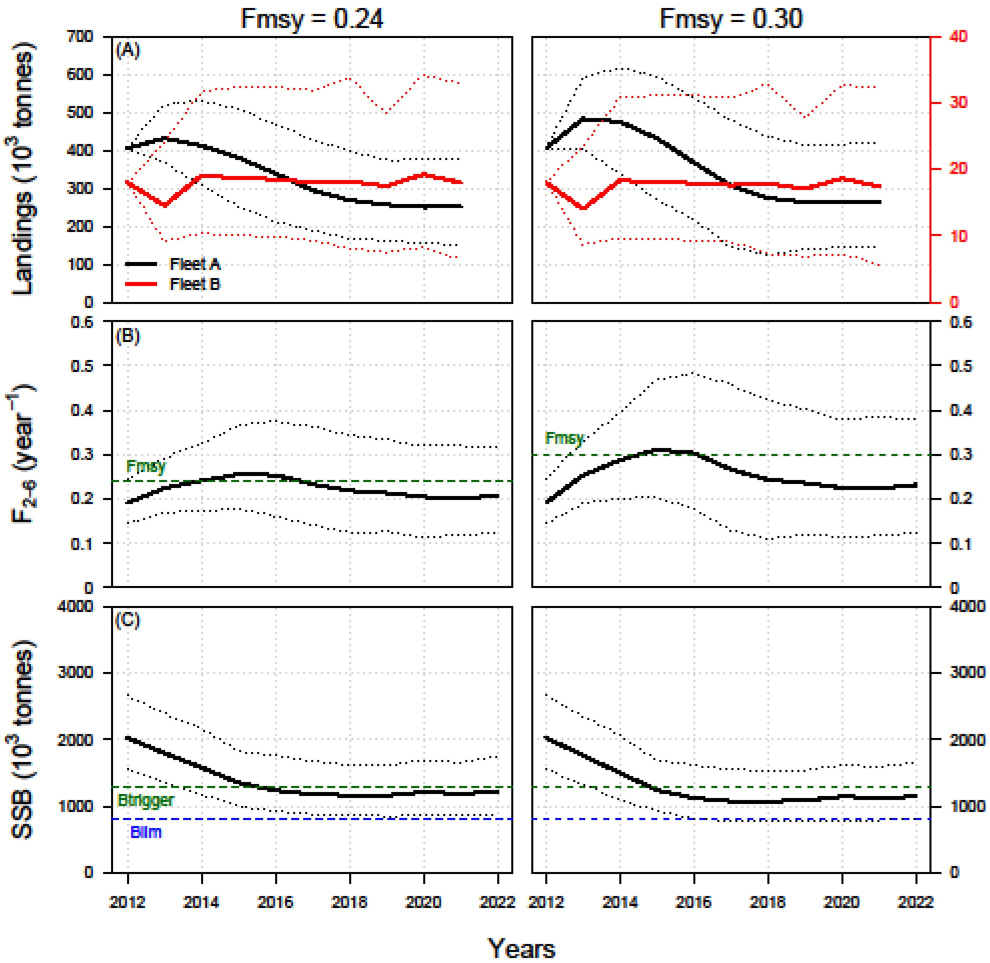
Scenario 69 and 78



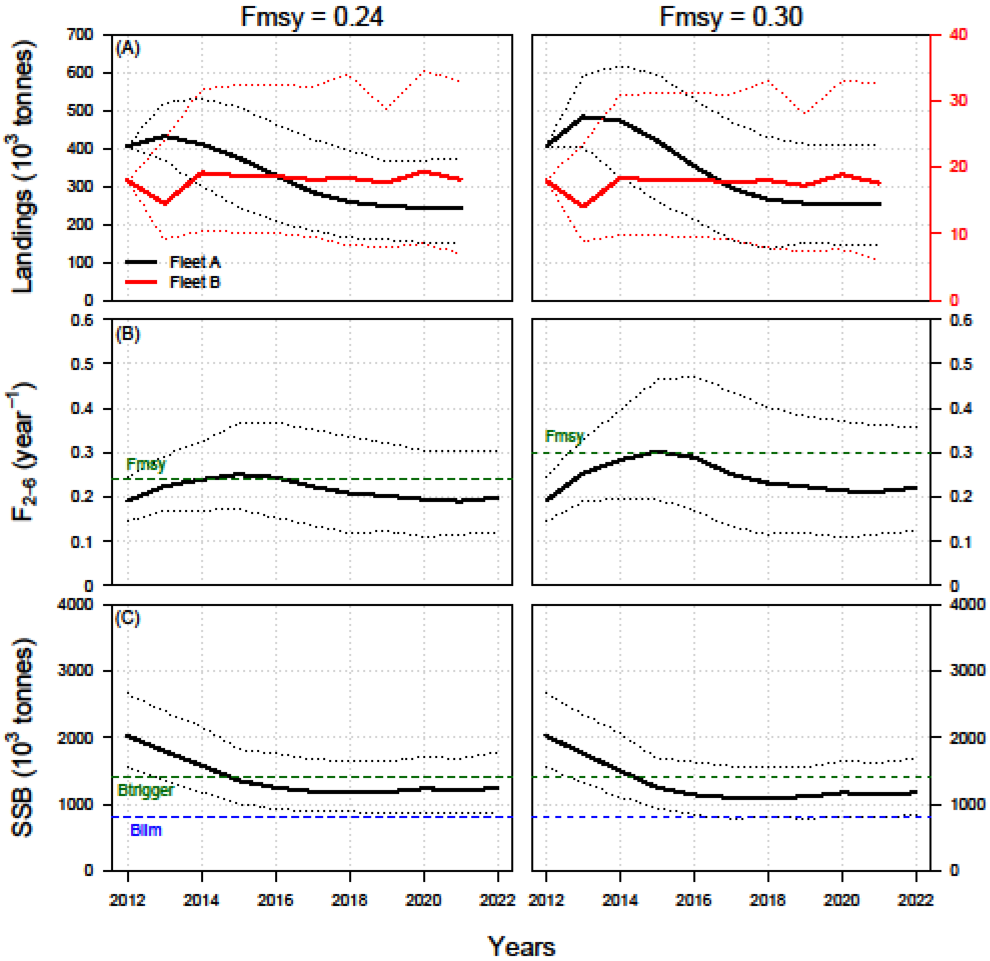
