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Report from the Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3–6

2–6 October 2017

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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Executive Summary

The Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3-6 (WKLIFE VII), chaired by Carl O'Brien (UK) and Manuela Azevedo (Portugal) met in Lisbon, Portugal, 2–6 October 2017, to further develop methods for stock assessment and catch advice for stocks in categories 3–6, focusing on the provision of sound advice rules.

The workshop participants divided into three subgroups (SG1, SG2 and SG3), each one dealing with a specific ToR:

ToR a) Evaluate the performance of the MSY advice rules for Category 3 stocks proposed by WKMSYCat34 for the cases where:

i) MSY proxy reference points are available from a stock production model, e.g. SPiCT, and the advice rule is based on a short-term forecast

ii) MSY proxy reference points are available, but not from a stock production model, and the advice rule is of the form $\boldsymbol{C_{y+1} = C_{current} r f b}$

ToR b) Evaluate the performance of the MSY advice rule for Category 4 stocks proposed in the WKMSYCat34 report; namely, $\boldsymbol{C_{y+1} = C_{current} f b}$.

ToR c) For case-specific stocks in Category 3, evaluate the performance of the two MSY advice rules proposed in the WKMSYCat34 report; namely

$$\boldsymbol{C_{y+1} = C_{current} r f b} \text{ and } \boldsymbol{C_{y+1} = I_{current} F_{proxy,MSY}\ min\left\{1,\ \frac{I_{current}}{I_{trigger}}\right\}}.$$

ToR d) Propose advice rules that lead to appropriate performance for catch advice according to an MSY approach, taking into account the findings from the evaluations in ToRs a), b) and c) and the outcomes in the WKMSYCat34 report.

ToR e) Review available information on the basis for an advice rule for category 3 to 6 stocks of short-lived species and consider the need for specific advice rules for these stocks.

SG1. Concluded with respect to ToR a) i) & ToR d):

- MSE framework should be used only for the relative comparison of different advice rules (not for absolute values).
- Using both percentile on F/F_{MSY} and on catch is recommended to account for all possible uncertainties.
- Advice rules affect different stocks in a different way: it was not possible to define a general rule and more tests will be needed.
- Uncertainty cap within the SPiCT advice rule seems to have no effect on the stock status.
- Further work should include finalizing the implementation of SPiCTadvice rules within FLR and the comparison between the SPiCT advice rules in the FLR and DLMtool framework, as well as more simulations and testing on species with different life-history traits.

SG2. Concluded with respect to ToRs a) ii) and c); ToR b) and considerations of ToR d):

FLR

- Between the four stocks selected (Norway lobster, pollock, turbot and whiting), two common behaviours were identified, with whiting and pollock behaving differently from Norway lobster and turbot.
- More testing on catch rule 3.2.1. (i.e. based on modifying current catch) revealed that performances improved when elements of the rule were used in combination.
- Introduction of tuning parameters (exponent z, multiplier x and catch constraint) helped the performances. In particular: increasing the exponent reduced overall risks with low effect on yield, decreasing the multiplier decreased risk but affect yield. Concerning the constraint, it was decided to consider constraints between 0.7 and 1.2, which seemed a good compromise between effect on risk and yield.
- More testing to be carried out considering short-lived species and a deeper analysis of life-history traits.

DLMtool

- Deterministic MSE was carried out to compare results between FLR and DLMtool. Similar results for biomass and F, however slightly different clusters of species.
- Additional simulation were carried out testing two different options for depletion. Depletion level =0.2 seemed to work better than depletion level of 0.1.
- M/k and L50/Linf strongly influenced the performances of the HCRs.

SG3.Concluded with respect to ToR e):

- It was highlighted that several of the management strategies investigated do not work for short-lived species: this led to the recommendation of having a dedicated workshop on assessment, harvest control rules and MSE for data-limited short-lived species.
- Due to the evolution of approaches to estimated reference points for Norway lobster and the potential issues identified by the benchmark meeting, WKLIFE VII recommended that a workshop be convened early in 2018 to explore historical performance of reference points, potential new data-limited reference points and performance of stock assessment models for all Norway lobster functional units.
- Stocks, timeline and resource needed to improve (subannual assessment model, discard uncertainty MSE) and test the SPiCT model has been defined.
- It was recommended to further develop the s6 model, especially to address category 4–6 stocks.
- DLMtool and FLR environments should be further explored to see if a seasonal OM for MSE is possible.

1 Introduction

1.1 Terms of reference

The Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3-6 (WKLIFE VII), chaired by Carl O'Brien (UK) and Manuela Azevedo (Portugal) met in Lisbon, Portugal, 2–6 October 2017, to further develop methods for stock assessment and catch advice for stocks in categories 3–6, focusing on the provision of sound advice rules.

Specifically, the workshop was tasked with addressing the following Terms of Reference (ToRs):

ToR a) Evaluate the performance of the MSY advice rules for Category 3 stocks proposed by WKMSYCat34 for the cases where:

i) MSY proxy reference points are available from a stock-production model, e.g. SPiCT, and the advice rule is based on a short-term forecast (Section 3.1 of WKMSYCat34 report);

ii) MSY proxy reference points are available, but not from a stock production model, and the advice rule is of the form $\boldsymbol{C_{y+1} = C_{current} r f b}$ (Sections 3.2.1 and 3.2.3 of WKMSYCat34 report).

ToR b) Evaluate the performance of the MSY advice rule for Category 4 stocks proposed in the WKMSYCat34 report (Sections 3.2.1 and 3.2.3); namely, $\boldsymbol{C_{y+1} = C_{current} f b}$.

ToR c) For case-specific stocks in Category 3, evaluate the performance of the two MSY advice rules proposed in the WKMSYCat34 report (Sections 3.2.1, 3.2.2 and 3.2.3); namely:

$$\boldsymbol{C_{y+1} = C_{current} r f b} \quad \text{and} \quad \boldsymbol{C_{y+1} = I_{current} F_{proxy,MSY}\, min\left\{1,\ \frac{I_{current}}{I_{trigger}}\right\}}.$$

ToR d) Propose advice rules that lead to appropriate performance for catch advice according to an MSY approach, taking into account the findings from the evaluations in ToRs a), b) and c) and the outcomes in the WKMSYCat34 report.

ToR e) Review available information on the basis for an advice rule for category 3 to 6 stocks of short-lived species and consider the need for specific advice rules for these stocks.

WKLIFE VII will report to ACOM no later than 27 October 2017.

1.2 Background

ICES provides advice on more than 260 stocks on an annual basis and more than sixty percent of these stocks are in categories 3–6 (Tables 1.2.1 and 1.2.2; see Table A7.1 for a complete list of all stock data categories used in the ICES advice in 2017). Further developments of the approaches used in providing advice on fishing opportunities for these stocks are needed. WKLIFE is the premier venue for method development and discussion of stock assessments and advice approaches for stocks in categories 3–6.

There is an increasing number of fish stocks in Categories 3 and 4 for which assessment of status relative to MSY proxy reference points is available but for which short-term forecasts and MSY-based advice are not available. At this year's meeting of WKLIFE, ICES wishes to address this issue.

WKMSYCat34 (ICES, 2017) identified a suite of potential MSY-consistent advice rules for category 3 and 4 stocks. The rules need to be tested by Management Strategy Evaluation (MSE) in order to check that they perform adequately in terms of meeting MSY objectives; i.e. maximising long-term yield, in a manner that is consistent with precautionary principles; i.e. having a low probability of falling outside biologically sustainable limits. Specifically, commenting on each ToR:

ToRs a)–c) address these rules and their evaluation using MSE, as proposed by ICES (2017).

Assuming a successful outcome for these evaluations,

ToR d) will propose advice rules for the setting of catches in 2019 based upon scientific advice in 2018.

For the case of generic MSE testing, which considers overall general features instead of details of particular stocks, WKLIFE VII further investigated the dataset with life-history parameters for 41 stocks considered by WKLIFE VI. For case-specific MSEs; i.e. focused on particular stocks, it was suggested that WKLIFE VII focus on stocks in western waters, for which MSY proxy reference points already exist (as per advice provided by ICES in 2016) but time constraints during the meeting meant that WKLIFE VII focused on generic testing only.

ToR e) addresses the need for specific advice rules for stocks of short-lived species. The current advice rule for category 3–6 is targeted at stocks of medium- and long-lived species and has proven difficult to apply for stocks of short-lived species. With this ToR WKLIFE VII is requested to review available information on advice rules for these stocks and, if needed, to propose a specific advice rule for stocks of short-lived species.

Table 1.2.1. ICES categorizes stocks by the data types used to provide advice; 1–6. Within these ICES stock categories, there are subcategories (i.e. methods) available for specific situations based on stock status (ICES, 2012) and advice types.

Category	Explanation
1	Data-rich, fully accepted analytical assessment and short-term forecast
1.20	category 1 method with extremely low biomass with a zero catch advice
1.50**	category 1 method with zero catch MSY advice and an advice for a 5000 t scientific monitoring quota
1.60	category 1 method with MSY and PA advice together (e.g. pra.27.1–2)
1.70	category 1 method with advice for effort, not catch
1.80	category 1 method with a management plan advice, but no reference points beyond B_{lim} (e.g. cap.27.1–2)
1.85	category 1 method with PA advice and no reference points (e.g. reb.27.1–2)
1.87	category 1 method with PA advice, but no reference points beyond B_{pa} (e.g. ghl.27.1–2)
1.90	category 1 data with no catch advice provided (e.g. sal.21.2–5)
2	Data-rich method (category 1), but with an assessment/forecast that is accepted for trends only
2.11	category 2 method with biomass $>MSYB_{trigger}$
2.12**	category 2 method with biomass $<MSYB_{trigger}$
2.13	category 2 method with extremely low biomass with a zero catch advice
3	Biomass/abundance trends-based assessment
3.10**	category 3 method with a known F ratio (F_{SQ} to $F_{0.1}$)
3.11**	category 3 method with biomass index $>MSYB_{trigger}$ and $F_{SQ} > F_{0.1}$
3.12**	category 3 method with biomass index $>MSYB_{trigger}$ and $F_{SQ} < F_{0.1}$
3.13**	category 3 method with biomass index $>MSYB_{trigger}$ and F_{SQ} to $F_{0.1}$ unknown
3.14	category 3 method with extremely low biomass and a zero catch advice
3.20	category 3 method using an abundance/biomass index and catch data
3.30	category 3 method using a F reference proxy
3.60*	category 3 method using a biomass index, F estimates and relative R from exploratory assessment with a management plan (e.g. cod.27.1–2coast)
3.70*	category 3 method using an abundance index, no landings data, no catch advice possible (e.g. syt.27.67)
3.80*	category 3 method with no known/reviewed method for catch advice (e.g. trs.27.22–32)
3.90	category 3 data, but quantified catch advice not provided
4	Catch only
4.11**	category 4 method recent catch >DCAC
4.12	category 4 method recent catch <DCAC
4.13**	category 4 method using catch curves to approximate F
4.14	category 4 method for *Nephrops*, data-borrowing
4.20**	category 4 method with extremely low biomass and a zero catch advice
5	Data-poor catch/landings only
5.10**	category 5 method, PSA risk assessment
5.20	category 5 method recent average catch
5.30	category 5 method with extremely low biomass and a zero catch advice

Category	Explanation
5.90	category 5 data, but catch advice not possible
6	Data-poor catch landings from bycatch stocks that are largely discarded at sea or rarely encountered
6.10**	category 6 method, PSA risk assessment
6.20	category 6 method recent average catch
6.30	category 6 method with extremely low biomass and a zero catch advice
6.90	category 6 data, but catch advice not possible

*** Method used for advice not reviewed by WKLIFE (ICES, 2012). See relevant ICES assessment Expert Group reports for further information on methodology.**

**** Method not used in the ICES advice in 2017.**

Table 1.2.1. Summary of the number of stocks in each ICES data category in 2017.

	ICES Data Category	Number of stocks in 2017
1	Data-rich, fully accepted analytical assessment and short-term forecast	101
2	Data-rich method (category 1), but with an assessment/forecast that is accepted for trends only	3
3	Biomass/abundance trends-based assessment	90
4	Catch only with some life-history information available	7
5	Data-poor catch/landings only	31
6	Data-poor catch landings from bycatch stocks that are largely discarded at sea or rarely encountered	32

1.3 Conduct of the meeting

The agenda for the workshop is presented in Annex 1.

Much intersessional work had taken place ahead of the WKLIFE VII meeting by participants and this was presented during the first day and a half of the workshop:

- Nuno Brites delivered a presentation about the performance of two harvest policies (varying effort and fixed effort) on profit, applied to two case studies (i.e. Pacific halibut and Bangladesh shrimp). The group highlighted the fact that the perspective used was merely from an economic point of view (no evaluation of sustainability) and the varying effort strategy was quite unrealistic, fluctuating from really high to really low values.
- Piera Carpi (Ewen Bell attending remotely) gave a presentation about the reference points estimation carried out for Norway lobster stocks, highlighting the issues that the WG have been facing and the fact that no satisfactory solution has been identified so far. The main discussion focused on the reliability of UWTV estimations and on the unjustified assumption of dome-shaped selectivity pattern.
- Tobias Mildenberger showed a series of simulations carried out with SPiCT through a new function calling the DLMtool package and generate advice rules based on suggestions from ICES WKMSYCat34. Tobias tested different percentiles of F/F_{MSY} and catch predictions for five different stocks within an MSE and testing the effect of annual vs. biennial advices. Further simulations were carried out within subgroup 1.

- Casper Berg presented an initial development of a seasonal SPiCT: however much further model development to account for seasonal surplus production and zero catches is needed.
- Quang Huynh presented simulations carried out with the latest development of DLMtool: introducingthe main features of the operating model and the HCRs built in the package; i.e. HCRs for category 3 and 4. Several options for the parameters were tested and the results presented. During the discussion, more simulations were requested and carried out within subgroup 2.
- Tanja Miethe used length-based sex-structured population models for European lobster and cuckoo ray to test the sensitivity of length-based indicators to the length at first capture. Tanja evaluated the difference in indicators and reference points estimation at $F_{40\%}$ (the fishing mortality which results in a spawning potential ratio of 40%, when SSB per recruit is 40% of that with no fishing) under non-equilibrium conditions.
- Mikael van Deurs presented an attempt on sprat in 3a to evaluate survey based TAC rules in an MSE framework using the OM from sprat in the North Sea and simulated survey indices by drawing random values from a lognormal distribution. They will further develop the approach for sprat 3a: it seems a promising approach for data-poor short-lived species.
- Alex Kokkalis presented MSE simulations carried out with the s6 model in DLMtool. The model requires only one length–frequency distribution and a reliable M/K parameter and it is therefore suitable for stocks in category 5–6 as well. It hasn't been tested for short-lived species.
- Rasmus Nielsen presented a document concerning the further development planned for SPiCT in relation to the assessment and the MSE for data-limited stocks. The discussion continued within subgroup 3.
- Simon Fischer presented simulations to evaluate the catch rules proposed from WKMSYCat34, using FLR. Two fishing histories were tested, including recruitment uncertainty and testing option for each one of the catch rule components (r, b, f) individually and combined. More simulations were requested and carried out within subgroup 2. Besides, the group noted a common behaviour among stocks with some similarities in the life-history traits (e.g. k, t_{max}, M/k): it was therefore suggested to work on one species per group, to reduce the simulations to be carried out during the meeting.
- Yves Reecht presented an adaptation of the LBSPR package to estimate life-history traits and life-history invariants: this was tested on shellfish in Ireland, for which some pre-fishery information are available as well as survey data.

The presentations were used to define the work programme for the remainder of the workshop and the identification of subgroups; three of which were identified:

- Subgroup 1 – focused on ToR a) i) and considerations on ToR d);
- Subgroup 2 – focused on ToRs a) ii) and c); ToR b) and considerations of ToR d); and
- Subgroup 3 – focused on ToR e) and SPiCT developments.

A number of participants worked by correspondence during the meeting and the facilities of web conferencing were relied upon for their full contribution to the workshop's

subgroups and plenary discussions. This worked well, and lively discussions resulted from this interaction.

1.4 Structure of the report

The structure of the report is as follows:

- Section 2 focuses on the advancement of fish stock assessment methods that is based on discussions initiated at WKLIFE VI with respect to Management Strategy Evaluation (MSE) toolkits;
- Section 3 focuses on the activities of subgroup 1;
- Section 4 focuses on the activities of subgroup 2;
- Section 5 focuses on the activities of subgroup 3;
- Section 6 focuses on calculation of predictions under different management scenarios with SPiCT;
- Section 7 focuses on SPiCT assessments with seasonal catches; and
- Section 8 focuses on the length-based spawning potential ratio (LBSPR) to calculate reference points for length-based indicators.

Instead of providing conclusions from the workshop at the end of the report, each of the sections 3–8 provides a synthesis of the material presented within each chapter in either a conclusions, discussion or recommendations section.

1.5 Follow-up process within ICES

By the close of the meeting, a number of Working Documents (WDs) were in preparation based on the presentations during this WKLIFE VII meeting. It was agreed by the authors that these would be finalised shortly, so that the ICES Secretariat can incorporate them into the Annexes 3, 4 and 5 to this report.

The participants at WKLIFE VII agreed to provide text for the draft workshop report by Friday 13 October 2017 and to then comment on the compiled draft report no later than 20 October 2017; when the report can be formatted by the ICES Secretariat. Subsequently, WDs will be incorporated into the report by the ICES Secretariat.

Recommendation: It is recommended by WKLIFE VII that there be an eighth meeting of WKLIFE in Lisbon, Portugal 8–12 October 2018 whose ToRs should be discussed by ACOM at their November 2017 consultation meeting and agreed intersessionally.

1.6 Relevant ongoing activities outside ICES

During WKLIFE VII, two projects were briefly presented that are of relevance to the activities of ICES in the development of methods for data-limited stocks (DLS):

- DRuMFISH (Data-poor stocks in Mixed FISHeries) - The DRuMFISH project aims to advance methods for advice on the status and management of data-poor stocks in mixed fisheries. Further details at www.drumfish.org
- MYDAS (MsY proxies for DAta-limited Stocks) - The overall aim is to develop and test a range of assessment models and methods to establish Maximum Sustainable Yield (MSY), or proxy MSY reference points across the spectrum of data-limited stocks. Further details at https://github.com/laurieKell/mydas/wiki

1.7 References

ICES. 2012. ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice. ICES CM 2012/ACOM 68. 42 pp.

ICES. 2017. Report of the Workshop on the Development of the ICES approach to providing MSY advice for category 3 and 4 stocks (WKMSYCat34). ICES CM 2017/ACOM:47.

2 Advancement of fish stock assessment methods

2.1 Management Strategy Evaluation toolkits – DLMtool and FLR

2.1.1 Introduction

WKLIFE needs an objective way to evaluate different data-limited assessment methods and harvest control rules (HCR). This can be achieved using a management strategy evaluation (MSE) tool which is a combination of an operating model (OM), an observation model (ObsM) and a management procedure (MP); i.e. an assessment method combined with a harvest control rule.

However, there are a number of advantages and disadvantages of adopting a standard computational platform for this work as discussed below.

2.1.1.1 Advantages and disadvantages

Advantages for the developer of a new assessment method or management procedure:

1) It may not necessary to develop an operating model for every stock because the software is sufficiently comprehensive and flexible to accommodate a range of stocks that are of interest to ICES.

2) Many management procedures from the scientific literature are potentially available in the tool.

3) Many quality control checks will already be in place through the previous experience with the tool.

4) If a commonly used software platform is adopted, the developer of new methods will have a large pool of expertise to call upon for assistance.

Advantages for ICES in obtaining results from a particular tool:

1) Candidate methods and management procedures proposed by ICES can also be readily implemented in the tool for evaluation.

2) The standardized output of the management strategy evaluation (MSE) from the tool provides a template for calculating performance metrics and reference points (e.g. B_{lim}) relevant to ICES.

3) In evaluating various methods and procedures, ICES needs to strive for a level playing field; i.e. methods are compared under comparable situations. This is promoted through the use of a common operating model.

4) ICES needs to have confidence in the reliability of the software being used to evaluate and compare methods. This is promoted by the adoption of a common suite of software.

Disadvantages of using a particular tool:

1) Everyone needs to become familiar with the tool (though not necessarily with all components of the tool).

2) There is an inherent trade-off between simplicity of use and flexibility in implementation. For example, DLMtool and FLR offer great flexibility, but this places a burden on the user to understand all the parameters going into the operating model. This burden of flexibility is somewhat reduced by the provision of default values but, nonetheless, someone has to judge the reasonableness of default values.

3) No tool contains unlimited flexibility. For example, a sex-specific operating model may be desirable for *Nephrops* stocks and an operating model with seasonal time-steps is desirable for short-lived stocks (these options are not necessarily explicitly available in a tool, e.g. DLMtool, or examples are not as common although the flexibility is available, e.g. FLR). Therefore, while extensibility may be a convenient feature of a package, it is likely that at some point fundamental modifications to the toolkit itself may be needed to accommodate new requirements. Two of the major tools available are written in open source R, so that modification to the code is possible but may not be trivial to do.

Next, we describe two available MSE tools, the DLMtool (Carruthers *et al.*, 2016) and FLR (Kell *et al.*, 2007).

2.2 DLMtool

2.2.1 Operating model

The DLM toolkit has a relatively flexible operating model that is split into four input objects:

- Stock: contains parameters that affect the population stock dynamics (depletion at the beginning of the management strategy, natural mortality, von Bertalanffy growth, maturation (specified in terms of length), discard mortality and stock–recruitment relationship).
- Fleet: contains parameters that describe the fleet selectivity, discard/retention behaviour, catchability coefficient and effort history.
- *Observation*: contains parameters about the precision (interannual variation) and bias (inaccuracy) of the data available to the management procedure.
- *Imp*: contains parameters that control the error in the implementation of the management advice.

WKLIFEVII evaluated and used version 4.4.1 of DLMtool. Major additions are now available compared to the previous version that was evaluated during WKLIFEVI. New features include:

- Age-varying natural mortality, which can be manually input as a either vector or a Lorenzen function re-parameterized for age instead of weight.
- Correlated operating model parameters. Operating models parameters are specified as a vector of minimum and maximum of Uniform distributions are presumed to be independent. However, correlations in operating model parameters can be induced by sampling outside the package from any desired distribution and correlation structure. These samples are then manually input into the operating model via the *cpars* object.
- Discard rate of the fleet and post-release mortality of the stock are now modelled. The vulnerability of the stock to the fishing gear as well as retention are specified; the product of both is the effective selectivity for retained catch and composition data. Dome-shaped vulnerability and retention can be parameterized as well.
- Addition of a new class for specifying error in TAC implementation and input controls.

2.2.2 Management procedure

A management procedure (MP) is a combination of an assessment method and a harvest control rule. New management procedures can be added to the DLMtool by programming a function that takes a *Data* object (which may include variables from the operating model) and returns the management advice. MPs that return the TAC for the terminal year have class *Output*, while MPs that returns effort or selectivity as the management advice have class *Input.* Hence, it is relatively straightforward to add a management procedure to the DLMtool.

2.2.3 Management strategy evaluation

The management strategy evaluation is run for a specified subset of available management procedures (*MPs*). The user can specify the number of simulations (*nsim*), number of TAC replicates (*reps*), number of projected years (*proyears*) and the interval between TAC recommendations (*interval*).

Several caveats should be noted:

- Most of the implemented procedures take as input the life-history parameters that are not known in reality for data-limited stocks (e.g. natural mortality, growth, von Bertalanffy asymptotic length, maturity) from the operating model. In DLMtool, the management procedure receives these parameters from the observation model subject to bias and precision error specified in the operating model. However, it may be difficult to appropriately quantify the bias and imprecision for the data-limited stocks. This is important in conditioning the operating model such that the management strategy evaluation is not overly optimistic towards methods that use life-history parameters over those that only use time-series of data (e.g. total catch, survey index) which may have lower observation error.
- The implemented methods (management procedures) are very inconsistent in terms of quantifying uncertainty of the TAC advice (reps). For example, in the delay difference management procedure (DD) the estimated parameters are resampled from normal distributions with hard coded CV of 0.1. Other methods take lognormally distributed random values for the input variables and repeat the assessment for each variable set. Management procedures should describe how stochasticity (if any) is implemented.
- Bin size of length distribution observation is fixed and equal to 0.03 * Linf + 2 * 0.1 * Linf.

2.2.4 Performance metrics

A suite of performance metrics are calculated by DLMtool, which can be accessed through the *summary* function after performing the management strategy evaluation (Table 2.2.1). A variety of plotting functions are also included in the R package to describe the behaviour of different management procedures.

Table 2.2.1. Management procedure summary statistics calculated in DLMtool. Variables *n = 1,…N*; *y = 1,…,Y*; and *m* index simulation iteration, projection year, and management procedure, respectively. The indicator function *I[k]* is equal to 1 when condition *k* is met and 0 otherwise. Reference yield (RefYd) is the annual MSY achievable from a fixed F strategy over the duration of the projection period.

Description	Equation
Yield: The ratio of catch (C) and reference yield (RfYd) in the last five years of the management advice	$Yield_m = 100 \times \frac{1}{N}\sum_{n=1}^{N}\left(\frac{1}{5}\sum_{y=Y-4}^{Y}\frac{C_{n,y,m}}{RfYd_n}\right)$
POF: Probability that overfishing is occurring (F >F_{MSY})	$POF_m = 100 \times \frac{1}{N}\sum_{n=1}^{N}\left(\frac{1}{Y}\sum_{y=1}^{Y} I[F_{n,y,m} > F_{MSY(n)}]\right)$
PX: Probability that the spawning–stock biomass (SSB) is less than X% of SSB_{MSY} (SSB<*X* * SSB_{MSY}, where *X* = 10, 50, 100%)	$PX_m = 100 \times \frac{1}{N}\sum_{n=1}^{N}\left(\frac{1}{Y}\sum_{y=1}^{Y} I[SSB_{n,y,m} < X \times SSB_{MSY(n)}]\right)$
Long-term yield (LTY): the probability that at least 50% of the reference yield is achieved in the last ten years of the management advice	$LTY_m = 100 \times \frac{1}{N}\sum_{n=1}^{N}\left(\frac{1}{10}\sum_{y=Y-9}^{Y} I[C_{n,y,m} > 0.5RfYd_n]\right)$
Short-term yield (STY): the probability that at least 50% of the reference yield is achieved in the first ten years of the management advice	$STY_m = 100 \times \frac{1}{N}\sum_{n=1}^{N}\left(\frac{1}{10}\sum_{y=1}^{10} I[C_{n,y,m} > 0.5RfYd_n]\right)$
Variability of yield (VY): The probability that the annual average variability of yield (AAVY) is less than 10%.	$VY_m = 100 \times \frac{1}{N}\sum_{n=1}^{N} I[AAVY_{n,m} < 0.1]$, where $AAVY_{n,m} = \frac{1}{Y-1}\sum_{y=1}^{Y-1}\left\lvert\frac{C_{n,y} - C_{n,y+1}}{C_{n,y+1}}\right\rvert$

2.2.5 Preliminary MSE with Category 3 length-based management procedures

Prior to the WKLIFE VII meeting, management procedures (MPs) were proposed for Category 3 stocks during WKMSYCat34 (ICES, 2017). Length-based MPs were selected for preliminary testing in DLMtool. This exercise was intended to develop the R code needed to test the MPs in DLMtool during the meeting. The management procedure was of the form:

$$TAC_{y+1} = C_y rfb$$

where the TAC in year *y+1* is the product of the catch in year *y*,*r* as the indicator of trends in stock biomass, *f* as the indicator of exploitation, and *b* as the indicator of relative stock status.

Two options were used for *r*:

- *r23:* 2-over-3 rule that uses the ratio of the mean of the index in the previous two years preceding the assessment to the mean of the index 3–5 years preceding the assessment.
- *r5sl:* the exponentiated estimated slope of the index in the five years preceding the assessment in log-space.

Four options were considered for *f*:

- *fLBI (Length-based indicator)*: the ratio of the mean length above $L_c$in year *y* and $L_{F=M}$, the mean length predicted when $F = M$ (Jardim *et al*., 2015). Here, L_c is the half-modal length, i.e. the first length at which the catch-at-length is at least half of that at the mode and *M, k,* and Linf are obtained from the observation model.
- *fBHE*:the ratio of *M* (the reference point) and $Z - M$, where *Z* is the estimated total mortality rate estimated from the Beverton–Holt equation from the mean length above $L_c$year *y*. Here, L_c is the half-modal length, and *M, k,* and Linf are obtained from the observation model.
- *fGH*:the ratio of $F_{0.1}$(the reference point) and $Z - M$, where *Z* is the estimated total mortality rate estimated in year *y* from the Gedamke-Hoenig method from the full time-series of mean lengths above L_c (Gedamke and Hoenig, 2006). Here, L_c is the first fully selected length (obtained from the observation model). All necessary life-history parameters were also obtained from the observation model. The Gedamke-Hoenig model was fit with up to four change points in mortality, and AIC was used to select the best model.
- *fGHe*:the ratio of $F_{0.1}$(the reference point) and F_y, the estimated fishing mortality rate estimated in year *y* from the Gedamke-Hoenig method with effort (Then *et al*., in press). Here, L_c is the first fully selected length from the observation model. All necessary life-history parameters were also obtained from the observation model. The effort time-series was the ratio of the catch and index. Both catchability and natural mortality are estimated in the model.

Finally, $b = \min(1, I_y/I_{trigger})$ with $I_{trigger} = 1.4\ I_{lim}$ (I_{lim} was calculated as the minimum value of the index observed over the entire time-series).

A total of 14 operating models were developed based on life-history parameters from FLife. The sandeel stock template was not used because use of DLMtool for short-lived species is not recommended according to the user manual. The operating models were designed to encompass a range of life histories (e.g. *M/k* and L_{mat}/L_{inf}) and not to represent any particular species or stock. The parameters from the stochastic simulations from Annex 4 were used except for depletion and effort history. Here, the mean depletion of 0.5 was assumed, and a generic fishing history resulting in the mean depletion at the beginning of the assessment period was used.

For each operating model, a total of 48 iterations (*nsim*) were used. The operating model parameters are stochastic among iterations and varied between 90–110% of mean values according to a uniform distribution. The historical period was 90 years followed by 50 years projection period, in which the management procedures were

applied biennially. Perfect TAC implementation was assumed and the observations were precise and unbiased (using a template provided by DLMtool). The eight possible management procedures from factorial combinations of *r* and *f* were tested.

Projection plots showing the median trajectory of spawning–stock biomass (SSB), fishing mortality and yield can be used to ascertain trends after repeated application of the management procedures (Figures 2.2.1, 2.2.2). Overall, no discernible differences were visible comparing the two methods for stock biomass trends (*r*). The management procedures with the Gedamke-Hoenig model for estimation of exploitation (fGH) was most precautionary, resulting in high SSB but yield decreasing towards zero. On the other hand, when the Gedamke-Hoenig with effort model is used, there is a better balance between risk and yield because higher median yields are achieved here than with Gedamke-Hoenig. The median SSB trajectories are also above SSB_{MSY} for all 14 stocks. Finally, management procedures with the Length-based indicator (fLBI) or the Beverton–Holt equation (BHE) are mixed. There is a range of outcomes for different stocks. The nine stocks excluding ling, lobster, rosefish, white anglerfish, and whiting receive very precautionary advice, which results in no yield.

Performance statistics were not calculated here since the simulation runs were exploratory.

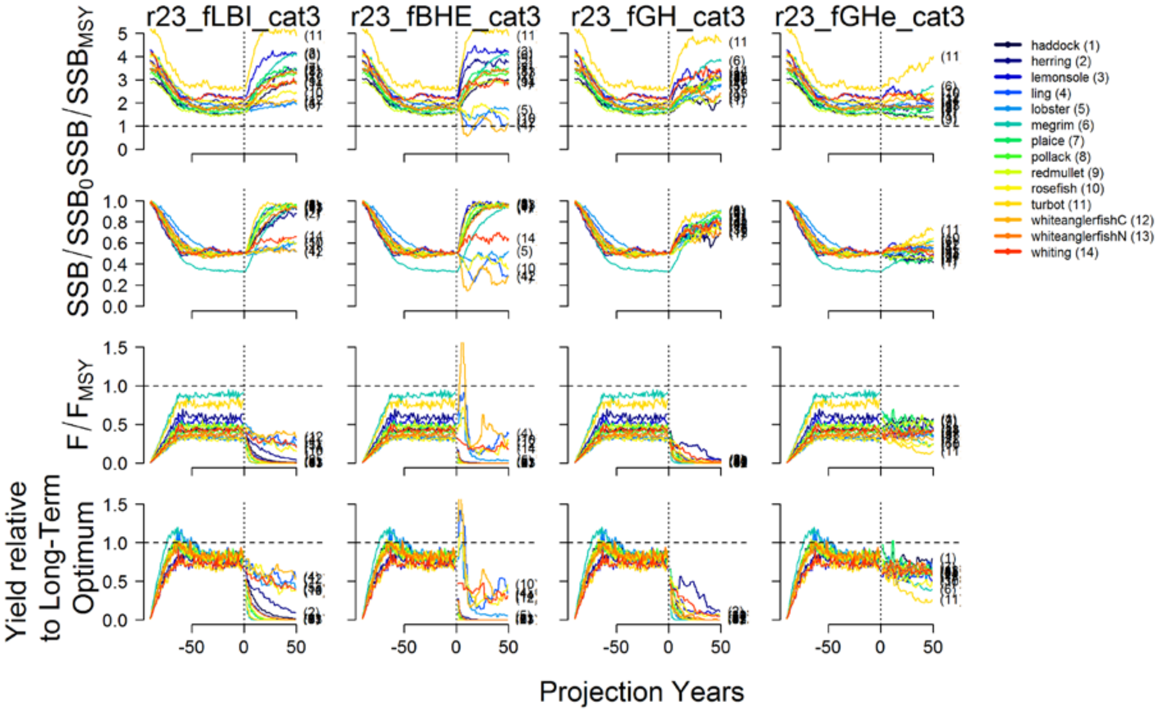

Figure 2.2.1. Projection plot of spawning–stock biomass, F/F$_{MSY}$, and yield of the 14 DLMtool operating models under the category 3 management procedures which use the 2-over-3 rule (r23) for stock biomass trends. Each line represents the median value from 48 simulation iterations.

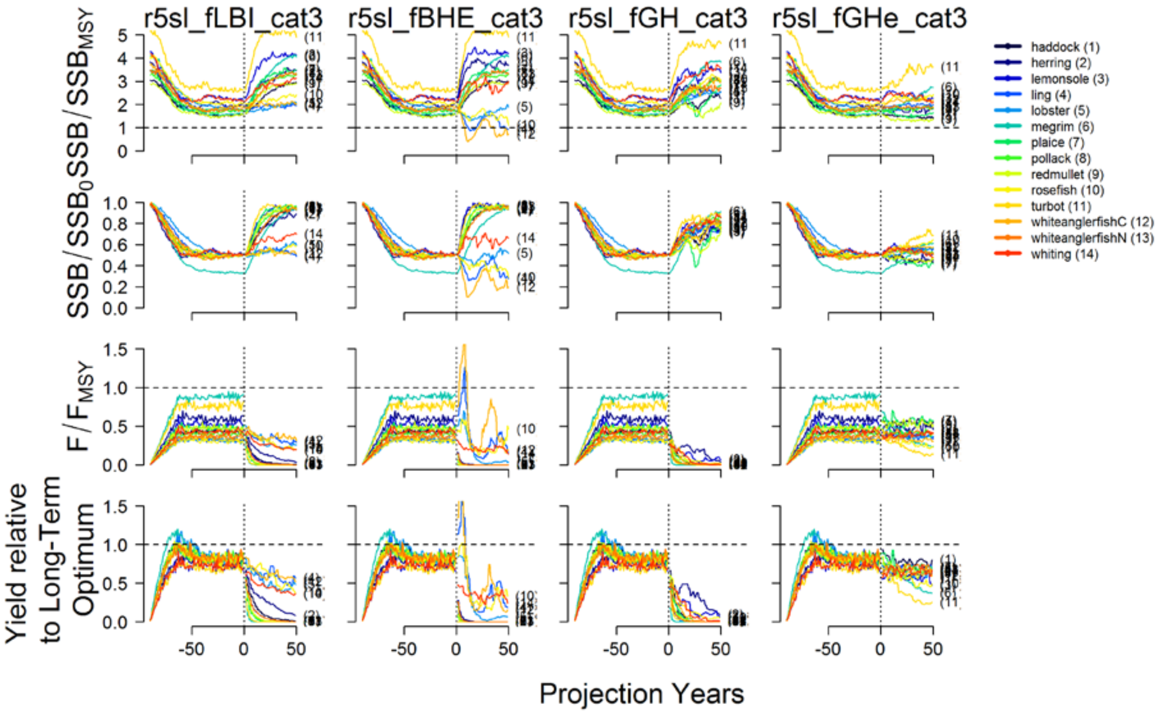

Figure 2.2.2. Projection plot of spawning–stock biomass, F/F$_{MSY}$, and yield of the 14 DLMtool operating models under the category 3 management procedures, which use the slope of the index in the most recent five years (r5sl) for stock biomass trends. Each line represents the median value from 48 simulation iterations.

2.3 FLR

ICES (2014) provides a comprehensive review of simulation work undertaken with respect to data-limited methods, principally using the FLR framework. The choice of simulation software to adopt can be a personal choice.

FLR (Fisheries Library in R, www.flr-project.org, Kell *et al.*, 2007) is a set of R packages for quantitative fisheries science. The packages are built around the FLCore package, which provides the core classes and methods. The set of FLR packages comprises packages for stock assessment methods (e.g. FLXSA, Fla4a, FLAssess), plotting (ggplotFL), forecasting (FLash, FLasher) and additional packages for more functionalities. FLR is open source and the source code is available from www.github.com/flr. One major advantage of FLR is its flexibility. Operating models for simulations can be created with classes from FLCore and already-existing methods can be applied to them, e.g. in an MSE simulation loop, FLash can be used to project the operating model forward. Additional required functionalities can be easily implemented as R code.

Operating models

In MSE simulations with FLR, the operating model is usually an object of class "FLStock". This class contains several slots related to the biology and fishery of the stock. This includes numbers, weights and biomass of the stock, landings, discards and catches, natural mortality, maturity, fishing mortality, the proportion of mortality which occurs before the start of the fishing season and additional specifications. Each of the slots in an "FLStock" is an object of class "FLQuant". "FLQuants" are basically 7-dimensional objects with the dimension quant (usually ages, but can also be lengths), year, unit, season, area and iter (iteration).

The stock–recruitment model can be set freely. Models already implemented in FLR include Beverton and Holt, Ricker, hockey-stick and geometric mean (amongst several others).

Creating operating models

Traditionally within ICES, FLR has been mainly used for data-rich stock assessments and simulations, and there has been some criticism that FLR lacks data-limited/poor methodologies. This view should be corrected as it is possible simulate stocks based solely on a set of life-history parameters. There are functions available that create stock objects, and this has been done in several simulations studies (e.g. Jardim *et al.*, 2015, ICES 2017a). The required code is now available in the FLR package FLife (https://github.com/flr/FLife/). With this package, it is possible to create entire stocks based on life-history parameters. The minimum input is L_∞ but additional parameters can be specified, and missing parameters are estimated with life-history relationships. This module is highly flexible and the growth function, maturity, natural mortality, selectivity, age range, etc. can be specified or default options are used. FLife was used to create the operating models for the MSE simulations conducted for WKLIFE as described in Section 4.1 and in the working document in Annex 3 of this report. Fifteen stocks were created and the life-history parameters used as input were the allometric parameters for the length–weight conversion (a, b), von Bertalanffy growth parameters (L_∞, t_0 and k) and the length/age at 50% maturity (L_{50} and a_{50}). This dataset has been included into FLife (as data(wklife)).

After creating FLStock objects with FLife any kind of fishing history can be created. For the simulations presented in Section 4.1 two distinctive histories have been developed, controlled by the fishing mortality (see Annex 3 of this report for more details).

Management procedures

Management procedures include a harvest control rule specifying future catch (or another manageable quantity), either based on a stock assessment or simply on available data from surveys, commercial data, etc.

For the FLR MSE simulations conducted for WKLIFE VII, the catch rules proposed by WKMSYCat34 (ICES, 2017) for ICES data-limited category 3 and 4 stocks were implemented. WKMSYCat34 proposed three main catch rules: Catch rule 3.1 (stocks with MSY proxy reference points derived from a stock production assessment model) is based on a SPiCT (Surplus Production in Continuous Time, Pedersen and Berg, 2017) assessment and forecast, and targets F_{MSY}, corrected by a biomass safeguard; catch rule 3.2.1 (catch rule based on modifying current catch) gives catch advice based on the current catch, catch length–frequencies, the trend in a stock size index and a biomass safeguard; catch rule 3.2.2 (catch rule based on applying an F_{proxy} to a stock size indicator) calculates catch advice based on a stock size index, a proxy for a harvest rate corresponding to MSY and a biomass safeguard.

The operating models in FLR are age structured, but catch rule 3.2.1 required catch length–frequencies. In order to obtain length–frequencies, the catch numbers-at-age were converted into catch numbers-at-length using growth parameters, and including variable length-at-age.

MSE simulation design

The different parts of an MSE simulation (operating model, observation model, management procedure) are combined into an MSE framework. This can be easily done with the modules and packages already implemented in FLR and extended with further functionalities.

There are attempts to develop a standardised MSE framework with FLR that can be easily adapted for different operating models and management procedures. Within the a4a (assessment for all, Jardim *et al*., 2017) initiative, such a framework was developed. In this framework, the different parts of the MSE simulation are modules that can be easily modified, exchanged and extended. For the FLR MSE simulations conducted for WKLIFE VII, this standard MSE framework was used as a basis and it was further developed to include data-limited methods.

Uncertainty in FLR simulations is usually implemented by repeating a scenario for a stock many times (implemented with the iteration dimension), each time with a unique error. Errors can be implemented wherever they are required (e.g. observations, implementation, recruitment) and with the required level of noise. Furthermore, it is possible to conduct projections deterministically without any uncertainty/bias which can help to understand certain patterns emerging from simulations, because it is possible to trace them back and they are not disguised by noise. For the simulations presented in this report, each scenario was repeated 500 times, where the "perfect knowledge" scenarios only included variation in recruitment (we do not present truly deterministic results, because recruitment variation is always included).

Parallelisation is not natively included into FLR, but can be implemented with various methods. It is possible to implement parallelization over any dimension that seems

feasible for an MSE simulation, such as parallelising over individual tested scenarios or splitting a scenario by the iteration dimension and computing the parts in parallel. By using parallel computing techniques, simulations can be executed on high performance computing systems and the time needed to obtain results is substantially reduced.

Performance statistics

In FLR MSE simulations, biological stocks are represented by objects of particular R classes (usually "FLStock"). During a simulation loop, the objects get extended in every management period cycle. At the end of the simulation period, the entire stock history is available, and any kind of performance statistics can be calculated. This includes statistics such as the risk that the stock falls below a certain biomass threshold. In the FLR simulations for WKLIFE VII, the risk of falling below a biomass limit (B_{lim}), the probability of stock collapses during the simulation, and the relative yield during the simulation period were calculated (see Annex 3 of this report for more details).

Conclusion and outlook

FLR provides a flexible framework for MSE simulations and can be extended for data-limited methods. An extensive evaluation of the catch rules proposed by WKMSYCat34 was conducted for WKLIFE and the results are presented in Section 4.1 and the working document in Annex 3 of this report. This simulation work focused on generic testing of the catch rules over a wide range of stocks and life-history types. The framework developed here can be regarded as a baseline for additional testing. It can be further developed to test more options for the generic testing of the catch rules. Due to its flexibility and modular approach, it can also be used for case specific testing. For case specific testing, operating models mimicking particular stocks can be developed (this includes life history, fishery details such as fishing history, fleet specifications, etc.) and tested within the already existing simulation framework.

2.4 References

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3 Simulation testing of advice rules based on SPiCT assessments, ToR a) i), and considerations on ToR d)

3.1 Introduction

The stochastic production model in continuous time (SPiCT; Pedersen and Berg, 2017) can provide stochastic catch predictions, which allows calculating the Total Allowable Catch (TAC) taking assessment uncertainty into account. The Workshop on the Development of the ICES approach to providing MSY advice for category 3 and 4 stocks (WKMSYCat34, ICES, 2017) suggested equation 3.1.1 as the advice rule based on production models with stochastic forecast, e.g. SPiCT:

$$F_{(y+1)} = F_{(y)} \frac{\min\left\{1, \mathrm{median}\left[\frac{B_{(y+1)}}{\mathrm{MSY}\ B_{\mathrm{trigger}}}\right]\right\}}{\mathrm{median}\left[\frac{F_{(y)}}{F_{\mathrm{MSY}}}\right]} \qquad \text{(eq 3.1.1)}$$

The advice rule based on this equation takes the median of F, F/F_{MSY} and B/B_{MSY} into account and consequently disregards the uncertainty associated with these quantities. The presentation by Mildenberger et al. (ICES, WKLIFE VII) introduced a new function ("spict2DLMtool"), which generates advice rules based on equation 3.1.1. The most recent version of the code is available in the forked SPiCT repository at https://github.com/tokami/spict/tree/dlmtool. The function allows accounting for assessment uncertainty by the option to specify any fractile of the distribution of the catch predictions, of F/F_{MSY} and B/B_{MSY}. Furthermore, it allows setting an uncertainty cap of specified lower and upper levels on the ratio of F/F_{MSY}. It is also possible combining fractiles on different quantities (and the uncertainty cap). In the presentation by Mildenberger *et al*. (WKLIFE VII), the application of this function was demonstrated by comparing the performance of various advice rules derived with above mentioned function within an Management Strategy Evaluation (MSE) framework using the DLMtool package (Carruthers and Hordyk, 2017).