Scenario 70 and 79



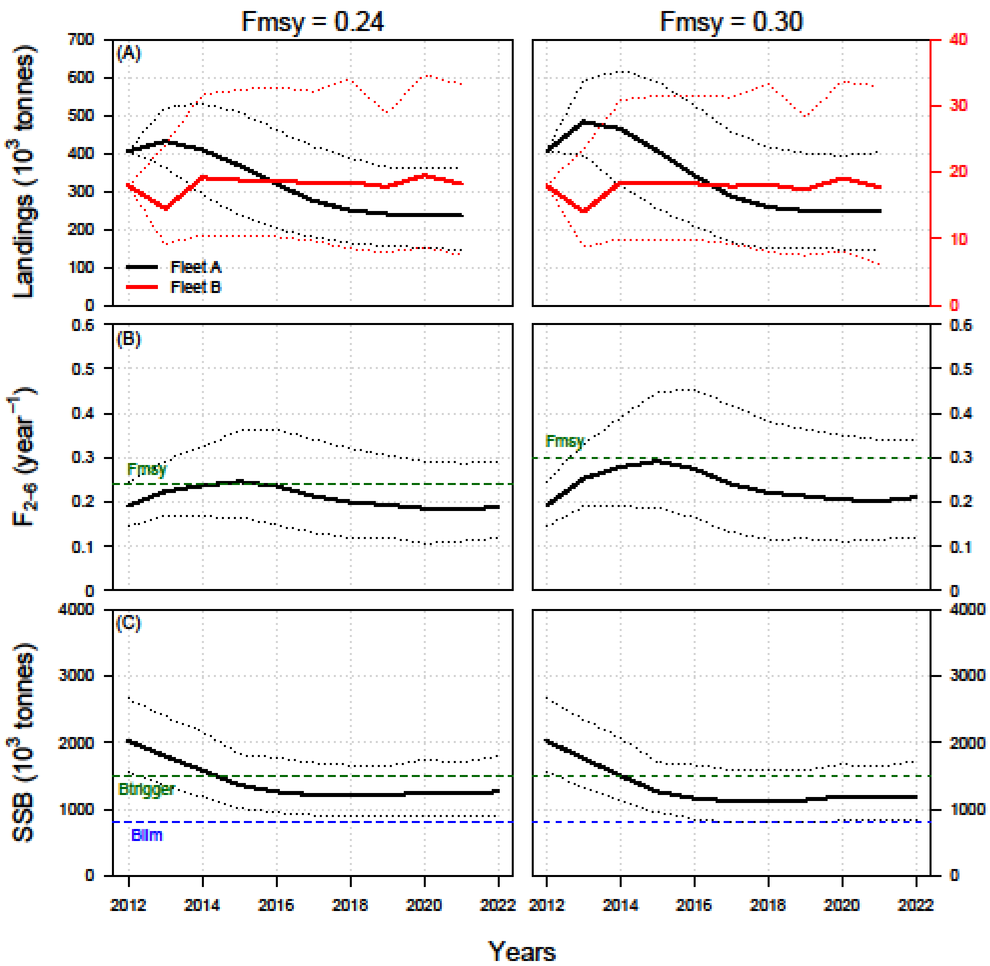