3.2 MSE simulations with SPicT applying DLMTool

During the workshop, a set of SPiCT-based advice rules were compared in an MSE framework using the DLMtool package. The simulations are based on five stocks based on Jardim *et al*. (2015): Haddock, Herring, Lobster, Redfish and Turbot.

The selection covers a range of different life-history traits and uncertainty ranges in input parameters. Six scenarios were defined in order to compare different aspects of SPiCT-based advice rules (Table 3.2.1).

Table 3.2.1. Defined simulation scenarios with two depletion levels (B_{MSY}, 0.5 B_{MSY}) at the end of the historic period, advice intervals (2 = biennial, 1 = annual), and uncertainty cap on F/F_{MSY}.

Scenario	Depletion level	Advice interval	Uncertainty cap
SCE1	B_{MSY}	2	FALSE
SCE2	0.5 B_{MSY}	2	FALSE
SCE3	B_{MSY}	1	FALSE
SCE4	0.5 B_{MSY}	1	FLASE
SCE5	B_{MSY}	2	TRUE/FALSE
SCE6	0.5 B_{MSY}	2	TRUE/FALSE

All scenarios were applied to all selected stocks. The following settings were kept constant for all scenarios and species: 25 historic years with a certain effort trajectory (roller-coaster scenario), 25 projection years and 100 simulations. The uncertainty cap used in two scenarios was set to a lower bound of 0.8 and an upper bound of 1.2 for the ratio F/F_{MSY}. In the case of herring, the low depletion level at the end of the historic years had to be adjusted in order for the operating model in DLMtool to converge. For this case, the lower bound was increased by 20% and the upper bound by 40%.

For all species and scenarios a number of different advice rules were tested (Table 3.2.2), including the 2 over 3 rule.

Table 3.2.2. Tested advice rules for all stocks and scenarios.

Advice rule	Catch
Two_Over_Three_Capped	
spict_C0.5_FFmsy0.5_BBmsy0.5_ucF	
spict_C0.4_FFmsy0.5_BBmsy0.5_ucF	
spict_C0.5_FFmsy0.4_BBmsy0.5_ucF	
spict_C0.4_FFmsy0.4_BBmsy0.5_ucF	
spict_C0.5_FFmsy0.5_BBmsy0.5_uCT	
spict_C0.4_FFmsy0.4_BBmsy0.5_uCT	

The combination of scenarios and advice rules addresses all remarks raised by WKMSYCat34 (ICES, 2017), which includes the exploration of different fractiles beside the median in equation 3.1.1, the comparison of annual vs. biennial advice, and the inclusion of an uncertainty cap. Restrictions had to be made in terms of the number of simulations and the number of different stocks, to allow the work to be performed and updated during the workshop. For this exercise however, 100 simulations seem to be sufficient as an increase to 300 simulations did not change the perception of the outcomes as tested for haddock.

3.3 Results

Figures 3.3.1 and 3.3.2 show the trajectories of biomass and fishing mortality over the course of the historic and projection years for scenarios 1 and 2 (SCE1 and SCE2) and the haddock stock. While SSB starts from the reference level for scenarios with depletion level B/B_{MSY} (SCE1, SCE3, SCE5; Figure 3.3.1), in scenarios with depletion level 0.5 B_{MSY} (SCE2, SCE4, SCE6) the median biomass in the last historic year is at half the reference level (Figure 3.2.2). While the SPiCT-based advice rules keep the stock around

reference levels independent of the initial depletion level (SCE1 vs. SCE2), the median of the 2 over 3 rule indicates a steadily decreasing trend in fishing mortality and steadily increasing trend in spawning–stock biomass (SSB).

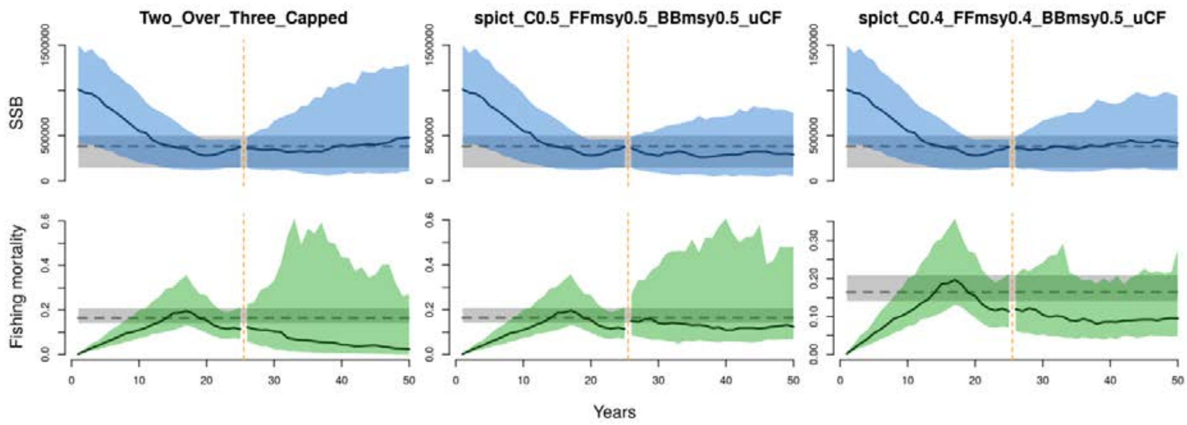

Figure 3.3.1. Trajectories of biomass and fishing mortality over historic and projection period for three different advice rules and the haddock stock in scenario SCE1. While the SPiCT-based advice rules keep the stock around reference levels, the median of the 2 over 3 rule shows steadily decreasing fishing mortality and steadily increasing spawning–stock biomass.

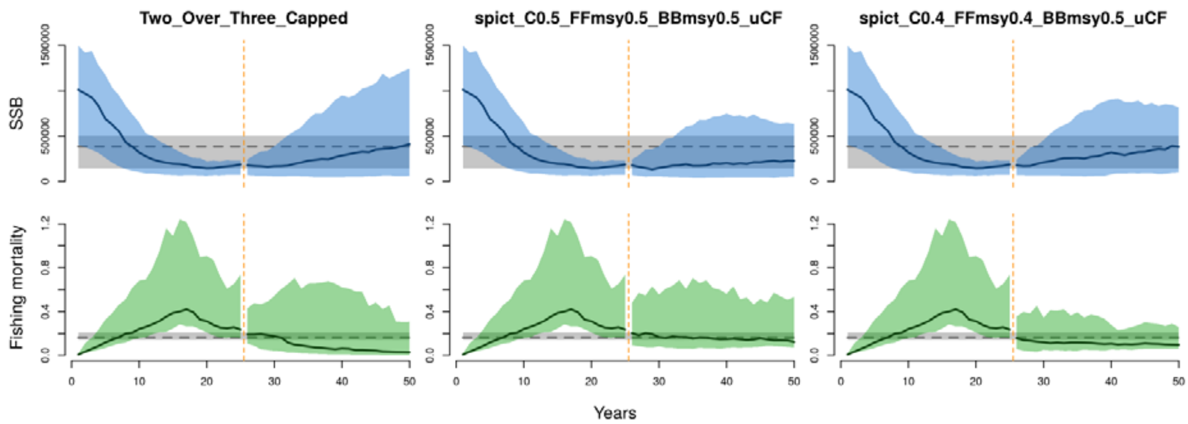

Figure 3.3.2. Trajectories of biomass and fishing mortality over historic and projection period for three different advice rules and the haddock stock in scenario SCE2. While the SPiCT-based advice rules keep the stock around reference levels, the median of the 2 over 3 rule shows steadily decreasing fishing mortality and steadily increasing spawning–stock biomass.

The comparison of the SPiCT advice rules for all scenarios with the haddock stock shows that there are almost no differences between biennial and annual advice intervals in the theoretical yield and the risk of $B < B_{lim}$, while the capped 2 over 3 rule shows higher risk and yield with biennial advice (e.g. SCE1 vs. SCE3 in Figure 3.3.3). In contrary, the initial depletion level affects not only the risk of the capped 2 over 3 rule but also of all SPiCT advice rules with a higher risk of low biomass values when starting at 0.5 B_{MSY} (e.g. SCE1 vs. SCE2 in Figure 3.3.3). The yield obtained with SPiCT advice rules is not affected by the depletion level. The figure also shows that the effect of an uncertainty cap for the SPiCT advice rules is not significant, while the uncertainty cap

in the 2 over 3 rule decreases the theoretical yield, but also the associated risk. For all scenarios, the theoretical yield obtained with the capped 2 over 3 rule is around half of the theoretical yield obtained with SPICT advice rules.

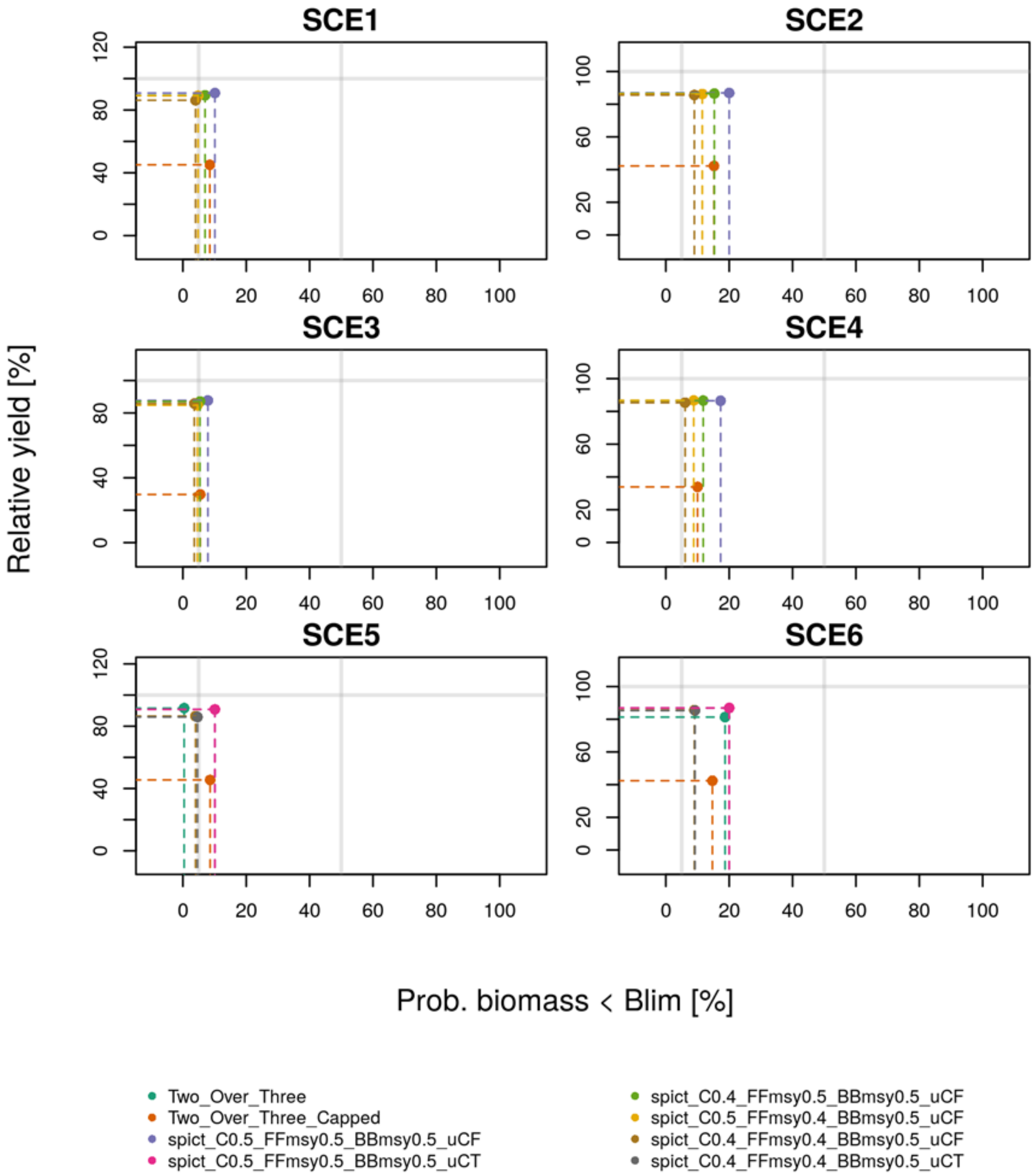

Figure 3.3.3. Trade-off plots for all scenarios based on the haddock stock. The y-axis shows the yield during the last five years relative to the highest theoretical yield which would have been obtained by fixing the fishing mortality. The x-axis displays the probability of the biomass in the last five years falling below the reference level B_{lim} (0.3 B_{MSY}). The reference probability of 5% is indicated by a grey line. The different points in the graph represent the different advice rules based on SPiCT and the 2 over 3 rule.

While the relative performance of the SPiCT advice rules with different fractiles is similar among the different scenarios, there are substantial differences in the trade-off of yield and risk between the different stocks (Figure 3.3.4). Regarding the effect of percentiles in the SPiCT advice rules, three different trade-off types can be identified

among the five stocks: (i) large effect on risk, small effect on yield (haddock); (ii) small effect on risk, large effect on yield (herring); and (iii) equal effect on risk and yield (e.g. redfish). These different effects are related to the life-history traits and their uncertainty and it remains to be shown indicated trends hold also for large number of simulations and species of the same functional groups. As consequence, a very precautionary advice rule can be chosen for species of the first group, where the yield is almost not affected.

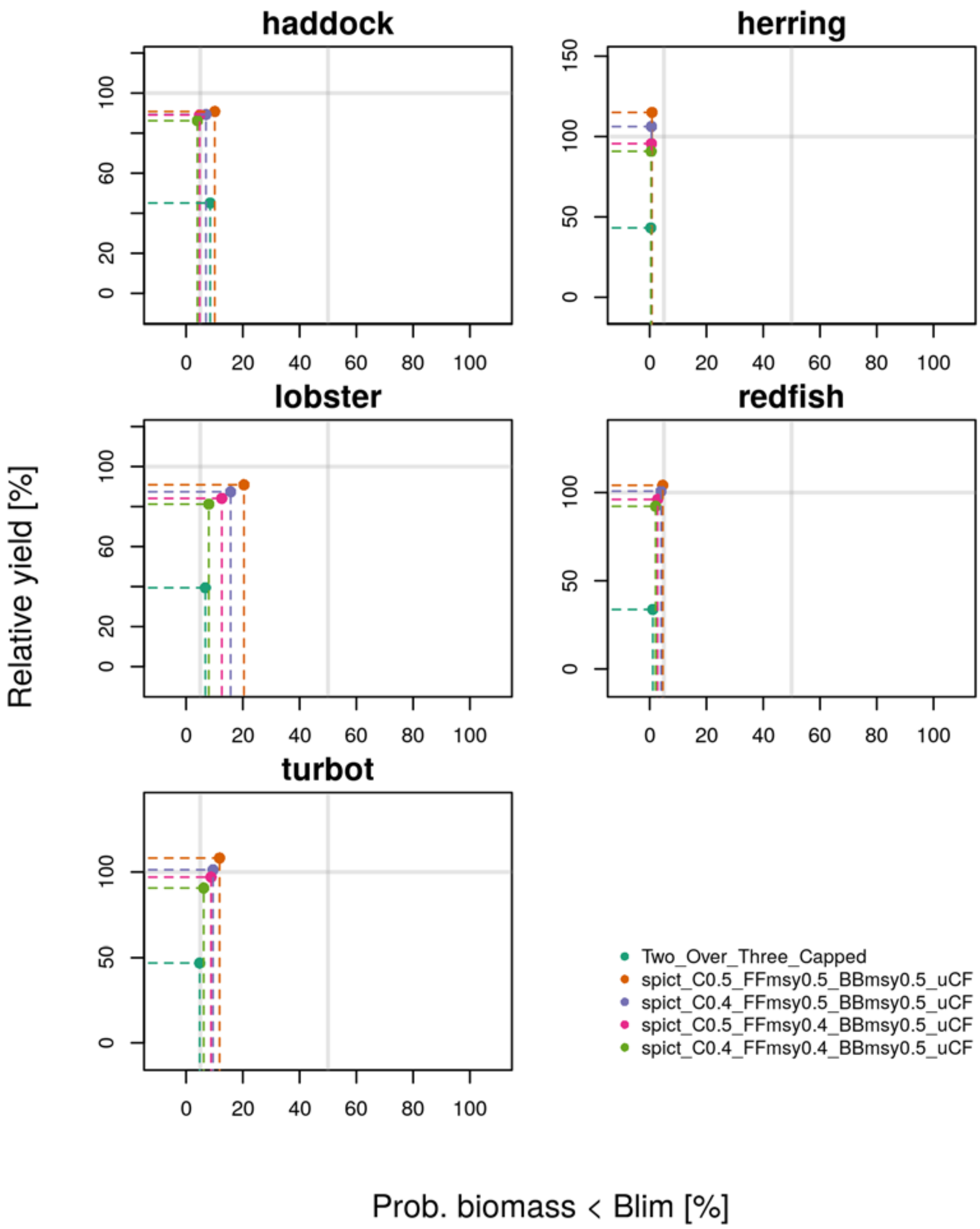

Figure 3.3.4. Trade-off plots of all species for scenario SCE1. The y-axis shows the yield during the last five years relative to the highest theoretical yield which would have been obtained by fixing the fishing mortality. The x-axis displays the probability of the biomass in the last five years falling below the reference level B_{lim} (0.3 B_{MSY}). The reference probability of 5% is indicated by a grey line. The different points in the graph represent the different advice rules based on SPiCT and the 2 over 3 rule.

As indicated above, annual advice with the capped 2 over 3 rule results in a very precautionary stock perception in terms of F/F_{MSY} and B/B_{MSY} in the last projection year (Figure 3.3.5) and in average the stock is further away from reference levels.

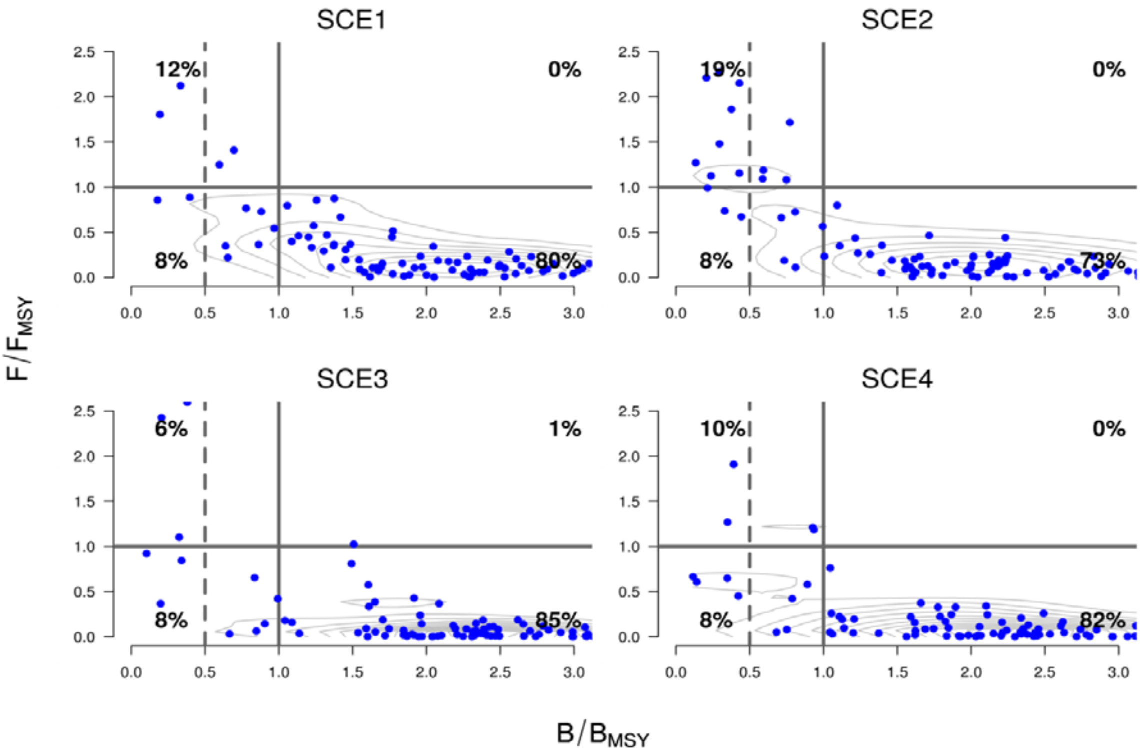

Figure 3.3.5. Kobe plot showing the stock status of the last year in terms of F/F_{MSY} and B/B_{MSY} for the 2 over 3 rule applied to the haddock stock for different scenarios (see Table 3.2.1 for details).

When it comes to the SPiCT advice rules, there are no major differences between annual and biennial advice for scenarios of the same depletion level (SCE1 vs. SCE3 and SCE2 vs. SCE4; shown for the median advice rule in Figure 3.3.6).

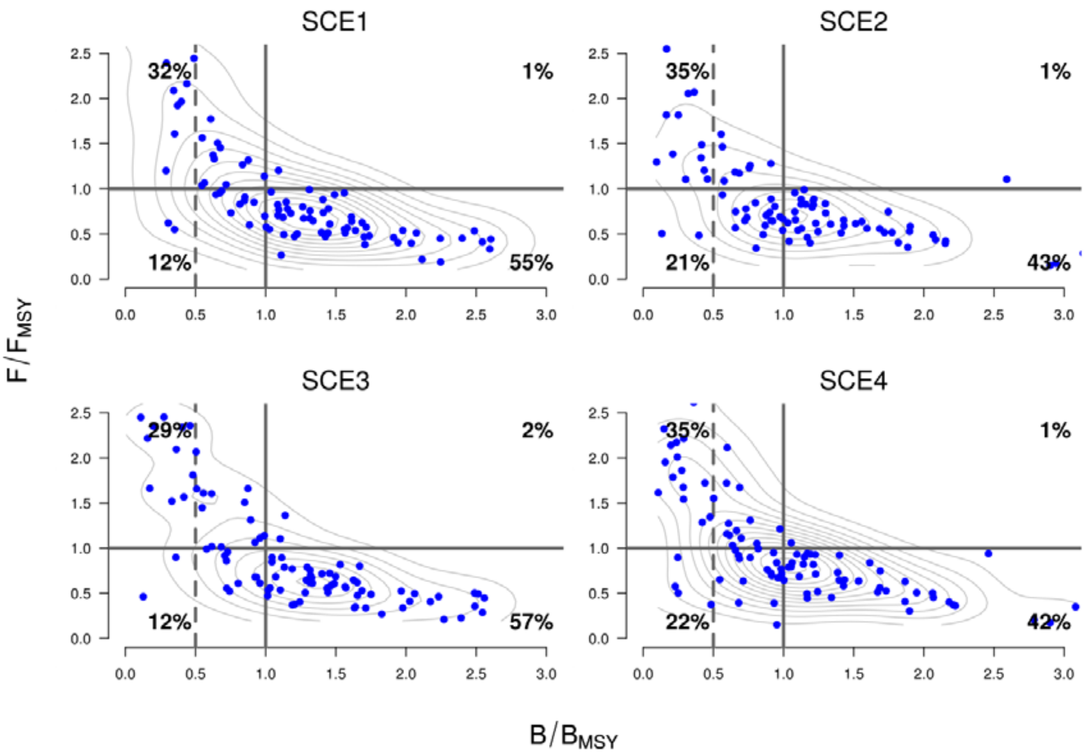

Figure 3.3.6. Kobe plot showing the stock status in the last projection year in terms of F/FMSY and B/BMSY for the median SPiCT advice rule (spict_C0.5_FFMSY0.5_BBMSY0.5_ucF) applied to the haddock stock for different scenarios (see Tables 3.2.1 and 3.2.2 for details).

The combination of the fractile on the catch predictions and the fractile on F/FMSY results in a more precautionary stock perception in terms of F/FMSY and B/BMSY in the last year of the projection period (upper left panel vs. lower left panel in Figure 3.3.7). The use of the uncertainty cap on the ratio of F/FMSY does not affect the stock perception in the last projection year among advice rules (in row comparison of panels in Figure 3.3.7).

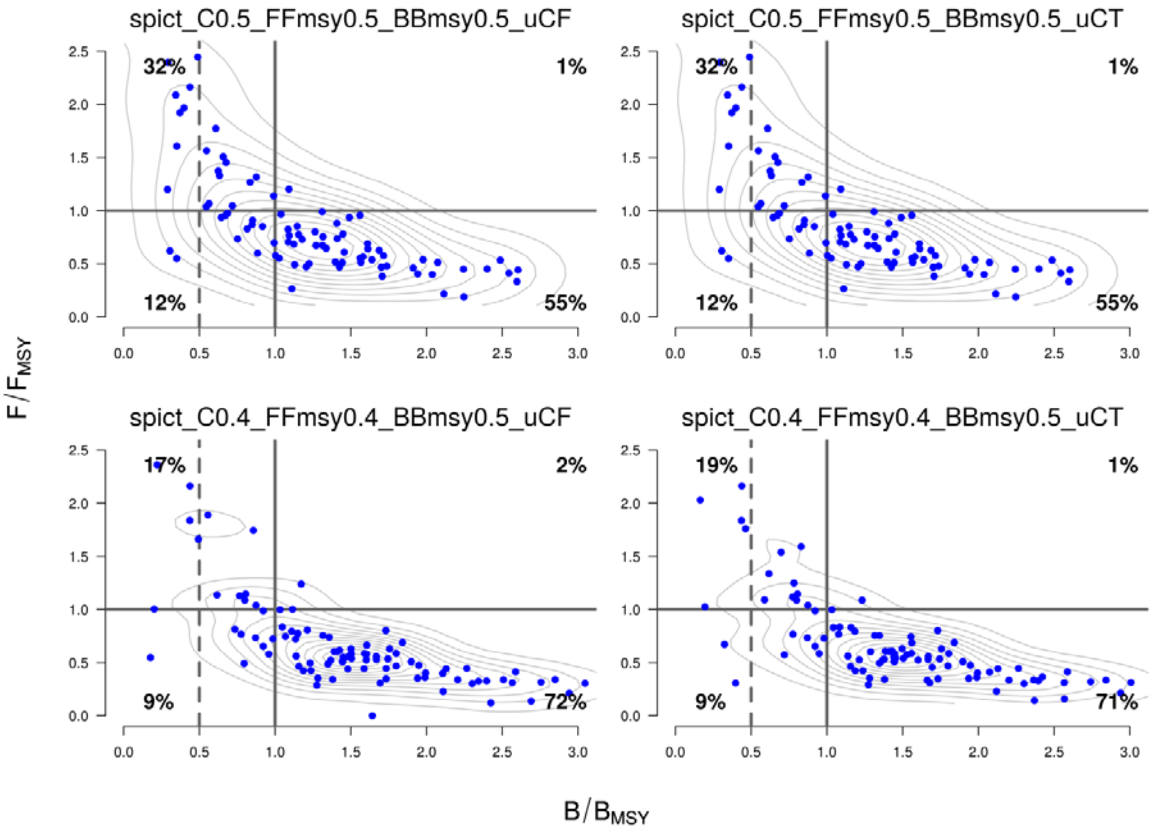

Figure 3.3.7. Kobe plot showing the haddock stock status in the last projection year in terms of F/F_{MSY} and B/B_{MSY} for different SPiCT advice rules (no uncertainty cap (uCF) vs. uncertainty cap (uCT), part of SCE5 (see Tables 3.2.1 and 3.2.2 for details).

3.4 Conclusions

Results from scenarios with two depletion levels show that one should be careful with the comparison of the performance of the advice rules with absolute values, such as the reference level of the biomass below B_{lim} of 5%. The different risk metrics are dependent on several factors, such as the number of projection years, the initial depletion level, the number of simulations, if advice is given annually or biennially, or the number of years considered for the estimation of the probability. The different absolute but similar relative results of scenarios SCE1 and SCE2 indicate that the MSE framework should mainly be used for the relative comparison of different advice rules. The effect of the fractiles within the advice rules differ between stocks, indicating that no general recommendation can be made about the universally optimum fractile. Different fractiles and combinations should be tested in stock-specific MSE frameworks. For all stocks and scenarios, the theoretical yield obtained with SPiCT advice rules is around twice as high as the yield obtained with the 2 over 3 rule. The differences of the performances of the advice rules might be related to the life-history traits of different functional groups. This could be approved by additional simulations for several representatives for each group (demersal, pelagic, shellfish, etc.).

In terms of how to account for uncertainty, a more general conclusion can be made: Using the fractile on F/F_{MSY} is more sensitive to the uncertainty around the F_{MSY} reference point, which may often be substantially larger than the corresponding uncertainty

around the predicted catch, although the opposite may also occur. Using the fractile method on the catch is addressing uncertainty on different parameters in the model than when used on F/F_{MSY}, hence using the combination of both should be the recommended option. The uncertainty cap on F/F_{MSY} within the SPiCT advice rules has no effect on the stock perception within the last years of the projection according to the results of these simulations. For some applications of SPiCT within the simulation framework, the TAC could not be calculated by the model and the default rule within the DLMtool package was applied (TAC = catch last year). This could be related to the fact that the model did not converge or that the uncertainty could not be calculated, which is not surprising considering the coefficients of variation in the observation model (DLMtool Obs model: "Imprecise_Unbiased") of 0.2–0.6 for the catch and index observations. It remains to be investigated what really caused the missing TACs, and how the maximum number of 25% NAs for one scenario can be reduced. Results of preliminary simulations (presentation) approved that lower observation noise (DLMtool Obs model: "Precise_Unbiased") decreased the number of NAs.

Future work

Since the implementation of SPiCT within the FLR package is not yet finalized, further work is required, e.g. including the option of choosing different fractiles in the SPiCT advice rules, or applications to stocks with different life-history parameters. Furthermore, SPiCT advice rules within the FLR and the DLMtool framework should be compared in order to approve the here presented results. Simulations with the DLMtool package should be repeated with a larger number of simulations (200 < nsim < 500). However, even with the use of high performance computers, this will require an extensive time period. Furthermore, more stocks should be tested, as this could reveal patterns between functional groups. It could be tested if there is a threshold in the applied fractile with regard to changes in obtained risks and yields, which could result in more general recommendations regarding the fractiles in SPiCT-based advice rules. The effect of different fleets with specific selectivities on the performance of the advice rules could be tested. Advance preliminary simulations with the biased observation model with the DLMtool package (presentation by Mildenberger *et al.*; ICES, WKLIFE VII). The effect of fractiles on B/B_{MSY} in equation 3.1.1 should be tested in combination with fractiles on the other quantities.

3.5 Considerations on ToR d)

According to the results of the MSE simulations performed in the frame of the WKLIFE VII, SPiCT based advice rules outperform the 2 over 3 rule allowing higher theoretical yields with similar risks. However, the uncertainty of the SPiCT assessment must be considered by means of fractiles smaller than 0.5 for the catch predictions or for F/F_{MSY}. In the best case, the fractiles for these quantities are combined, as this accounts for the uncertainty around predicted catch as well as the uncertainty around reference levels. It remains to be tested in stock-specific MSE simulations which fractiles yield acceptable risks and the combination of fractiles smaller than 0.4 should be considered. The uncertainty cap is not necessary according to presented results and there are no significant differences between annual and biennial advice for SPiCT based advice rules.

3.6 References

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Jardim, E., Azevedo, M. and Brites, N. M. 2015. Harvest control rules for data-limited stocks using length-based reference points and survey biomass indices. *Fisheries Research*, 171:12–19.

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4 Simulation testing of WKMSYCat34 catch rules

4.1 FLR

4.1.1 Introduction

This section describes the generic MSE simulations that were conducted using FLR (www.flr-project.org, www.github.com/flr). Stocks chosen for these generic simulations are a subset (15 stocks) of those used for the PA buffer simulations in 2016 (ICES, 2017a; Jardim *et al.*, 2015), which nevertheless covered a wide range of life-history characteristics, with parameters based on published data checked carefully for quality, sample size, age–length range and plausibility (Table 4.1.1.1). Although the life-history parameters were case-specific, the simulations were generic because of the way the simulations were set up (working document in Annex 3). Any missing life-history parameters were estimated using life-history relationship through the FLR package FLife (www.flr-project.org).

The age-structured operating models were constructed using FLR packages FLife and FLBRP (www. flr-project.org), based on the life-history parameters (Table 4.1.1.1). Virgin biomass was set at 1000, the maximum age was defined as the age at 95% L_{∞}, natural mortality was length-dependent (Gislason *et al.*, 2010), and the stock–recruit relationship was Beverton–Holt with a steepness of 0.75. B_{lim} was defined as the SSB that, under equilibrium conditions, produces recruitment at 70% virgin levels. Age at 50% maturity was taken as the age at 100% selection, so stocks were exploited before they were fully mature. Ages were converted to lengths using the growth parameters (Table 4.1.1.1), and the resultant lengths spread (thus introducing variation in length-at-age) with a normal distribution (sd=1, cut off at ± 2 sd; maximum length=L_{∞}).

We adopt the Management Strategy Evaluation (MSE) terminology of Rademeyer *et al.* (2007) and Punt *et al.* (2016):

OM – operating model, describing the "true" underlying dynamics of the stock and fishery;

MS – management strategy, describing the management rules being tested;

Tuning – describing the use of control parameters to "tune" the management strategy to improve performance (e.g. with respect to risk and average yield);

risk – probability of SSB <B_{lim}, averaged over the projection period;

probability of collapse – proportion of iterations for which the SSB falls below 0.1% of virgin biomass;

relative yield – average yield in the projection period relative to average yield in the last 25 years of the historic period.

Two catch histories were defined by fishing for 75 years at 50% F_{MSY}, then fishing for 25 years according to two scenarios:

- "one-way" – fishing mortality was increased exponentially to 80% F_{crash} by the end of the 25 years;
- "roller-coaster" – fishing mortality was increased exponentially to 75% F_{crash} within 8–11 years (depending on the absolute difference between 50% F_{MSY}

and 75% F_{crash} with a faster increase for a bigger difference), kept there for five years, then reduced exponentially to F_{MSY} by the end of the 25 years.

Therefore, at the start of the period of management (for which catch rules would be tested), the OMs from both catch histories were severely depleted. The one-way OM was at its lowest stock levels, while the roller-coaster OMs were already recovering (although not recovered; see Figure 4.1.2.1 in the next section for the catch history of the last 25 years).

A total of 500 iterations were conducted for each simulation test, which comprised the combination of one of 15 stocks, one of two catch histories and a management strategy (one of the catch rules described in WKMSYCat34, ICES, 2017b). All simulation tests were for a projection period of 100 years and included recruitment variability (lognormal multiplicative factor of 0.3) and autocorrelation (0.2). The approach to simulation testing was to start with "perfect knowledge" scenarios, where all the information used by the management strategies being tested were known perfectly (i.e. survey indices, reference points, length frequencies, and catch and life-history parameters were taken from the OM without error); the reason for this is, if the management strategy does not perform well with perfect knowledge, even with tuning, then there is little point in keeping it. The perfect knowledge scenarios formed part of the exploratory work, and is not presented in this section (see Annex 3). The simulation tests presented here include observation error (CVs on the stock size index, length frequencies, and catch and life-history parameters were 0.2, 0.2, 0.1 and 0.1 respectively), and M/k (where required) was always set to 1.5, regardless of what the true value was in the OM.

The following subsections deal with the categories of catch rules described in WKMSYCat34 (ICES, 2017b), namely catch rules 3.2.1 (catch rules based on modifying current catch), 3.2.2 (catch rule based on applying an F_{proxy} to a stock size indicator), and catch rule 3.1 (using the biomass dynamic model SPiCT). Our focus was primarily on catch rules 3.2.1, with some testing on catch rule 3.2.2, but only one test on catch rule 3.1 due to time limitations and the knowledge that it was been covered elsewhere (the latter was more of a "proof of concept" run).

In almost all cases (apart from one example in the WD in Annex 3), a biennial TAC was used (the advice was set in one year based on the catch rule, then held constant for the next year).

The source code for the simulations is available from https://github.com/shfischer/wklifeVII.

Table 4.1.1.1. List of stocks used for testing the WKMSYCat34 catch rules, along with life-history parameters. The stocks shaded grey were selected from each group of more than one stock (final column) for further analysis of the 3.2.1 catch rule during the meeting. a and b are the allometric parameters for the length–weight conversion, L_∞, t_0 and k are von Bertalanffy growth parameters, L_{50} and a_{50} is the length/weight at 50% maturity, a_{max} the maximum age used in the simulation and M is calculated as the mean M over all ages, weighted by the maturity ogive.

NAME	COMMON NAME	AREA	STOCK CODE	A	B	L∞	L50	A50	T0	K	AMAX	M	M/K	L50/L∞	GROUP
Pollachius pollachius	Pollack	North Sea	pol.27.3a4	0.0076	3.069	85.6	47.1	*4.1*	*-0.1*	0.19	16	0.21	1.12	0.55	1
Molva molva	Ling	Widely	lin.27.3a4a6–91214	0.0036	3.108	119	74	*7.2*	*-0.1*	0.14	22	0.14	1.01	0.62	1
Lophius piscatorius	White an-glerfish	Celtic Seas	mon.27.78abd	0.0198	2.895	105.555	73	*6.2*	*-0.38*	0.18	17	0.18	0.99	0.69	1
Lophius piscatorius	White an-glerfish	North Sea	anf.27.3a46	0.0297	2.841	106	61	*4.7*	*-0.1*	0.18	17	0.20	1.10	0.58	1
Pleu-ronectes platessa	Plaice	Celtic Seas	ple.27.7fg	0.011	2.958	48	22.9	*2.7*	*-0.1*	0.23	13	0.32	1.40	0.48	2
Melano-grammus aeglefinus	Had-dock	Celtic Seas	had.27.7a	0.0113	2.96	79.9	42.3	*2*	*-0.36*	0.2	15	0.26	1.30	0.53	2
Nephrops norvegicus	*Nephrops*	Biscay-Iberia	nep.fu.2829	0.00028	3.229	70	28.4	*2.5*	*-0.1*	0.2	15	0.28	1.38	0.41	2

NAME	COMMON NAME	AREA	STOCK CODE	A	B	L∞	L50	A50	T0	K	AMAX	M	M/K	L50/L∞	GROUP
Lepidorhombus whiffiagonis	Megrim	North Sea	lez.27.4a6a	0.0022	3.3433	54	23	*3*	*-0.1*	0.12	25	0.18	1.54	0.43	3
Sebastes norvegicus	Redfish	Northern	reb.27.5a14	0.0178	2.972	50.2	40.3	*14.8*	*0.08*	0.11	28	0.12	1.07	0.80	4
Mullus surmuletus	Red mullet	Celtic Seas	mur.27.67a–ce–k89a	0.0057	3.243	47.5	16.9	*2.0*	*-0.1*	0.21	15	0.35	1.66	0.36	5
Scopthalmus maximus	Turbot	North Sea	tur.27.4	0.0149	3.079	66.7	34.2	*2.2*	*0.29*	0.32	10	0.40	1.25	0.51	5
Microstomus kitt	Lemon sole	North Sea	lem.27.3a47d	0.0123	2.971	37	27	*3.0*	*-0.1*	0.42	8	0.46	1.10	0.73	6
Merlangius merlangus	Whiting	Celtic Seas	whg.27.7b–ce–k	0.0103	2.395	38	28	*2.5*	*-1.01*	0.38	7	0.44	1.15	0.74	6
Clupea harengus	Herring	Celtic Seas	her.27.nirs	0.0048	3.198	33	23	*1.9*	*-0.1*	0.606	5	0.76	1.25	0.70	NA
Ammodytes spp.	Sandeels	North Sea	San.sa.4	0.0049	2.783	24	12	*0.6*	*-0.1*	1	3	1.21	1.21	0.50	NA

***italic* values estimated with FLife.**

4.1.2 Catch rule 3.2.1

The catch rule to be tested was:

$$C_{y+1} = C_{\text{current}}\, r\, f\, b \qquad 4.1.2.1$$

where

$$b = \min\{1; \frac{I_{current}}{w \times I_{lim}}\} \qquad 4.1.2.2$$

and C_{current} was taken as C_{y-1}, I_{current} as I_{y-1}, I_{lim} as the lowest survey index in the final 25 years of the historic period (set at the start of the projection period and not updated during an iteration), and w set to 1.4 (although other values were explored; see Figure 4.1.2.3 below and in Annex 3).

Exploratory work (Annex 3) assumed perfect knowledge and initially investigated the individual components of equation 4.1.2.1, r, f and b. WKMSYCat34 listed several options for each of these components, and these were investigated in turn. This exploratory work found that, when used individually and without additional tuning, r and f showed very poor performance (even with perfect knowledge), while there were clear benefits to having the protection element b (Annex 3). The exploratory work also found that, on balance the "2 over 3" rule (referred to as option a of the r component in the WKMSYCat34 report (ICES, 2017b)) outperformed the "slope" rule (option b, which was slower-reacting), particularly for the one-way OMs. Furthermore, the $L_{mean}/L_{F=M}$ rule (referred to as option a of the f component in the WKMSYCat34 report) outperformed the other two options (b and c). Therefore, for further work in terms of combining the three components r, f and b and introducing observation error and assumptions (M/k=1.5), only options a of both the r and f components were explored (this combination is called the base 3.2.1 rule [management strategy] below).

Figure 4.1.2.1 illustrates the performance of the base 3.2.1 rule, and it is clear from this that certain OMs can be grouped in terms of their response to the base 3.2.1 rule, illustrated in Figure 4.1.2.2 by highlighting this grouping behaviour with colour coding. The stocks her.27.nirs and san.sa.4 (Celtic Sea herring and North Sea sandeel 4 stocks) were omitted from this figure (and subsequent analyses) because it was discovered (from analysis of the 3.2.2 catch rule in the next section) that lags were not appropriately taken into account for these stocks, which caused cyclical behaviour for that rule). This led to the selection of a representative stock from each group of stocks for further analyses conducted during the meeting (but the two single-stock groups, lez.27.4a6a and reb.27.5a14, were not considered further because of the desire to conduct more analysis with fewer stocks, rather than fewer analyses with more stocks). The four representative stocks eventually selected for further analyses (one from each multistock group) were nep.fu.2829, pol.27.3a4, tur.27.4 and whg.27.7b–ce–k, this selection aiming for a diverse set of stocks.

When evaluating the performance of the catch rule in terms of risk, aiming for a particular level of risk (e.g. the ICES precautionary criterion of 5%) becomes arbitrary in generic testing. It depends on the way the simulation framework is set up (e.g. observation errors used, etc.), and should therefore not be examined in absolute terms. But, even when considered in relative terms, how does one judge the performance of an MS when it comes to risk? To get around this problem, the approach used in 2016 to test different PA buffer sizes (ICES, 2017a) used the concept of control parameters (in that case the size and duration of the PA buffer) to tune the MS in order to find the control parameter space that no long resulted in large improvements in risk. There is of course

a trade-off between improvements in risk and deterioration in other performance statistics such as average yield. This approach was also used in the work carried out during the meeting.

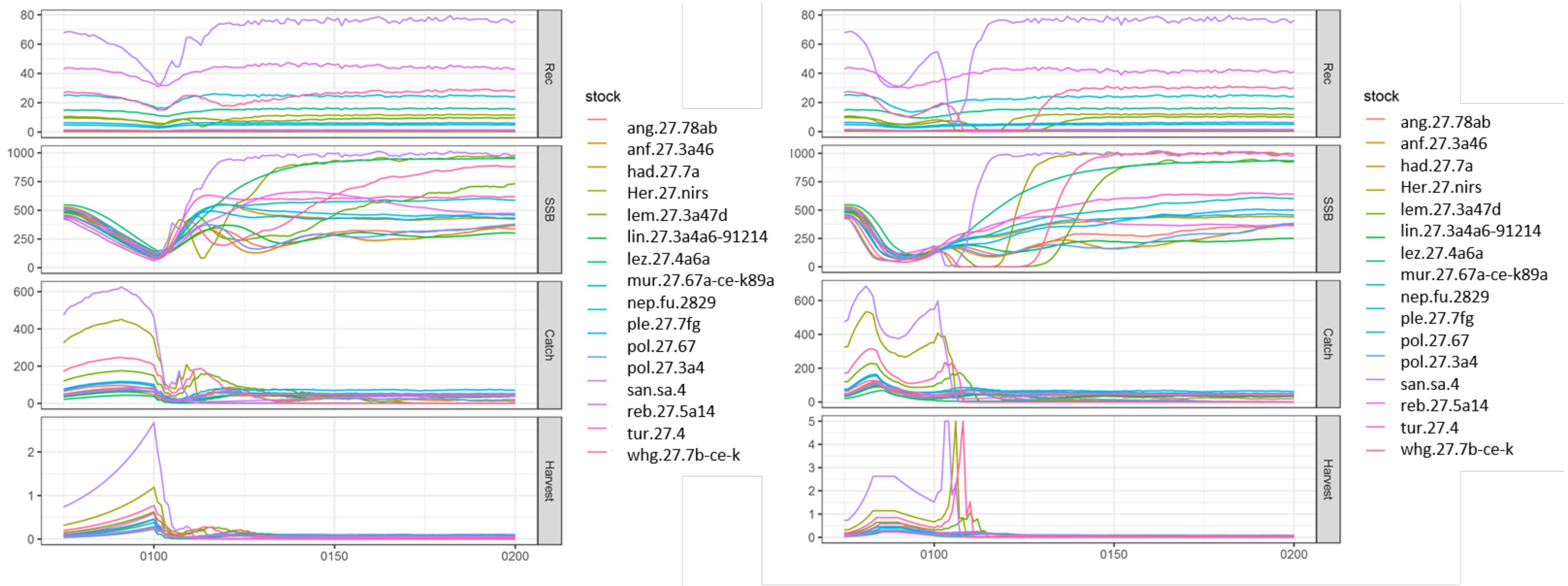

Figure 4.1.2.1. Performance of the base 3.2.1 rule (combination of *r*="2 over 3", *f*=$L_{mean}/L_{F=M}$ and *b* with *w*=1.4) for the 15 one-way OMs (left) and the 15 roller-coaster OMs, in terms of (from the top) recruitment, SSB, catch and fishing mortality. Each solid line represents the median of 500 iterations.

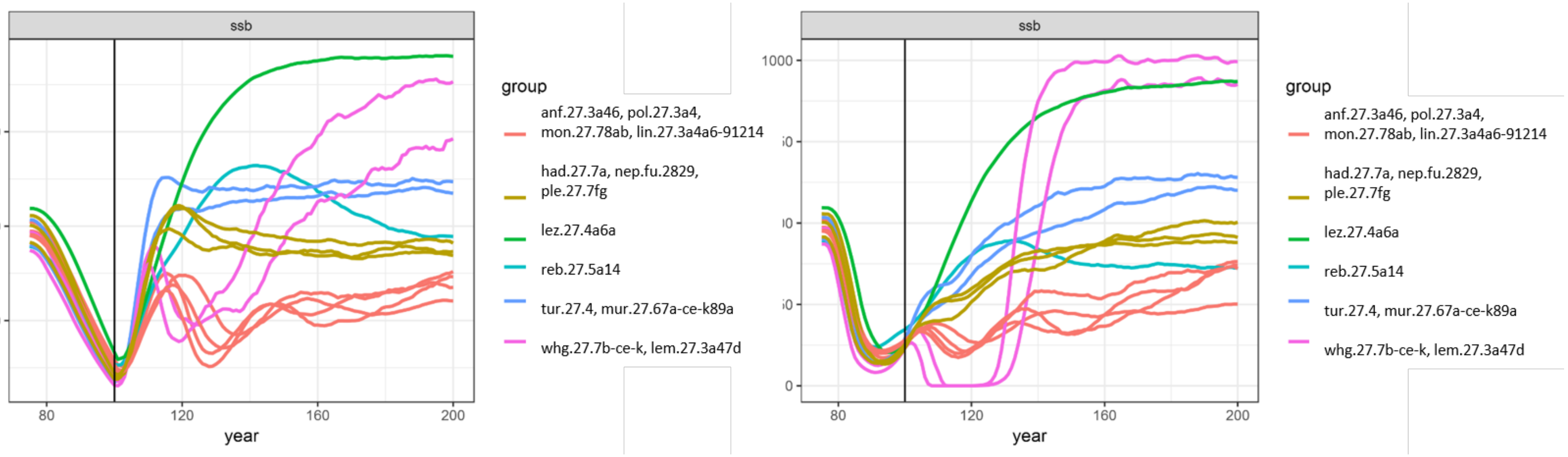

Figure 4.1.2.2. A repeat of the SSB plots in Figure 4.1.2.1 (one-way left, and roller-coaster right), highlighting similar behaviour for groups of stocks (6 groups in total), omitting stocks her.27.nirs and san.sa.4 (Celtic Sea herring and North Sea sandeel area 4).

Initial individual tuning with w, x, and z

In order to achieve improved performance of the base 3.2.1 rule (e.g. in terms of risk and relative yield), the MS required further tuning, and this could be achieved by treating w (Equation 4.1.2.2) as a control parameter, and introducing two further control parameters z and x as follows:

$$C_{y+1} = C_{\text{current}}\, r\, f\, b^{z} x \qquad 4.1.2.3$$

where z (the exponent of b) acts on the descending limb of the protection rule by, for example, bringing it down more quickly (quadratic reduction if z=2 instead of linear when z=1), and where x (the advice multiplier) acts on the whole catch rule (so if $0< x<1$, then it scales the entire rule down, which is similar to increasing the $L_{F=M}$ target in the f component of the base 3.2.1 rule).

Figure 4.1.2.3 illustrates the effect of control parameters w and x on the probability of collapse for the pol.27.3a4 stock. This shows a quick reaction to small changes in x, but a slower reaction to large changes in w, where w would need to be 3–4 to start having a substantial effect; for this reason, w was not considered further as a control parameter and its value kept at 1.4.

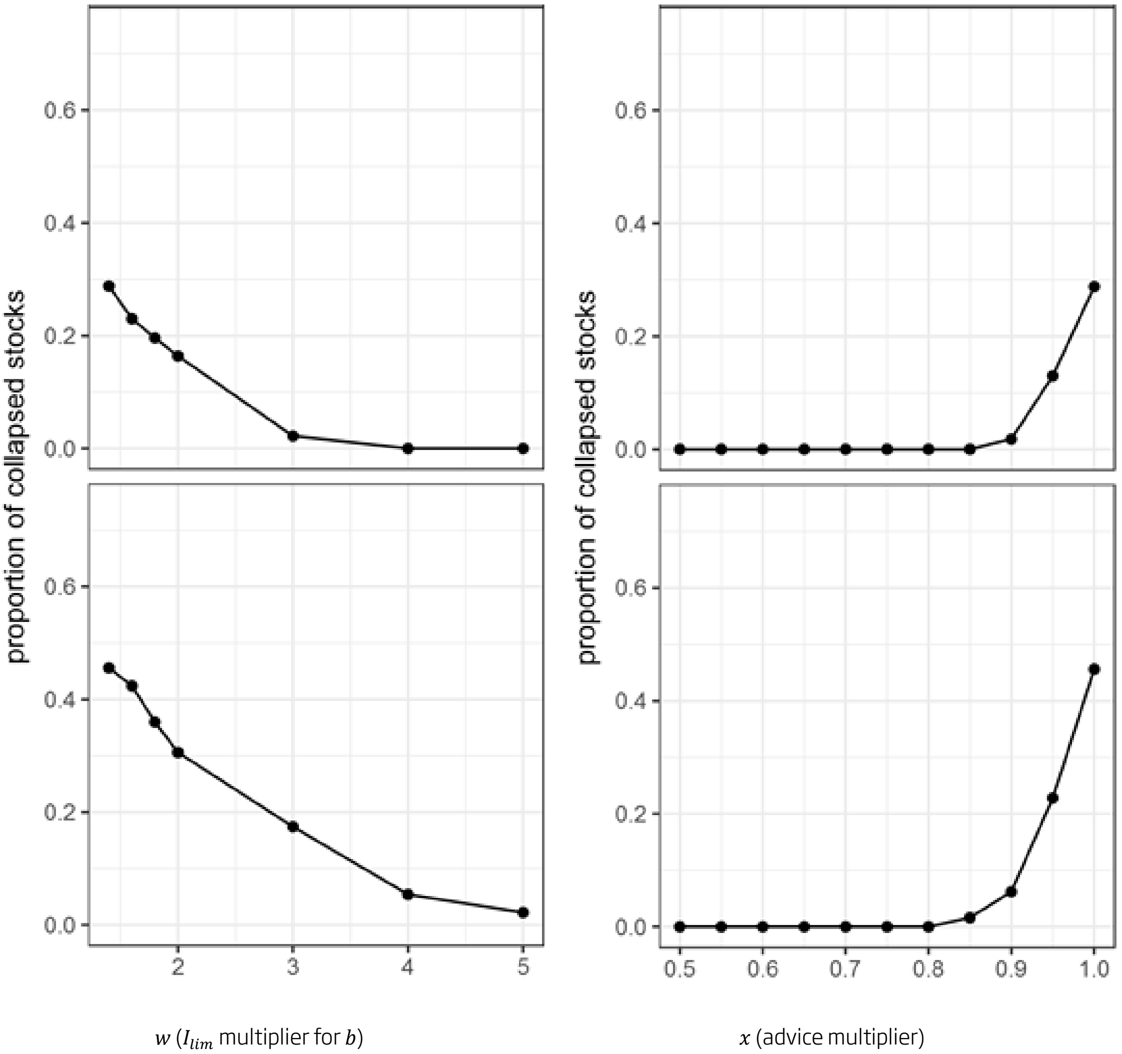

Figure 4.1.2.3. Initial tuning with w (I_{lim} multiplier for b) (left) and x (advice multiplier) (right) based on the pollack stock (pol.27.3a4) only, and looking at the probability of collapse. The one-way trip OM is in the top row, and the roller-coaster OM in the bottom.

Figure 4.1.2.4 explores the effect of the control parameter x on risk, probability of collapse and relative yield for the four selected stocks and two catch histories, while Figure 4.1.2.5 does the same for control parameter z. These two analyses were done individually for each control parameter in order to explore the region to be used for further work across both control parameter dimensions. On the basis of this analysis, x values of 0.8–1 and z values of 1–3 (regions which showed the largest improvements in risk without too much loss in relative yield) were selected for two-dimensional tuning using these two control parameters.

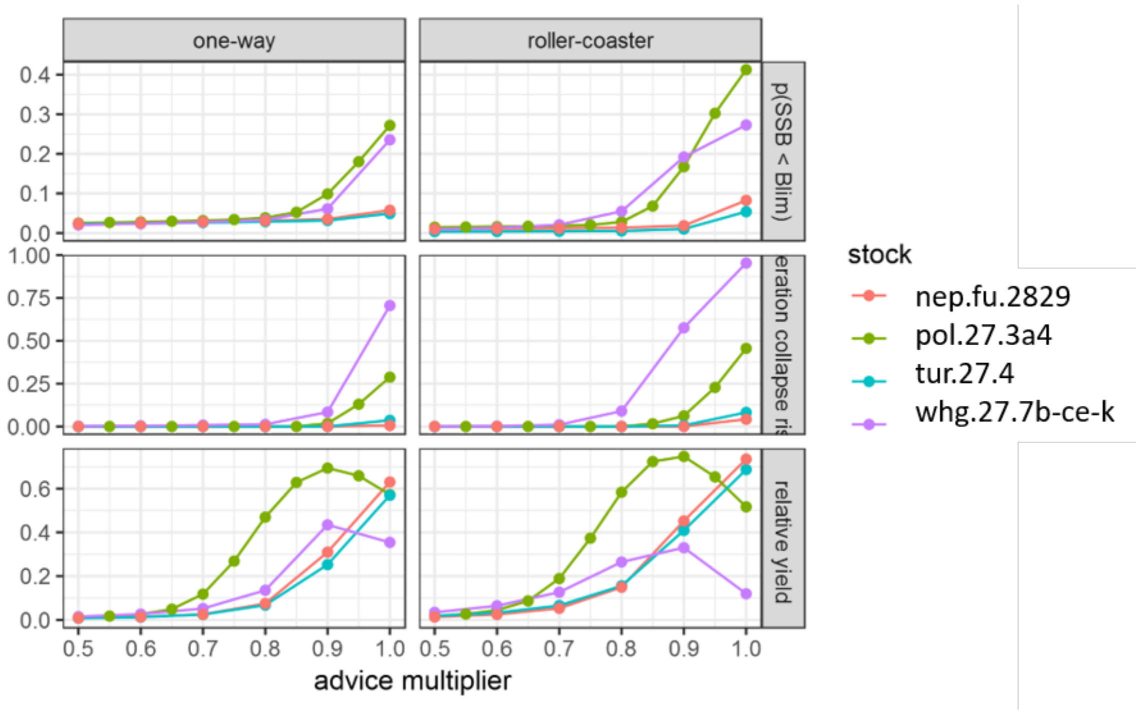

Figure 41.2.4. Initial tuning of the base 3.2.1 rule with *x* (the advice multiplier) on the four selected stocks for the one-way (left) and roller-coaster (right) OMs, considering risk (top), probability of collapse (middle) and relative yield (bottom). [Note, pol.27.3a4 has more points, simply because it was tested first; see Figure 4.1.2.3.]

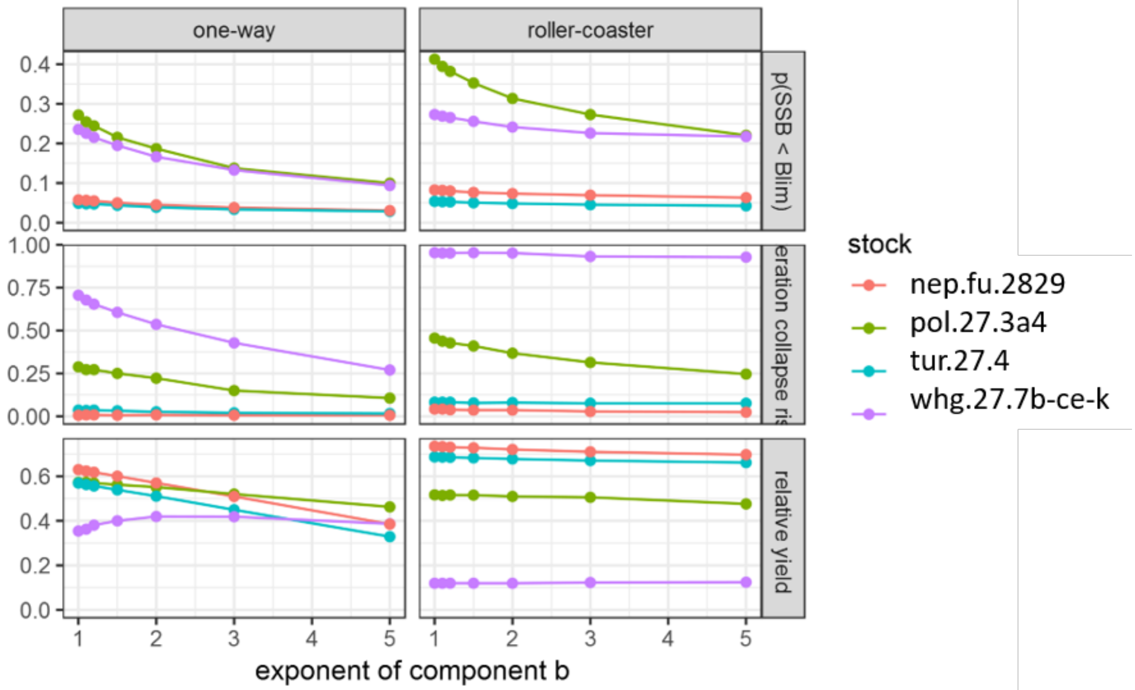

Figure 4.1.2.5. Initial tuning of the base 3.2.1 rule with *z* (the exponent of *b*) on the four selected stocks for the one-way (left) and roller-coaster (right) OMs, considering risk (top), probability of collapse (middle) and relative yield (bottom).

2-dimensional tuning with x and z

Having established the region of x and $z$values to explore, Figure 4.1.2.6 presents a finer 2-dimensional grid for these control parameters in terms of risk, probability of

collapse and relative yield for the base 3.2.1 rule. A lower $x$always leads to a lower risk and probability of collapse, but is also associated with a loss in relative yield (so there is a clear trade-off), except for the cases where risk is initially higher; in these cases, relative yield initially increases despite the lower exploitation level as x decreases, because risk and probability of collapse are reduced and there are more iterations where the stock is in a healthier state and is therefore able to produce better yields. Increases in z do not have as dramatic an effect on risk and probability of collapse (and in some cases almost no effect) except when risk is high; in those cases, increasing z can have a strong positive effect on risk and probability of collapse without too much loss in yield.

A pattern also emerges in Figure 4.1.2.6, whereby the behaviour of nep-2829 and tur-nsea are similar to each other, and that of pol.27.3a4 and whg.27.7b–ce–k are similar to each other, but quite different from the former two stocks. Comparing some life-history traits (Table 4.1.1.1), pol.27.3a4 and whg.7e–k have an M/k ratio of 1.12 and 1.15 respectively, while the M/k ratios for nep.FU2829 and tur.27.4 are 1.25 and 1.38 respectively; therefore, the former two have lower M/k ratios than the latter two; they also have a higher L_{50}/L_{∞} (i.e. mature later relative to L_{∞}; Table 4.1.1.1). A lower M/k value implies the fish attain a maximum length at a younger age relative to the maximum age (i.e. they grow quickly to a maximum length and then effectively stop growing but continue to age at that length), so that rules based on length (such as the base 3.2.1 rule) are not as effective for such stocks (because measures such as mean length do not change until the stock is heavily depleted).

Patterns are clearer in Figures 4.1.2.7–8, which plot the same information as Figure 4.1.2.6, but along one dimension at a time. Taking the lower M/k stocks for the one-way OMs first (pol.27.3a4 and wgh.27.7b–ce–k; Figure 4.1.2.7), there is a strong positive effect on risk and probability of collapse when reducing x from 1, with a positive effect on relative yield as well (at least initially), with relative yield peaking around 0.9–0.95. For these stocks, there seems also to be a benefit for risk and probability of collapse in moving from z=1 to z=2 for a reasonably small loss in relative yield, but a further increase to z=3 has a smaller risk benefit but the same further loss in yield. Similar conclusions can be drawn when considering the roller-coaster OMs for these same stocks (Figure 4.1.2.8), but with a further decrease in x (down to 0.85) attaining further improvements in risk/probability of collapse and relative yield peaking around 0.85–0.9. On balance, for lower M/k stocks where the length based catch rule is not expected to be as effective, results indicate that x=0.9 and z=2 generally improves performance of the base 3.2.1 catch rule in terms of risk, probability of collapse and relative yield compared to setting x=1 and z=1.

For higher M/k stocks (nep.fu.2829 and tur.27.4), the benefits to risk and probability of collapse in reducing x appear small for both the one-way and roller-coaster OMs (Figures 4.1.2.7–8), but this is because these performance statistics are already low (compared to the lower M/k stocks); in relative terms, the improvements are still substantial, at least initially (risk is reduced by more than 60% by implementing x=0.95). There is, however, an associated large drop in relative yield as x is reduced. Increasing z to 2 or 3 results in little or no improvement in terms of risk and probability of collapse, but leads to a loss in relative yield for the one-way OMs (Figure 4.1.2.7). The choice of control parameter for higher M/k stocks is more difficult because there is a trade-off in terms of risk/probability of collapse on one hand, and relative yield on the other. When discussed during the WG, it was felt that in the light of the uncertainty and to better ensure precautionarity, conservation performance criteria should get priority. Therefore, there is some justification in setting x=0.95 and z=1.

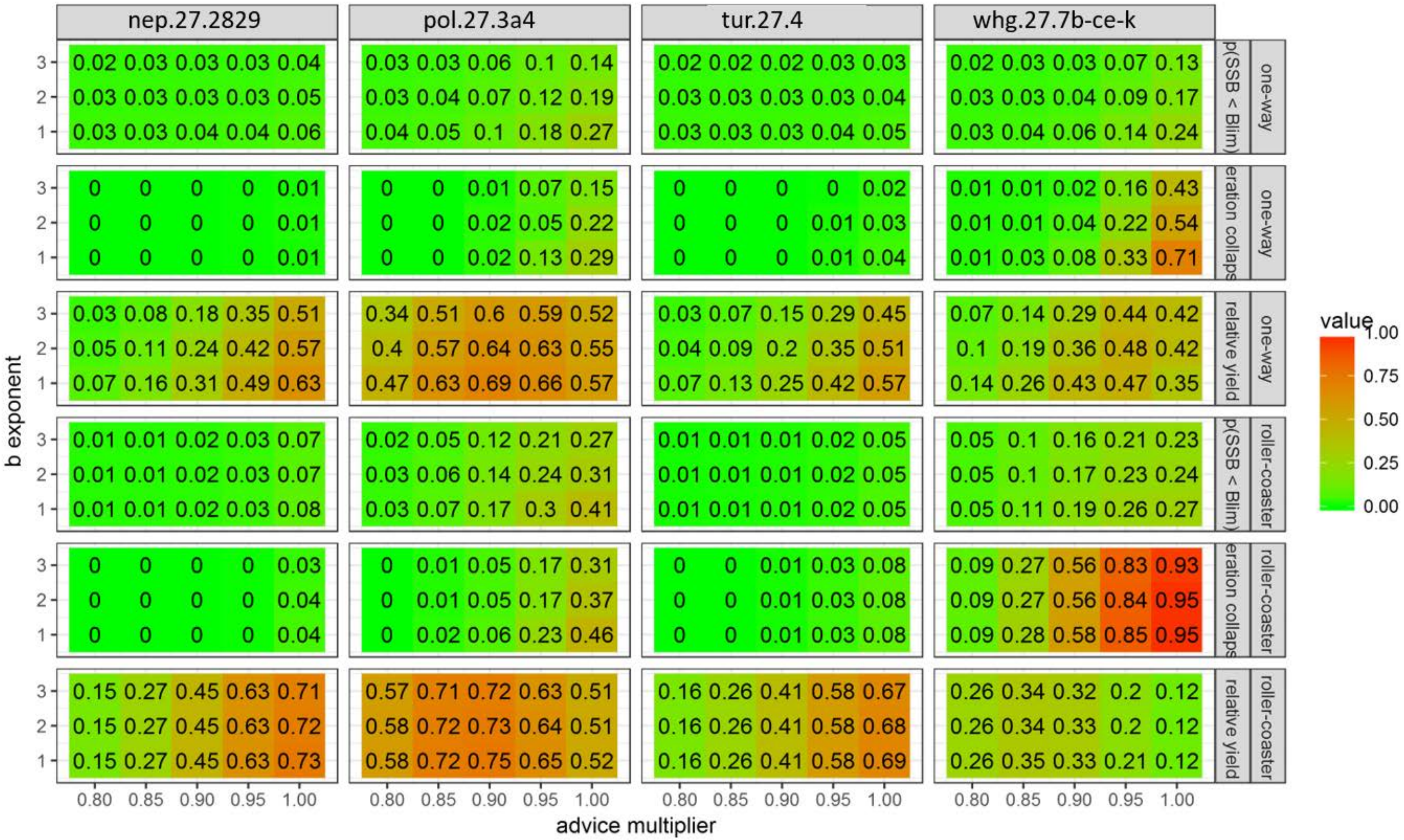

Figure 4.1.2.6. Refined 2-dimensional tuning of the base 3.2.1 rule, across a grid of values for x (advice multiplier on the horizontal axis) and z (b exponent on the vertical axis). Columns indicated the four selected stocks, while the first three rows are for the one-way OMs and the last three rows for the roller-coaster OMs; within each set of three rows, performance statistic for risk [P(SSB<B_{lim})] (top), probability of collapse (middle) and relative yield (bottom) are shown.

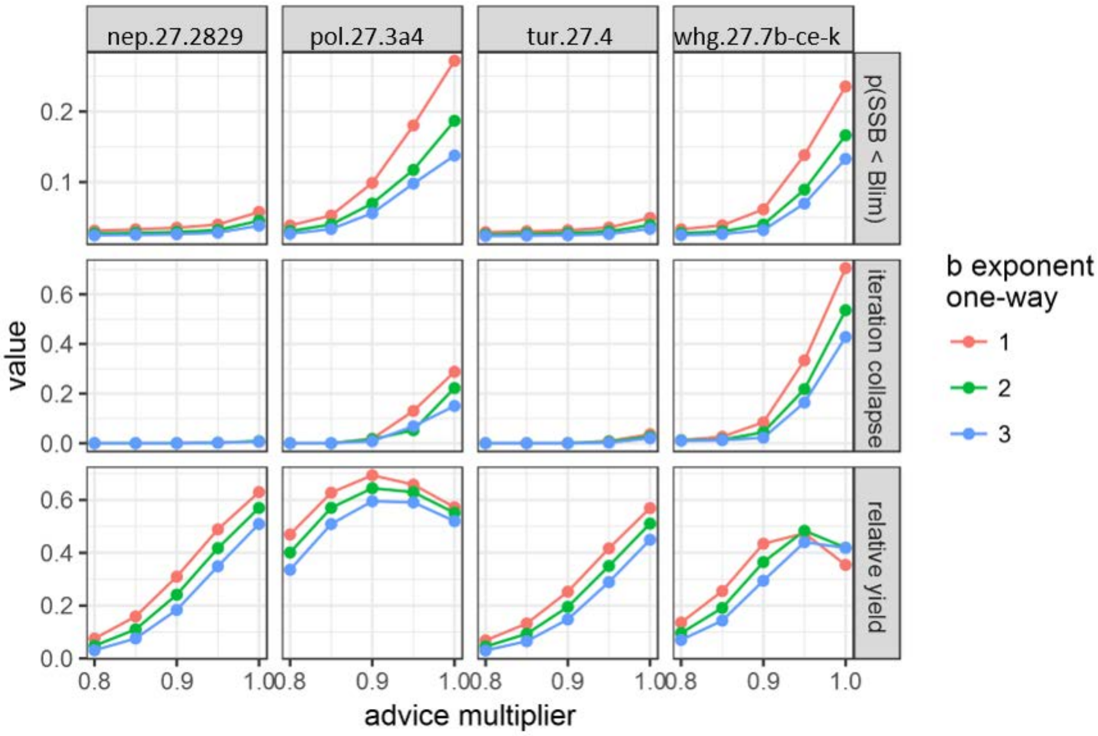

Figure 4.1.2.7. The same information is presented as in Figure 4.1.2.6, but for the one-way OMs, where different coloured lines represent different *z* (*b* exponent) values, and dots within a line different *x* (advice multiplier) values.

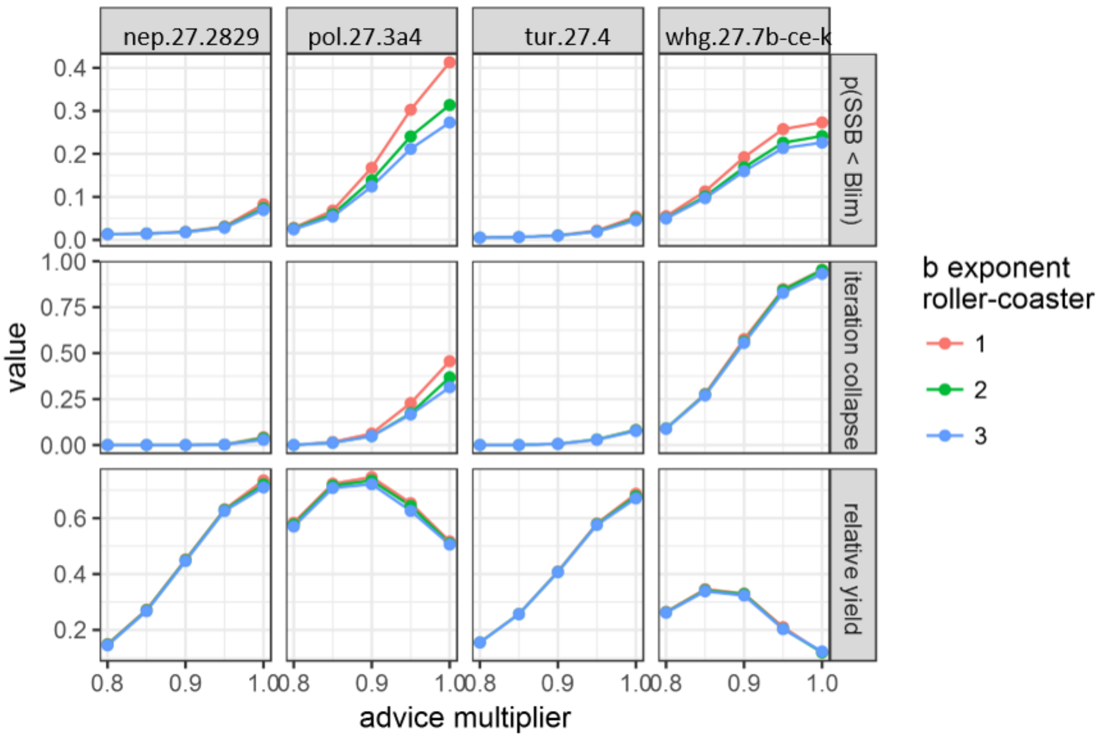

Figure 4.1.2.8. The same information is presented as in Figure 4.1.2.6, but for the roller-coaster OMs, where different coloured lines represent different *z* (*b* exponent) values, and dots within a line different *x* (advice multiplier) values.

Initial individual tuning with upper constraint

TAC constraints can also be used to tune MSs, and this idea was pursued here, while leaving control parameters *x* and *z* both set to 1 (it was simply too time-consuming to explore all possible combinations during the meeting). We started off by just considering the upper constraint, and its influence on performance statistics. Figure 4.1.2.9 explores the effect of introducing an upper TAC constraint on risk, probability of collapse and relative yield for the four selected stocks and two catch histories. The upper constraint has little or no effect on all performance statistics if it is 1.5 or larger, and starts to have a substantial effect for values below 1.3. The values of 1.1, 1.2 and 1.3 were selected for further analysis.

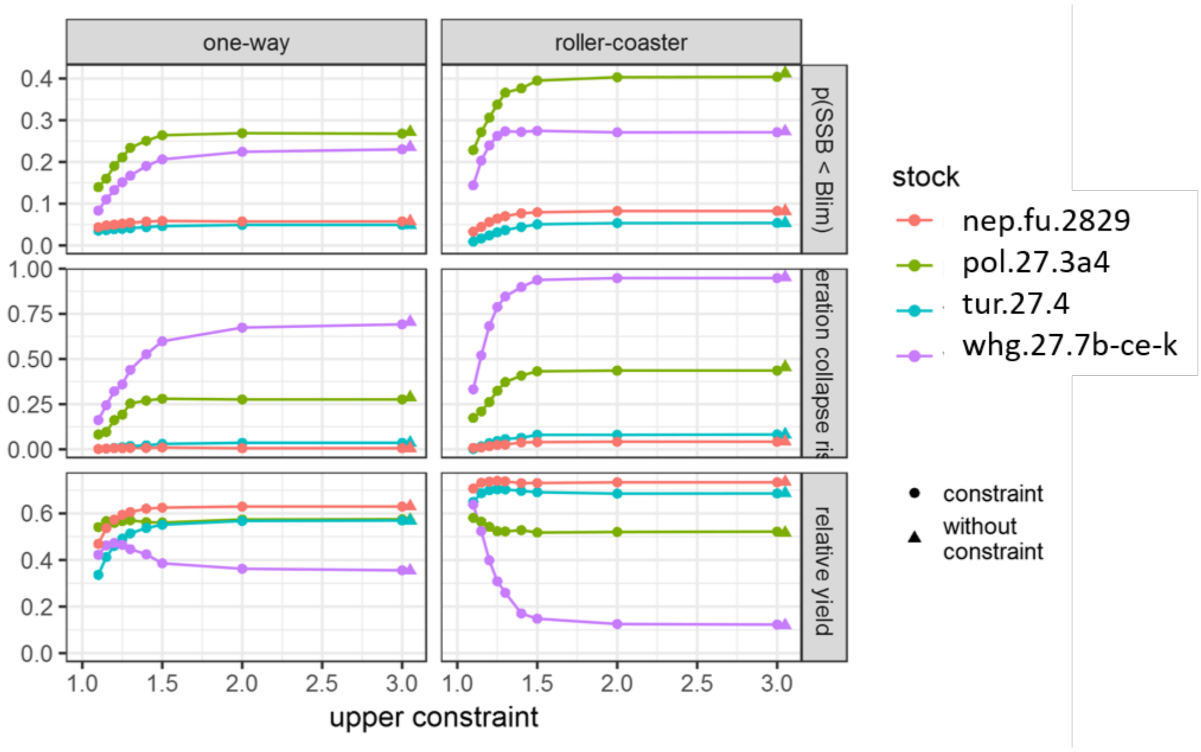

Figure 4.1.2.9. Initial tuning of the base 3.2.1 rule with the upper TAC constraint on the four selected stocks for the one-way (left) and roller-coaster (right) OMs, considering risk (top), probability of collapse (middle) and relative yield (bottom). Values for the upper constraint (left to right on the horizontal axis) were 1.1. 1.15, 1.2, 1.25, 1.3, 1.4, 1.5, 2 and 3). The solid triangles represent the values if no upper constraint is implemented.

2-dimensional tuning with upper and lower constraint

Figure 4.1.2.10 presents a finer 2-dimensional grid for combinations of upper and lower constraints for the base 3.2.1 rule with control parameters *x* and *z* set to 1. As expected, risk and probability of collapse are reduced by reducing both the upper and lower constraints, thus restricting increases and allowing larger decreases. The effect on relative yield is more complex. For the one-way OMs, when risk and probability of collapse are high, then reducing both the upper and lower limits initially has a positive effect on relative yields, because there are then more iterations with healthy stocks that can then produce better yields. Results are slightly different for the roller-coaster OMs; risk and probability of collapse remain high for the lower M/k stocks (pol.27.3a4 and whg.27.7b–ce–k), so relative yield continues to increase when the upper and lower constraints are reduced; the pattern is similar for the higher M/k stocks (nep.fu.2829 and

tur.27.4), although the increase in relative yield is sometimes reversed when the upper and lower constraints are around their lowest values.

Patterns are clearer in Figures 4.1.2.11–12, which plot the same information as Figure 4.1.2.10, but along one dimension at a time: a general reduction in risk and probability of collapse for when the upper and lower constraints are reduced, but a more complicated picture for relative yields. For the one-way OMs and higher M/k stocks (nep.fu.2829 and tur.27.4; Figure 4.1.2.11), there is not much further improvement in risk/probability of collapse for a lower TAC constraint smaller than 0.7, and reducing the upper constraint has a negligible effect on risk/probability of collapse but a negative effect on relative yields if set too low (e.g. compare the distance between 1.1 and 1.2, and between 1.2 and 1.3); the average yield peaks at a lower constraint of 0.7. For the one-way OMs and lower M/k stocks (pol.27.3a4 and whg.27.7b–ce–k; Figure 4.1.2.11), reducing both the upper and lower constraints has a strong effect positive on risk and probability of collapse, but the rate of improvement slows down for reductions in the lower constraints; relative yield actually improves in most cases when the upper constraint is reduced, reflecting that risk and probability of collapse is very high to start with, and stays high longer and does not reduce as far as the higher M/k stocks (the number of iterations with healthier stocks is less, so there is more scope for relative yield to improve as the upper constraint is reduced); relative yield either peaks or the rate of improvement slows around a lower constraint of 0.7. So for the one-way OMs, a lower limit of 0.7 seems reasonable for all stocks, while an upper constraint of 1.2 could be used for the higher M/k stocks, but lower M/k stocks could benefit from a smaller upper constraint (e.g. 1.1).

Results for the roller-coaster OMs lead to similar conclusions (Figure 4.1.2.12), despite slightly different behaviour. For the higher M/k stocks (nep.fu.2829 and tur.27.4) There is not much further improvement in risk/probability of collapse beyond a lower constraint of 0.7, and there is a slight improvement when reducing the upper constraint from 1.3 to 1.2 (and bigger improvement when reducing it from 1.2 to 1.1). Relative yield is counter-intuitively increased with reductions in the upper constraint when the lower limit is set high (0.9), pointing to the possibility of transient behaviour being hidden in performance statistics summarising performance over the entire projection period, and requires closer scrutiny. Relative yields improve in some cases until a lower constraint of 0.7 is reached, and then do not change much beyond that, while relative yields are similar or slightly larger from an upper constraint of 1.2 compared to 1.1. For the lower M/k stocks (pol.27.3a4 and whg.27.7b–ce–k), risk and probability of collapse either continue to reduce or do not improve much beyond a lower constraint of 0.7, while there are moderate to large reductions when reducing the upper constraint from 1.2 to 1.1 (differences are smaller between 1.3 and 1.2). On relative yield improvements are less beyond a lower constraint of 0.7, while there are moderate large improvements when the upper constraint is reduced from 1.2 to 1.1.

In summary, results appear to indicate a lower constraint of 0.7 for all stocks and OMs, with an upper constraint of 1.2 likely being adequate for higher M/k stocks, but a tighter upper constraint of 1.1 being more beneficial for lower M/k stocks.

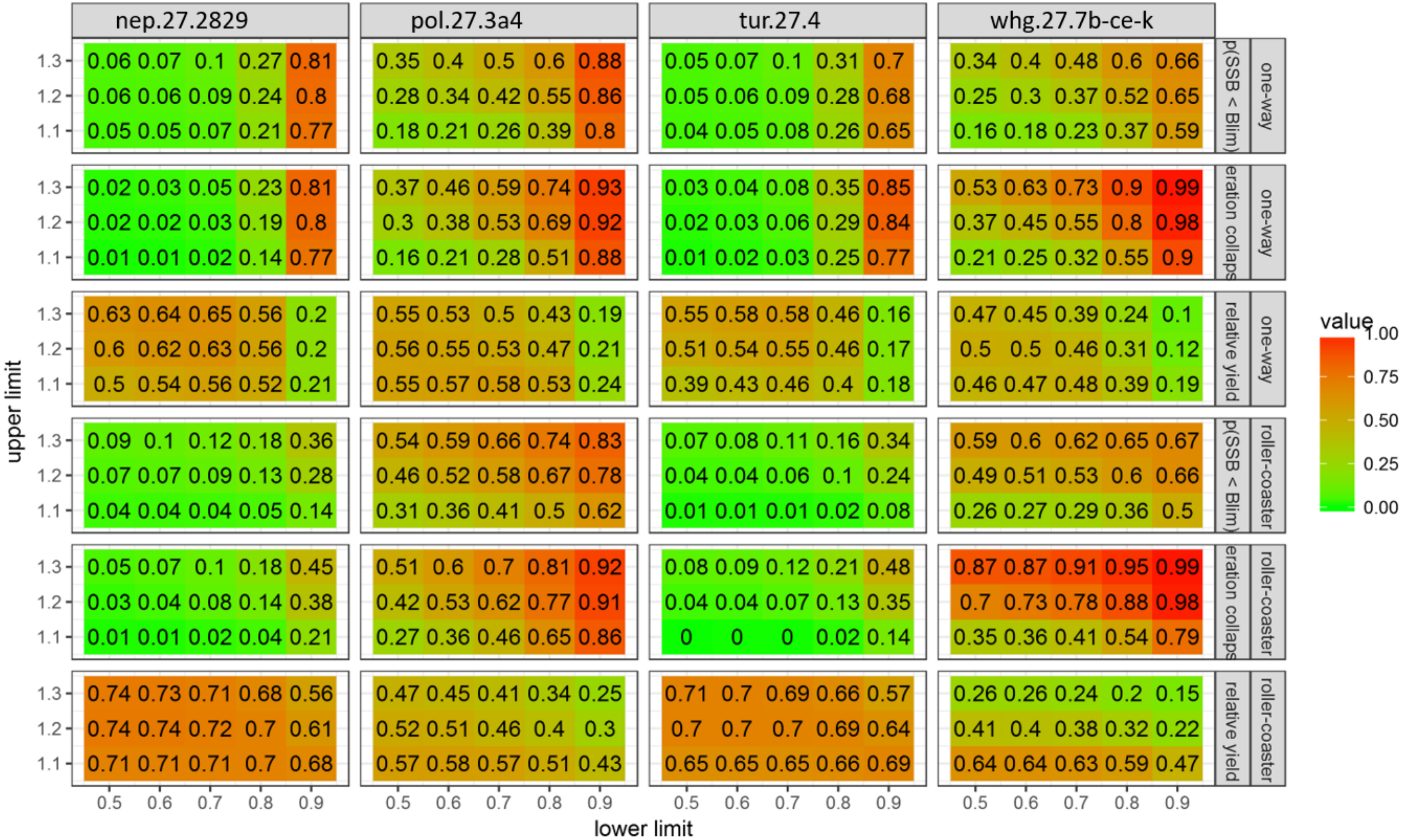

Figure 4.1.2.10. Refined 2-dimensional tuning of the base 3.2.1 rule, across a grid of values for lower (horizontal axis) and upper (vertical axis) TAC constraints. Columns indicated the four selected stocks, while the first three rows are for the one-way OMs and the last three rows for the roller-coaster OMs; within each set of three rows, performance statistic for risk [P(SSB<B_{lim})] (top), probability of collapse (middle) and relative yield (bottom) are shown.

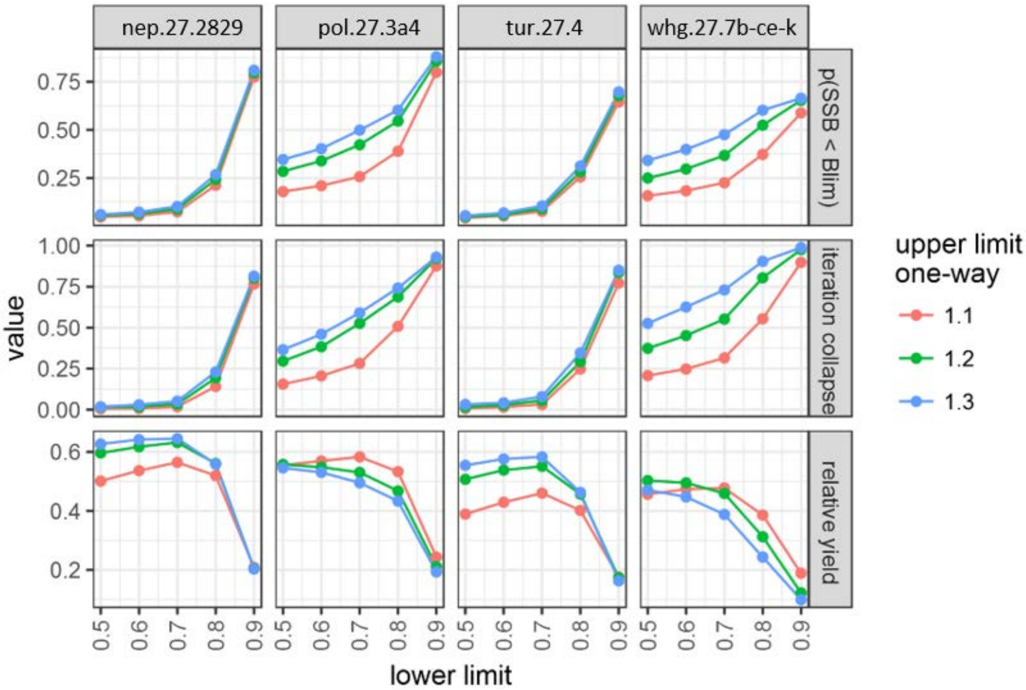

Figure 4.1.2.11. The same information is presented as in Figure 4.1.2.10, but for the one-way OMs, where different coloured lines represent different upper TAC constraints, and dots within a line different lower TAC constraints.

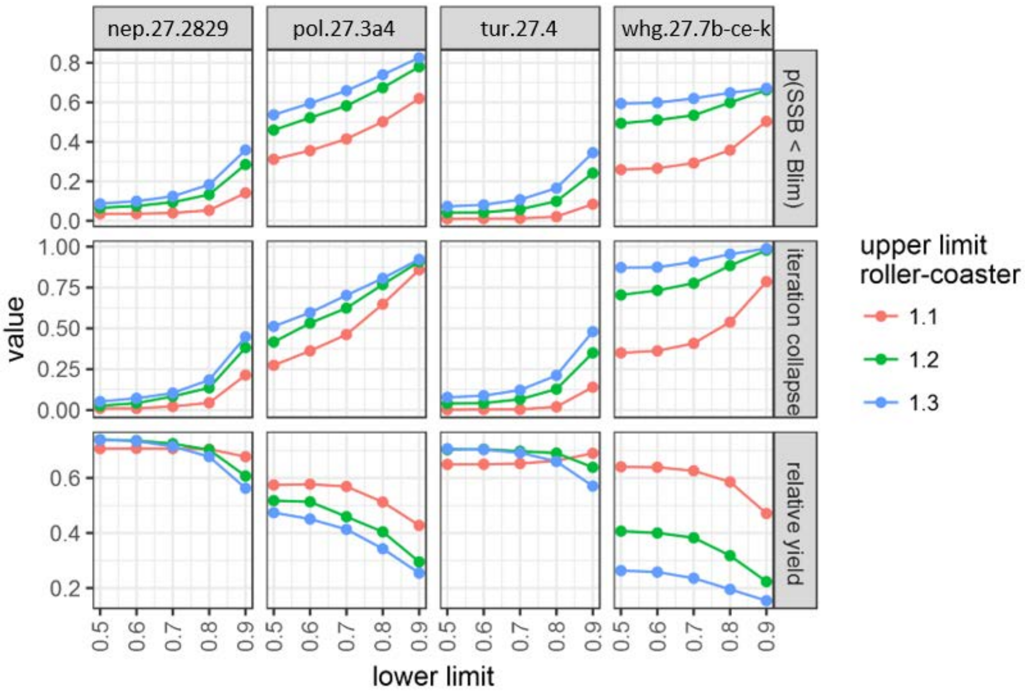

Figure 4.1.2.12. The same information is presented as in Figure 4.1.2.10, but for the roller-coaster OMs, where different coloured lines represent different upper TAC constraints, and dots within a line different lower TAC constraints.