Scenario 71 and 61



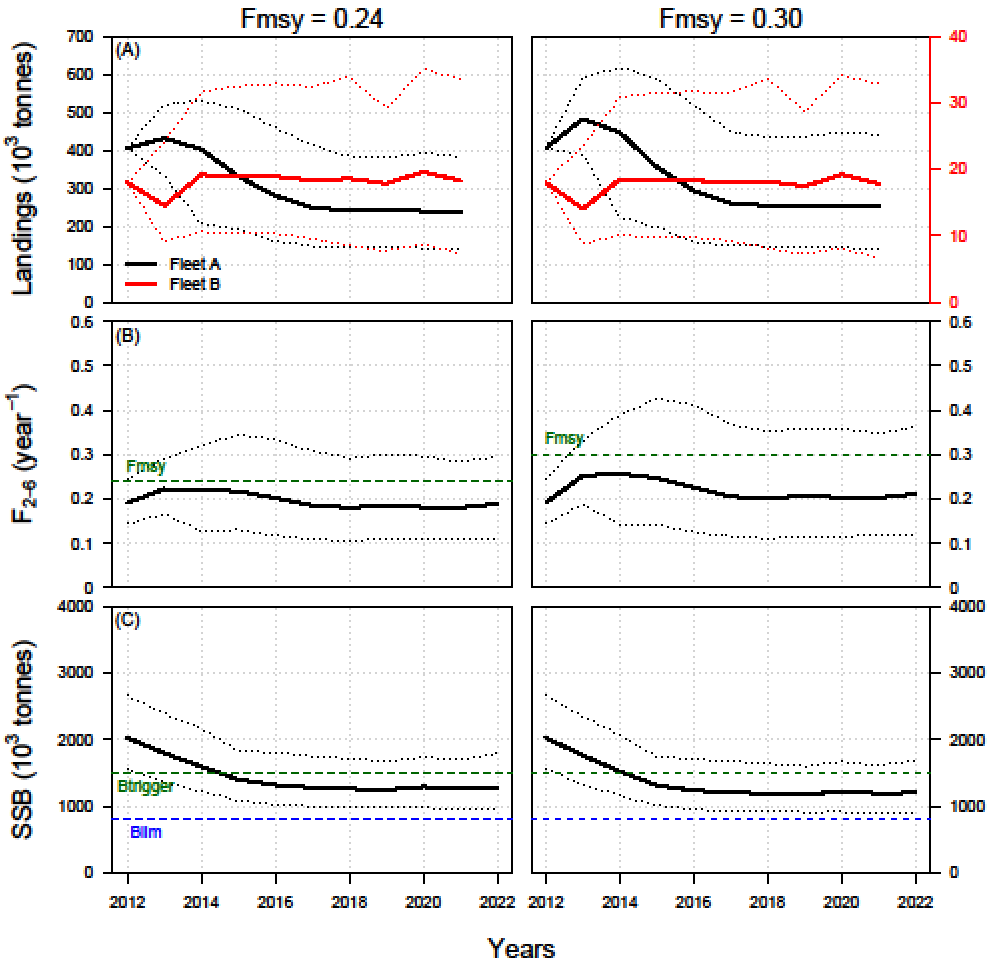
Scenario 82 and 90



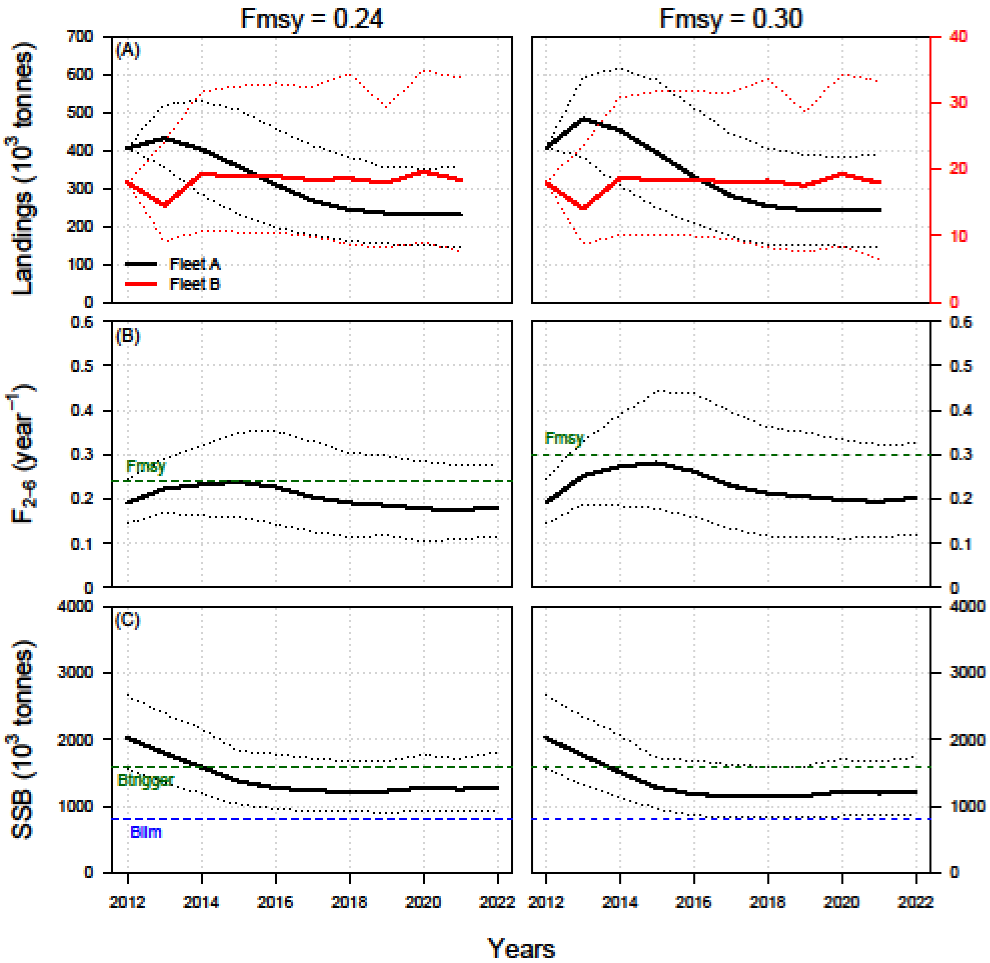
Scenario 83 and 91



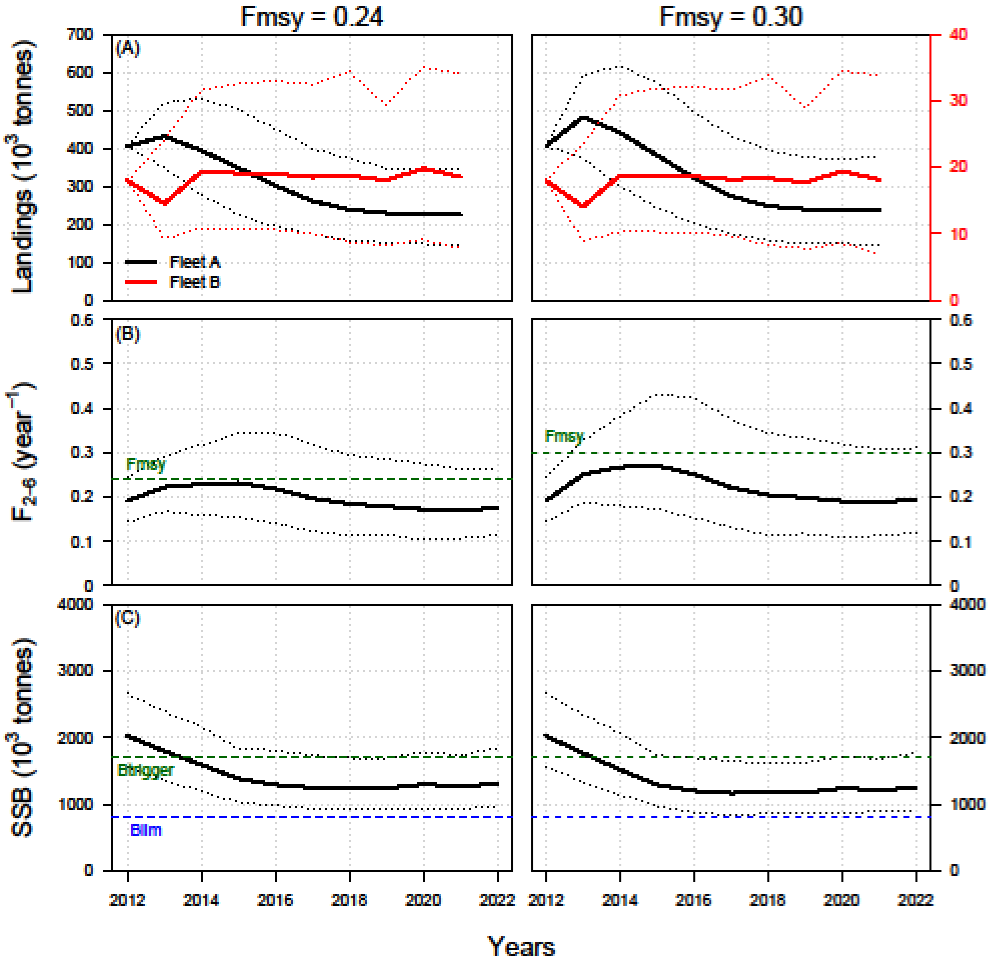