4.1.3 Catch rule 3.2.2 (the F_{proxy} rule)

The catch rule to be tested was:

$$C_{y+1} = I_{\text{current}} F_{proxy,MSY}\ b \quad 4.1.3.1$$

where

$$b = \min\{1; \frac{I_{current}}{w \times I_{lim}}\} \quad 4.1.3.2$$

and the survey index I_{current} was set as I_{y-1}, I_{lim} as the lowest survey index in the final 25 years of the historic period (set at the start of the projection period and not updated during an iteration), and w set to 1.4.

In the perfect knowledge simulation, no observation error is included and $F_{proxy,MSY}$ is set to the "true" F_{MSY} (in terms of Catch/Index) from the OM (Figure 4.1.3.1). Under perfect knowledge conditions, this MS appears to work satisfactorily for most stocks (SSB recovers and is stabilised) apart from to shorter-lived stocks (her.27.nirs and san.sa.4) for which the rule induces strong cyclical behaviour. This is likely being caused by the time-lag assumed between the availability of data (year y-1) and the management being imposed based on these data (year y+1). In reality, the gap between the latest available data and when management is implemented, based on these data is far shorter (weeks and months rather than two years; this effect being compounded by biennial advice), so the MS, as currently simulated, was not deemed appropriate to these shorter-lived stocks and these stocks were consequently ignored in further analyses. Nevertheless, behaviour of the MS for these stocks could be improved by using control parameters (see the WD in Annex 3 for more details).

Figure 4.1.3.2 illustrates the rule for pol.27.3a4 and the one-way OM when observation error was included (on survey index and $F_{proxy,MSY}$), and contrasts this with the perfect knowledge run. We see here that performance is similar in the two cases and the rule appears to recover the stock to its MSY level within a reasonably short time. It should be noted, however, that this MS relies on a good approximation for F_{MSY}, and if this is not well approximated, could target a level that is inappropriate (e.g. an F above F_{MSY}). Control parameters similar to x and z used for the base 3.2.1 rule could be considered to deal with this problem, but this was not explored during the meeting.

Further analyses were conducted before the meeting and are described in the WD in Annex 3.

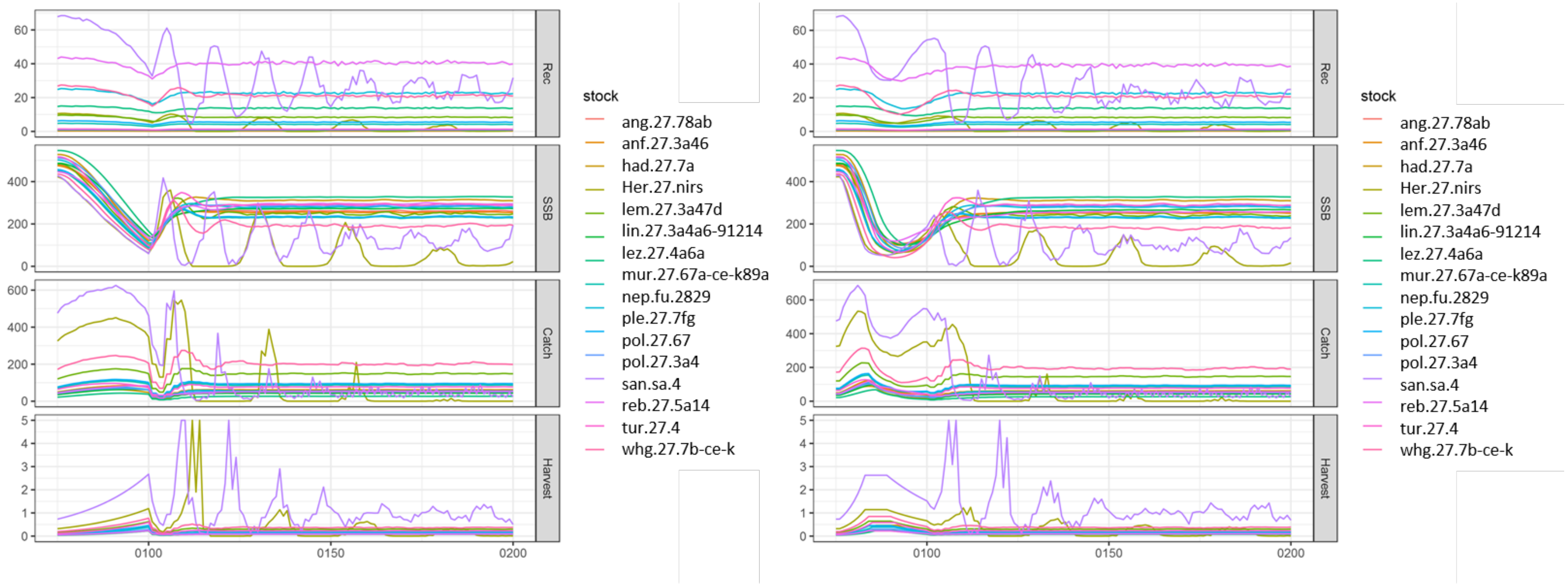

Figure 4.1.3.1. Application of catch rule 3.2.2 (the F_{proxy} rule) for the 15 stocks listed in Table 4.1.1.1 for the one-way (left) and roller-coaster (right) OMs, assuming perfect knowledge (but including recruitment variation). Solid lines indicated the median from 500 iterations.

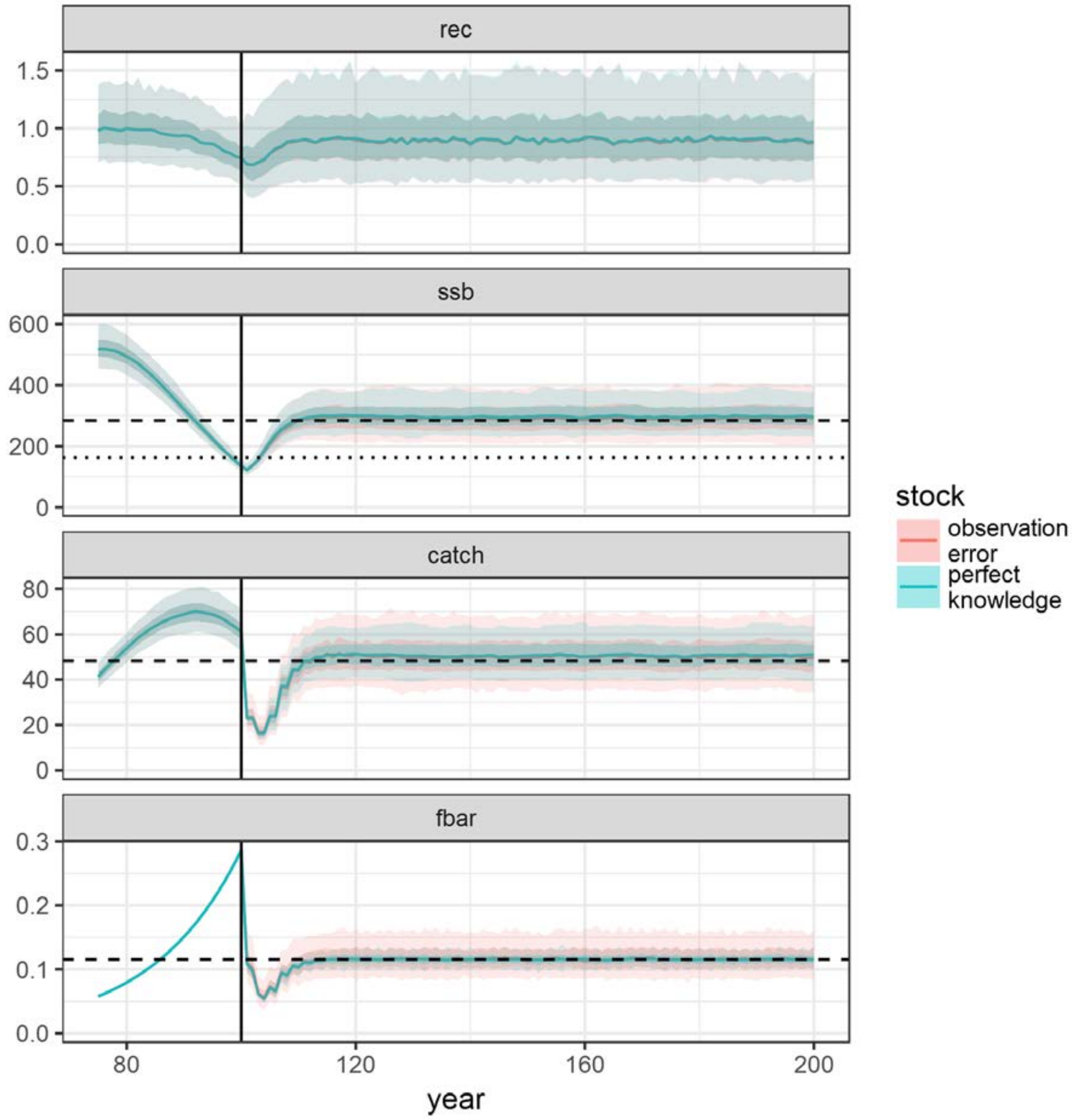

Figure 4.1.3.2. Application of catch rule 3.2.2 (the F_{proxy} rule) for the pol.27.3a4 for the one-way OM. The plot provides a comparison between the run assuming perfect knowledge, and that including observation error. Solid lines indicated the median from 500 iterations. Long-dashed horizontal lines are the MSY values, while the dotted line in the SSB plot indicates B_{lim}.

4.1.4 Catch rule 3.1

This MS requires the application of a model such as SPiCT (Pedersen and Berg, 2017), which includes a forecasting methodology. This MS has been investigated elsewhere in this report, so this run was more of a "proof of concept" to demonstrate that performance of SPiCT coupled with its forecasting methodology could also be explored with FLR. Figure 4.1.4.1 illustrates the performance of SPiCT and its forecast on pol.27.3a4 for the roller-coaster OM where observation error is included, and it appears to slightly overshoot B_{MSY} and undershoot F_{MSY} towards the end of the projection period, but gets the MSY level of catch more-or-less right. This is perhaps not surprising given that the OM is age-structure, while SPiCT is an aggregated biomass-based model. For more detail, see the WD in Annex 3.

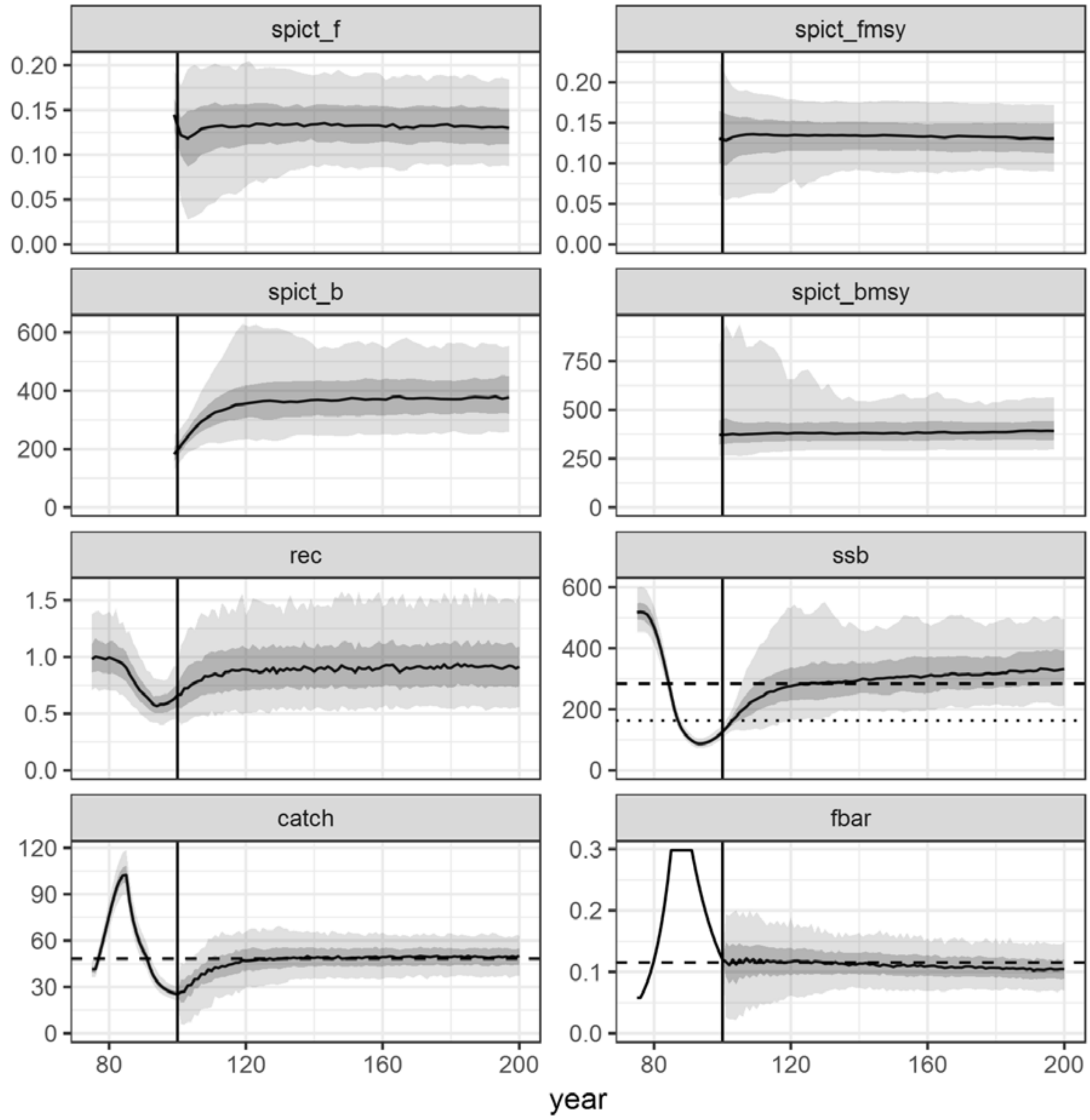

Figure 4.1.4.1. Application of SPiCT with its forecasting methodology to pol.27.3a4 for the roller-coaster OM, including observation error. The two top rows are SPiCT estimates, while the two bottom rows are OM summaries. The solid black trajectories are medians with 50% (dark grey) and 95% (lighter grey) confidence envelopes. The solid vertical line indicates the end of the historic period and start of the projection period (during which SPiCT is applied). The Long-dashed horizontal lines are the MSY values, while the dotted line in the SSB plot indicates B_{lim}.

4.1.5 Conclusions and discussion

Catch rule 3.2.1

The following conclusion are extracted from the working document (Annex 3), the conclusions from the work during the workshop follow afterwards:

- The individual components of the catch rule showed poor performance when implemented on their own:
  - From the three tested options for component f, option a seemed to perform best. The resulting value for f showed its potential to track general stock trends but the interpretation of the absolute values is questionable

as it depends on the definition of the reference length. The calculation of the reference length depends crucially on the assumptions and can deviate substantially from the real length at MSY in both directions. This can cause major issues as this might lead to a misspecification of the target.

- There can be large time-lag between the peaks in SSB and f.

- Using the catch rule as intended by WKMSYCat34, i.e. combining all individual components together, could alleviate some of the issues.
- Option a from component r (2 over 3 rule) seemed to perform best with more stable trends and smaller oscillations.
- Combinations with options b or c for component f showed very poor performance.
- From the tested combinations of the individual options for the components, the combination r:a & f:a & b:a seemed to work best but still failed entirely for some stocks.
    - Under perfect knowledge assumptions, the catch rule worked reasonably for some stocks but not at all for others.
- Including observation error and making realistic assumptions (M/K ratio) caused high uncertainty (collapse <-> virgin biomass), led to less stability and for some stocks a misspecification of the MSY target.
- The advised catch is the product of several factors (the components of the catch rule). If only one factor failed (i.e. very large or very low/zero), the entire catch rule failed.
- The new catch is always based on the last catch. This causes some serious issues:
    - If the catch is zero at any point, either because of a zero advice or due to a stock collapse, the catch can never(!) recover, as it is always a factor of zero, i.e. zero.
    - There is always a time-lag between the stock dynamic and the catch advice.
    - As the advice does not have an absolute target, the advised catch oscillates around its target until it reaches this value. This might be reasonable for some stocks but others are less resilient and these oscillations can cause stock collapses.
- Preliminary tuning of catch rule described in the working document presented to WKLIFE showed that the catch rule can be improved.
    - An advised catch multiplier could improve the performance, reduce the risk (both in terms of risk of falling below B_{lim} and the risk of stock collapses) and even lead to higher yield
    - Modifying the calculation of $I_{trigger} = w\ I_{lim}$ (by changing w) did not satisfactorily improve the performance.
- None of the options of catch rule 3.2.1 worked for the two pelagic/shorter-lived stocks (her.27.nirs, san.sa.4).
- More generic testing of the catch rules and assumptions is crucial. Before the catch rule is applied, it should be thoroughly tested and fine-tuned with stock-specific MSE simulations.

These conclusions can be extended by the work conducted during the workshop:

From the analyses presented on the base 3.2.1 rule, it appears that length-based methods are not ideal for lower M/k stocks, requiring the use of either control parameters (x and z) or TAC constraints lower and upper) in order to improve performance statistics (both in terms of risk and probability of collapse on the one hand, and relative yields on the other); analyses presented did not look at combinations of control parameters and TAC constraints. For higher M/k stocks, there is generally a trade-off between risk/probability of collapse and relative yield, so tuning the rule with control parameters x and z to improve the one generally leads to a deterioration in the other.

In general, for control parameters x and z:

- For lower M/k stocks (M/k ≤ 1.15), setting x=0.9 and z=2 generally improves performance of the base 3.2.1 catch rule in terms of all the performance statistics considered (risk, probability of collapse and relative yield) compared to setting x=1 and z=1.
- For higher M/k stocks (M/k ≥ 1.25), setting x=0.95 and z=1 improves risk/probability of collapse while limiting the loss in relative yield.

In general, for upper and lower TAC constraints:

- For lower M/k stocks (here M/k ≤ 1.15), restricting increases in TAC more tightly (upper constraint of no more than 1.1) generally leads to improved performance across all performance statistics (risk, probability of collapse and relative yield).
- For higher M/k stocks (M/k ≥ 1.25), the upper constraint has a marginal effect on risk/probability of collapse, but smaller values can have a negative effect on relative yield; a value of 1.2 seems a reasonable compromise.
- For the upper constraints indicated above, a lower constraint of 0.7 appears reasonable for both higher and lower M/k stocks, where not much more is gained in terms of risk/probability of collapse by going to smaller values, while restricting losses in relative yield.

Catch rule 3.2.2

The F_{proxy} rule seems to work well (apart from shorter-lived stocks), but the $F_{proxy,MSY}$ used by the rule needs to be a reasonable approximation for F_{MSY}. In reality is quite difficult to determine a historic period corresponding to MSY and poorly chosen period can lead to poor performance.

Control parameters such as x and z could be used to deal with uncertainty in the quality of this approximation.

Catch rule 3.1

SPiCT (with its forecasting methodology) appears to achieve the MSY catch level accurately, while drifting slightly above B_{MSY} and below F_{MSY} through time. The management based on SPiCT works directly on the (observed) fishing mortality and has an absolute target. In contrast to the other catch rules, this does not lead to strong oscillations in stock dynamics as observed for catch rules 3.2.1 and 3.2.2.

General conclusions

In general, if there are more data available, this should be reflected in the use of a catch rule. Catch rule 3.1 (SPiCT) seemed to outperform catch rules 3.2.1 (length-based methods) and 3.2.2 (Icelandic rule) and catch rule 3.2.2 seemed to outperform catch rule 3.2.1 (with default parametrizations, see working document in Annex 3). If a reasonable SPiCT fit is available, catch rule 3.1 seems appropriate and if a sustainable historic period can be detected, catch rule 3.2.2 could be considered.

The usual caveats to this type of simulation work applies, namely that conclusions are heavily based on the assumptions made and the way the simulations are set up (observation errors assumed, etc.). However, it should be noted that the OMs reflect a stock that was severely depleted (one-way OM) and a stock that had been severely depleted and was now recovering (but not yet recovered; roller-coaster OM); furthermore, age at 50% maturity coincided with age at 100%, which implied substantial fishing on immature fish was taking place. So, the MSs (the various catch rules) tested were subject to harsh OMs, and were therefore tested under harsh conditions. The justification for this approach is that one often does not know how depleted a stock is, so developing MSs that can recover stocks under such conditions would be beneficial.

Future work

Nevertheless, there are many areas that require further work/exploration:

- A wider range of M/k stocks would produce firmer conclusions on the behaviour of the catch rules relative to M/k; analyses presented already highlight important differences related to M/k.
- Conclusions were based on a restricted set of stocks because of time constraints during the meeting; the work needs to be expanded to a wider range of stocks.
- The base 3.2.1 rule (the "2 over 3" rule for r combined with the L_{mean}/L_{∞} for f, and the protection component b) did not perform well with lower M/k stocks, likely because L_{mean}/L_{∞} is less responsive for these stocks (rapid growth to the largest lengths so these lengths contain many ages); alternatives for these stocks should be explored (e.g. $L_{max5\%}/L_{SPR40\%}$, which focuses only on the largest individuals).
- For the base 3.2.1 rule, there were cases where some stocks were driven very low, and catches low as a result, in some cases these stocks managed to recover to virgin levels, despite having nearly collapsed, because catch never recovers. These stocks should have been deemed "collapsed" and not allowed to recover. This may affect the risk performance statistic (which measures the annual risk of being below B_{lim}) but will not affect the probability of collapse statistic (which records if a stock collapsed during an iteration). This effect needs to be dealt with in future work.
- Category 4 rules (where r=1) need further exploration with tuning and alternatives (such as to $L_{max5\%}/L_{SPR40\%}$) to see if performance can be improved (the WD in Annex 3 indicated poor performance when f was used in isolation).
- Cross combinations with the control parameters (x and z) and TAC constraints (upper and lower) were not attempted, so these need further exploration, including techniques for testing performance across multiple dimension.

- Further exploration of the F_{proxy} rule to investigation the behaviour of the rule and the use of control parameters when the quality of the approximation $F_{proxy,MSY}$ is uncertain.
- Further work on the implementation of SPiCT into the FLR framework, with reasonable assumptions about what to do if the assessment fails, should be explored.
- The simulation work conducted prior and during WKLIFE VII is only a first glimpse into the performance of catch rules for category 3–4 data-limited stocks. More testing is crucial and as such, work requires particular focus and attention.

4.1.6 References

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5 Future directions of work for DLS stocks; issues

Subgroup 3 addressed ToR e) of the terms of reference; i.e. to review available information on the basis for an advice rule for category 3 to 6 stocks of short-lived species and consider the need for specific advice rules for these stocks.

5.1 Short-lived species

A definition of which species should be considered short-lived, was discussed in WKLIFE VII: this definition differs slightly from the one provided in the ICES advice technical guidelines (ICES, 2017a), since it includes life-history characteristics. In particular, the subgroup agreed that the definition applies to species with an early maturity, a fast growth and therefore a relatively short lifespan and/or species that show marked interannual and seasonal variability of recruitment and biomass. This includes anchovy, sprat, sardine, capelin, Norway pout, sandeel, red mullet and herring.

Based on this definition, five category 3 and 4 stocks were identified:

- Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters);
- Sprat (*Sprattus sprattus*) in Division 3.a (Skagerrak and Kattegat);
- Sprat (*Sprattus sprattus*) in divisions 7.d and 7.e (English Channel);
- Striped red mullet (*Mullus surmuletus*) in Subarea 4 and divisions 7.d and 3.a (North Sea, eastern English Channel, Skagerrak and Kattegat);
- Herring (*Clupea harengus*) in Subdivision 31 (Bothnian Bay).

Anchovy in Division 9.a and sprat in division 3.a are scheduled for a benchmark in 2018 and could potentially be moved to category 1: this would leave only three data-limited short-lived species.

Based on the simulation results carried out by subgroup 2, subgroup 3 highlighted the fact that several of the management strategies investigated do not work for short-lived-species, such as herring and sandeel (which were the only two short-lived species tested): the impression is that this might be related to the higher growth rate (*k*parameter) typical for these species, and therefore a seasonal modelling approach might resolve the problem.

So far, of the methodologies that have been presented to WKLIFE VII, the more promising for short-lived species seems to be the survey based TAC rules in an MSE-like framework (Section 5.4); however, the results were still preliminary and the model still needs improvement.

All these considerations lead to the conclusion that a workshop on assessment, harvest control rules and MSE for data-limited short-lived species is most needed; despite the fact that the species currently in the list are just a handful, the discussions and outcomes will be relevant to a wider range of situations. The workshop should be held in the first half of 2018 and the subgroup suggested to have a chair from DTU Aqua.

Recommendation: Early in 2018, convene an ICES Workshop on DLS short-lived species that addresses both assessment methods; e.g. seasonal SPiCT, and long-term management strategy evaluations; building on the work of WKLIFE VII. Two chairs are recommended (Rasmus Nielsen, Denmark and ANOTHER to be identified). It is suggested, that the workshop focus on the five stocks identified by WKLIFE VII in Section 5.1 of their report.

5.2 Category 3 and 4 stocks

ACOM submitted a list of stocks to be lifted from category 3 to category 1:

- Kattegat Cod (cod.27.21);
- Eastern Baltic Cod (cod.27.25–32);
- Plaice Baltic Sea subdivisions 24–32 (ple.27.24–32);
- Lemon sole, North Sea (lem.27.3a47d);
- Witch flounder, North Sea (wit.27.3a47d);
- *Nephrops* in Atlantic Iberian waters East and southwestern and southern Portugal (nep.fu.2829);
- Anglerfish in subareas 4 and 6, and Division 3.a (anf.27.3a46);
- Black-bellied anglerfish in divisions 7.b–k, 8.a–b, and 8.d (ank.27.78ab);
- Plaice, Western English Channel (ple.27.7e).

These stocks should therefore be removed from the list of stocks to be tested with SPiCT.

Table 5.2.1 presents an additional list of category 3 and 4 stocks and was compiled to identify the species to be assessed using a production model; e.g. SPiCT, and those to be assessed using other tools, such as DLMtool or FLR.

Table 5.2.1. Prioritization of assessment method development for ICES data category 3–4 stocks going forward.

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
anf.27.3a46	Anglerfish (*Lophius budegassa, Lophius piscatorius*) in subareas 4 and 6, and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)	3.20	2017	2018	fail	fail	Awaiting benchmark results
ank.27.78ab	Black-bellied anglerfish (*Lophius budegassa*) in divisions 7.b–k, 8.a–b, and 8.d (west and southwest of Ireland, Bay of Biscay)	3.20	2016	Unknown	NA	NA	Awaiting benchmark results
cod.27.21	Cod (*Gadus morhua*) in Subdivision 21 (Kattegat)	3.20		2017	fail	fail	Awaiting benchmark results
cod.27.25–32	Cod (*Gadus morhua*) in subdivisions 25–32, eastern Baltic stock (eastern Baltic Sea)	3.20	2017	2018	SPiCT	SPiCT	Awaiting benchmark results
lem.27.3a47d	Lemon sole (*Microstomus kitt*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	3.20	2017	Unknown	SPiCT	SPiCT	Awaiting benchmark results
nep.fu.2829	Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 28–29 (Atlantic Iberian waters East and southwestern and southern Portugal)	3.20	2017	2019	$F_{0.1}$ from a length-based analysis, est. by mean-length Z method assuming knife-edge length selection	NA	Awaiting benchmark results

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
ple.27.7e	Plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel)	3.20	2016	2017	Based on segmented regression simulation of recruitment without error	EqSim	Awaiting benchmark results
ple.27.24–32	Plaice (*Pleuronectes platessa*) in subdivisions 24–32 (Baltic Sea, excluding the Sound and Belt Seas)	3.20	2017	Unknown	fail	fail	Awaiting benchmark results
bss.27.8ab	Sea bass (*Dicentrarchus labrax*) in divisions 8.a–b (northern and central Bay of Biscay)	3.20	2016	Unknown	fail	fail	Awaiting benchmark results
mon.27.78abd	White anglerfish (*Lophius piscatorius*) in divisions 7.b–k, 8.a–b, and 8.d (southern Celtic Seas, Bay of Biscay)	3.20	2016	Unknown	SPiCT	SPiCT	Awaiting benchmark results
wit.27.3a47d	Witch (*Glyptocephalus cynoglossus*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	3.20		2017	SPiCT	SPiCT	Awaiting benchmark results
nep.fu.25	Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and northern Galicia)	3.14	2016	Unknown	mean-length Z	NA	DLMtool/ FLR
nep.fu.31	Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay and Cantabrian Sea)	3.14	2016	Unknown	mean-length Z	NA	DLMtool/ FLR

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
nep.fu.2627	Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal)	3.14	2016	Unknown	mean-length Z	NA	DLMtool/ FLR
ple.27.7h–k	Plaice (*Pleuronectes platessa*) in Divisions 7h–k (Celtic Sea South, southwest of Ireland)	3.14	2016	2017	Median point estimates of Eqsim with segmented	Bpa	DLMtool/ FLR
boc.27.6–8	Boarfish (*Capros aper*) in subareas 6–8 (Celtic Seas, English Channel, and Bay of Biscay)	3.20	2017	2018	fail	fail	DLMtool/ FLR
bll.27.22–32	Brill (*Scophthalmus rhombus*) in subdivisions 22–32 (Baltic Sea)	3.20	2017	2017	fail	fail	DLMtool/ FLR
dab.27.22–32	Dab (*Limanda limanda*) in subdivisions 22–32 (Baltic Sea)	3.20	2017	2017	LBI	NA	DLMtool/ FLR
fle.27.3a4	Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	3.20	2017	Unknown	Expected mean length	NA	DLMtool/ FLR
fle.27.2628	Flounder (*Platichthys flesus*) in subdivisions 26 and 28 (east of Gotland and Gulf of Gdańsk)	3.20	2017	Unknown	fail	fail	DLMtool/ FLR
fle.27.2729–32	Flounder (*Platichthys flesus*) in subdivisions 27 and 29–32 (northern central and northern Baltic Sea)	3.20	2017	Unknown	LBI	NA	DLMtool/ FLR

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
aru.27.5b6a	Greater silver smelt (*Argentina silus*) in divisions 5.b and 6.a (Faroes grounds and west of Scotland)	3.20	2016	2017	Expected mean length of catch above Lmean when F = M	NA	DLMtool/ FLR
aru.27.123a4	Greater silver smelt (*Argentina silus*) in subareas 1, 2, and 4, and in Division 3.a (Northeast Arctic, North Sea, Skagerrak and Kattegat)	3.20	2016	2017	fail	fail	DLMtool/ FLR
aru.27.6b7–1012	Greater silver smelt (*Argentina silus*) in subareas 7–10 and 12, and Division 6.b (other areas)	3.20	2016	2017	fail	fail	DLMtool/ FLR
hom.27.3a4bc7d	Horse mackerel (*Trachurus trachurus*) in divisions 3.a, 4.b–c, and 7.d (Skagerrak and Kattegat, southern and central North Sea, eastern English Channel)	3.20	Not attempted or planned	Not attempted or planned	LBI; Expected mean length of catch above Lc when F=M, assuming M/K = 1.5.	NA	DLMtool/ FLR
lin.27.5b	Ling (*Molva molva*) in Division 5.b (Faroes grounds)	3.20		2017	Expected mean length	NA	DLMtool/ FLR
lin.27.1–2	Ling (*Molva molva*) in subareas 1 and 2 (Northeast Arctic)	3.20		2017	Expected mean length	NA	DLMtool/ FLR
lin.27.3a4a6–91214	Ling (*Molva molva*) in subareas 6–9, 12, and 14, and Divisions 3.a and 4.a (Northeast Atlantic and Arctic Ocean)	3.20	2016	2017	Expected mean length	NA	DLMtool/ FLR
sol.27.7h–k	Sole (*Solea solea*) in Divisions 7.h–k (Celtic Sea South, southwest of Ireland)	3.20	2016	2017	Median point estimates of EqSim with segmented regression S–R relationship	Bpa	DLMtool/ FLR

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
mur.27.3a47d	Striped red mullet (*Mullus surmuletus*) in Subarea 4 and divisions 7.d and 3.a (North Sea, eastern English Channel, Skagerrak and Kattegat)	3.20	2017	Unknown	Expected mean length	NA	DLMtool/ FLR
sal.27.32	Salmon (*Salmo salar*) in Subdivision 32 (Gulf of Finland)	3.80	Not attempted or planned	Not attempted or planned	NA	NA	DLMtool/ FLR
trs.27.22-32	Sea trout (*Salmo trutta*) in subdivisions 22–32 (Baltic Sea)	3.80	Not attempted or planned	Not attempted or planned	NA	NA	DLMtool/ FLR
reb.2127.sp	Beaked redfish (*Sebastes mentella*) in ICES subareas 5, 12, and 14 (Iceland and Faroe grounds, North of Azores, East of Greenland) and NAFO subareas 1 and 2 (shallow pelagic stock < 500 m)	3.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
cod.21.1a–e	Cod (*Gadus morhua*) in NAFO divisions 1.A-E, offshore (West Greenland)	3.14	2017	Unknown	NA	NA	SPiCT
cod.27.5b2	Cod (*Gadus morhua*) in Subdivision 5.b.2 (Faroe Bank)	3.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
ele.2737.nea	European eel (*Anguilla anguilla*) throughout its natural range	3.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
rjr.27.23a4	Starry ray (*Amblyraja radiata*) in subareas 2 and 4, and Division 3.a (Norwegian Sea, North Sea, Skagerrak and Kattegat)	3.14	Not attempted or planned	Not attempted or planned	-	-	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
reb.27.14b	Beaked redfish (*Sebastes mentella*) in Division 14.b, demersal (Southeast Greenland)	3.20	2017	Unknown	NA	NA	SPiCT
reb.27.5a14	Beaked redfish (*Sebastes mentella*) in Subarea 14 and Division 5.a, Icelandic slope stock (East of Greenland, Iceland grounds)	3.20	2017	Unknown	NA	NA	SPiCT
bsf.27.nea	Black scabbardfish (*Aphanopus carbo*) in subareas 1, 2, 4–8, 10, and 14, and divisions 3.a, 9.a, and 12.b (Northeast Atlantic and Arctic Ocean)	3.20	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
sho.27.89a	Black-mouth dogfish (*Galeus melastomus*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
sbr.27.10	Blackspot sea bream (*Pagellus bogaraveo*) in Subarea 10 (Azores grounds)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
sbr.27.9	Blackspot sea bream (*Pagellus bogaraveo*) in Subarea 9 (Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
rjh.27.9a	Blonde ray (*Raja brachyura*) in Division 9.a (Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjh.27.4c7d	Blonde ray (*Raja brachyura*) in divisions 4.c and 7.d (southern North Sea and eastern English Channel)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
jaa.27.10a2	Blue jack mackerel (*Trachurus picturatus*) in Subdivision 10.a.2 (Azores grounds)	3.20	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
bll.27.3a47de	Brill (*Scophthalmus rhombus*) in Subarea 4 and divisions 3.a and 7.d–e (North Sea, Skagerrak and Kattegat, English Channel)	3.20		2017	SPiCT	SPiCT	SPiCT
rjn.27.8c	Cuckoo ray (*Leucoraja naevus*) in Division 8.c (Cantabrian Sea)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjn.27.9a	Cuckoo ray (*Leucoraja naevus*) in Division 9.a (Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjn.27.3a4	Cuckoo ray (*Leucoraja naevus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjn-678abd	Cuckoo ray (*Leucoraja naevus*) in subareas 6 and 7 and divisions 8.ab and 8.d	3.20	Unknown	Unknown	-	-	SPiCT
dab.27.3a4	Dab (*Limanda limanda*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	3.20	2017	2017	SPiCT	SPiCT	SPiCT
fle.27.2223	Flounder (*Platichthys flesus*) in subdivisions 22 and 23 (Belt Seas and the Sound)	3.20	2017	2017	LBI	NA	SPiCT
fle.27.2425	Flounder (*Platichthys flesus*) in subdivisions 24 and 25 (west of Bornholm and southwestern central Baltic)	3.20	2017	Unknown	LBI	NA	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
gfb.27.nea	Greater forkbeard (*Phycis blennoides*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	3.20	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
gug.27.3a47d	Grey gurnard (*Eutrigla gurnardus*) in Subarea 4 and divisions 7.d and 3.a (North Sea, eastern English Channel, Skagerrak and Kattegat)	3.20	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
syc.27.8abd	Lesser-spotted dogfish (*Scyliorhinus canicula*) in divisions 8.a–b and 8.d (Bay of Biscay)	3.20	2017	Unknown	-	-	SPiCT
syc.27.8c9a	Lesser-spotted dogfish (*Scyliorhinus canicula*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
syc.27.3a47d	Lesser-spotted dogfish (*Scyliorhinus canicula*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
syc.27.67a–ce–j	Lesser-spotted dogfish (*Scyliorhinus canicula*) in Subarea 6 and divisions 7.a–c and 7.e–j (West of Scotland, Irish Sea, southern Celtic Seas)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
lez.27.6b	Megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall)	3.20	2017	2018	SPiCT	SPiCT	SPiCT
ple.27.7fg	Plaice (*Pleuronectes platessa*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)	3.20	2016	2017	SPiCT	SPiCT	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
raj.27.1012	Rays and skates (Rajidae) (mainly thornback ray (*Raja clavata*)) in subareas 10 and 12 (Azores grounds and north of Azores)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rje.27.7fg	Small-eyed ray (*Raja microocellata*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea North)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
sdv.27.nea	Smooth-hound (*Mustelus* spp.) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	3.20	2017	Unknown	-	-	SPiCT
rjm.27.8	Spotted ray (*Raja montagui*) in Subarea 8 (Bay of Biscay)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjm.27.9a	Spotted ray (*Raja montagui*) in Division 9.a (Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjm.27.7ae–h	Spotted ray (*Raja montagui*) in divisions 7.a and 7.e–h (southern Celtic Seas and western English Channel)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjm.27.3a47d	Spotted ray (*Raja montagui*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjm.27.67bj	Spotted ray (*Raja montagui*) in Subarea 6 and divisions 7.b and 7.j (West of Scotland, west and southwest of Ireland)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
spr.27.3a	Sprat (*Sprattus sprattus*) in Division 3.a (Skagerrak and Kattegat)	3.20		2018	NA	NA	SPiCT
spr.27.7de	Sprat (*Sprattus sprattus*) in divisions 7.d and 7.e (English Channel)	3.20		2017; reference points not agreed by ACOM.	NA	NA	SPiCT
rjc.27.9a	Thornback ray (*Raja clavata*) in Division 9.a (Atlantic Iberian waters)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjc.27.7afg	Thornback ray (*Raja clavata*) in divisions 7.a and 7.f–g (Irish Sea, Bristol Channel, Celtic Sea North)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjc.27.3a47d	Thornback ray (*Raja clavata*) in Subarea 4 and in divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	3.20	2017	Unknown	NA	NA	SPiCT
rjc.27.6	Thornback ray (*Raja clavata*) in Subarea 6 (West of Scotland)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
rjc.27.8	Thornback ray (*Raja clavata*) in Subarea 8 (Bay of Biscay)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
tur.27.3a	Turbot (*Scophthalmus maximus*) in Division 3.a (Skagerrak and Kattegat)	3.20	Unknown	Unknown	fail	fail	SPiCT
tur.27.4	Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)	3.20		2017	SPiCT	SPiCT	SPiCT
tur.27.22–32	Turbot (*Scophthalmus maximus*) in subdivisions 22–32 (Baltic Sea)	3.20	2017	2017	fail	fail	SPiCT
usk.27.1–2	Tusk (*Brosme brosme*) in subareas 1 and 2 (Northeast Arctic)	3.20		2017	fail	fail	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
usk.27.3a45b6a7–912b	Tusk (*Brosme brosme*) in subareas 4 and 7–9, and divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic)	3.20	2016	2017	SPiCT	SPiCT	SPiCT
rju.27.7de	Undulate ray (*Raja undulata*) in divisions 7.d and 7.e (English Channel)	3.20	Not attempted or planned	Not attempted or planned	-	-	SPiCT
bli.27.5a14	Blue ling (*Molva dypterygia*) in Subarea 14 and Division 5.a (East Greenland and Iceland grounds)	3.30		2017	HR	NA	SPiCT
cod.2127.1f14	Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)	3.30	2017	Unknown	NA	NA	SPiCT
aru.27.5a14	Greater silver smelt (*Argentina silus*) in Subarea 14 and Division 5.a (East Greenland and Iceland grounds)	3.30		2017	HR	NA	SPiCT
cod.27.1–2coast	Cod (*Gadus morhua*) in subareas 1 and 2 (Norwegian coastal waters cod)	3.60	2017	2018	NA	NA	SPiCT
syt.27.67	Greater-spotted dogfish (*Skyliorhinus stellaris*) in subareas 6 and 7 (West of Scotland, southern Celtic Sea, and the English Channel)	3.70	Not attempted or planned	Not attempted or planned	-	-	SPiCT
ane.27.9a	Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters)	3.90	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
sho.27.67	Black-mouth dogfish (*Galeus melastomus*) in subareas 6 and 7 (West of Scotland, southern Celtic Seas, and English Channel)	3.90	Not attempted or planned	Not attempted or planned	-	-	SPiCT

2017 Stock Key Label	2017 Stock Description	2017 Data Category	Proxy Reference Points Attempted In	Proxy Reference Points Planned For	Current Proxy Method F	Current Proxy Method B	Method priority for assessment development
pol.27.67	Pollack (*Pollachius pollachius*) in subareas 6–7 (Celtic Seas and the English Channel)	4.12	2016	2017	NA	NA	SPiCT
nep.fu.10	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 10 (northern North Sea, Noup)	4.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
nep.fu.32	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 32 (northern North Sea, Norway Deep)	4.14		2017	NA	NA	SPiCT
nep.fu.33	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 33 (central North Sea, Horn's Reef)	4.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
nep.fu.34	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 34 (central North Sea, Devil's Hole)	4.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT
nep.fu.30	Norway lobster (*Nephrops norvegicus*) in Division 9.a, Functional Unit 30 (Atlantic Iberian waters East and Gulf of Cadiz)	4.14	2016	2018	NA	NA	SPiCT
nep.fu.5	Norway lobster (*Nephrops norvegicus*) in divisions 4.b and 4.c, Functional Unit 5 (central and southern North Sea, Botney Gut-Silver Pit)	4.14	Not attempted or planned	Not attempted or planned	NA	NA	SPiCT

5.3 Stocks of *Nephrops*

5.3.1 Responding to recommendation from WGBIE

A working document (WD) submitted to, and reviewed by, the Working Group for the Bay of Biscay and the Iberian Waters Ecoregion (WGBIE) in 2017 was presented at WKLIFE VII.

5.3.2 Response and proposal from WKLIFE

The WD presented an approach to the calculation of MSY reference points for Norway lobster (*Nephrops norvegicus*) stocks with new UWTV surveys. WKLIFE VII, after reviewing the method, recommended that a workshop be established to review MSY reference points for all Norway lobster stocks using UWTV surveys, together with the examination of assumptions about natural mortality and growth.

Recommendation: The approaches to estimation of reference points for *Nephrops* stocks have evolved since their inception at the first *Nephrops* Benchmark group in 2010. This evolution has occurred, through necessity, mainly around the working groups (WGNSSK and WGCSE) but has not been subject to dedicated scrutiny. Attempts to determine reference points for stocks during the 2016 *Nephrops* Benchmark meeting highlighted some potential issues with the approach that could not be satisfactorily resolved, and it is now apposite to undertake a detailed review of the methods used to determine MSY reference points for *Nephrops* stocks. There are now multiple stocks with both UWTV surveys and reference point estimation covering several years and a wide geographic range within the ICES area, and a meta-analysis of the performance of the reference point setting would seem appropriate. In addition, the data situation; i.e. low confidence in reported landings, that occurred for many stocks prior to 2006 is now considered to have been resolved and therefore the scope for dynamic population assessment models may now have become more feasible. It is recommended, that a workshop be convened early in 2018 at which the following are explored:

a) The historical performance of the existing reference points, including detection of systematic bias.

b) Data-limited and non-parametric reference points.

c) Performance of dynamic assessment models.

5.4 Survey-based TAC rules in an MSE-like framework for short-lived species

With the approaching ICES benchmark of sprat in mind, an attempt was made to evaluate a survey-based TAC rule for sprat in 3.a (DLS). The objective was to explore the possibility of testing the TAC rule in an MSE-like framework. The operating model from the MSE framework (and the B_{lim} reference point) used for North Sea sprat (Category 1) was applied, following the assumption that life-history parameters, recruitment dynamics, and exploitation patterns of sprat in the North Sea are not significantly different from 3.a sprat. In the default simulations, the survey-based TAC rule was implemented by simulating survey indices by drawing random values from a lognormal distribution with a mean equal to the stock number of a given age produced by the operating model and a coefficient of variation (CV) of 0.4. The starting TAC used to initiate default simulations was 40 000 tonnes, which is roughly 25% of the geometric mean spawning stock. The CV chosen for the simulations of the survey index affected $P(S<B_{lim})$ and a complete decoupling of the survey from the dynamics in the operating

model resulted in an increase in P(S<B_{lim}) from ~0.01 to ~0.025 (on average for year 5 to year 20). A fixed TAC of 40 000 tonnes every year also resulted in P(S<B_{lim}) ~0.025. A non-precautionary starting TAC; e.g. 70 000 tonnes, caused a considerable downward trend in TAC and consequently, a downward trend in P(S<B_{lim}) over time. However, although less steep, the downward trend in TAC could be observed also when starting out at a precautionary TAC level; i.e. 40 000 tonnes. This pattern is presumably a consequence of how the TAC rule is formulated. Based on these result, it is proposed, that this approach can be used to adjust how the TAC rule is formulated and avoid unintended TAC responses.