Scenario 84 and 92



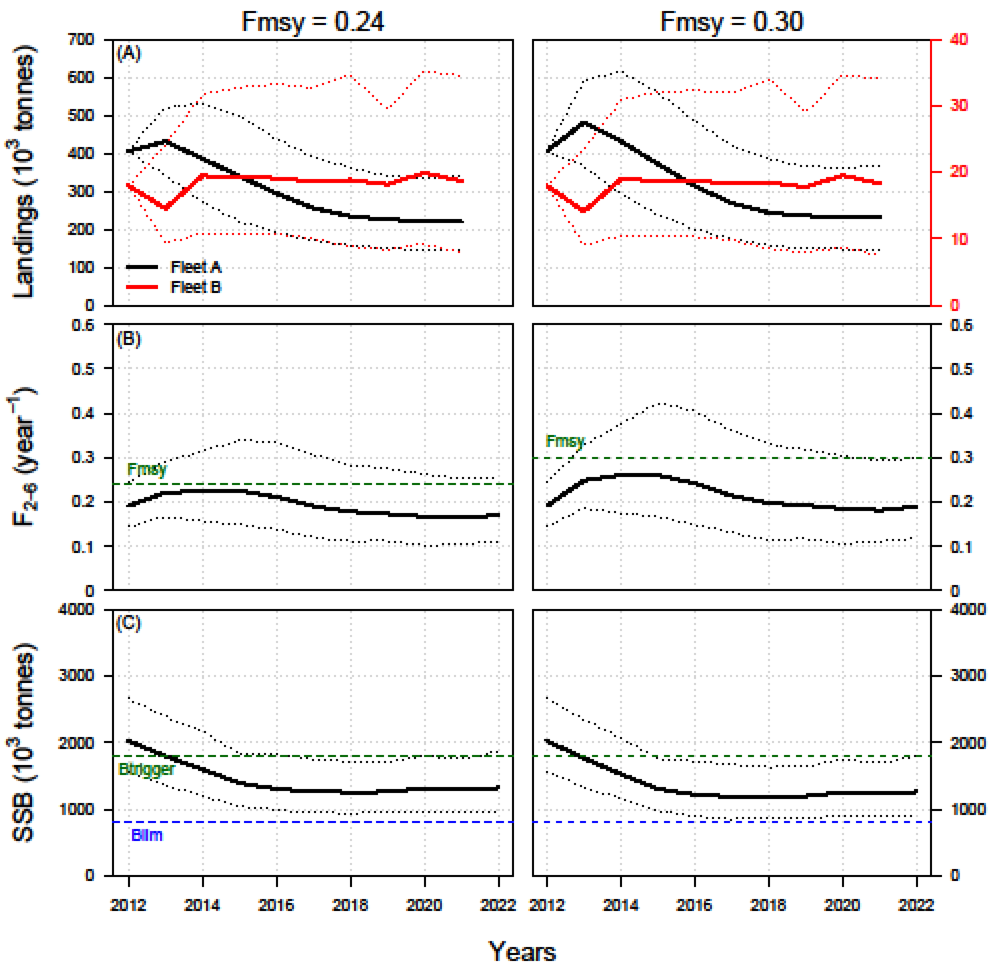
Scenario 80 and 81



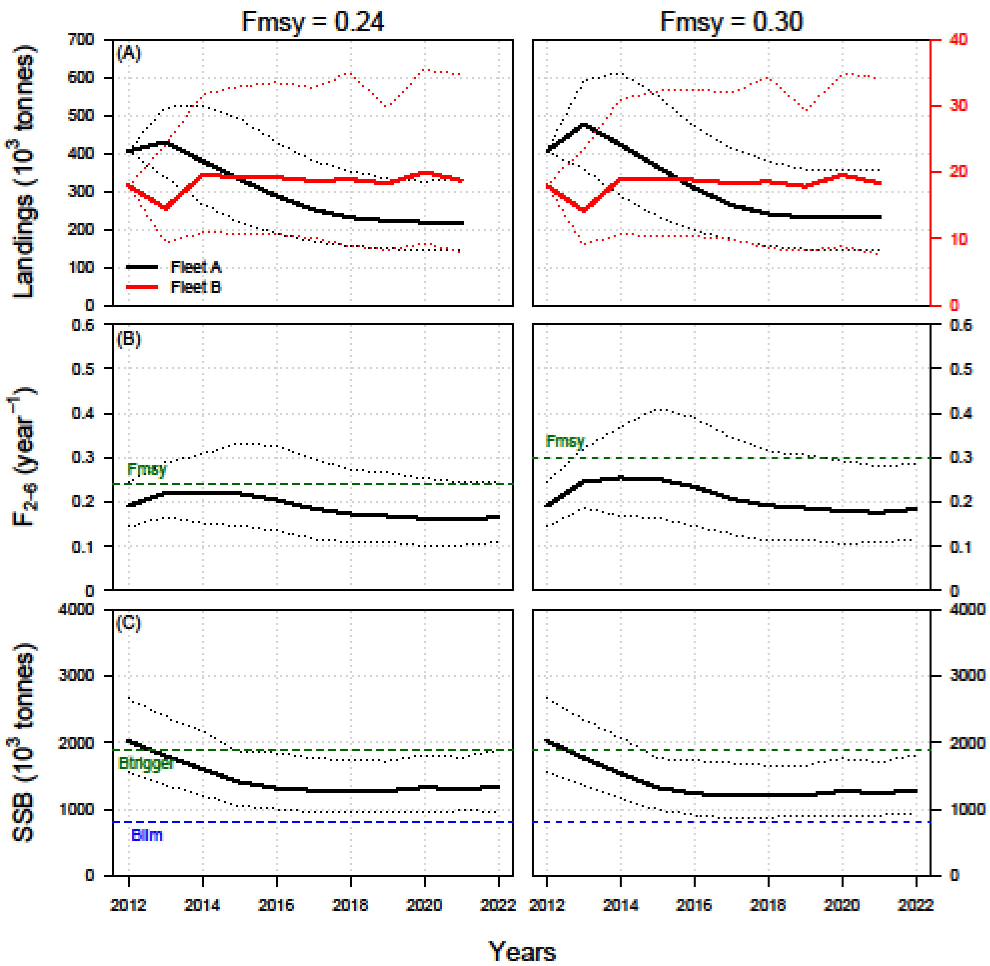
Scenario 85 and 93