There is interest in making further developments in relation to this particular case (sprat in 3.a) and the approach presented here prior to the sprat benchmark in 2018, in order to come up with informed suggestions for improvement to the TAC rule.

Two important questions: (i) to what extent are the results of this type of evaluation dependent on the chosen operating model? And, (ii) how can more realism be added to the simulated survey index. It is anticipated, that considerable progress could be made within 2–3 weeks with a dedicated full-time study.

5.5 Further methodological developments in assessment models and MSE tools for DLS

5.5.1 Development on assessment models

WKLIFE VII agreed with DTU Aqua that further methodological developments are necessary. In particular, the need is recognized to further develop assessment methods, namely SPiCT and s6, and the short-term projections of F and catch for data-limited stocks.

Currently, ICES has 170 category 3–6 stocks for which the method developments presented below could be applied. The s6 model may be used for category 4–6 stocks. The SPiCT model may be applicable to the 96 category 3 stocks, eight of which are already using SPiCT for their reference points in the ICES 2017 advice: the models were considered adequate for advice based on several criteria; i.e. the quality of the input data, model diagnostics, whether the data covered the production curve range, confidence bounds around the F/F_{MSY} and B/B_{MSY} relative plots, and retrospective patterns on these relative plots (ICES, 2017b). These eight stocks are therefore immediately available for application of SPiCT for an MSY approach for category 3 stocks using the work plan outlined below. Noting this, as SPiCT is further developed, it will potentially allow the provision of MSY advice for more ICES stocks including short-lived stocks, stocks with mixed temporal data; i.e. seasonal and yearly data, and stocks with discarding issues. Model developers are focusing on Eastern Baltic cod and sprat in 3.a in order to leverage existing work and focus on stocks of national Danish interest.

The following improvements to the SPiCT model are foreseen:

- Subannual (quarterly/monthly) assessment models: The seasonal SPiCT will not only include seasonal fishery data, but will also have the surplus production parameter applied on a seasonal basis. Besides, such model development will enable to take account of seasonal zero catches. Here quantiles/percentiles on landings/catch and reference points less than the median can be included as well. The larger number of datapoints available when using data on a seasonal basis, should be able to partly improve the fit of the

assessments of short-lived data-limited stocks, where the seasonal component is relevant.

- ICES should progress this work with relevant stock assessors and data providers as a first step as the following are required in order to prioritize stocks: Quarterly data (landings / catches);
- Acoustic survey indices with adequate time-series (besides trawl survey indices) when available;
- Relevant information on quarterly production differences (spawning season, main growth season, etc.) when available.

Nine stocks are identified that could move from category 3 to category 1 via a traditional benchmark. Eight stocks are candidates for category 3 MSY advice using SPiCT. Five stocks are short-lived, and for those, methods are being developed for application in spring 2018.

Timeline: The WKProxy process, with 28 stocks ran from October through to June. The current process (developing MSY advice for category 3 and 4 stocks) needs more time (an additional year).

Planned work in the short to medium term: The development of the generic model will be done under two specific case studies, namely the i) Eastern Baltic cod and ii) sprat in 3a. The generic model could then be applied to all stocks for which adequate data on a seasonal basis are available. In the case studies, as well as for all other stocks where the developed model extension will be applied, the performance of an annual assessment should be compared with the performance of the seasonal assessments.

The two case studies chosen to develop the generic model development include a long-lived and a short-lived species:

i) Eastern Baltic cod;

ii) sprat 3.a; simulation and estimation with SPiCT.

Timeline: 3–4 months tentatively;

Resources needed: 3–6 man months;

Sources: Mainly supported by ongoing projects.

Availability to ICES: February 2018 for 2018 advice as a best-case scenario.

Applicability to ICES in 2018: five short-lived stocks; eight stocks currently using SPiCT for reference points.

Follow-up workshops to apply the SPiCT model to priority stocks due to the large number of category 3 stocks (96).ICES will discuss further with the Commission to prioritize stocks. Table 5.5.5.1 presents the ICES stocks in categories 3–6 with TACs.

Table 5.5.5.1. ICES data category 3–6 stocks with TACs in 2017.

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
nep.fu.25	Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and northern Galicia)	WGBIE	3.14
nep.fu.31	Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay and Cantabrian Sea)	WGBIE	3.14
nep.fu.2627	Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 26–27 (Atlantic Iberian waters East, western Galicia, and northern Portugal)	WGBIE	3.14
ple.27.7h–k	Plaice (*Pleuronectes platessa*) in divisions 7h–k (Celtic Sea South, southwest of Ireland)	WGCSE	3.14
reb.2127.sp	Beaked redfish (*Sebastes mentella*) in ICES subareas 5, 12, and 14 (Iceland and Faroe grounds, North of Azores, East of Greenland) and NAFO subareas 1 and 2 (shallow pelagic stock <500 m)	NWWG	3.14
cod.21.1a–e	Cod (*Gadus morhua*) in NAFO divisions 1.A–E, offshore (West Greenland)	NWWG	3.14
cod.27.5b2	Cod (*Gadus morhua*) in Subdivision 5.b.2 (Faroe Bank)	NWWG	3.14
rjr.27.23a4	Starry ray (*Amblyraja radiata*) in subareas 2 and 4, and Division 3.a (Norwegian Sea, North Sea, Skagerrak and Kattegat)	WGEF	3.14
anf.27.3a46	Anglerfish (*Lophius budegassa, Lophius piscatorius*) in subareas 4 and 6, and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)	WGCSE	3.20
ank.27.78ab	Black-bellied anglerfish (*Lophius budegassa*) in divisions 7.b–k, 8.a–b, and 8.d (west and southwest of Ireland, Bay of Biscay)	WGBIE	3.20
cod.27.21	Cod (*Gadus morhua*) in Subdivision 21 (Kattegat)	WGBFAS	3.20
cod.27.25–32	Cod (*Gadus morhua*) in subdivisions 25–32, eastern Baltic stock (eastern Baltic Sea)	WGBFAS	3.20
lem.27.3a47d	Lemon sole (*Microstomus kitt*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	WGNSSK	3.20

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
nep.fu.2829	Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 28–29 (Atlantic Iberian waters East and southwestern and southern Portugal)	WGBIE	3.20
ple.27.7e	Plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel)	WGCSE	3.20
ple.27.24–32	Plaice (*Pleuronectes platessa*) in subdivisions 24–32 (Baltic Sea, excluding the Sound and Belt Seas)	WGBFAS	3.20
mon.27.78abd	White anglerfish (*Lophius piscatorius*) in divisions 7.b–k, 8.a–b, and 8.d (southern Celtic Seas, Bay of Biscay)	WGBIE	3.20
wit.27.3a47d	Witch (*Glyptocephalus cynoglossus*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	WGNSSK	3.20
boc.27.6–8	Boarfish (*Capros aper*) in subareas 6–8 (Celtic Seas, English Channel, and Bay of Biscay)	WGWIDE	3.20
fle.27.3a4	Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGNSSK	3.20
aru.27.5b6a	Greater silver smelt (*Argentina silus*) in divisions 5.b and 6.a (Faroes grounds and west of Scotland)	WGDEEP	3.20
aru.27.123a4	Greater silver smelt (*Argentina silus*) in subareas 1, 2, and 4, and in Division 3.a (Northeast Arctic, North Sea, Skagerrak and Kattegat)	WGDEEP	3.20
aru.27.6b7–1012	Greater silver smelt (*Argentina silus*) in subareas 7–10 and 12, and Division 6.b (other areas)	WGDEEP	3.20
hom.27.3a4bc7d	Horse mackerel (*Trachurus trachurus*) in divisions 3.a, 4.b–c, and 7.d (Skagerrak and Kattegat, southern and central North Sea, eastern English Channel)	WGWIDE	3.20
lin.27.5b	Ling (*Molva molva*) in Division 5.b (Faroes grounds)	WGDEEP	3.20
lin.27.1-2	Ling (*Molva molva*) in subareas 1 and 2 (Northeast Arctic)	WGDEEP	3.20
lin.27.3a4a6–91214	Ling (*Molva molva*) in subareas 6–9, 12, and 14, and divisions 3.a and 4.a (Northeast Atlantic and Arctic Ocean)	WGDEEP	3.20
sol.27.7h–k	Sole (*Solea solea*) in Divisions 7.h–k (Celtic Sea South, southwest of Ireland)	WGCSE	3.20

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
reb.27.14b	Beaked redfish (*Sebastes mentella*) in Division 14.b, demersal (Southeast Greenland)	NWWG	3.20
reb.27.5a14	Beaked redfish (*Sebastes mentella*) in Subarea 14 and Division 5.a, Icelandic slope stock (East of Greenland, Iceland grounds)	NWWG	3.20
bsf.27.nea	Black scabbardfish (*Aphanopus carbo*) in subareas 1, 2, 4–8, 10, and 14, and divisions 3.a, 9.a, and 12.b (Northeast Atlantic and Arctic Ocean)	WGDEEP	3.20
sbr.27.10	Blackspot sea bream (*Pagellus bogaraveo*) in Subarea 10 (Azores grounds)	WGDEEP	3.20
sbr.27.9	Blackspot sea bream (*Pagellus bogaraveo*) in Subarea 9 (Atlantic Iberian waters)	WGDEEP	3.20
rjh.27.9a	Blonde ray (*Raja brachyura*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20
rjh.27.4c7d	Blonde ray (*Raja brachyura*) in divisions 4.c and 7.d (southern North Sea and eastern English Channel)	WGEF	3.20
jaa.27.10a2	Blue jack mackerel (*Trachurus picturatus*) in Subdivision 10.a.2 (Azores grounds)	WGHANSA	3.20
bll.27.3a47de	Brill (*Scophthalmus rhombus*) in Subarea 4 and divisions 3.a and 7.d–e (North Sea, Skagerrak and Kattegat, English Channel)	WGNSSK	3.20
rjn.27.8c	Cuckoo ray (*Leucoraja naevus*) in Division 8.c (Cantabrian Sea)	WGEF	3.20
rjn.27.9a	Cuckoo ray (*Leucoraja naevus*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20
rjn.27.3a4	Cuckoo ray (*Leucoraja naevus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGEF	3.20
rjn-678abd	Cuckoo ray (*Leucoraja naevus*) in subareas 6 and 7 and divisions 8.ab and 8.d	WGEF	3.20
dab.27.3a4	Dab (*Limanda limanda*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGNSSK	3.20
gfb.27.nea	Greater forkbeard (*Phycis blennoides*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGDEEP	3.20
lez.27.6b	Megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall)	WGCSE	3.20

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
ple.27.7fg	Plaice (*Pleuronectes platessa*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)	WGCSE	3.20
rje.27.7fg	Small-eyed ray (*Raja microocellata*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea North)	WGEF	3.20
rjm.27.8	Spotted ray (*Raja montagui*) in Subarea 8 (Bay of Biscay)	WGEF	3.20
rjm.27.9a	Spotted ray (*Raja montagui*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20
rjm.27.7ae–h	Spotted ray (*Raja montagui*) in divisions 7.a and 7.e–h (southern Celtic Seas and western English Channel)	WGEF	3.20
rjm.27.3a47d	Spotted ray (*Raja montagui*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	WGEF	3.20
rjm.27.67bj	Spotted ray (*Raja montagui*) in Subarea 6 and divisions 7.b and 7.j (West of Scotland, west and southwest of Ireland)	WGEF	3.20
spr.27.3a	Sprat (*Sprattus sprattus*) in Division 3.a (Skagerrak and Kattegat)	HAWG	3.20
spr.27.7de	Sprat (*Sprattus sprattus*) in divisions 7.d and 7.e (English Channel)	HAWG	3.20
rjc.27.9a	Thornback ray (*Raja clavata*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20
rjc.27.7afg	Thornback ray (*Raja clavata*) in divisions 7.a and 7.f–g (Irish Sea, Bristol Channel, Celtic Sea North)	WGEF	3.20
rjc.27.3a47d	Thornback ray (*Raja clavata*) in Subarea 4 and in divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	WGEF	3.20
rjc.27.8	Thornback ray (*Raja clavata*) in Subarea 8 (Bay of Biscay)	WGEF	3.20
tur.27.4	Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)	WGNSSK	3.20
usk.27.1-2	Tusk (*Brosme brosme*) in subareas 1 and 2 (Northeast Arctic)	WGDEEP	3.20
usk.27.3a45b6a7-912b	Tusk (*Brosme brosme*) in subareas 4 and 7–9, and Divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic)	WGDEEP	3.20
rju.27.7de	Undulate ray (*Raja undulata*) in divisions 7.d and 7.e (English Channel)	WGEF	3.20
cod.2127.1f14	Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)	NWWG	3.30

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
aru.27.5a14	Greater silver smelt (*Argentina silus*) in Subarea 14 and Division 5.a (East Greenland and Iceland grounds)	WGDEEP	3.30
cod.27.1-2coast	Cod (*Gadus morhua*) in subareas 1 and 2 (Norwegian coastal waters cod)	AFWG	3.60
sal.27.32	Salmon (*Salmo salar*) in Subdivision 32 (Gulf of Finland)	WGBAST	3.80
ane.27.9a	Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters)	WGHANSA	3.90
pol.27.67	Pollack (*Pollachius pollachius*) in subareas 6–7 (Celtic Seas and the English Channel)	WGCSE	4.12
nep.fu.10	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 10 (northern North Sea, Noup)	WGNSSK	4.14
nep.fu.32	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 32 (northern North Sea, Norway Deep)	WGNSSK	4.14
nep.fu.33	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 33 (central North Sea, Horn's Reef)	WGNSSK	4.14
nep.fu.34	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 34 (central North Sea, Devil's Hole)	WGNSSK	4.14
nep.fu.30	Norway lobster (*Nephrops norvegicus*) in Division 9.a, Functional Unit 30 (Atlantic Iberian waters East and Gulf of Cadiz)	WGBIE	4.14
nep.fu.5	Norway lobster (*Nephrops norvegicus*) in divisions 4.b and 4.c, Functional Unit 5 (central and southern North Sea, Botney Gut-Silver Pit)	WGNSSK	4.14
alf.27.nea	Alfonsinos (*Beryx* spp.) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGDEEP	5.20
rjh.27.7e	Blonde ray (*Raja brachyura*) in Division 7.e (western English Channel)	WGEF	5.20
rjh.27.7afg	Blonde ray (*Raja brachyura*) in divisions 7.a and 7.f–g (Irish Sea, Bristol Channel, Celtic Sea North)	WGEF	5.20
rjh.27.4a6	Blonde ray (*Raja brachyura*) in Subarea 6 and Division 4.a (North Sea and West of Scotland)	WGEF	5.20
nep.27.6aoutFU	Norway lobster (*Nephrops norvegicus*) in Division 6.a, outside the functional units (West of Scotland)	WGCSE	5.20

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
nep.27.4outFU	Norway lobster (*Nephrops norvegicus*) in Subarea 4, outside the functional units (North Sea)	WGNSSK	5.20
nep.27.7outFU	Norway lobster (*Nephrops norvegicus*) in Subarea 7, outside the functional units (southern Celtic Seas, southwest of Ireland)	WGCSE	5.20
ple.27.89a	Plaice (*Pleuronectes platessa*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20
pol.27.89a	Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20
rng.27.5a10b12ac14b	Roundnose grenadier (*Coryphaenoides rupestris*) in divisions 10.b and 12.c, and subdivisions 12.a.1, 14.b.1, and 5.a.1 (Oceanic Northeast Atlantic and northern Reykjanes Ridge)	WGDEEP	5.20
san.sa.6	Sandeel (*Ammodytes* spp.) in subdivisions 20–22, Sandeel Area 6 (Kattegat)	HAWG	5.20
rji.27.67	Sandy ray (*Leucoraja circularis*) in subareas 6–7 (West of Scotland, southern Celtic Seas, English Channel)	WGEF	5.20
rjf.27.67	Shagreen ray (*Leucoraja fullonica*) in subareas 6–7 (West of Scotland, southern Celtic Seas, English Channel)	WGEF	5.20
rje.27.7de	Small-eyed ray (*Raja microocellata*) in divisions 7.d and 7.e (English Channel)	WGEF	5.20
sol.27.8c9a	Sole (*Solea solea*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	WGBIE	5.20
rjc.27.7e	Thornback ray (*Raja clavata*) in Division 7.e (western English Channel)	WGEF	5.20
gag.27.nea	Tope (*Galeorhinus galeus*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	5.20
whg.27.3a	Whiting (*Merlangius merlangus*) in Division 3.a (Skagerrak and Kattegat)	WGNSSK	5.20
whg.27.89a	Whiting (*Merlangius merlangus*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20
bli.27.nea	Blue ling (*Molva dypterygia*) in subareas 1, 2, 8, 9, and 12, and divisions 3.a and 4.a (other areas)	WGDEEP	5.30

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
rjb.27.89a	Common skate (*Dipturus batis*-complex) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGEF	5.30
san.sa.5r	Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 5r (northern North Sea, Viking and Bergen banks)	HAWG	5.30
san.sa.7r	Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 7 (northern North Sea, Shetland)	HAWG	5.30
ldb.27.7b–k8abd	Four-spot megrim (*Lepidorhombus boscii*) in divisions 7.b–k, 8.a–b, and 8.d (west and southwest of Ireland, Bay of Biscay)		5.90
raj.27.89a	Rays and skates (*Rajidae*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGEF	5.90
cod.27.6b	Cod (*Gadus morhua*) in Division 6.b (Rockall)	WGCSE	6.20
ple.27.7bc	Plaice (*Pleuronectes platessa*) in divisions 7.b–c (West of Ireland)	WGCSE	6.20
rng.27.1245a8914ab	Roundnose grenadier (*Coryphaenoides rupestris*) in subareas 1, 2, 4, 8, and 9, Division 14.a, and in subdivisions 14.b.2 and 5.a.2 (Northeast Atlantic and Arctic Ocean)	WGDEEP	6.20
sol.27.7bc	Sole (*Solea solea*) in divisions 7.b and 7.c (West of Ireland)	WGCSE	6.20
whg.27.6b	Whiting (*Merlangius merlangus*) in Division 6.b (Rockall)	WGCSE	6.20
agn.27.nea	Angel shark (*Squatina squatina*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30
bsk.27.nea	Basking shark (*Cetorhinus maximus*) in Subareas 1–10, 12 and 14 (Northeast Atlantic and adjacent waters)	WGEF	6.30
sbr.27.6–8	Blackspot sea bream (*Pagellus bogaraveo*) in subareas 6–8 (Celtic Seas, the English Channel, and Bay of Biscay)	WGDEEP	6.30
rjb.27.67a–ce–k	Common skate (*Dipturus batis*-complex flapper skate (*Dipturus cf. Flossada*) and blue skate (*Dipturus cf. intermedia*) in Subarea 6 and divisions 7.a–c and 7.e–k (Celtic Seas and western English Channel)	WGEF	6.30

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
rjb.27.3a4	Common skate (*Dipturus batis*-complex) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGEF	6.30
sck.27.nea	Kitefin shark (*Dalatias licha*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30
guq.27.nea	Leafscale gulper shark (*Centrophorus squamosus*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30
pra.27.4a	Northern shrimp (*Pandalus borealis*) in Division 4.a (Northern North Sea, Fladen Ground)	NIPAG	6.30
ory.27.nea	Orange roughy (*Hoplostethus atlanticus*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGDEEP	6.30
por.27.nea	Porbeagle (*Lamna nasus*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30
cyo.27.nea	Portuguese dogfish (*Centroscymnus coelolepis, Centrophorus squamosus*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30
rhg.27.nea	Roughhead grenadier (*Macrourus berglax*) in subareas 5–8, 10, 12 and 14 (Northeast Atlantic and Arctic Ocean)	WGDEEP	6.30
tsu.27.nea	Roughsnout grenadier (*Trachyrincus scabrus*) in subareas 1–2, 4–8, 10, 12, 14 and Division 3a (Northeast Atlantic and Arctic Ocean)	WGDEEP	6.30
rng.27.3a	Roundnose grenadier (*Coryphaenoides rupestris*) in Division 3.a (Skagerrak and Kattegat)	WGDEEP	6.30
thr.27.nea	Thresher sharks (*Alopias* spp.) in Subareas 10, 12, divisions 7.c–k, 8.d–e, and subdivisions 5.b.1, 9.b.1, 14.b.1 (Northeast Atlantic)	WGEF	6.30
rju.27.8c	Undulate ray (*Raja undulata*) in Division 8.c (Cantabrian Sea)	WGEF	6.30
rju.27.7bj	Undulate ray (*Raja undulata*) in divisions 7.b and 7.j (west and southwest of Ireland)	WGEF	6.30
rja.27.nea	White skate (*Rostroraja alba*) in subareas 1–10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category
raj.27.3a47d	Rays and skates (*Rajidae*) in Subarea 4 and in divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	WGEF	6.90
raj.27.67a–ce–h	Rays and skates (*Rajidae*) in Subarea 6 and divisions 7.a–c and 7.e–h (Rockall and West of Scotland, southern Celtic Seas, western English Channel)	WGEF	6.90
rju.27.9a	Undulate ray (*Raja undulata*) in Division 9.a (Atlantic Iberian waters)	WGEF	6.90
rju.27.8ab	Undulate ray (*Raja undulata*) in divisions 8.a–b (northern and central Bay of Biscay)	WGEF	6.90

- Catch uncertainty: The SPiCT assessment model will include discard uncertainty; i.e. it will calculate partial Fs for landing and discards, respectively, indicating the uncertainty around each (as well as combined F uncertainty). Here, as well, quantiles/percentiles on the landings/discards and on the reference points less than the median can be included.

Many of the data-limited stocks are bycatch species and significant fishing mortality is originating from discard for many of those species. Furthermore, because of changes in targeting, processing and market demands/prices for those species the discard rates have changed over time; i.e. variable discard rates over time and between years (and seasons). Accordingly, the landings may not be fully representing the actual fishing mortality. In order to obtain a better perception of stock level and development as well as in order to improve the assessments and their reliability, it will be a clear advantage to develop a SPiCT model able to take into account discards and discard-fishing mortality historically as well as at present.

Planned work in the short to medium term: The development of the generic model will be done under specific case studies (not finally selected yet; see later in this report). The generic model will accordingly be able to and available for application to stocks when adequate data on landings and discards are available. In the case studies, as well as for all other stocks where the developed model extension is applied, the performance of standard SPiCT assessments without discard are compared with assessments including discard as an average discard rate, and assessments where discards and landings are dealt with as separate time-series.

The actual case study stocks are still to be decided; however, note that for the two first types of comparisons, part of the evaluation has already been carried out for witch flounder and lemon sole in the North Sea, Skagerrak-Kattegat and Eastern Channel (J. Rasmus Nielsen).

Timeline: 3–6 months tentatively.

Resources needed: 3–6 man-months.

Sources: Mainly supported by ongoing projects.

Availability to ICES: July 2018 (for case studies).

Applicability to ICES in 2018: the practice of reconstructing historic discards in ICES is problematic for SPiCT application. Many DLS may have had high discard rates, and the raising may be inaccurate and this has serious implications for the usability of SPiCT. Resources are needed to comb through InterCatch to investigate for which stocks this will be an issue. Stocks for which the historic series is unreliable may not be SPiCT candidates.

For stocks in categories 4-6, the s6 assessment method is proposed for the very data-poor cases, where potentially stochastic length-based assessments can be used. The minimum requirement for this method is a single year length distribution data and, accordingly, also applies to category 5 and possibly 6 stocks when a realistic M/K parameter can be provided (either for the current stock or a similar comparable stock). As such, s6 may be applicable to 74 category 4–6 stocks depending on data quality and how representative the data are.

Planned work in the short to medium term: this work will gain from the development of the more generic OM described under the MSE section below, which is basically made on size basis. This will enable evaluation of performance of the model according to more realistic simulations on a case specific basis (case studies to be decided upon) providing catch advice according to the MSY approach.

Recommendation: To further develop the s6 method in the near term especially to address category 4–6 stocks-length distributions from category 1 stocks should be made more readily available to method developers. Possible stocks for testing are white anglerfish in 8.c and 9.a, northern hake, and Norway lobster *Nephrops* in 23–24.

Timeline: tentatively, 1–2 years;

Resources needed: 4–6 man months;

Sources: Additional funding required to reduce this timeline.

Availability to ICES: 2018, 2019.

Applicability to ICES: category 4, 5, 6 stocks.

5.5.2 Development on MSE methods and frameworks and evaluation of different HCRs

The following improvements should be considered:

- MSE operational model that can include subannual (quarterly / monthly) time-steps, i.e. with more frequency than annual time-steps. Establish a simulation model that can be used as an OM in a MSE on a seasonal basis (important for short-lived species) and able to deal with discard.

DLMtool and FLR environments should be further explored to see if a seasonal OM for MSE is possible. DLMTool does not currently support this, but it could be possibly accommodated. It could be done in FLR, but it would require additional resources.

Planned work in the short to medium term:

1) Start with species-specific simulation model that is addressing Norway pout as a short-lived category 1 stock.

Timeline: 3–4 months;

Resources needed: 3–5 man-months;

Sources: Mainly supported by ongoing projects.

2) Parallel track starting with a species-specific version addressing sprat in 3.a involving simulation with a seasonal SPiCT (see bullet 1);

Timeline: 3–4 months for the baseline SPiCT approach;

Resources needed: 3 man-months;

Sources: Mainly supported by ongoing projects.

3) Continue with a more generic advanced version enabling, among others, simulation of discard. This simulation framework should be generic and should be able to cover both category 1 and category 3 stocks, and it should be able to cover both short-lived and long-lived species. The OM will consider an array of dimensions such as length, age, season, effort, fleet (fleet landings, fleet discards), etc.

Timeline: 6–24 months;

Resources needed: 9–18 man-months;

Sources: Partly under existing projects, but additional resources needed.

Applicability to ICES: DLS method development generally.

- Evaluation of survey based TAC rules in MSE-like frameworks for short-lived DLS (see Section 5.4).

Planned work in the short to medium term: development of one case study, namely Sprat 3.a.

Timeline: 3–4 months tentatively;

Resources needed: one man-month;

Sources: Supported by ongoing projects.

5.6 References

ICES. 2017a. ICES Advice Technical Guidelines - ICES fisheries management reference points for category 1 and 2 stocks. Published 20 January 2017. 19 pp.

ICES. 2017b. Report of the Working Group on Assessment of Demersal Stocks in the North Sea and Skagerrak, 26 April–5 May 2017, ICES HQ. ICES CM 2017/ACOM:21. 1077 pp.

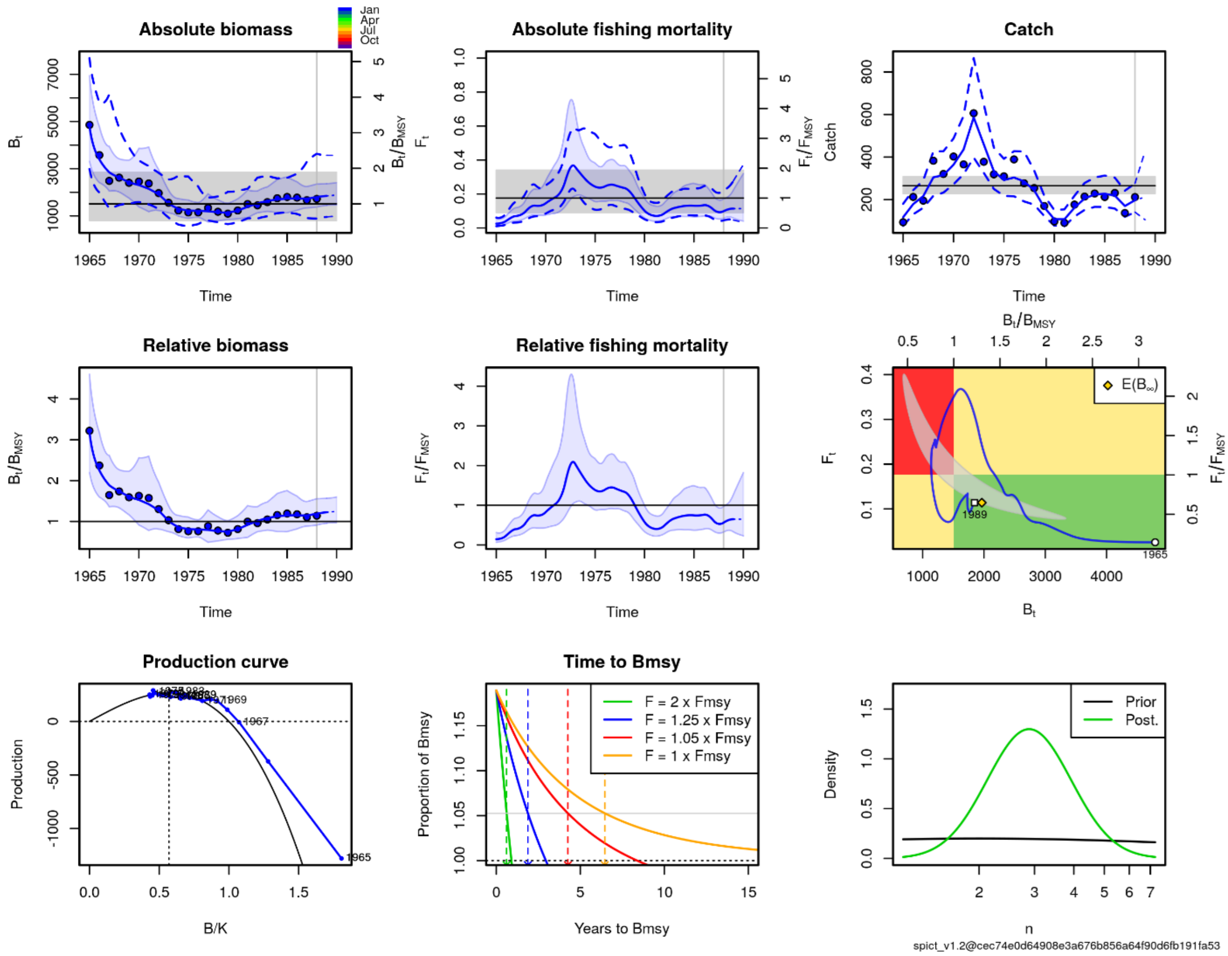
6 Calculating predictions under different management scenarios with SPiCT

6.1 Forecasting

The stochastic production model SPiCT (Pedersen and Berg, 2017) allows predicting catch, biomass and fishing mortality under different management scenarios by means of the function "manage". By default, six scenarios are considered: (i) Keep constant catch; (ii) Keep constant fishing mortality; (iii) Fish at F_{MSY}; (iv) No fishing; (v) Reduce fishing mortality by 25%; (vi) Increase fishing mortality by 25%. The prediction is made for the catch (C), the exploitable biomass (B), the fishing mortality (F), the relative biomass (B/B_{MSY}), and the relative fishing mortality (F/F_{MSY}). For these values, the function also estimates the 95% confidence intervals. In addition, the values perc.dB and perc.dF indicate the percentage difference between the predicted biomass relative to the biomass in the last assessment year and the predicted fishing mortality relative to the fishing mortality in the last assessment year, respectively. The code below illustrates how to make predictions based on the SPiCT assessment for the example data "pol$hake" (within the SPiCT package).

```
require(spict)
Loading required package: spict
Loading required package: TMB
Welcome to
spict_v1.2@cec74e0d64908e3a676b856a64f90d6fb191fa53


exampleDat <- pol$hake
exampleFit <- fit.spict(exampleDat)
plot(exampleFit)
```




```
exampleMan <- manage(exampleFit)
mansummary(exampleMan)

Observed interval, index:  1965.00 - 1988.00
Observed interval, catch:  1965.00 - 1989.00

Fishing mortality (F) prediction: 1990.00
Biomass (B) prediction:           1990.00
Catch (C) prediction interval:    1989.00 - 1990.00


Predictions
                           C      B     F B/Bmsy F/Fmsy perc.dB perc.dF
1. Keep current catch 212.0 1877.8 0.114  1.246  0.648     1.7     0.0
2. Keep current F     212.0 1877.8 0.114  1.245  0.648     1.7     0.0
3. Fish at Fmsy       318.6 1777.2 0.176  1.179  1.000    -3.7    54.4
4. No fishing           0.2 2075.2 0.000  1.376  0.001    12.4   -99.9
5. Reduce F 25%       161.0 1925.7 0.085  1.277  0.486     4.3   -25.0
6. Increase F 25%     261.8 1830.9 0.142  1.214  0.810    -0.8    25.0


95% CIs of absolute predictions
                        C.lo  C.hi   B.lo   B.hi  F.lo
F.hi
1. Keep current catch 211.9 212.1 1013.4 3479.4 0.053
0.244
```

```
2. Keep current F     105.2 427.2  987.4 3571.1 0.035
0.373
3. Fish at Fmsy       161.3 629.2  897.7 3518.6 0.054
0.576
4. No fishing           0.1   0.5 1166.2 3692.9 0.000
0.000
5. Reduce F 25%        79.2 327.4 1030.6 3598.2 0.026
0.280
6. Increase F 25%     131.1 522.5  945.4 3545.9 0.043
0.466

95% CIs of relative predictions
                      B/Bmsy.lo B/Bmsy.hi F/Fmsy.lo
F/Fmsy.hi
1. Keep current catch     0.986     1.573     0.379
1.107
2. Keep current F         0.971     1.597     0.230
1.821
3. Fish at Fmsy           0.894     1.554     0.356
2.811
4. No fishing             1.098     1.725     0.000
0.002
5. Reduce F 25%           1.005     1.623     0.173
1.366
6. Increase F 25%         0.936     1.576     0.288
2.277
```

6.2 Candidate stocks for application to catch advice in 2018

- brill (*Scophthalmus rhombus*) in Subarea 4 and divisions 3.a and 7.d–e (North Sea, Skagerrak and Kattegat, English Channel);
- dab (*Limanda limanda*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat);
- lemon sole (*Microstomus kitt*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel);
- megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall);
- white anglerfish (*Lophius piscatorius*) in divisions 7.b–k, 8.a–b, and 8.d (southern Celtic Seas, Bay of Biscay);
- plaice (*Pleuronectes platessa*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea);
- tusk (*Brosme brosme*) in subareas 4 and 7–9, and divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic);
- witch (*Glyptocephalus cynoglossus*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel).

6.3 References

Pedersen, M.W. and C.W. Berg. 2017. A stochastic surplus production model in continuous time. Fish and Fisheries. DOI: 10.1111/faf.12174.

7 SPiCT assessments with seasonal catches

7.1 Introduction

SPiCT is able to deal with catches aggregated on any time interval; i.e. it is possible to use, for example, quarterly or monthly catches. In the SPiCT paper (Pedersen and Berg, 2017) simulation study 2 compares the performance of SPiCT applied to simulated data aggregated on a yearly and a quarterly basis. The conclusion was that the uncertainty on B_MSY, sigma_B and sigma_I was substantially reduced when using quarterly data. A similar conclusion was made in an example using real data on Eastern Baltic cod. There are thus indications that SPiCT assessments with quarterly resolved catches will perform better compared to having only yearly catches. Short-lived species have faster dynamics and for those, it seems reasonable to assume that it is even more relevant to consider sub-annual catches.

SPiCT has been tested much more extensively with yearly catches, and sub-annual catches usually requires a seasonal process equation for the fishing mortality, which makes it a bit more complicated. Also, the process equation for the biomass (the surplus production) may also be improved by incorporating seasonal oscillations, which is not yet an option in SPiCT.

Finally, if catches on a finer time-scale are used, zero catches are more likely to occur, and SPiCT can at the moment only handle positive observations.

7.2 Ongoing developments

Using sub-annual catches appears like a promising way to improve SPiCT assessments, and it should therefore be sought to obtain sub-annual data whenever possible.

Further testing and model development may, however, be needed before it is advisable for non-experts to use SPiCT with seasonal catches, but this work is already in progress.

7.3 References

Pedersen, M.W. and C.W. Berg. 2017. A stochastic surplus production model in continuous time. Fish and Fisheries. DOI: 10.1111/faf.12174.

8 Length-based spawning potential ratio (LBSPR) to calculate reference points for length-based indicators

The Length-Based Spawning Potential Ratio (LB-SPR) model, published by Hordyk *et al*. (2016), has been developed as a tool to manage data-limited stocks, based on the appreciation that size distribution is one of the easiest to collect and/or most widely available type of data in data-poor fisheries. It is based on assumptions about how life-history traits and Beverton–Holt life-history invariants (BH-LHI), together with exploitation characteristics, shape the size distribution and spawning potential ratio (SPR) of a population at equilibrium. It notably links the size distribution of the population with the ratio M/k, where M is the natural mortality and k the initial growth rate from a von Bertalanffy growth function, L_∞ and CV_{L_∞}(coefficient of variation on L_∞, to take into account the variability of growth among individuals). In the case where the population is exploited, the effect of the ratio F/M is also integrated, assuming a selectivity curve following a sygmoid (described by the parameters Ls_{50} and Ls_{95}). This model extends previous versions (Prince *et al*., 2015; Hordyk *et al*., 2015a; Hordyk *et al*. 2015b) by notably adding the possibility to take into account a size dependent natural mortality ($M_L = M_{L\infty}\left(\frac{L_\infty}{L}\right)^c$) as well as differential fishing mortality-at-age of individual with different L_∞ (aka Lee's phenomenon) through the use of growth type groups (GTG). The SPR is an emergent property of the model, that can be estimated if a maturity ogive (Lm_{50} and Lm_{95}) and optionally a fecundity parameter (exponent for scaling fecundity with length; 3 by default) are provided.

The model is implemented as an R package (LBSPR, available on the CRAN). It notably provides a function to simulate a population distribution and its SPR given a set of life-history and exploitation parameters. However, if SPR is provided instead of F/M, the function estimates by optimization the ratio F/M leading to this SPR at equilibrium and given the life-history characteristics provided. It is therefore possible to approximate the size distribution at equilibrium for a population exploited at MSY using the proxy SPR=0.4.

8.1 Sensitivity analysis of reference points for length-based indicators

This method has been used during the workshop to estimate reference points for two length-based indicators; the mean length of the 5% biggest individuals ($L_{max5\%}$) and the mean length ($\bar{L}_{(SPR=0.4)}$) of all individuals in the catch. These are based on simulated size frequencies at SPR = 0.4 (MSY proxy) for different sets of life-history and exploitation (selectivity) characteristics. The sensitivities of the two reference point values to life-history and exploitation characteristics are investigated and compared to those of the mean length reference point ($\bar{L}_{(F=M)}$) used for the HCR testing through MSEs (rule fLBI, Section 2). This last reference point was based on the estimate of mean length at $F = M$, based on the equation (Jardim *et al*., 2015):

$$\bar{L}_{(F=M)} = \frac{{}^{k}/_{M} \cdot L_\infty + 2 \cdot L_c}{{}^{k}/_{M} + 2}.$$

The reference point $\bar{L}_{(F=M)}$ depends on the L_c(length at catch, $\approx Ls_{50}$, assuming a cutting-edge-like selectivity) but is independent of maturation strategy and assumes a $CV_{L_\infty} = 0$.

8.1.1 M/k and CV(L_∞)

The sensitivity of the three reference points to variations of M/k and CV(L_∞) over a wide range of values (expected to cover sensible values, and probably beyond for CV(L_∞)) have been tested and compared among reference points on analogous scales. Simplifying assumptions were used in the LB-SPR model to limit the number of parameters affecting the differences between $\bar{L}_{(SPR=0.4)}$ and $\bar{L}_{(F=M)}$ and to facilitate the interpretation: constant mortality over the range of sizes, cutting-edge selectivity and maturity, fecundity proportional to the cubic length (*i.e.* proportional to the weight).

Figure 8.1.1 describes the contrast of the three reference points over the M/k – CV(L_∞) space, as a percentage reduction compared to the unfished situation ($SPR = 1$, $F/M = 0$).

The contrast for $L_{max5\%}$ reference point is highly variable (Figure 8.1.1 A) across values of M/k and becomes very low (i.e. it is close to the value expected in the unexploited situation) for values of $M/k < 1$. Therefore, the outcome of an HCR using this reference point for low value of M/k will be very sensitive to observation errors or violation of the equilibrium assumption. This, combined with a value of the reference point which is sensitive to both M/k and CV(L_∞) (particularly for M/k<0.5 and CV(L_∞) > 0.2, Figure 1.2.2 A), makes $L_{max5\%}$ of limited use for populations with a low M/k and/or when these life-history characteristics are very uncertain.

The contrast on $\bar{L}_{(SPR=0.4)}$, on the other hand, presents a low sensitivity to M/k (Figure 8.1.1 B), associated with a relatively low variability of its values for $M/k > 0.5$ (Figure 8.1.2 B) and appears quite insensitive to variations in CV(L_∞). This reference point therefore seems a good candidate in cases where M/k and CV(L_∞) are not surely known.

If $\bar{L}_{(F=M)}$ values seem just as insensitive as those from $\bar{L}_{(SPR=0.4)}$ to variations of the two parameters when the contrast is calculated relative to L_∞ (Figure 8.1.2 C). The differences observed in the contrasts to $\bar{L}_{(SPR=1.0)}$ (Figure 8.2.1 C) reflect the inadequacy of $\bar{L}_{(F=M)}$ to take into account the effect of variability of individual growth (increase the skewness on the right of the distribution, especially for low M/k), which are rendered by $\bar{L}_{(SPR=1.0)}$. The apparent more negative shift compared to values obtained with $\bar{L}_{(SPR=0.4)}$ is expected to make the $\bar{L}_{(F=M)}$ reference point less conservative (underestimates F and overestimates SPR).

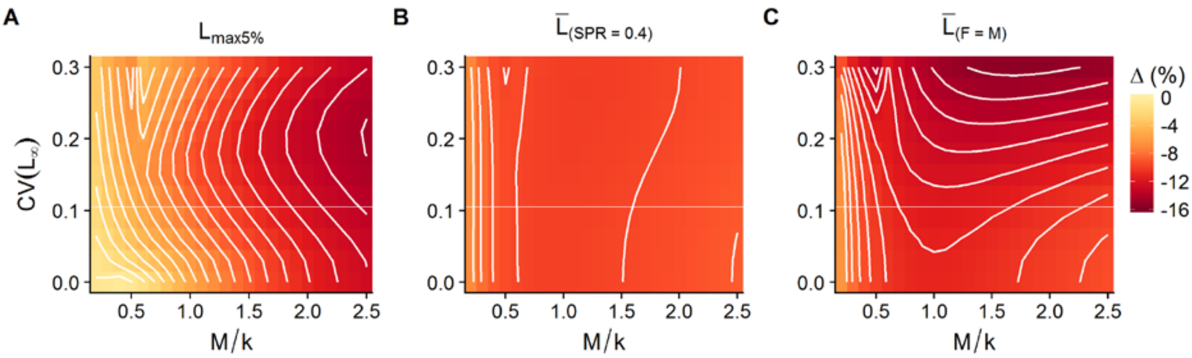


Figure 8.1.1. Contrast (% reduction compared to $F = 0$) over the M/k – CV(L_∞) space. The unexploited reference for $\bar{L}_{(F=M)}$ is $\bar{L}_{(SPR=1.0)}$, deemed to be an accurate enough estimate of the mean length in the unexploited population at equilibrium. Contours are equally spaced to highlight the differences in gradients. (Ls50=Lm50).

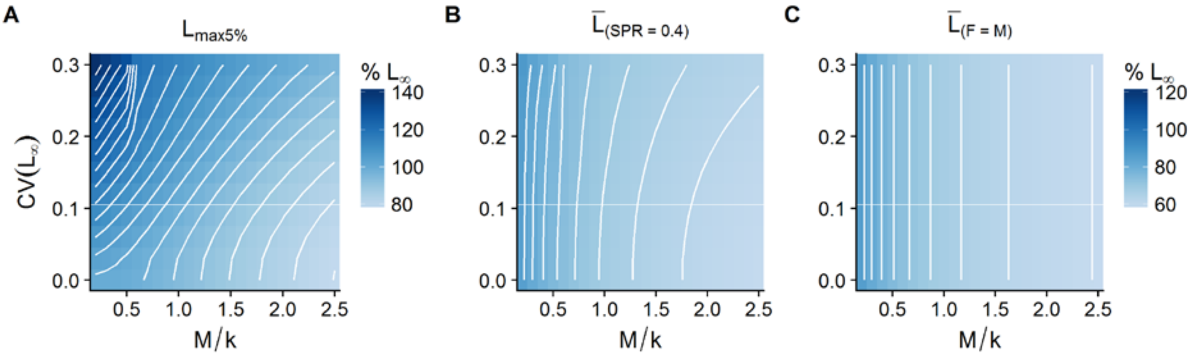


Figure 8.1.2. Values (% of L_∞) of reference points over the M/k – CV(L_∞) space. The range of value is the same on both colour scales (60%) and contours are equally spaced to highlight the differences in gradients.

8.1.2 Length-at-maturity (Lm_{50}) and length-at-capture (Ls_{50})

The same exercise has been carried out for the sensitivity to length-at-maturity and at-capture, with the simplifying assumption of cutting edge maturity and selectivity (only the latter enters calculation of $\bar{L}_{(F=M)}$). Other parameters were kept constant and set at typical values of $M/k = 1.5$ and $\mathrm{CV}(L_\infty) = 0.1$. As Lm_{50} does not relate to $\bar{L}_{(F=M)}$, the absence of variation of this reference point with length-at-maturity will only reflect its failure to take this effect into account, and the emphasis will be placed on the differences with $\bar{L}_{(SPR=0.4)}$, with which it shares the same reference for the unexploited situation ($\bar{L}_{(SPR=1.0)}$).

$L_{max5\%}$ exhibits a low to medium contrasts, varying moderately for values of $Ls_{50} <$ 50% L_∞. For this same range of Ls_{50}, the reference point is pretty insensitive to variations of Lm_{50} (Figure 8.1.3 A). The strong variations in the contrast for values of $Ls_{50} >$ 50% L_∞, especially when $Lm_{50} <$ 50% L_∞, arise from theoretically infinite F when $Ls_{50} \gg Lm_{50}$, while $SPR > 0.4$ (the "true" reference point is undefined). In such a case, the reference is estimated very close to Ls_{50} (exploitation truncates the distribution), which result in an increased contrast. The strong asymmetry in the gradient reflects the fact that when $Ls_{50} \leq Lm_{50}$, variations of Ls_{50} have nearly no effect on the reference point. Figure 8.1.4 A shows that in the cases where $Ls_{50} <$ 60% L_∞ or $Ls_{50} \leq Lm_{50}$, the value of the reference point is pretty stable. It could therefore prove a good candidate for an HCR when $Ls_{50} <$ 50% L_∞ or $Ls_{50} \leq Lm_{50}$, even if Ls_{50} is uncertain, or for high values of Ls_{50}, if known to be reliable enough. The contrast being nevertheless relatively low, its sensitivity to violation of assumptions and observation error should be investigated thoroughly.

As for $\bar{L}_{(SPR=0.4)}$, it exhibits a medium contrast over the whole range of explored parameter values (Figure 8.1.3 B), but its value is very sensitive to variations of Ls_{50} (Figure 8.1.4 B). In contrast, its value varies very few along the Lm_{50} gradient. It is therefore expected to be useful for an HCR, provided that the selectivity of exploitation is very well known.

The pattern shown by the contrast of $\bar{L}_{(F=M)}$, once again highlights a negative shift in its values for decreasing values of Ls_{50}, as it shares the same unexploited reference independent of maturation schedule. This means that it would be only relevant to Ls_{50} around 45% L_∞ (where the same contrast seems to apply) and less conservative below (slightly more above 50% L_∞).

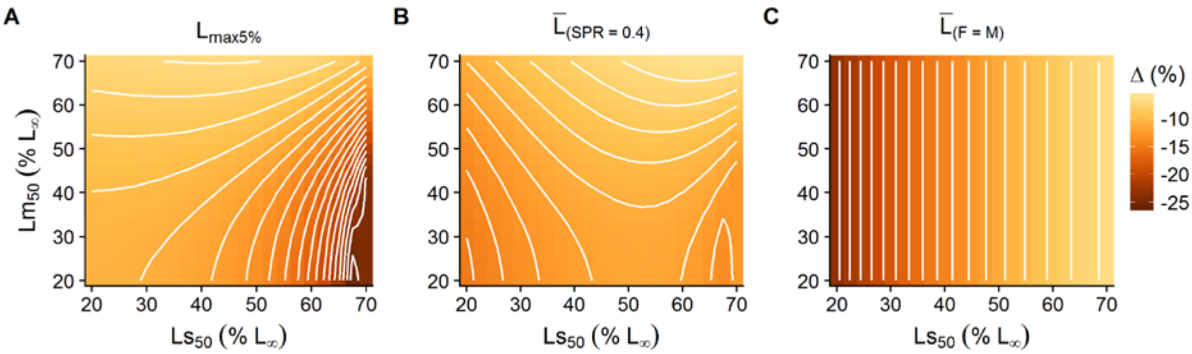


Figure 8.1.3. Contrast (% reduction compared to $F = 0$) over the $Lm_{50} - Ls_{50}$ space. The unexploited reference for $\bar{L}_{(F=M)}$ is $\bar{L}_{(SPR=1.0)}$, deemed to be an accurate enough estimate of the mean length in the unexploited population at equilibrium. Contours are equally spaced to highlight the differences in gradients.

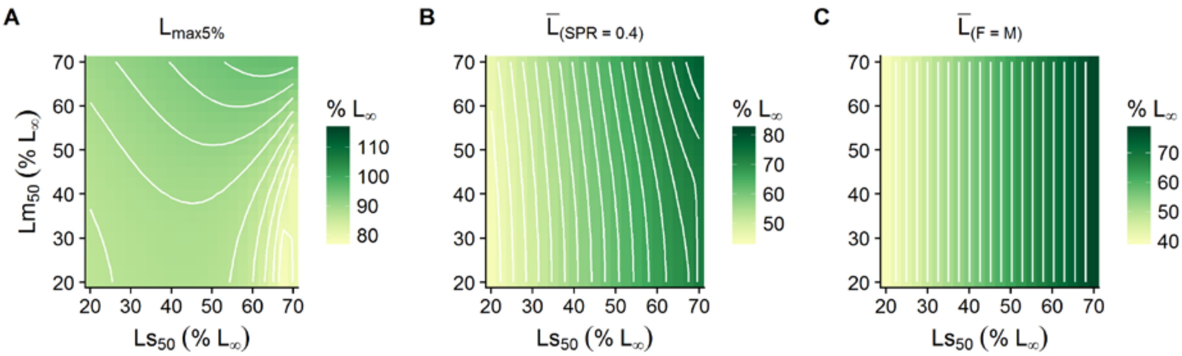


Figure 8.1.4. Values (% of L_∞) of reference points over the $Lm_{50} - Ls_{50}$ space. The range of value is the same on all colour scales (38%) and contours are equally spaced to highlight the differences in gradients.

A sensitivity analysis to misspecification (±15%) of selectivity parameters (Ls_{50}, Figure 8.1.5) and length-at-maturity (Lm_{50}, Figure 8.1.6) across values of M/k. The reference ($\Delta = 0$) was set at $Ls_{50} = Lm_{50} = 0.5 \cdot L_\infty$. Without surprise, it globally confirms that $L_{max5\%}$ is insensitive to variations in Ls_{50}, when Ls_{50} is close to Lm_{50} (Figure 8.1.5 A). Although it seems slightly more sensitive for high values of M/k. The high sensitivity of both $\bar{L}_{(SPR=0.4)}$ and $\bar{L}_{(F=M)}$ to variations of Ls_{50}, already observed for $M/k = 1.5$ seem consistent across the range of M/k (Figures 8.1.5 B and C).

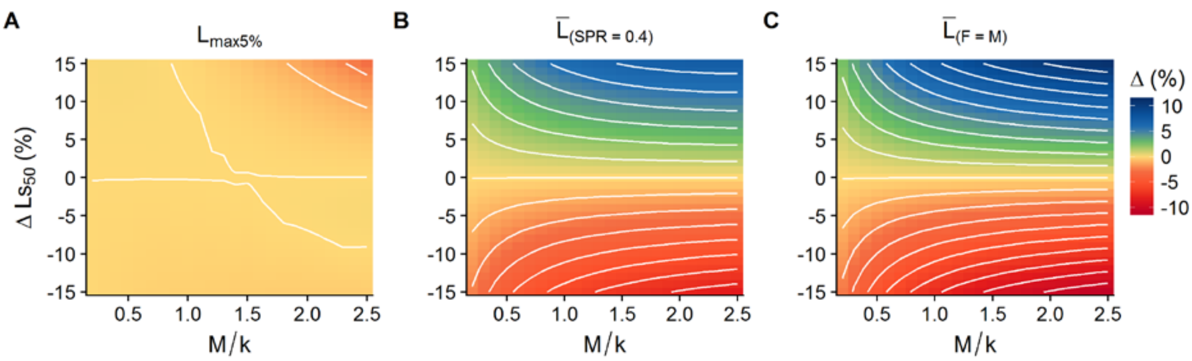


Figure 8.1.5. Sensitivity of reference points to misspecification ofLs_{50}(±15%). The same colour scale and equally spaced contours are used to highlight the differences in gradients.

In contrast, the relatively marked sensitivity of $L_{max5\%}$ to variations in Lm_{50} for $M/k = 1.5$ and $Ls_{50} \approx Lm_{50} \approx 0.5 \cdot L_{\infty}$, is not constant across values of M/k. The reference point reveals a higher sensitivity to misspecification of Lm_{50} at high values of M/k and nearly no sensitivity below $M/k = 1$ (Figure 8.1.6 B). The same trend is observed for the reference point $\bar{L}_{(SPR=0.4)}$, but with quite lower sensitivity overall (Figure 8.1.6 B). The absence of sensitivity in $\bar{L}_{(F=M)}$ only reflects the that its calculation does not account for Lm_{50}.

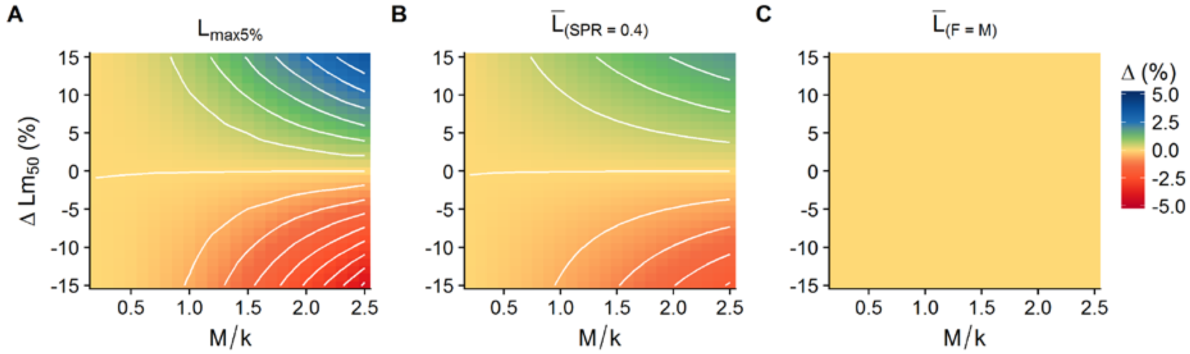


Figure 8.1.6. Sensitivity of reference points to misspecification ofLm_{50}($\pm$15%). The same colour scale and equally spaced contours are used to highlight the differences in gradients. The absence of gradient for $\bar{L}_{(F=M)}$ reflects the fact that this reference point does not account for size-at-maturity and then highlights an inherent limitation.

8.2 Reference points for length-based indicators ($CV_{L_\infty} = 0$) for life-history type case studies

The mean length of the largest 5% of individuals in the catch, $L_{max5\%}$ was introduced by Probst *et al.* (2013). As this indicator is derived from data in the right hand tail of the length distribution, it is assumed to be less affected by recruitment variability than the mean length in the catch. Theoretical reference points for $L_{max5\%}$ can be calculated for different values of length at first capture L_c. We use a simple age-per-recruit model and the von Bertalanffy growth equation to derive reference points based on a SPR=0.4 (WD Miethe *et al.*, Annex 5).MSY proxy reference point $L_{max5\%}^{F_{SPR=0.4}}$and limit reference point $L_{max5\%}^{F_{max}}$ are presented for a range of values of L_c together with the respective fishing mortality F and yield. **F_{max}** represents the fishing mortality rate that maximizes equilibrium yield-per-recruit. Three different life histories were considered, i) type I life history with M/k>1, ii) type II life history (M/k<1) elasmobranch with longer lifespan and iii) type II life history of short-lived clupeid. Both elasmobranch and clupeid stock are also characterized by relatively high ratio in L_{mat}/L_{∞}.

As three case studies we use life-history parameters (listed in Annex 5) for crustacean European lobster *Homarus gammarus* in the Irish Sea, elasmobranch Cuckoo ray *Leucoraja naevus*in the North Sea and clupeid *Clupea harengus* in the Celtic Sea. Reference points are calculated for the larger sex for each stock (males for lobster, females for Cuckoo ray) and for males for herring (same life-history parameters for both sexes).

Natural mortality for the stocks was estimated using the length-based updated Pauly estimator recommended by Then *et al.* (2015):

$$M = 4.118k^{0.73}L_{\infty}^{-0.33}$$

We find a good contrast between $L_{max5\%}^{F_{SPR=0.4}}$ and $L_{max5\%}^{F=0}$ for stock of life-history type I (Figure 8.2.1a). Relatively high natural mortality leads to an equilibrium size distribution dominated by juveniles. Fishing truncates the size distribution at the right tail; and the exploitation level can be inferred from a reduction in the mean size of the largest 5% in the catch. For L_c>> L_{mat}, the majority of mature individuals in the stock are protected, such that at some point SPR will always be above 40%. In this case, the respective fishing mortality can increase to infinity and the mean length of the largest 5% will be equal to L_c as all individuals above L_c are caught entirely (Figure 8.2.1b). To avoid inefficiently high fishing mortality but also ensure high yield, an L_c slightly above L_{mat} can be recommended. We find that the reference point is relatively constant over a wide range of values of L_c. Lower values of $L_{max5\%}^{F_{SPR=0.4}}$ are suggested for high values of L_c. However, in case of uncertainty in L_c and unknown discard mortality, a reference point $L_{max5\%}^{F_{SPR=0.4}}$ at L_c=L_{mat} can be recommended.

For life-history type II, both example ray and herring stock, the contrast between between $L_{max5\%}^{F_{SPR=0.4}}$ and $L_{max5\%}^{F=0}$ is relatively low (Figure 8.2.2a). Due to relatively low natural mortality (M/k<1) population size distributions are dominated by adults. The degree of truncation in the length distribution, as measured by $L_{max5\%}$, is lower. With additional observation error, a change in the indicator value following increasing exploitation level may not be recognized accurately.

The maximum yield reference point appears to be particularly unsuitable for herring, because fishing mortality may increase indefinitely at L_c<L_{mat} (Figure 8.2.2c). The assumption of constant recruitment to ensure high yield in a fast-growing stock may not be appropriate, when mature individuals are fully exploited.

The presented reference points depend on the assumption of equilibrium dynamics, constant natural mortality-at-age and constant fishing mortality as well as constant recruitment. In the following section, it is tested whether reference points $L_{max5\%}^{F_{SPR=0.4}}$ and $L_{F=M}$ represent SPR=0.4 under non-equilibrium conditions using a stochastic population simulation model.

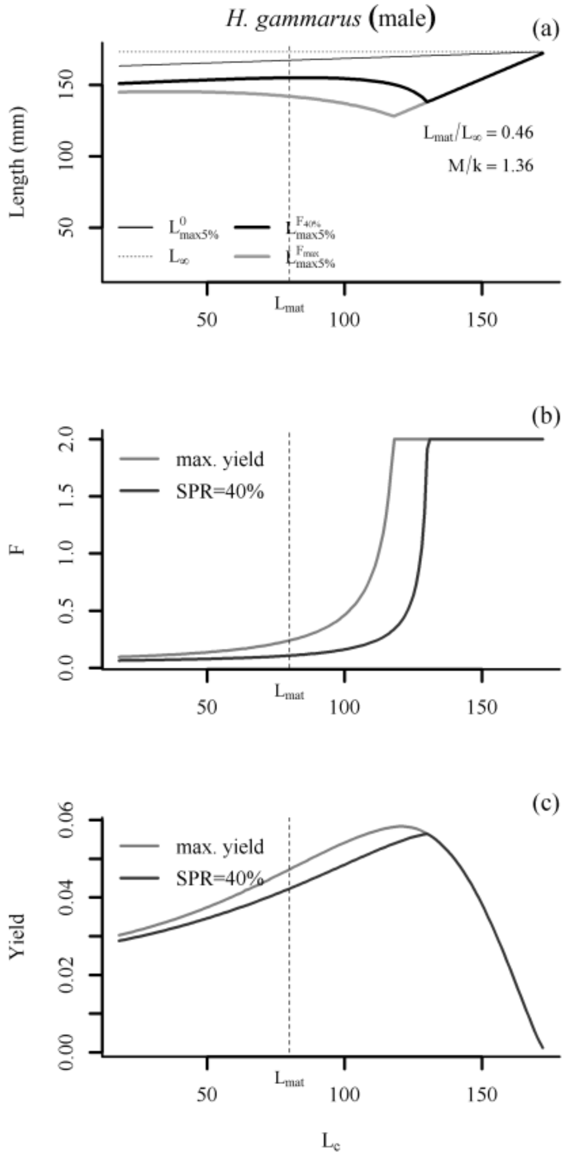


Figure 8.2.1. Theoretical reference points for $L_{max5\%}$, type I life history, European lobster. (a) $L^0_{max5\%}$ from an unexploited stock, $L^{F_{40\%}}_{max5\%}$ exploited at SPR=0.4 (bold black), $L^{F_{max}}_{max5\%}$ from the stock exploited at F_{max} (bold grey), (b) $F_{40\%}$, fishing mortality for exploitation at 40% SPR, limited by value 2. (c) Corresponding standardized yield.

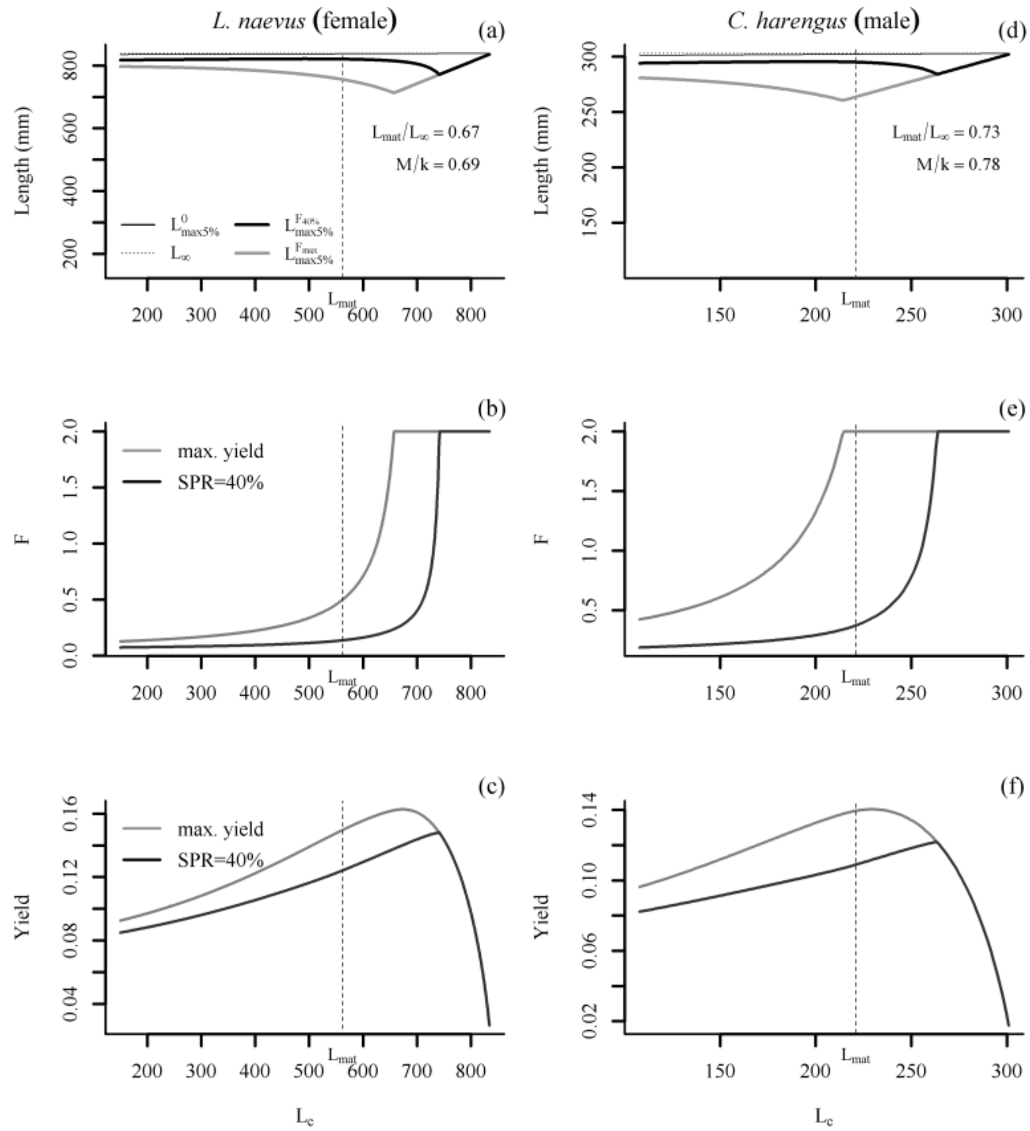


Figure 8.2.2. Theoretical reference points for $L_{max5\%}$, type II life history, Cuckoo ray and Atlantic herring. (a) $L^{0}_{max5\%}$ from an unexploited stock, $L^{F40\%}_{max5\%}$ exploited at SPR=0.4 (bold black), $L^{F_{max}}_{max5\%}$ from the stock exploited at F_{max} (grey), (b) $F_{40\%}$, fishing mortality for exploitation at 40% SPR, limited by value 2. (c) Corresponding standardized yield.

8.3 Testing reference points $L^{F40\%}_{max5\%}$ and $L_{F=M}$ under non-equilibrium conditions

We use length-based sex-structured population models parameterized for European lobster, *Homarus gammarus*, and Cuckoo ray, *Leucoraja naevus*, to compare the reference points for two length-based indicators $L_{max5\%}$ and $\bar{L}$ under non-equilibrium conditions with regard to SPR=40%.

The simulation models and parameter settings according to life histories of European lobster in the North Sea and Cuckoo ray in the Irish Sea are described in detail in Annex 6 (WD Miethe *et al.*).Reference points are calculated following Jardim *et al.*, 2015 for $L_{F=M}$ and Miethe *et al.* (WD, Annex 5, 6) for $L^{F_{SPR=0.4}}_{max5\%}$ with CV(L_∞) and constant natural mortality at length.

For the model, length classes are constructed with varying bin width such that individuals grow into the next length class within a single time-step. This results in a parsimonious number of length classes for each sex. The use of very small time-steps or many narrow length classes can thereby be avoided, improving computational efficiency. The population is subject to both fishing and natural mortality, which occur simultaneously and continuously through time. Natural mortality is assumed to be constant over time, length and for both sexes. Fishing selectivity is stochastic. For both stocks, a stochastic Beverton–Holt spawning–stock recruitment relationship was assumed. Simulations start at population equilibrium at SSB_0. In year 10, fishing is implemented at a constant catch that results in an overexploited stock, which collapsed within the simulation period (100 years) without management. We run 1000 simulations for each scenario of fishery selectivity (L_c). Indicator values are calculated from randomly resampled catches (1% of the total number of individuals caught). Using the simulation model, the median length-based indicator value when the overexploited stocks reached a median SPR of 40% was determined. The two stocks differ in their life-history strategy with regard to M/k and L_{mat}/L_∞, with lobster (type I) having a high M/k ratio and a relatively low L_{mat}/L_∞ and cuckoo ray (type II) with a low M/k and higher L_{mat}/L_∞.

Simulation results for L_c slightly above L_{mat} for lobster (90 mm) and a constant catch of 2000 t (Figure 8.3.1) and for Cuckoo ray for L_c=450mm below L_{mat} with a constant catch of 400 t (Figure 8.3.2). Catches drop as stock biomass decreases and cannot support a set constant catch. Recruitment declines following the drop in SSB. Both length-based indicators decrease with exploitation and truncation of size distribution and drop below their reference point in year 40 (35 for Cuckoo ray).

Similar simulations were run for other values of L_c. Median indicator values in the first exploitation year (unexploited size distribution) and when SSB reaches 40% are shown in Figures 8.3.3 and 8.3.4. Because the population is at equilibrium during the first ten years of the simulation, median indicator values match well the theoretical prediction for F=0. Due to non-equilibrium dynamics, $L_{max5\%}$ is slightly higher than its reference point at SPR=40% (Figure 8.3.3a). For a population exploited at $F_{SPR=0.4}$ for a longer period of time, observed indicator values are expected to be closer the reference point as stock size, recruitment and length distributions stabilize at a new equilibrium.

In comparison, the median $\bar{L}$are relatively close to the reference points for L_c>L_{mat}. At very low L_c, median indicator values differ more from the reference point. This indicates that the reference point will not be precautionary for low values of L_c. The effect of recruitment on $\bar{L}$is stronger than for $L_{max5\%}$. As SSB decreases with overexploitation also recruitment decreases leading to higher mean length in the catch than under non-equilibrium conditions. Similarly for cuckoo ray (Figure 8.3.4) the reference point $L_{F=M}$ will not be precautionary for L_c<L_{mat}. In contrast for L_c>>L_{mat} tend to be more precautionary also for stocks with type II life history.

As indicated in the previous section, type II life histories show less contrast in the $L_{max5\%}$ reference points. A change in indicator values may be too small to notice and infer exploitation status. While the contrast in mean length, $\bar{L}$, is stronger in response to fishing, the sensitivity to L_c remains a disadvantage if uncertainty in the estimate is large.

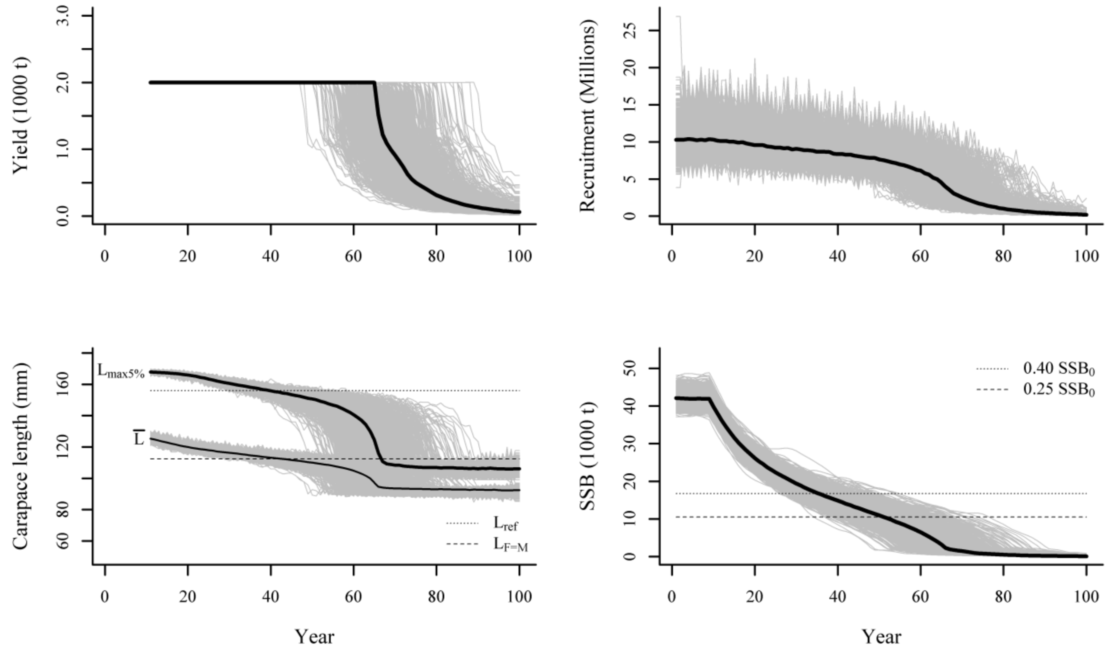


Figure 8.3.1. European lobster simulation results (1000 runs in grey and annual medians in black) for L_c=90 mm, a constant catch of 2000 t. Length-based indicators for males only.

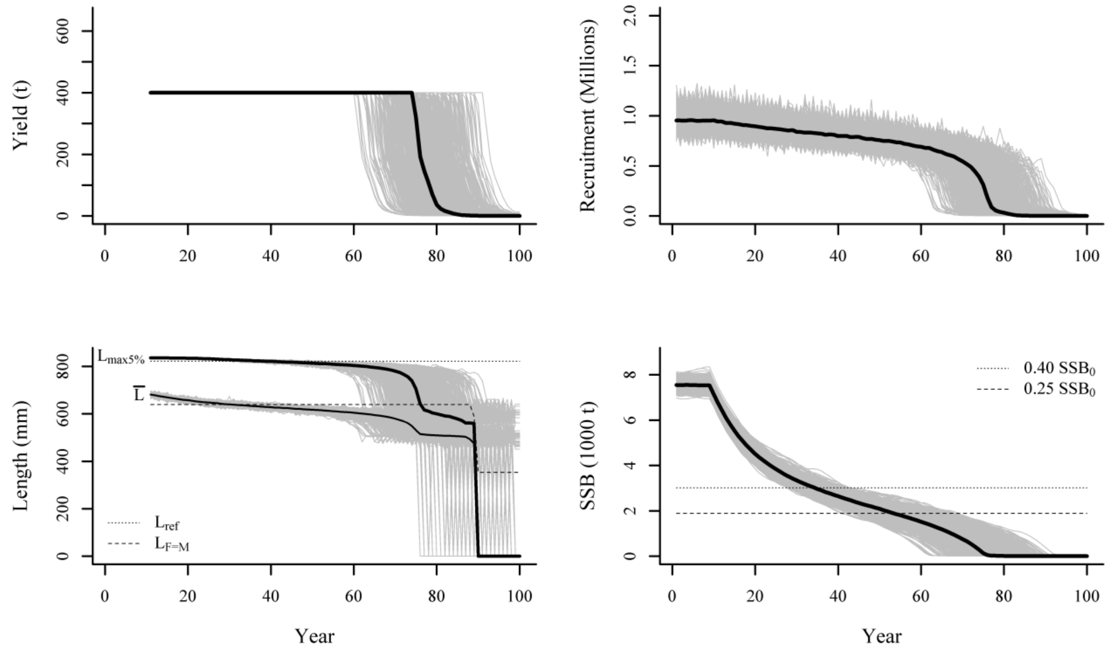


Figure 8.3.2. Cuckoo ray simulation results (1000 runs and annual medians) for L_c=450 mm, a constant catch of 400 t. Length-based indicators for males only.

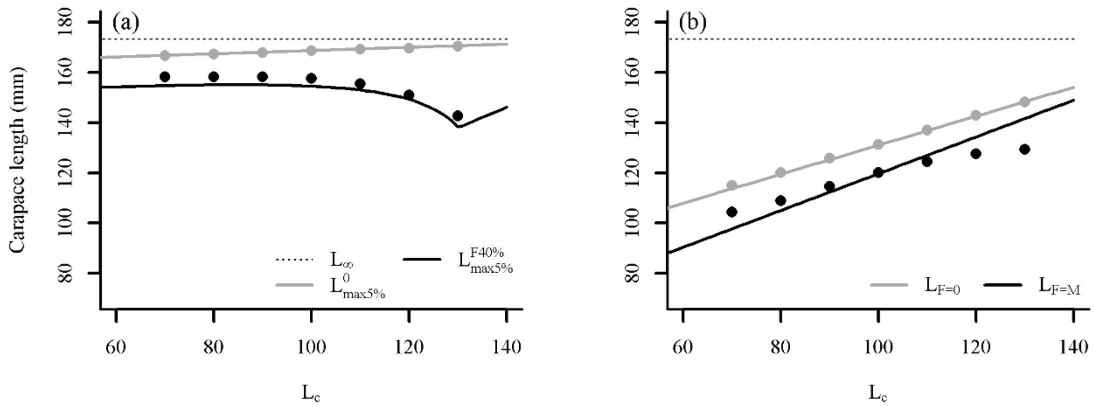


Figure 8.3.3 Reference point comparison for European lobster. Comparison of theoretical reference point and simulation medians (for 1000 runs) (dots), in grey theoretical value at F=0 (first year of exploitation) and in black at $F_{SPR=0.4}$.

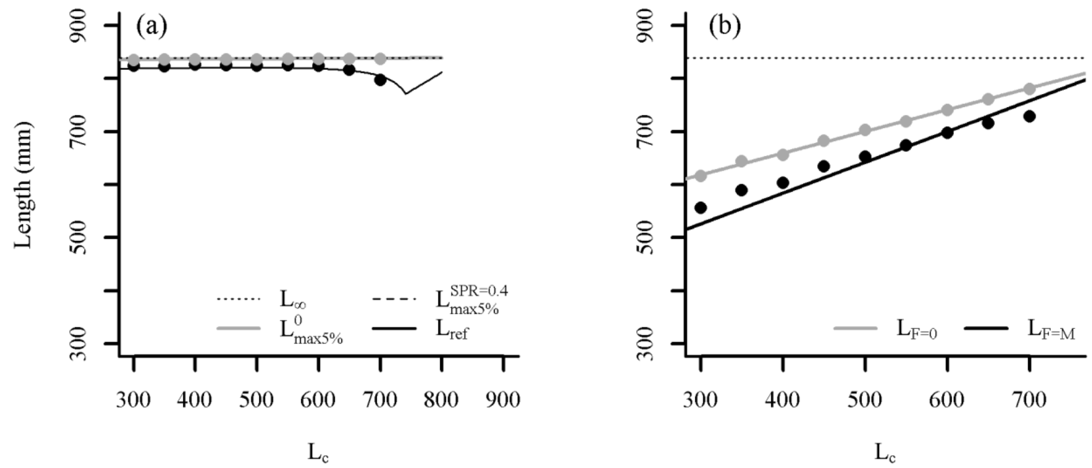


Figure 8.3.4 Reference point comparison for Cuckoo ray. Comparison of theoretical reference point and simulation medians (for 1000 runs) (dots), in grey theoretical value at F=0 (first year of exploitation) and in black at $F_{SPR=0.4}$.

8.4 Comparison of harvest control rules using length-based indicators for category 3 stocks in DLMtool

8.4.1 Operating model and harvest control rules

A total of 14 operating models are developed based on life-history parameters from FLife as detailed in Sections 2, 4 and Annex 4. The parameters from the stochastic simulations from Annex 4 are used. The various operating models are selected to cover a range of life histories (e.g. *M/k* and L_{mat}/L_{∞}), and may not represent any particular species or stock. The DLMtools R package for developing MSEs for data-limited harvest control rules (HCRs) were used to perform MSEs. The operating model was age-structured. For this purpose, length parameters (selectivity, maturity) are converted to age-based parameters, and the model includes age-varying natural mortality. Among the 300 iterations, operating model parameters for life-history parameters (growth, maturity, natural mortality), selectivity, were stochastically sampled according to a uniform distribution with the means calculated based on FLife and the minimum and maximum of the distribution as 90% and 110% of the mean, respectively. For steepness,

the bounds were 0.7 and 0.9 (with a mean of 0.8). Age-specific natural mortality (M) was specified by converting length-specific M (calculated from the method of Gislason *et al.*, 2010) with von Bertalanffy parameters. Logistic selectivity was assumed for all stocks.

All operating models had a common historical period of 100 years, which a large increase in effort depletes the stock until year 80, followed by a decrease in effort until year 100 when the projection period begins. The projection period was 100 years in which the management procedures were applied biennially. Perfect TAC implementation was assumed, and the observations were very precise using the *Perfect_Info* template provided by DLMtool. The operating model is parameterized with $\mathrm{CV}(L_\infty) = 0.1$ and L_{s50}=L_{mat}.

The harvest control rules were evaluated under two depletion scenarios: first, when depletion is 0.1 (i.e. the biomass is at 10% of that at virgin conditions), and second, when depletion is 0.2 at the beginning of the projection period. These conditions can evaluate whether the harvest control rules can recover the population when it is heavily depleted, and how the control rules would perform when stock status is more optimistic.

The TAC is adjusted following a harvest control rule:

$$TAC_{y+1} = C_y\, r\, f b$$

where the TAC in year *y+1* is the product of the catch in year *y*, *r* as the indicator of trends in stock biomass and *f* as the indicator of exploitation.

For r the following option was used:

- *r23:* 2-over-3 rule that uses the ratio of the mean of the index in the previous two years preceding the assessment to the mean of the index 3–5 years preceding the assessment.

Two management options for *f* were compared:

- *fLBI (Length-based indicator)*: the ratio of the mean length above L_c in year *y* and $L_{F=M}$, the mean length predicted when *F* = *M* (Jardim *et al.*, 2015). Here, L_c is the half-modal length, i.e. the first length at which the catch-at-length is at least half of that at the mode and L_∞ is obtained from the observation model. M/k are set to 1.5 for data-limited stocks.
- *fLmax5*: the ratio of the mean length of the largest 5% $L_{\mathrm{max5\%}}$ in year *y* and $L^{F40\%}_{\mathrm{max5\%}}$, the mean length of the largest 5% in the catch predicted when *F* = $F_{40\%}$ (CV(L_∞)=0.1). Here, L_∞ are obtained from the observation model. M/k are set to 1.5 for data-limited stocks.

For *b*,the minimum of 1 or $I_y/I_{trigger}$ (with $I_{trigger}$ = 1.4 I_{lim}; I_{lim} was calculated as the minimum value of the index observed over the entire time-series) was used. Based on the simulations in Section 2.2, no discernible differences were observed between the two choices for *r*. Thus, no further comparison was made here between the 2-over-3 rule and five-year slope rule.

8.4.2 Results

Results show a variety of different outcomes depending on the stocks (Figure 8.4.1). For simplicity, a subset of five stocks were selected to identify model behaviour depending on different life-history types (Figure 8.4.2).

With implementation of the harvest control rules, some stocks recover to unexploited SSB but deliver no yield (turbot, megrim, plaice and red mullet). These stocks are characterized relatively high M/k, and low L_{mat}/L_{∞}. For fLmax%, the trade-off between risk and yield was weaker. There was generally a higher median yield for fLmax5% than for fLBI for most example stocks (Table 8.4.3).

Stocks with high M/k and high L_{mat}/L_{∞}(rosefish and whiteanglerfishC) remain overexploited under both advice rules (Tables 8.4.1 and 8.4.2).

For pollack, yield goes to down while biomass recovers only using fLBI rule, under fLmax5% SSB recovers and yield increases closer to optimal level (Figure 8.4.1). Whiting recovers above SSB_{MSY} following both rules and delivers yield close to optimum. Norway lobster show some oscillations in (stronger for fLmax5%).

Under fLBI, stocks for which the control rule is sufficiently precautionary did not produce much yield. For stock with high L_{mat}/L_{∞}(whiteanglerfishN and ling) fLmax5% performed slightly better than fLBI (Table 8.4.3).

The 14 operating models differ in L_{s50}/L_{m50}. The effect on fishing mortality on stocks and on the performance of harvest control rules depend on length at first capture relative to L_{mat}. The management of a fishery targeting mature and immature individuals have strong effect in particular in late maturing stocks. Further analysis, using observed values of L_{s50} are suggested. Furthermore, the ratio age at first capture relative to the maximum age can give more information on exploitation level as individuals accumulate the effects of mortality over a lifetime.

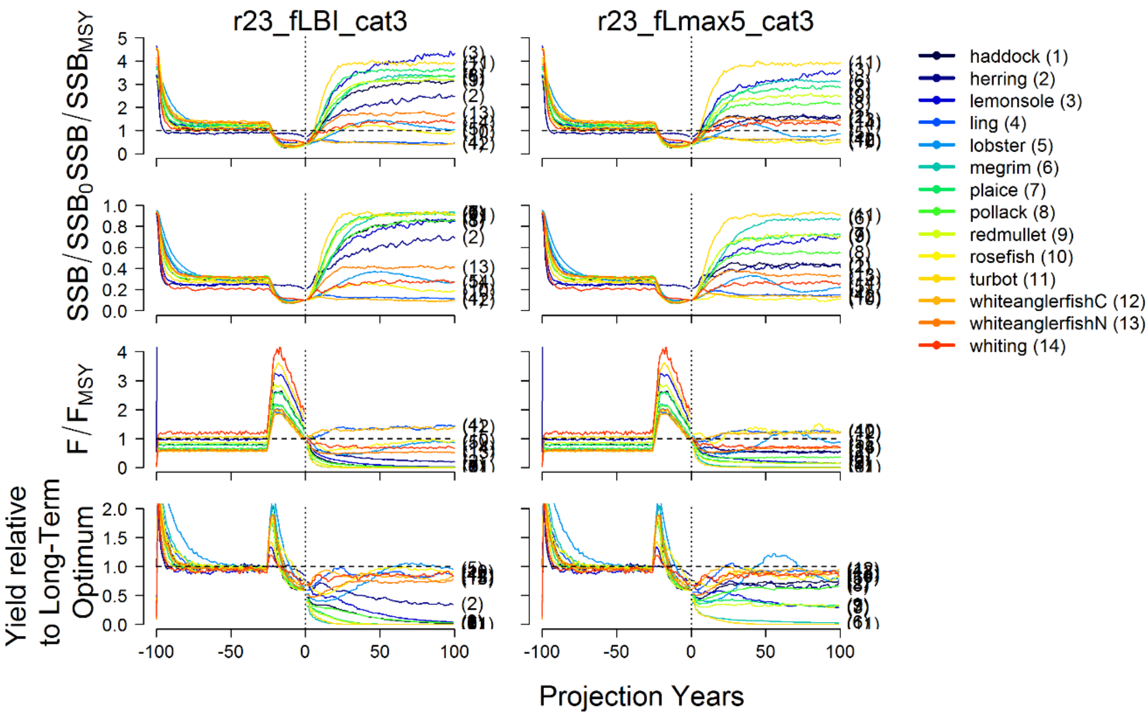


Figure 8.4.1. Management strategy evaluation of two length-based harvest control rules when depletion = 0.1 (10% of virgin biomass) at the beginning of the management period. The category 3 management procedures use the 2-over-3 rule (r23) for stock biomass trends. Individual lines represent median trajectories in spawning–stock biomass, fishing mortality, and yield of the 14 stocks (from 300 simulations). The long-term optimum yield is the achievable MSY from a fixed-F harvest strategy over the course of the 100 years of the projection period.

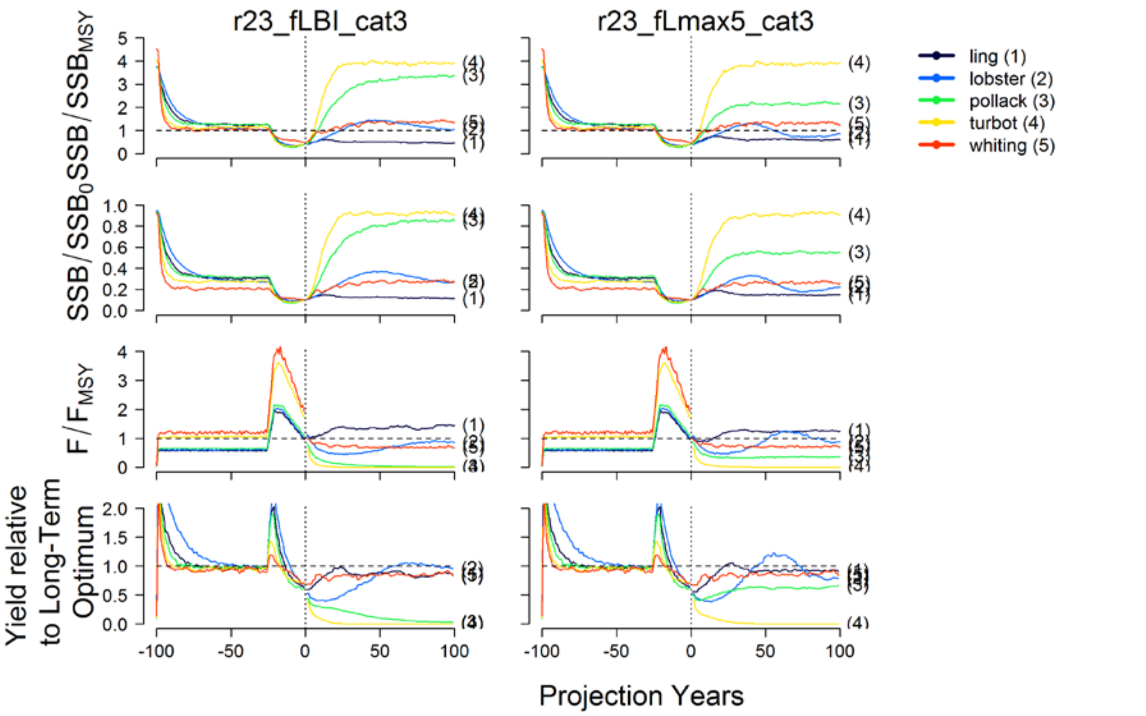


Figure 8.4.2. Subset of operating models from the management strategy evaluation of two length-based harvest control rules when depletion = 0.1 (10% of virgin biomass) at the beginning of the management period. Individual lines represent median trajectories in spawning–stock biomass, fishing mortality, and yield.