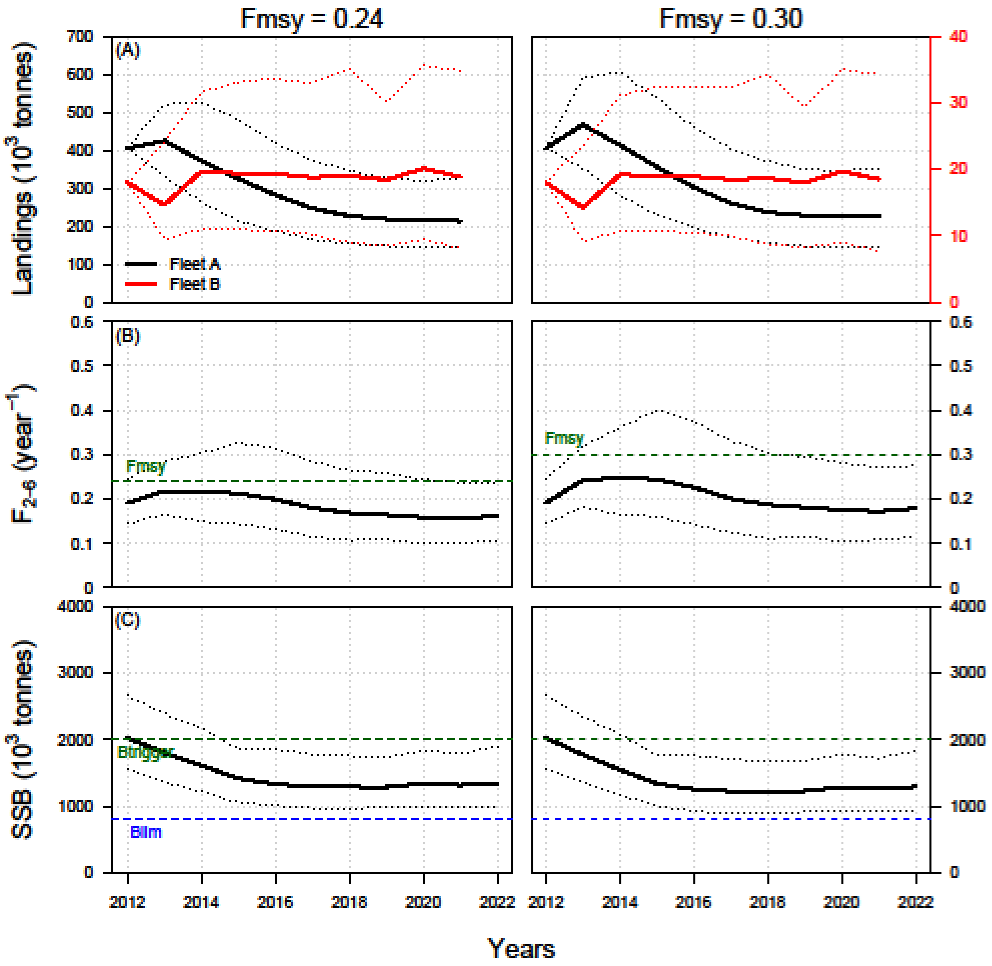
Scenario 86 and 94



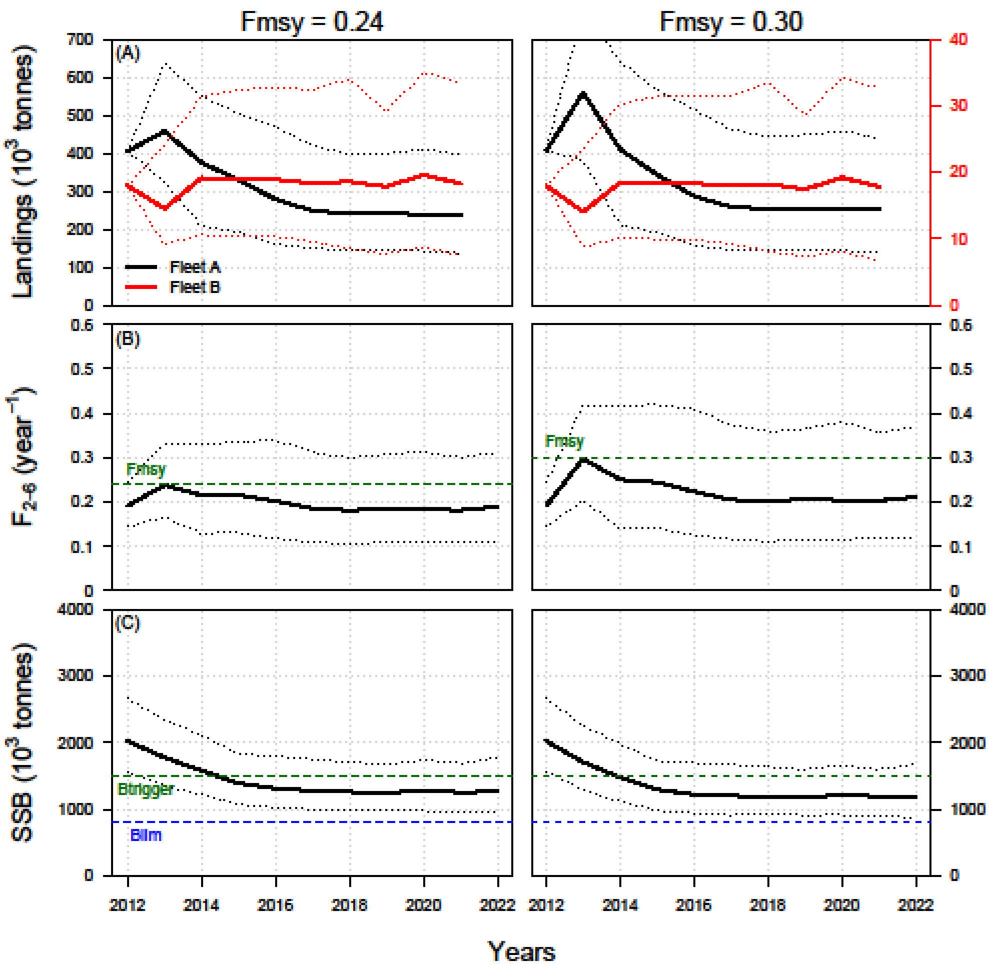
Scenario 87 and 95



Scenario 88 and 96



Scenario 89 and 97



Scenario 98 and 99