Table 8.4.1. Summary table for r23_fLBI_cat3. Performance statistics of operating models in the depletion-0.1. Green indicates PB_{lim} < 5%, POF < 50%, P50 < 50%, Yield > 50%.

				r23_fLBI_cat3			
Stock	M/K	Lm50/L∞	Ls50/Lm50	P[B<Blim]	P[F>Fmsy]	P[B<0.5BMSY]	Yield
haddock	0.99	0.38	0.08	3	1	3	15
herring	0.89	0.70	-0.03	2	4	2	41
lemonsole	0.83	0.73	0.46	4	2	2	9
ling	0.76	0.62	0.22	54	76	50	86
lobster	0.96	0.46	0.43	11	24	10	101
megrim	1.02	0.43	0.39	3	0	3	0
plaice	1.00	0.48	0.25	2	0	2	0
pollack	0.84	0.55	0.24	3	1	3	15
redmullet	1.12	0.36	0.04	2	1	3	1
rosefish	0.71	0.80	0.62	30	37	21	95
turbot	0.90	0.51	0.07	2	0	1	0
whiteanglerfishC	0.73	0.69	0.25	64	73	56	80
whiteanglerfishN	0.80	0.58	0.21	8	13	5	75
whiting	0.87	0.74	0.52	24	25	12	92
Green:				< 5%	< 50%	< 50%	> 50%

Table 8.4.2. Summary table for r23_fLmax5_cat3.

			r23_fLmax5_cat3			
Stock	M/K	Lm50/L∞	P[B<Blim]	P[F>Fmsy]	P[B<0.5BMSY]	Yield
haddock	0.99	0.38	7	14	8	71
herring	0.89	0.70	5	15	5	76
lemonsole	0.83	0.73	4	3	2	36
ling	0.76	0.62	38	70	31	91
lobster	0.96	0.46	21	37	18	85
megrim	1.02	0.43	3	0	4	15
plaice	1.00	0.48	3	1	2	36
pollack	0.84	0.55	4	3	3	63
redmullet	1.12	0.36	4	3	4	37
rosefish	0.71	0.80	56	59	47	88
turbot	0.90	0.51	2	0	2	0
whiteanglerfishC	0.73	0.69	43	67	31	91
whiteanglerfishN	0.80	0.58	7	12	4	88
whiting	0.87	0.74	24	25	12	93
Green:			< 5%	< 50%	< 50%	> 50%

Table 8.4.3. Summary table difference between fLBI and fLmax5%.

Stock	M/K	Lm50/L∞	Ls50/Lm50	ΔP[B<Blim]	ΔP[F>Fmsy]	ΔP[B<0.5BMSY]	ΔYield
haddock	0.99	0.38	0.08	-4	-13	-5	-56
herring	0.89	0.70	-0.03	-3	-11	-3	-35
lemonsole	0.83	0.73	0.46	0	-1	0	-27
ling	0.76	0.62	0.22	16	6	19	-5
lobster	0.96	0.46	0.43	-10	-13	-8	16
megrim	1.02	0.43	0.39	0	0	-1	-15
plaice	1.00	0.48	0.25	-1	-1	0	-36
pollack	0.84	0.55	0.24	-1	-2	0	-48
redmullet	1.12	0.36	0.04	-2	-2	-1	-36
rosefish	0.71	0.80	0.62	-26	-22	-26	7
turbot	0.90	0.51	0.07	0	0	-1	0
whiteanglerfish C	0.73	0.69	0.25	21	6	25	-11
whiteanglerfish N	0.80	0.58	0.21	1	1	1	-13
whiting	0.87	0.74	0.52	0	0	0	-1

8.5 Conclusions

- Choice of indicator and reference point depending on life-history type. Both advice rules, using mean length and mean length of the largest 5%, perform worse for stocks with low M/k. If length distributions are dominated by large individuals, a truncation in length distribution due to fishing is less pronounced.
- An assumption of M/k for data-limited stocks of 1.5 for stocks with low M/k contributed to the low performance of the harvest control rule.
- The choice of advice rule depends on level of uncertainty in M/k and L_c estimate. If L_c is highly uncertain, due to unknown discard and discard mortality or recruitment variability (cohorts affecting the estimate) an advice rule based on $L_{max5\%}$ may be preferable.
- The performance of advice rules needs to be tested for different values of L_{s50}, because reference points may be less appropriate to $L_{s50}<L_{m50}$ (in particular if the reference point calculation does not account for L_{m50} such as $L_{F=M}$), when immature individuals are targeted.

8.6 References

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Then, A. Y., Hoenig, J. M., Hall, N. G., and Hewitt, D. A. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72: 82–92.

Annex 1: Workshop agenda

Daily schedule (except 2 October: Start at 10:00 am and 6 October: Finish at 13:00 pm:

09:00	start
11:00	Coffee-break
13:00	Lunch
16:00	Coffee-break
18:00	end

02 October

10:00–10:30

General meeting set-up, accessing WiFi, meeting facility orientation, introductions& meeting ToRs.

10:30–11:30

Presentation & plenary discussion:

d) **Nuno Brites** - "Fishing in randomly varying environments: comparison between constant and variable effort harvesting policies"

12:00–13:10

e) **Piera Carpi** - "Update model for HR estimation for *Nephrops* stocks"

14:10-16:10

f) **Tobias Mildenberger** -"MSE with SPICT applied to the DLMtool package"

g) **Casper** -"Seasonal assessment with SPICT"

16:45–18:00

h) **Quang** - "Evaluation of length-based methods harvest control rules for Category 3, 4 stocks in DLMtool"

i) **Tanja** -"Reference points for a length-based indicator (using a spawning potential ratio of 40% for the length-based reference point Lmax5%"

j) **José** -"Drumfish"

03 October

09:00–11:00

k) **Mikael** -"Evaluation of survey based TAC rules in an MSE-like framework"

l) **Alex** -"MSE with the S6-model applied to the DLMtool package"

m) **Rasmus** -"Aspects related to methodological development in relation the assessment models and in relation to the MSE"

n) **José** -"FLife in FLR"

11:30–13:00

o) **Simon** -"MSE testing of WKMSYCat34 catch rules"

14:00–16:00

p) **Yves** -"MYDAS project"

q) **Yves** -"Adaptation of the LB-SPR model to assess life-history traits/invariants"

Plenary session: definition of subgroups/link to ToRs & task allocation.

Subgroups work

16:30–18:00

Plenary session: subgroup work progress and discussion

04 October

09:00–17:00

Subgroups work

17:00–18:00

Plenary session: subgroup work progress and discussion

05 October

09:00–18:00

Subgroups work

Report writing and collation

20:00 WKLIFE group dinner

06 October

09:00–13:00

Plenary session: conclusions & recommendations adoption

Annex 2: WKLIFE VII List of participants

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Annex 3: Working document: MSE testing of WKMSYCat34 rules in FLR

MSE testing of WKMSYCat34 rules in FLR

Working document for ICES WKLIFE VII 2017

Simon Fischer*, José De Oliveira, Karin Olsson, Ernesto Jardim, Finlay Scott & Iago Mosqueira

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A3.1 Summary

This working document describes extensive simulation testing of the catch rules proposed by ICES WKMSYCat34 (ICES, 2017b). These catch rules are for data-limited stocks in ICES categories 3-4.

Operating models based on 15 data-limited stocks were developed and a range of catch rules was tested with generic full-feedback Management Strategy Evaluation (MSE) simulations.

The first catch rule (catch rule 3.2.1) used length based methods to come up with a new TAC advice based on modifying the current catch. In general, the catch rule did not perform well and failed frequently when applied with the default parametrization. The performance of the catch rule could be partially improved by fine-tuning its components. The catch rule was very sensitive to assumptions and vulnerable to uncertainty. A universal solution with this catch rule seemed unlikely.

The second catch rule (rule 3.2.2) was based on applying an Fproxy to a stock size indicator. For reasonable values of Fproxy, used as target in this rule, it performed well for most stocks.

The last tested catch rule tested here (rule 3.1) was based on a SPiCT (Surplus Production in Continuous Time) assessment and forecast. Only one trial run was conducted but the results look promising. If SPiCT achieves a reasonable fit, the results indicate good results as this catch rules works on modifying the fishing mortality directly.

The simulations conducted in this working document are generic and only a first start. More testing and further development is crucial.

A3.2 Table of contents

A3.3 Introduction

This working document describes extensive simulation testing of the catch rules proposed by WKMSYCat34 (ICES, 2017b).

Management Strategy Evaluation (MSE) simulations were carried out using FLR (Fisheries Library in R http://www.flr-project.org/, Kell et al., 2007). As a template for the MSE framework, the standard MSE developed within the a4a (assessment for all initiative, Jardim et al., 2015, Jardim et al. 2017) was used and extended to data-limited methods.

The source code for the simulations is available from https://github.com/shfischer/wklifeVII.

A3.4 Operating model

A3.4.1 Stocks

The biological stocks were created based on a set of life-history parameters. The creation of the stocks was very similar to the work conducted in WKLIFE VI (see ICES, 2017a for details).

The life-history parameters used for the 15 operating model stocks are shown in Table A3.1. Compared to earlier WKLIFE approaches, the parameters were sourced from other publications and represent particular stocks in a certain stock areas, rather than

the mean of different populations. The life-history parameters were chosen after checking their reasonability. This included whether the data were based on sufficient samples, age/length ranges and whether the stocks created from them were reasonable in terms of age range, growth, productivity, etc. The stock list comprised various life-histories and types, e.g. demersal and pelagic species, flatfish, one crustacean, etc.

Table A3.1. Life-history parameters used for generating the 15 operating model stocks. italic values estimated with FLife

NAME	COMMON NAME	AREA	STOCK	A	B	L_{INF}	L_{50}	A_{50}	T_0	K
Pollachius pollachius	Pollack	North Sea	pol.27.3a4	0.0076	3.069	85.6	47.1	*4.1*	*-0.1*	0.19
Molva molva	Ling	Widely	lin.27.3a4a6-91214	0.0036	3.108	119	74	7.2	*-0.1*	0.14
Lophius piscatorius	White anglerfish	Celtic Seas	mon.27.78abd	0.0198	2.895	105.6	73	*6.2*	-0.38	0.18
Lophius piscatorius	Anglerfish	North Sea	anf.27.3a46	0.0297	2.841	106	61	*4.7*	*-0.1*	0.18
Pleuronectes platessa	Plaice	Celtic Seas	ple.27.7h-k	0.011	2.958	48	22.9	*2.7*	*-0.1*	0.23
Melanogrammus aeglefinus	Haddock	Celtic Seas	had.27.7a	0.0113	2.96	79.9	*42.3*	2	-0.36	0.2
Nephrops norvegicus	Nephrops	Biscay-Iberia	nep.27.2829	0.00028	3.229	70	28.4	*2.5*	*-0.1*	0.2
Lepidorhombus whiffiagonis	Megrim	North Sea	lez.27.4a6a	0.0022	3.3433	54	23	3	*-0.1*	0.12
Sebastes norvegicus	Redfish	Northern	reb.27.5a14	0.0178	2.972	50.2	40.3	*14.8*	0.08	0.11
Mullus surmuletus	Striped red mullet	Celtic Seas	mur.27.67a-ce-k89a	0.0057	3.243	47.5	16.9	*2.0*	*-0.1*	0.21
Scopthalmus maximus	Turbot	North Sea	tur.27.4	0.0149	3.079	66.7	34.2	2.2	0.29	0.32
Microstomus kitt	Lemon sole	North Sea	lem.27.3a47d	0.0123	2.971	37	27	*3.0*	*-0.1*	0.42
Merlangius merlangus	Whiting	Celtic Seas	whg.27.7b-ce-k	0.0103	2.395	38	28	*2.5*	-1.01	0.38
Clupea harengus	Herring	Celtic Seas	her.27.nirs	0.0048	3.198	33	23	*1.9*	*-0.1*	0.606
Ammodytes spp.	Sandeels	North Sea	san.sa.4	0.0049	2.783	24	12	*0.6*	*-0.1*	1

Table A3.2. Some further life-history characteristics for the 15 operating model stocks.

STOCK	A_{MAX}	M	M/K	L_{50}/L_{INF}
pol.27.3a4	16	0.21	1.12	0.55
lin.27.3a4a6-91214	22	0.14	1.01	0.62
mon.27.78abd	17	0.18	0.99	0.69
anf.27.3a46	17	0.20	1.10	0.58
ple.27.7h-k	13	0.32	1.40	0.48
had.27.7a	15	0.26	1.30	0.53
nep.27.2829	15	0.28	1.38	0.41
lez.27.4a6a	25	0.18	1.54	0.43
reb.27.5a14	28	0.12	1.07	0.80
mur.27.67a-ce-k89a	15	0.35	1.66	0.36
tur.27.4	10	0.40	1.25	0.51
lem.27.3a47d	8	0.46	1.10	0.73
whg.27.7b-ce-k	7	0.44	1.15	0.74
her.27.nirs	5	0.76	1.25	0.70
san.sa.4	3	1.21	1.21	0.50

The biological stocks were created from the life-history parameters using the FLR package FLife (https://github.com/flr/FLife/, http://www.flr-project.org/FLife/). The dataset used in this working document has already been implemented into FLife as "wklife". The only difference is that the life-history parameters for Nephrops were later changed to represent a more reasonable stock.

Missing life-history parameters were estimated in FLife. In FLife, most stock characteristics are first defined in terms of length and then converted into ages. The final result is an age structured operating model. For the creation of the biological stocks, mostly default parameters from FLife were used (maturity, selectivity, natural mortality, growth, etc.).

The maximum age was defined as the rounded age where the growth reached 95% of L_∞. The age groups used for calculating the mean fishing mortality were obtained by fishing the stock for several years at ½F_{MSY} and determining which ages contributed most to the catch.

An age-dependent natural mortality was modelled according to Gislason et al. (2010).

Fisheries selectivity was modelled with an asymptotic curve where the age at 50% maturity was the first age with full fisheries selectivity. For more details see the WKLIFE VI report and the FLife documentation.

The virgin biomass was set to a value of 1000 for all stocks. Recruitment was modelled with a Beverton & Holt model and a steepness of 0.75, i.e. all stocks had the same relative recruitment over the entire SSB range but the absolute virgin recruitment value was stock-specific.

The survey index used in the MSE simulations was modelled with a logistic function and the inflection point set at 10% of the maximum age.

A3.4.2 Fishing history

Two separate fishing histories governed by the fishing mortality were developed. The starting point of the fishing history for all stocks was a stock at virgin conditions (virgin biomass, no fishing). From here, the stocks were fished for 75 years at ½FMSY (years 1-75) in order to have a lightly fished stock in equilibrium condition. Starting from this point, two different fishing histories were applied to all stocks for another 25 years (year 76-100):

One-way trip history:

- For the "one-way" trip, the fishing mortality was increased exponentially from ½F_{MSY} to 75% of F_{crash} within 25 years (i.e. the natural logarithm of the targeted fishing mortalities is a straight line). This led to a strong depletion and the stocks showed a decreasing trend. At the end of this fishing history the stocks are highly overfished.

Roller-coaster history:

- For the roller-coaster scenario, the fishing mortality was increased exponentially from ½FMSY to 80% of F_{crash}, F_{crash} was then maintained for 5 years and the fishing mortality was then decreased negative exponentially down to F_{MSY} until the end of the 25-year fishing history period. The initial increase in fishing mortality happened within 8-11 years and depended on the absolute difference between the absolute values of ½F_{MSY} and 80% of F_{crash}, with shorter

time periods for larger differences. With this approach, stocks with high fishing mortalities had more time to recover. The roller-coaster fishing history caused high depletion levels but at the end of the period the stocks had already started to recover. At the end of the historical period both fishing histories had similar depletion levels between around 5-15% of virgin biomass.

Figure A3.1 shows the two fishing histories (medians) for all stocks and Figure A3.2 the full history for one example stock (pol.27.3a4).

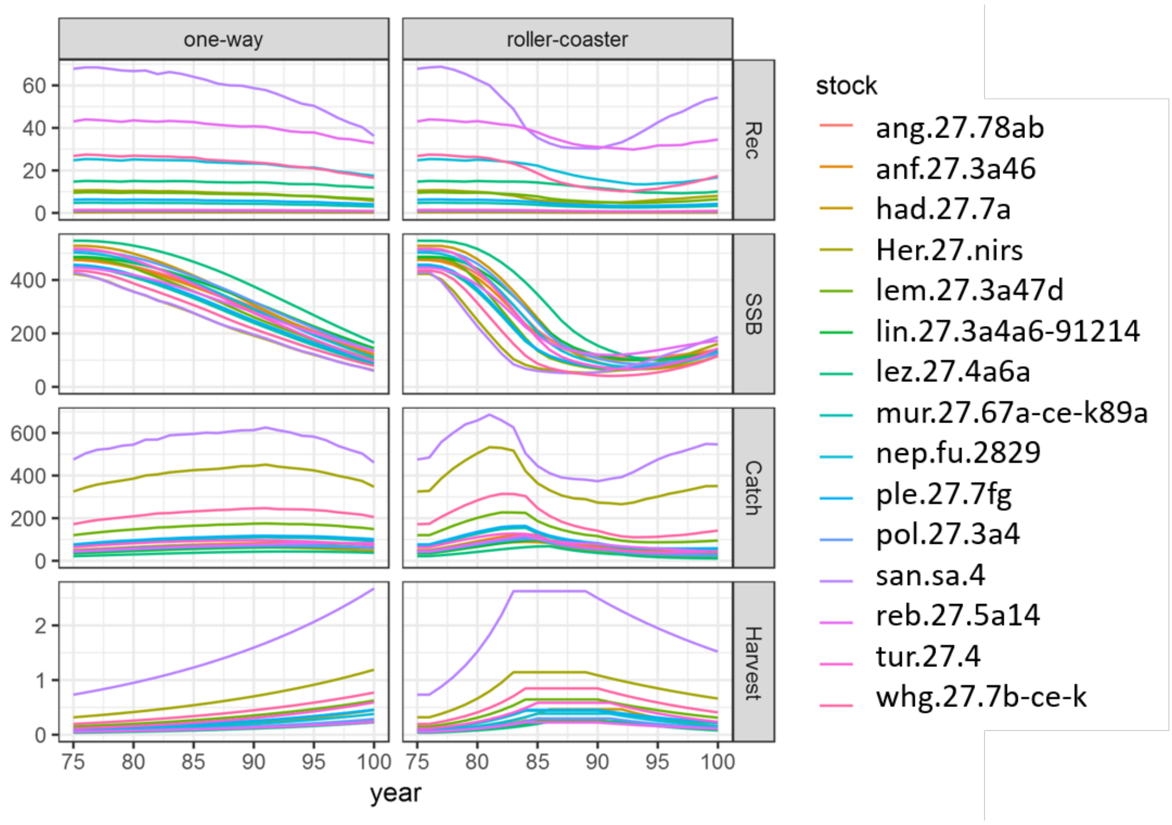

Figure A3.1.The two fishing histories (one-way and roller-coaster) for all 15 stocks. The solid lines represent the medians of 500 iterations.

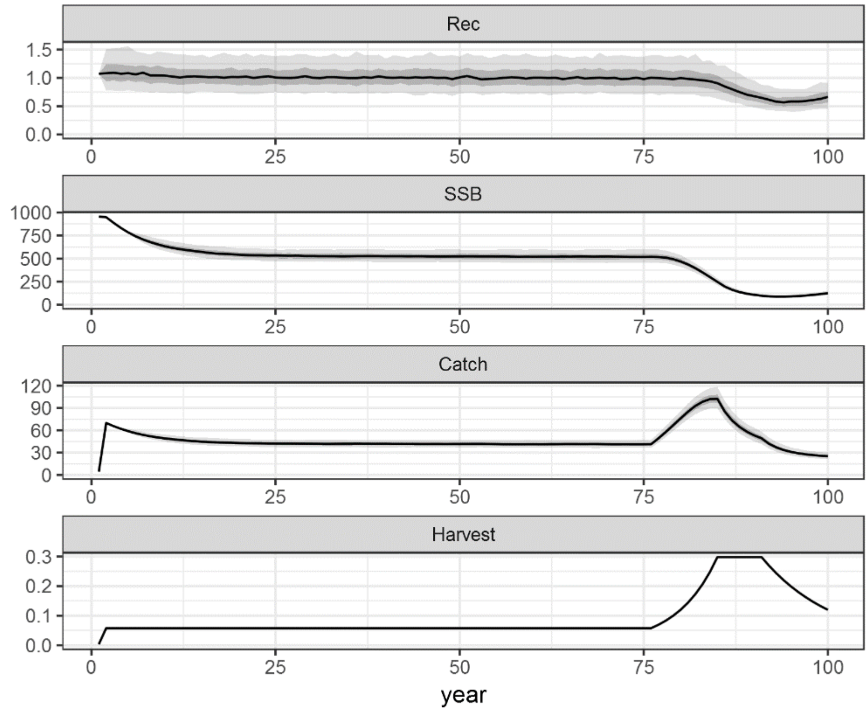

Figure A3.2. One example fishing history: the roller-coaster scenario for pol.27.3a4. The solid line represents the median of 500 iterations, surrounded by the 50% (dark grey) and 90% (light grey) confidence intervals.

A3.4.3 Observation model

The survey index selectivity used in the MSE simulations was modelled with a logistic function and the inflection point was set at 10% of the maximum age.

Some of the catch rules tested in this working document relied on catch length frequencies. The length frequencies were created by converting the ages from the operating model into lengths with the allometric relationship parameters *a* and *b*. In order to get more length classes, each length class was spread with a normal distribution with the mean equal to the calculated length, a standard deviation of 1 and a cut-off at ±2sd. The catch abundances from each age class after spreading were normalized and then the catch numbers coming from different age classes were aggregated into 1cm length classes. A further cut-off was applied limiting the length classes within the range 1-$L_\infty$and the resulting catch distribution was normalized again, so that catches at lengths above the maximum length were not lost.

A3.4.4 Simulation specifications

The simulations were projected forward for a total of 100 years (years 101-200). By default, a biennial TAC was used, i.e. the TAC was set every second year.

The simulations adopted the usual ICES management cycle where data are available up to and including the last year (y-1), the assessment is conducted in the intermediate year (y) and the advice is for the following year (y+1).

The simulations included recruitment uncertainty, implemented as a lognormal multiplicative noise component with a standard deviation of 0.3 and autocorrelation of 0.2.

This uncertainty was independent for each iteration and predefined for each iteration individually, but identical for all stocks.

Unless otherwise specified, the simulations included only this recruitment uncertainty and no other source of uncertainty or bias.

A3.4.5 Peformance statistics

Each scenario was simulated with 500 iterations, each with independent uncertainty. Unless otherwise stated, the plots with the stock trends in this working document show only the median, to allow several stocks to fit into the same plot.

For the calculation of risks, a value for B_{lim} had to be defined. The definition of B_{lim} as proposed by WKMSYCat34 was adopted. This meant that B_{lim} was set at the SSB level where the recruitment is at 70% of virgin recruitment (Figure A3.3). As all stocks used a Beverton & Holt stock recruitment model with a steepness of 0.75, 70% of recruitment corresponded to a value of 162.79 or 16.279% of virgin biomass.

Mainly the following three performance statistical characteristics were calculated:

- **p(SSB < B_{lim})**: The risk of the SSB falling below B_{lim}. This was calculated as the average risk during the entire 100-year simulation period (years 101-200).
- **iter collapse**: The proportion of the 500 iterations that collapsed at any point during the 100-year simulation period. A stock collapse was defined as a state when the SSB dropped below a level of 1, i.e. below 0.1% of the virgin biomass.
- **Relative yield**: The relative yield was the average yield over the entire simulation period (years 101-200) divided by the average yield in the historical period (years 75-100).

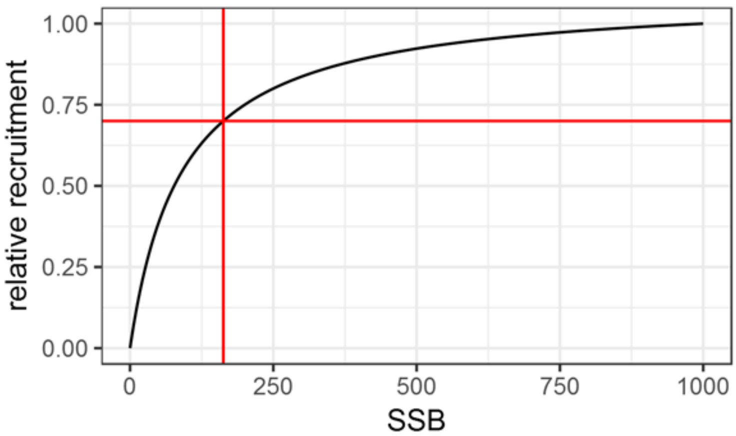

Figure A3.3. Stock recruitment function used for all operating models including the definition of B_{lim} (the point where the red lines intersect)

A3.5 Catch rules tested

A3.5.1 Catch rule 3.2.1

A3.5.1.1 Introduction

Catch rule 3.2.1 (equation 3.2.1.1 from WKMSYCat34, ICES, 2017) has the form:

$$C_{y+1} = C_{current} \times r \times f \times b$$

$C_{y+1}$is the new advised catch, $C_{current}$ is the last available catch (usually the catch in year $y - 1$, or an average over recent years), r is a component accounting for the trend in stock biomass, f is a proxy for $F_{MSY}/(\text{current exploitation})$ and b a stock size safeguard.

There are different methods proposed by WKMSYCat34 for r and f. Category 3 data-limited stocks should use a combination of the factors of the catch rule. For category 4 stocks the WKMSYCat34 proposal is to use $r = 1$ and $b = 0.8$ every four years and $b = 1$ in between.

For the simulations conducted in this working document, $C_{current}$ was always set to C_{y-1}.

A3.5.1.2 Testing components individually

The first set of simulations for catch rule 3.2.1 was conducted assuming perfect knowledge in the management procedure. These simulations included only recruitment uncertainty.

The components of the catch rule (r, f, b) were initially tested individually. This meant for example that the for the testing of r, the remaining components f and b were set to 1 and the catch rule was simplified to $C_{y+1} = C_{current} \times r$.

The reason for testing the components on their own was to see how they behave and whether they are able to track the stock characteristics they are supposed to represent. With this approach it was possible to identify particular options for components that do not work at all or show poor performance and exclude them from further analyses. Furthermore, assumptions about the components could be explored and what effect they caused.

A3.5.1.2.1 Component r

The first set of simulations for catch rule 3.2.1 was conducted assuming perfect knowledge in the management procedure. These simulations included only recruitment uncertainty.

The components of the catch rule (r, f, b) were initially tested individually. This meant for example that the for the testing of r, the remaining components f and b were set to 1 and the catch rule was simplified to $C_{y+1} = C_{current} \times r$.

The reason for testing the components on their own was to see how they behave and whether they are able to track the stock characteristics they are supposed to represent. With this approach it was possible to identify particular options for components that do not work at all or show poor performance and exclude them from further analyses. Furthermore, assumptions about the components could be explored and what effect they caused.

Component r works on a stock size index and is supposed to represent the current trend (e.g. increasing, decreasing, stable). Two options were proposed by WKMSYCat34.

Option a) is the “usual” “2 over 3” rule as currently used for ICES category 3 stocks (average of the stocks index in the two most recent years, divided by the average of the three preceding years).

Option b) is defined as$\exp(w \times slope)$, with $w = 1$ or 2 and slope calculated as a straight line fitted to the logarithm of the stock size index in the last 5 years, i.e. a linear regression of the logarithmic stock size index. In the simulations described in this working document, only $w = 1$ was tested.

WKMSYCat34 proposed additional more sophisticated options, e.g. using a SPiCT assessment and applying options a and b to the estimated stock biomass. This was not evaluated.

Figure A3.4 and Figure A3.5 show the results for option a, Figure A3.6 and Figure A3.7 for option b and Figure A3.8 the performance statistics.

Option a ("2 over 3" rule)

Initially, both options lead to a decrease in advised catch. On average (median of the stock trend) the "2 over 3" rule was able to keep the SSB at a low level for some stocks during the simulation period but in the one-way trip 7 and in the roller-coaster trip 8 of the 15 stocks collapsed. In the summary plots, a recovery of the SSB towards unexploited levels is evident for these stocks. The reason for this recovery is that these stocks collapsed earlier and once a stock has collapsed, the catch is reduced to or very close to zero. If the stock started to recover at a later point in the simulation, the catch did not recover as it was always based on recent catches (i.e. 0). For nine stocks, a substantial proportion of the iterations collapsed during the simulation period for both fishing histories (Figure A3.8, rows 3 & 4).

Option b (slope)

The performance of option b depended on the fishing history before the simulation started. In the one-way trip, the median SSBs of all stocks collapsed shortly after the implementation of the management (Figure A3.6). This is also illustrated by the proportion of collapsed iterations in Figure A3.8, which are at or very close to 1 for all stocks. This means that this catch rule entirely failed here. Some stocks showed signs of recovery later on, but this is only because the catch stayed at zero once the stock had collapsed.

The performance of the same catch rule in the roller-coaster trip is much better, with lower risk of stock collapses.

Figure A3.9 shows the result for one example stock (pol.27.3a4) for the one-way trip. The first element in the plot shows the results of the component r, which determines the new catch advice. Both options lead to a reduction of catch at the beginning after the implementation of the catch rule but the reduction is stronger for option a ("2 over 3" rule). For option a, this led to a substantial reduction of catch and the stocks started to recover after a few years and finally stabilizes at a low level below B_{lim}. For option b (slope), the reduction did not seem to be strong enough at the beginning and the stock kept decreasing until the fishing mortality reached the maximum allowed value in the simulation (maxF = 5) and the stock collapsed.

In conclusion, neither option for r worked well on their, caused a high risk of stock collapses and lead to high uncertainty even without including observation error. The performance of option a seemed to be more stable irrespective of the fishing history as it led to a stronger translation of the stock trend into the catch advice. Option b caused smaller changes to the advised catch. This might work well if the stock is in a more or less stable condition but if the stock size is decreasing, the catch reduction is unlikely to be strong enough.

Option b can be made more responsive if *w* in the calculation of the component *b* is set to 2 instead of 1, but this still leads to smaller changes compared to the "2 over 3" rule.

For combinations of the components of catch rule 3.2.1, option a for component r was selected, as it appears to be more responsive and this is a desired feature if a stock is in poor condition and catches should be reduced.

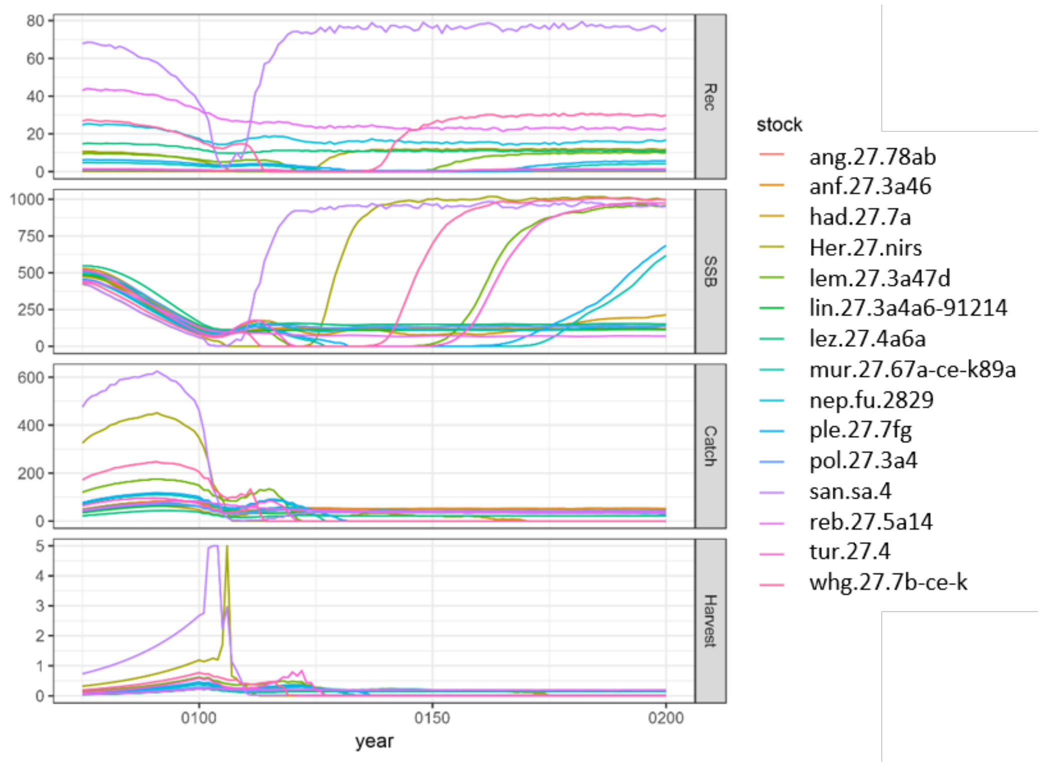

Figure A3.4. Simulation results of option a ("2 over 3" rule) of component r of catch rule 3.2.1 for one-way trip fishing history. Shown are the medians from 500 iterations for each stock.

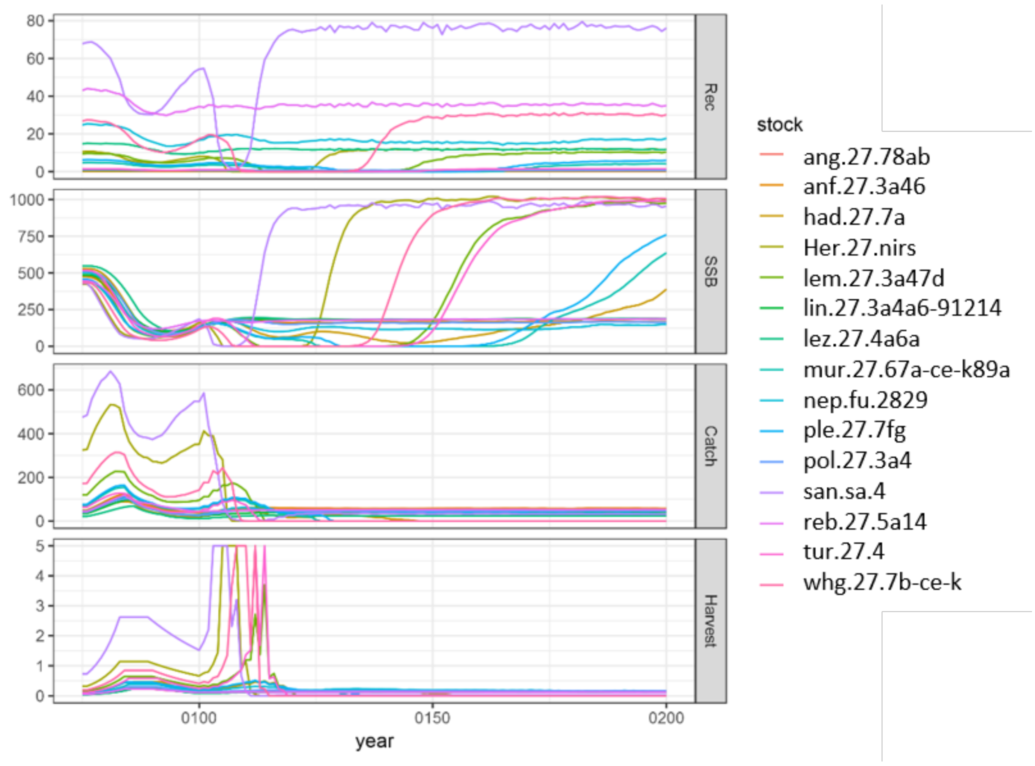

Figure A3.5. Simulation results of option a ("2 over 3" rule) of component r of catch rule 3.2.1 for roller-coaster fishing history.

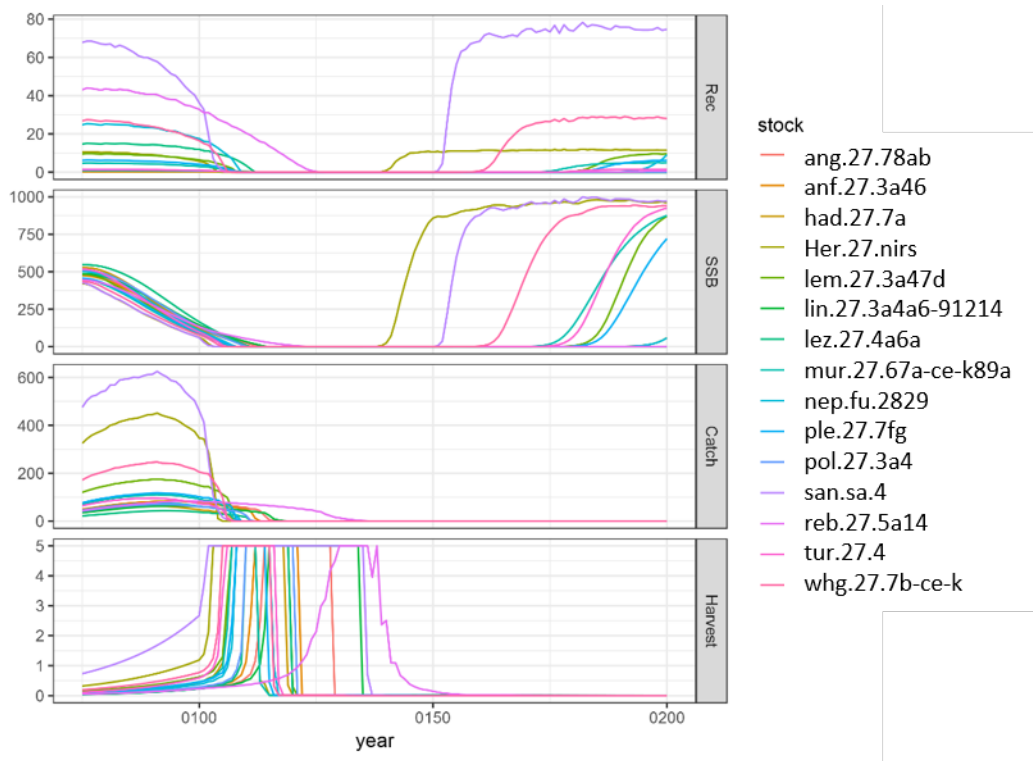

Figure A3.6. Simulation results of option b (slope) of component r of catch rule 3.2.1 for one-way trip fishing history.

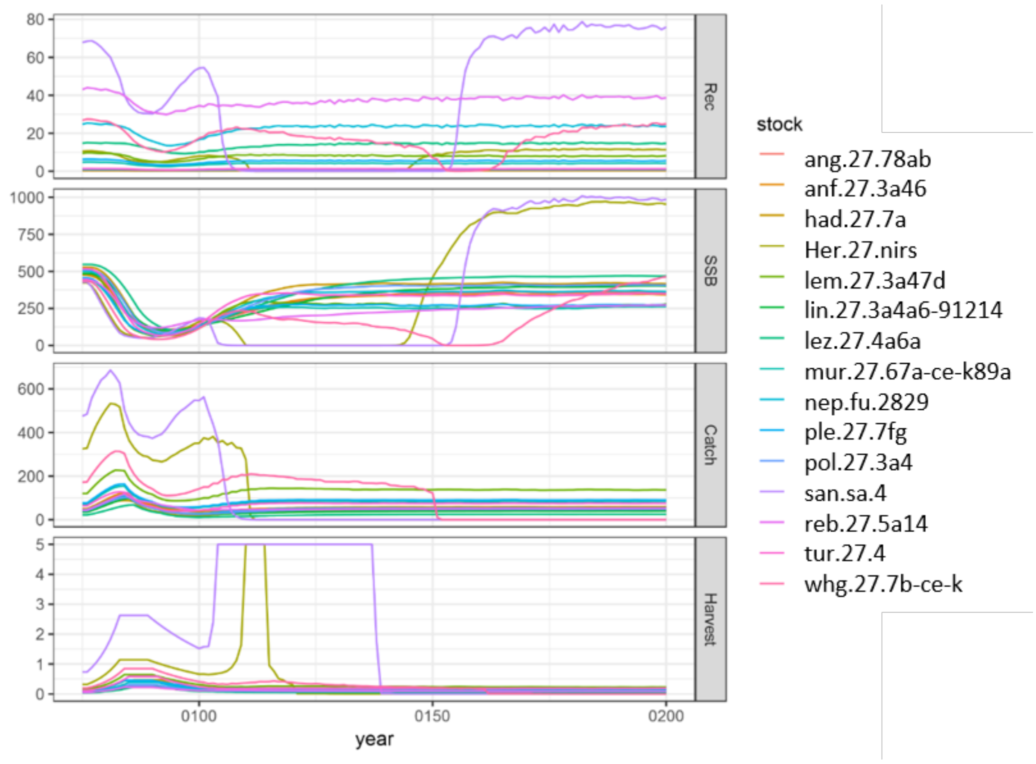

Figure A3.7. Simulation results of option b (slope) of component r of catch rule 3.2.1 for roller-coaster fishing history.

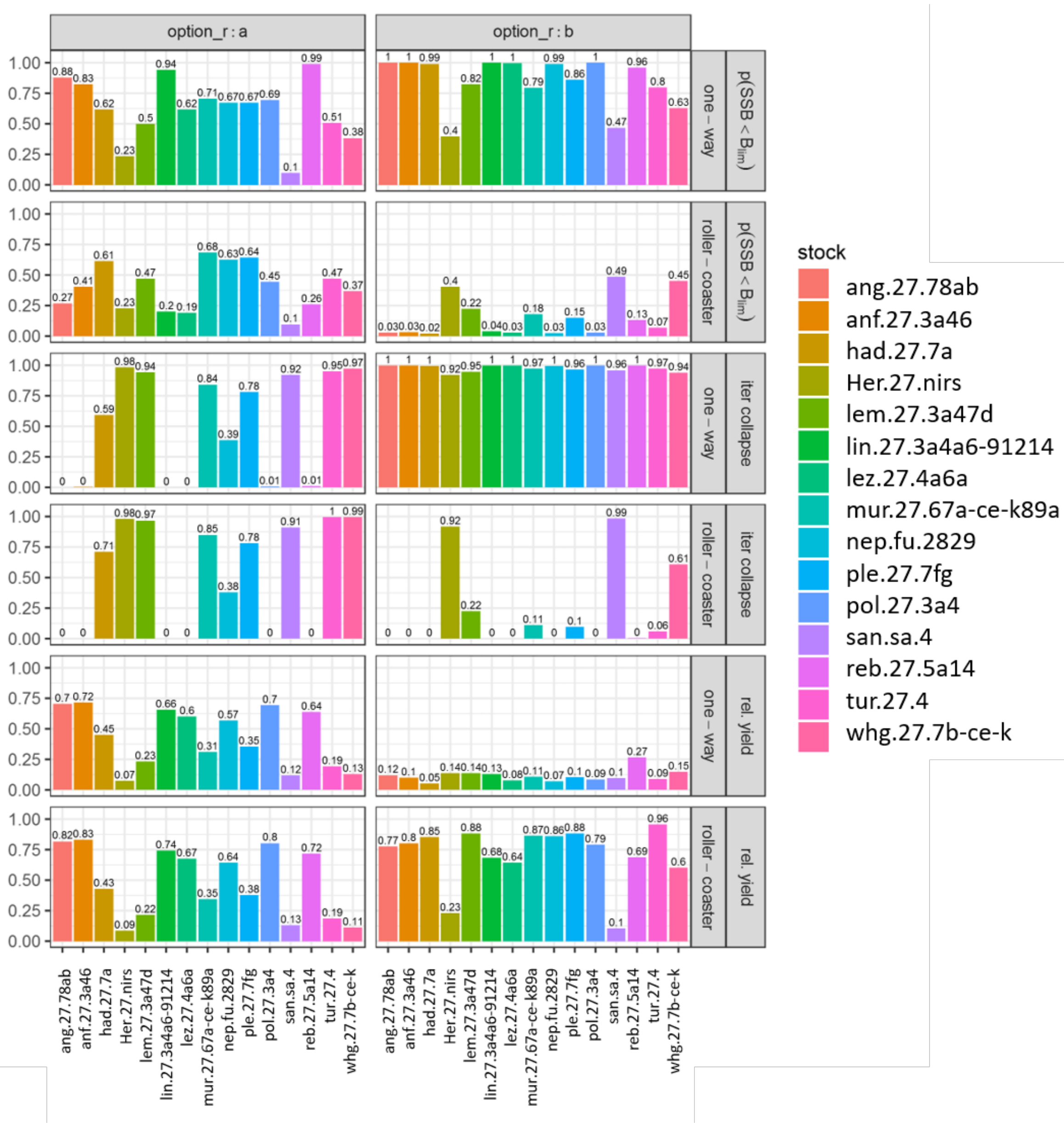

Figure A3.8. Performance statistics for testing component r of catch rule 3.2.1. Rows 1 & 2 show the risk of dropping below B_{lim}, rows 3 & 4 the proportion of iterations that collapsed during the simulation and rows 5 & 6 the yield during the simulation period compared to the yield before the simulation started, for the two options for b and for both fishing histories.

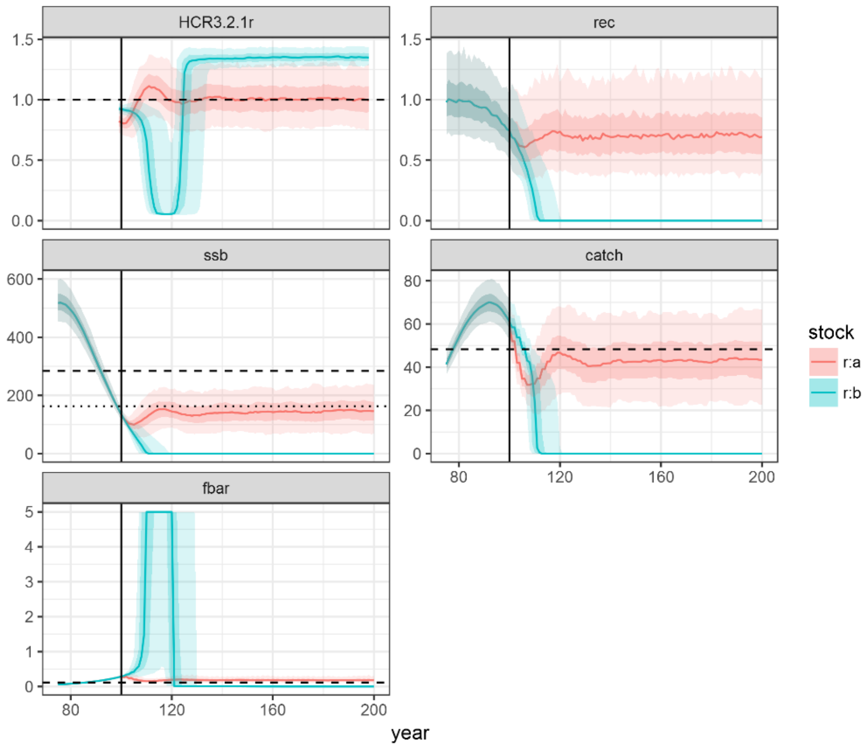

Figure A3.9 Results for pol.27.3a4 for catch rule 3.2.1, testing the options of component r individually. The solid lines indicate the median and the shaded areas the 50% and 90% confidence intervals. The dashed lines represent MSY levels and the dotted line BMSY.

A3.5.1.2.2 Component f

Component f of catch rule 3.2.1 from WKMSYCat34 is supposed to be a proxy for the ratio of F_{MSY}/(current exploitation). Three options were proposed.

Option a is defined as $f = L_{current}/L_{F=M}$ where $L_{current}$ is the current mean length in the catch above the length of first capture and $L_{F=M}$ is a reference point derived from the Beverton–Holt equilibrium formula assuming $F = M$:

$$L_{F=M} = \frac{L_\infty + \frac{2M}{K} * L_c}{1 + \frac{2M}{K}}$$

Option b is calculated as $f = M/(Z_{current} - M)$, where $Z_{current}$ is also derived from the Beverton–Holt equilibrium formula as $Z_{current} = K(L_\infty - L_{current})/(L_{current} - L_c)$.

Option c is calculated as $f = F_{0.1}/(Z_{current} - M)$, where$Z_{current}$ is calculated with the Gedamke & Hoenig (2006) method and $F_{0.1}$ comes from a length-based Yield-Per-Recruit model.

More sophisticated options were mentioned in WKMSYCat34 but not evaluated in the simulations.

For the simulation described in this working document the term "recent" was always regarded as the value from the last data year (i.e. y-1). The length of first capture was calculated as the first length class where the catch is above 50% of the length class with the maximal catch.

Option a

The first set of simulations for option a was conducted with perfect knowledge. For these simulations the length reference point was not approximated with the Beverton–Holt equilibrium formula but instead extracted from the operating model. The reference length used was obtained by fishing the stocks at F_{MSY} for 100 years outside the MSE simulation. The resulting stock plots for all 15 stocks and the two fishing histories are shown in Figure A3.10 and Figure A3.11. The performance for the one-way trip was very poor and all stocks without exception collapsed early or within 20 years. For the roller-coaster scenario all stocks initially increased in stock size but eventually 14 of the 15 stocks collapsed.

Figure A3.12 and Figure A3.13 show the results from one stock (pol.27.3a4) for both fishing histories. In the one-way trip the mean length was below the reference length at the beginning of the simulation. This led to a reduction in catch but the stock kept dropping further until it collapsed. Some iterations could recover later during the simulation but most of them collapsed again by the end of the simulation. At the beginning of the roller-coaster scenario the mean length was also below the reference length and the catches were reduced, leading to an increase in SSB. Once the mean length surpassed the reference length the catches increased again. After several years the stock increase slowed down and the SSB peaked while the catches were still increasing (as the mean length was still above its reference). This led to a reduction in SSB and the catches eventually peaked around 20 years after the SSB maximum. At this point the stock was already at a low level and collapsed shortly later.

For the next set of simulations for option a, the reference length was calculated from the Beverton–Holt equilibrium formula but M and K were extracted from the operating model without uncertainty. The results for these simulations are shown in Figure A3.14 and Figure A3.15. The resulting stock dynamics were in general similar to the results presented so far. Some stocks collapsed earlier, other ones did not collapse but showed strong long-term oscillations and an equilibrium was never reached.

For the last set of simulations for option a, the reference length was calculated from the Beverton–Holt equilibrium formula, assuming a $M/K = 1.5$. The resulting stock dynamics are presented in Figure A3.16 and Figure A3.17. Many stocks collapsed very early, other ones survived but with low catches and without reaching stability (unless catches were reduced to zero and the stock reached virgin biomass).

Figure A3.18 shows the risks of stock collapse for the scenarios testing component f of catch rule 3.2.1. The risks are very high considering that the simulations did not include any uncertainties/observation noise and the risk calculated is the risk of a total stock collapse (i.e. dropping below 0.1% of virgin biomass) and not just the risk of dropping below B_{lim}. The results from this plot must be considered carefully. For some stocks the risks were lower when the reference length was calculated with the Beverton–Holt equilibrium formula, for other ones higher. Lower risks did not necessarily imply a better performance as lower risk can be achieved by reducing the catch to very low levels or even down to zero. The likely explanation for this change in both directions is the specification of the reference length. For some stocks the calculated length was higher than the actual length at MSY, for other stocks it was lower (Figure A3.19).

In general, the performance was very poor and even when the actual MSY length was known, the catch rule failed frequently.

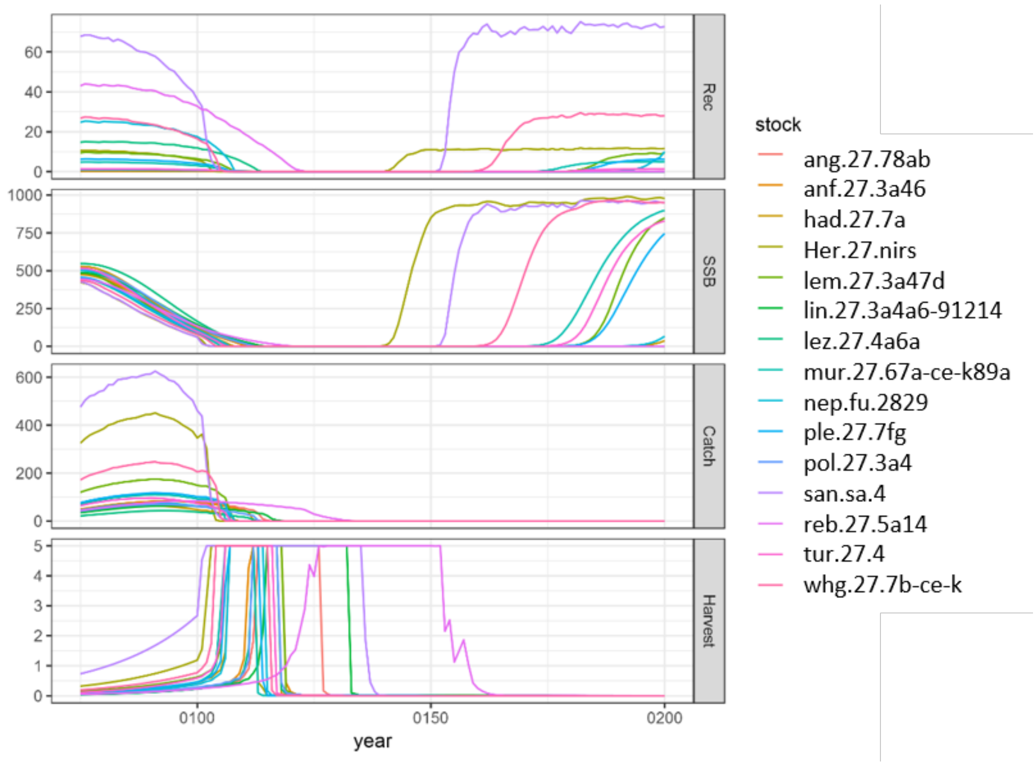

Figure A3.10. Stock plot with MSE results for component f option a (assuming perfect knowledge) of catch rule 3.2.1 for the one-way trip.

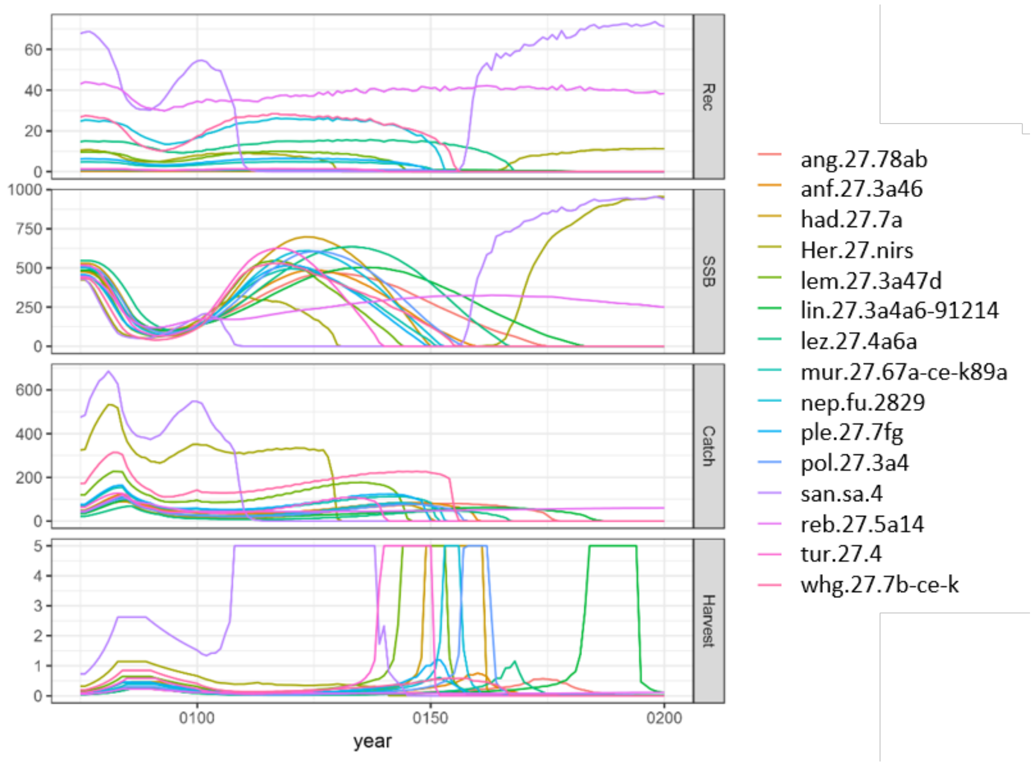

Figure A3.11. Stock plot with MSE results for component f option a (assuming perfect knowledge) of catch rule 3.2.1 for the roller-coaster trip.

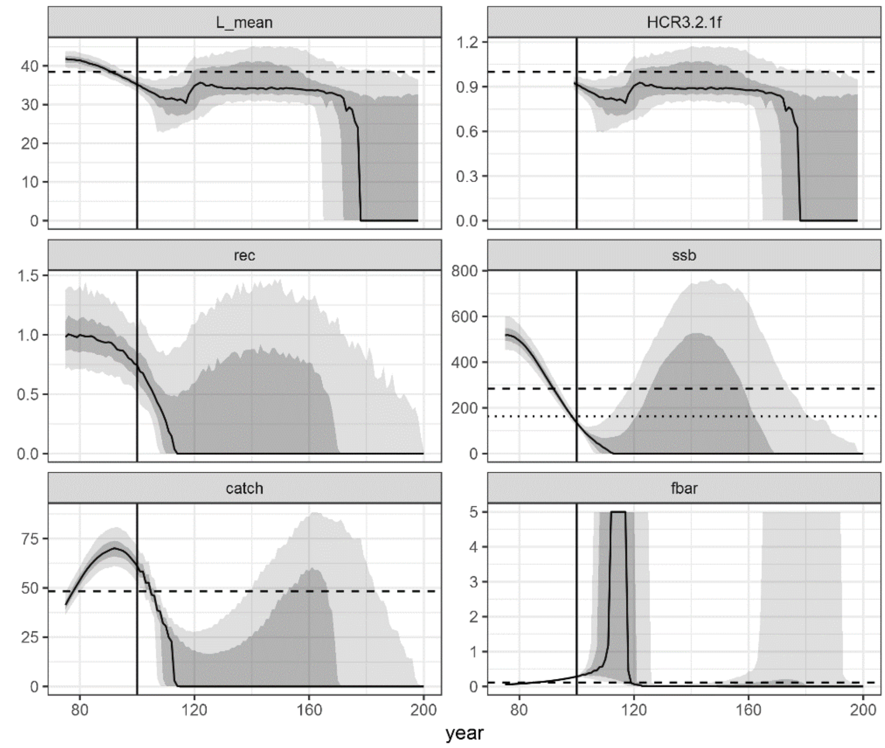

Figure A3.12. Example pol.27.3a4 MSE results for component f option a (assuming perfect knowledge) of catch rule 3.2.1 for the one-way trip.

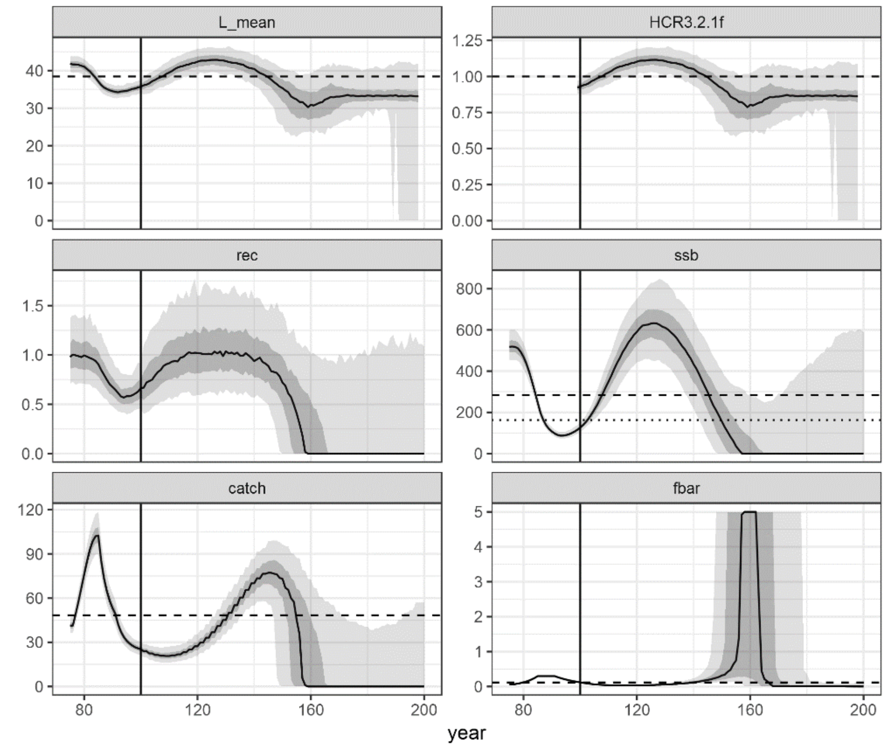

Figure A3.13. Example pol.27.3a4 MSE results for component f option a (assuming perfect knowledge) of catch rule 3.2.1 for the roller-coaster trip.

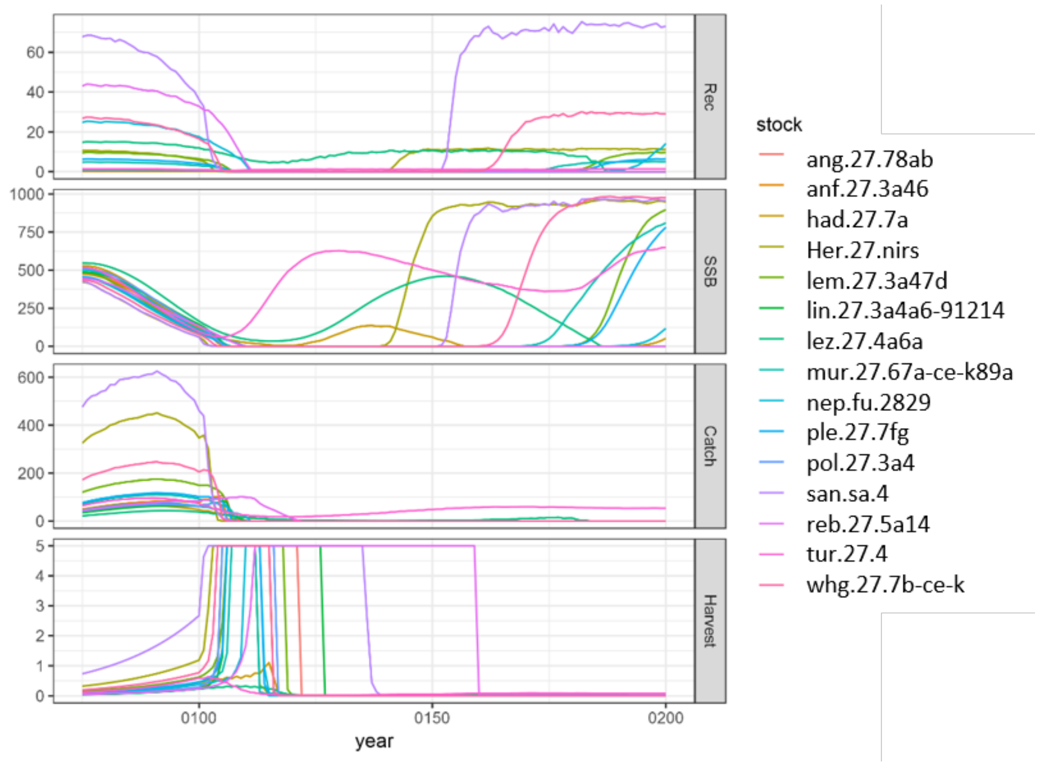

Figure A3.14. Stock plot with MSE results for component f option a (borrowing M & K from operating model) of catch rule 3.2.1 for the one-way trip.

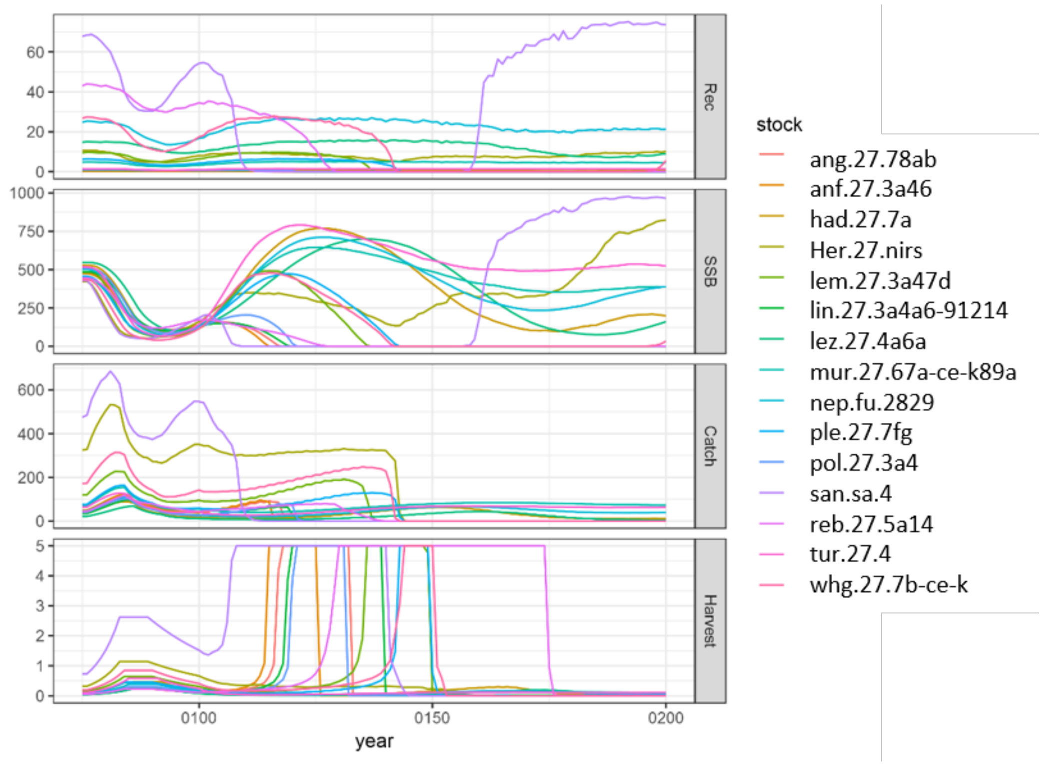

Figure A3.15. Stock plot with MSE results for component f option a (borrowing M & K from operating model) of catch rule 3.2.1 for the roller-coaster trip.

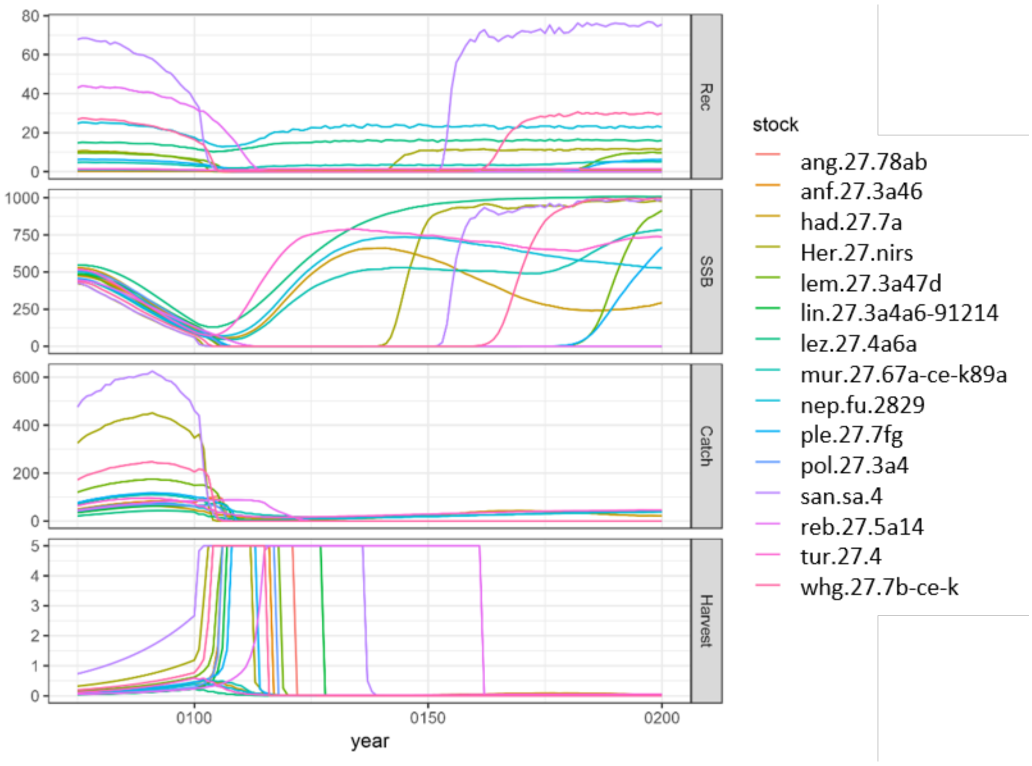

Figure A3.16. Stock plot with MSE results for component f option a (assuming M/K = 1.5) of catch rule 3.2.1 for the one-way trip.

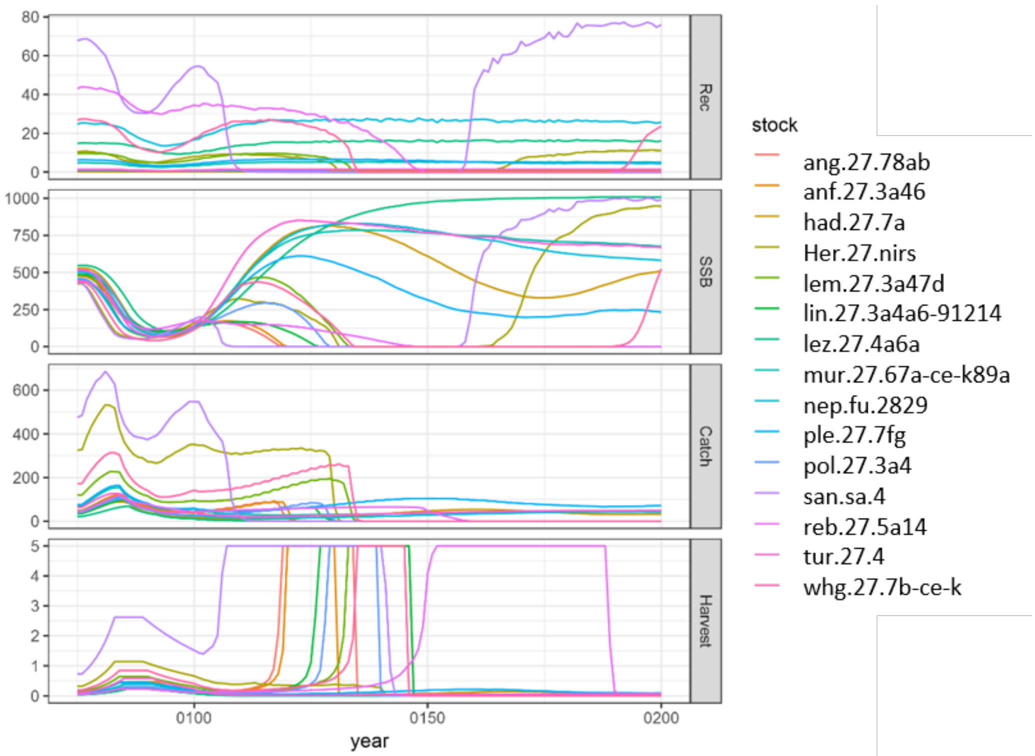

Figure A3.17. Stock plot with MSE results for component f option a (assuming M/K = 1.5) of catch rule 3.2.1 for the roller-coaster trip.

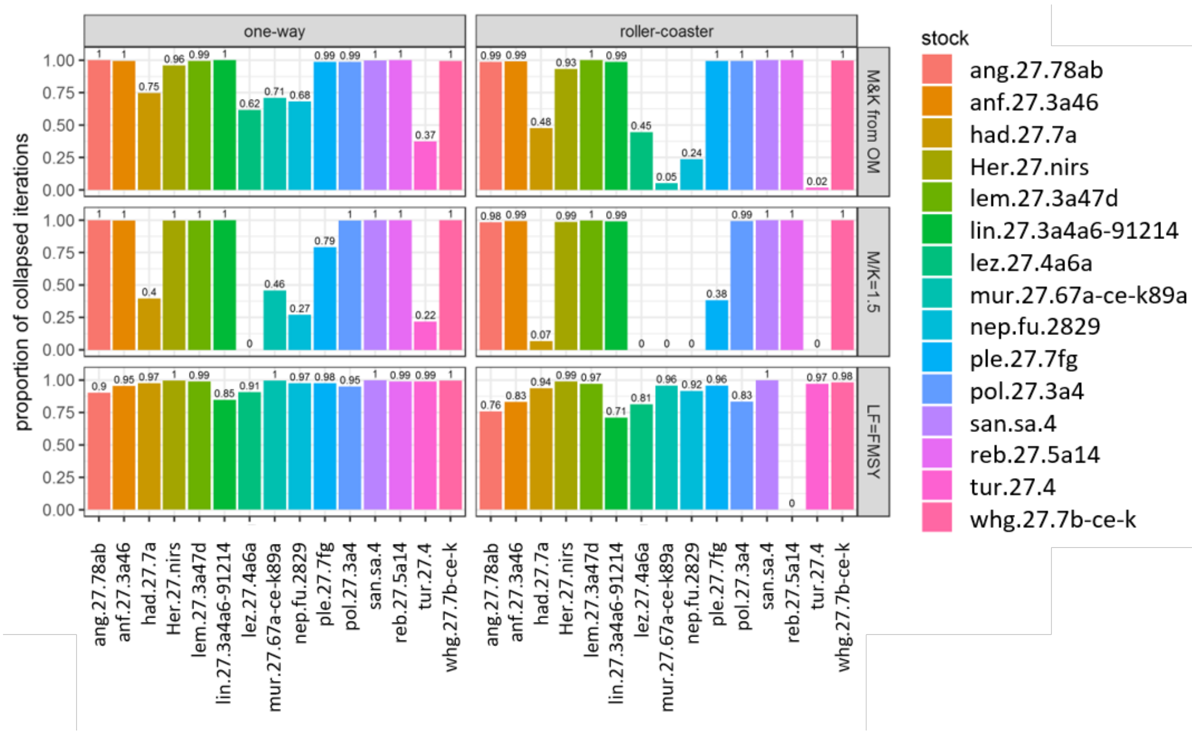

Figure A3.18. Risk of stock collapse for option a of component b of catch rule 3.2.1 for different parametrizations. In the first two rows the reference length is calculated with the Beverton–Holt equilibrium formula, in the third the length actual MSY length is used.

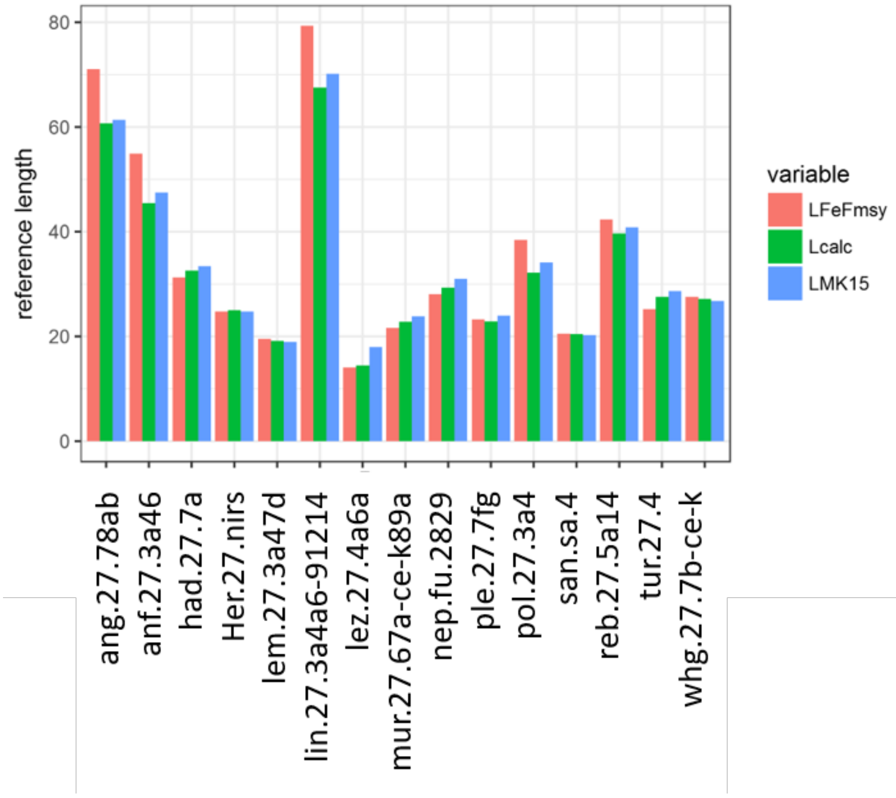

Figure A3.19. Reference lengths used for option a for component f of catch rule 3.2.1. LFeFmsy is the actual length obtained when fishing at F_{MSY}, Lcalc is calculated with

the Beverton–Holt equilibrium formula using M & K from the operating model and LMK15 when assuming M/K = 1.5.

Option b

Similar to the simulations for option a, two different parametrizations were used to calculate f from option b. The proposal from WKMSYCat34 is $f = M/(Z_{current} - M)$, where the M in the numerator is a proxy F_{MSY}. In the simulations described in this working document, the M in the denominator was always extracted from the operating model.

For the first set of simulations, the real F_{MSY} from the operating model was used, i.e. $f = F_{MSY}/(Z_{current} - M)$. The results for these simulations for all stocks and the fishing histories are presented in Figure A3.20 and Figure A3.21. The performance of this catch rule was very poor. Some stocks collapsed very early, for other stocks the catch was reduced to very low levels or even down to zero and the stocks consequently recovered to high levels or virgin biomass. Few stocks seemed to survive without zero catches, but the stock trends were unstable.

The second set of simulations used the default parametrization with M in the numerator. The results are plotted in Figure A3.22 and Figure A3.23. The performance was worse than for the previous simulation. All stocks except for one collapsed during the simulation. The surviving stock (reb.27.5a14) only survived during the simulation period because the catches were reduced to extremely low levels and the stock consequently recovered to close to virgin conditions.

In conclusion it can be said, that the catch rule failed entirely, either because the catches were too high and the stocks collapsed, or because the catches were reduced to much.

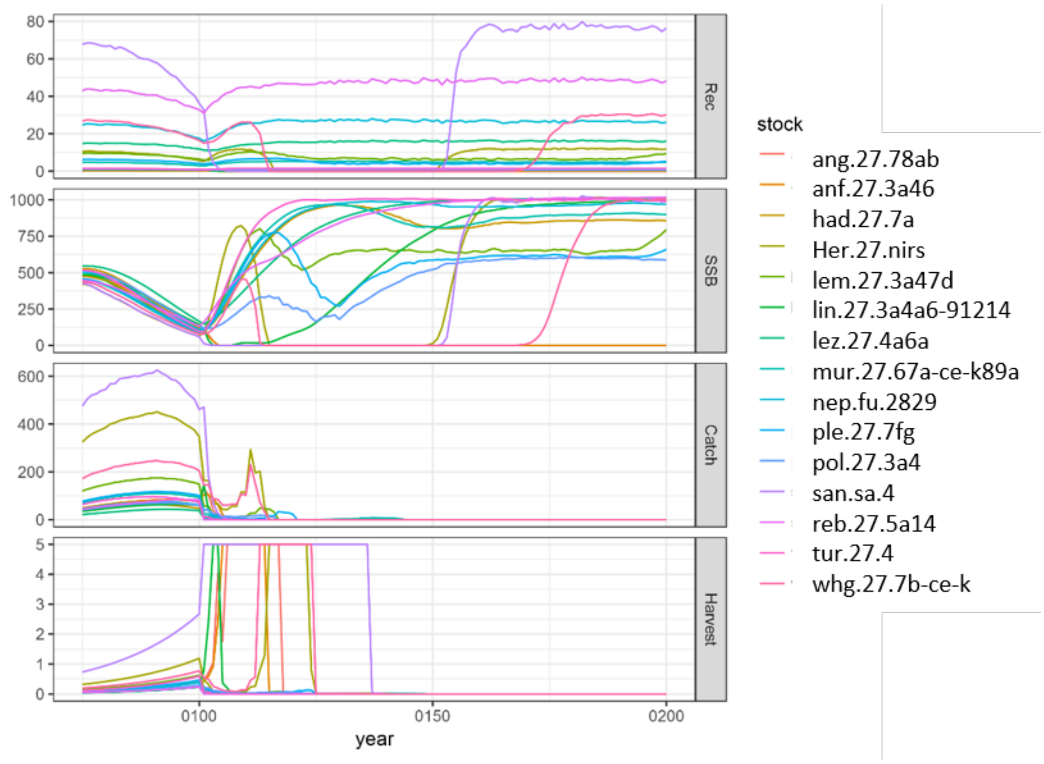

Figure A3.20. Stock plot with MSE results for component f option b (using actual F*MSY* in numerator) of catch rule 3.2.1 for the one-way trip.

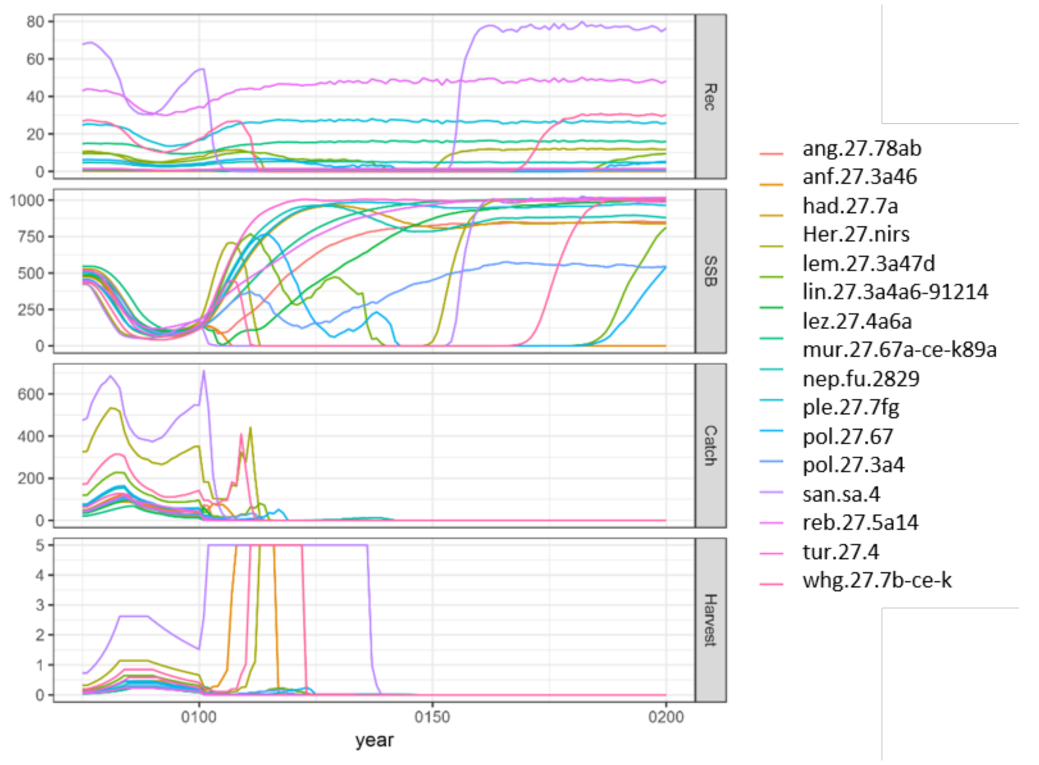

Figure A3.21. Stock plot with MSE results for component f option b (using actual F*MSY* in numerator) of catch rule 3.2.1 for the roller-coaster trip.

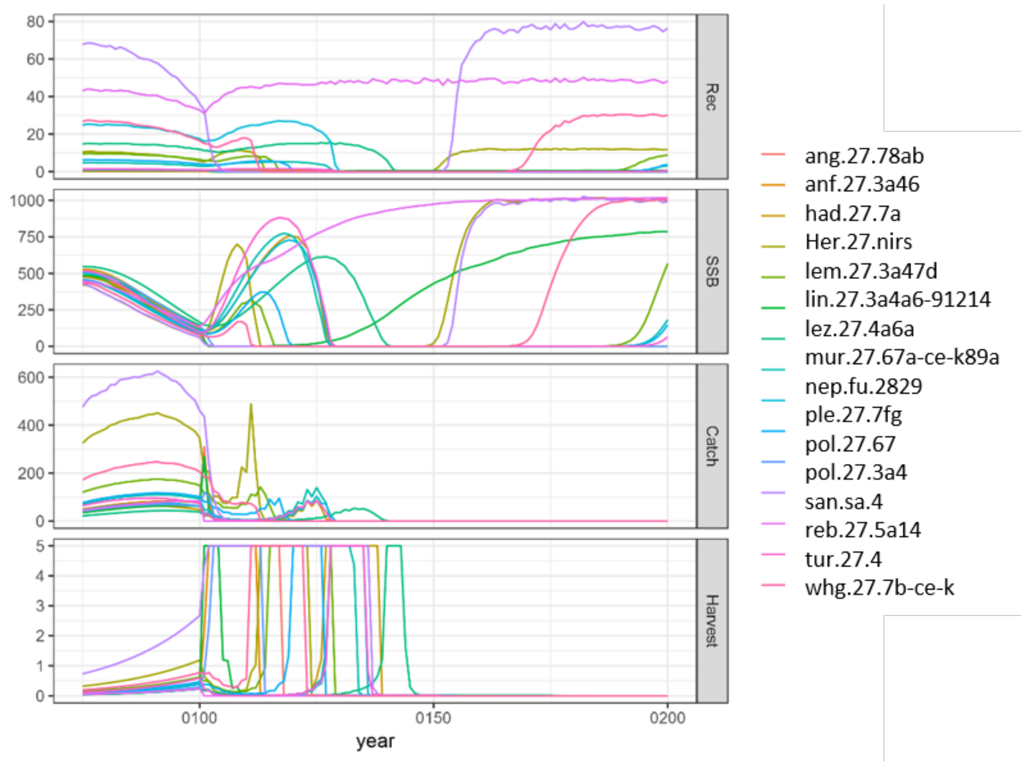

Figure A3.22. Stock plot with MSE results for component f option b (using M from operating model) of catch rule 3.2.1 for the one-way trip.

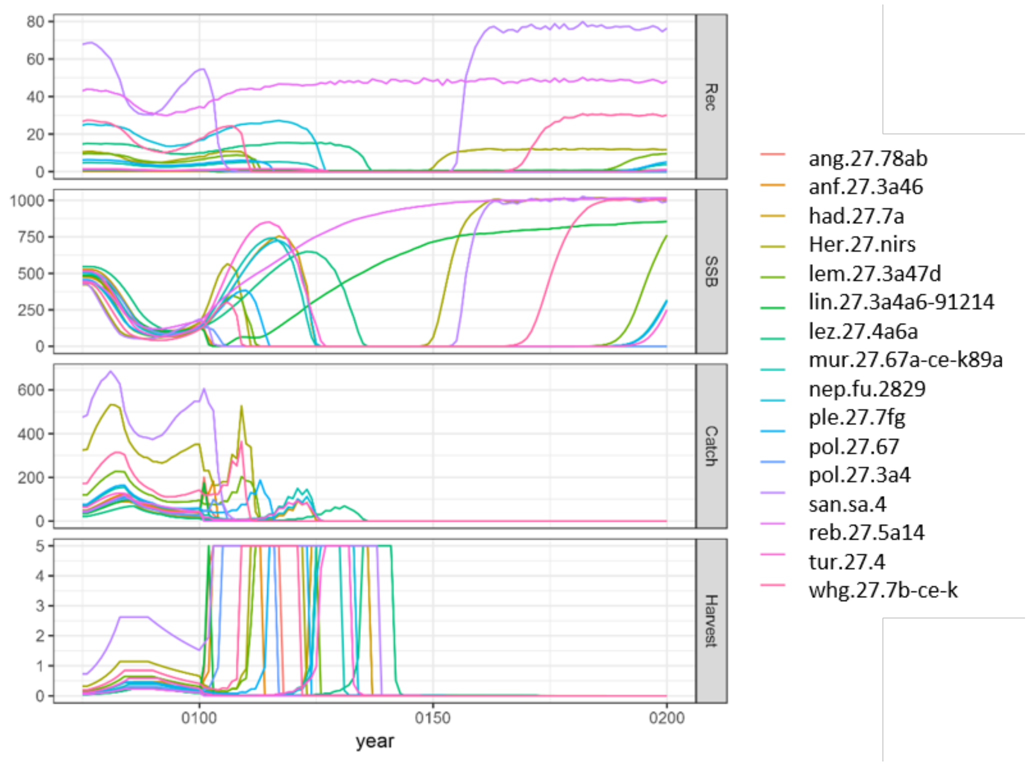

Figure A3.23. Stock plot with MSE results for component f option b (using M from operating model) of catch rule 3.2.1 for the roller-coaster trip.

Option c

Option c of component f uses the Gedamke & Hoenig (2006) method. For the simulations in this working document the method as provided by ICES on https://github.com/ices-tools-dev/ICES_MSY was used. This parametrization of the method calculates a mean Z over a time-series. For the implementation in the MSE simulations the mean Z was calculated using only one year of data (y-1). Effort data were not included.

In the calculation of $f = F_{0.1}/(Z_{current} - M)$ the $F_{0.1}$ usually comes from a Yield-Per-Recruit analysis. M was extracted from the operating model. For the first simulations runs, $F_{0.1}$ was replaced with F_{MSY}, i.e. $f = F_{MSY}/(Z_{current} - M)$. The results for this are shown in Figure A3.24 and Figure A3.25. The results for the runs using $F_{0.1}$ are shown in Figure A3.26 and Figure A3.27.

The MSE simulations for option c were slow due to the fact that Z had to be solved numerically with an optimization process. The calculated values for Z and the resulting f were frequently very unreasonable, e.g. Z could be smaller than M, which then led to negative fs or the optimization ran into other computational issues causing the simulations to crash. Consequently, a lower limit of $f = 0$ was imposed and the number of iterations was reduced to 1/10, i.e. 50 iterations.

The performance of option c was very poor. Some stocks collapsed early, for other ones the catches were massively reduced, causing the stock to recover to very high levels and the remaining stocks showed erratic and unstable behaviour.

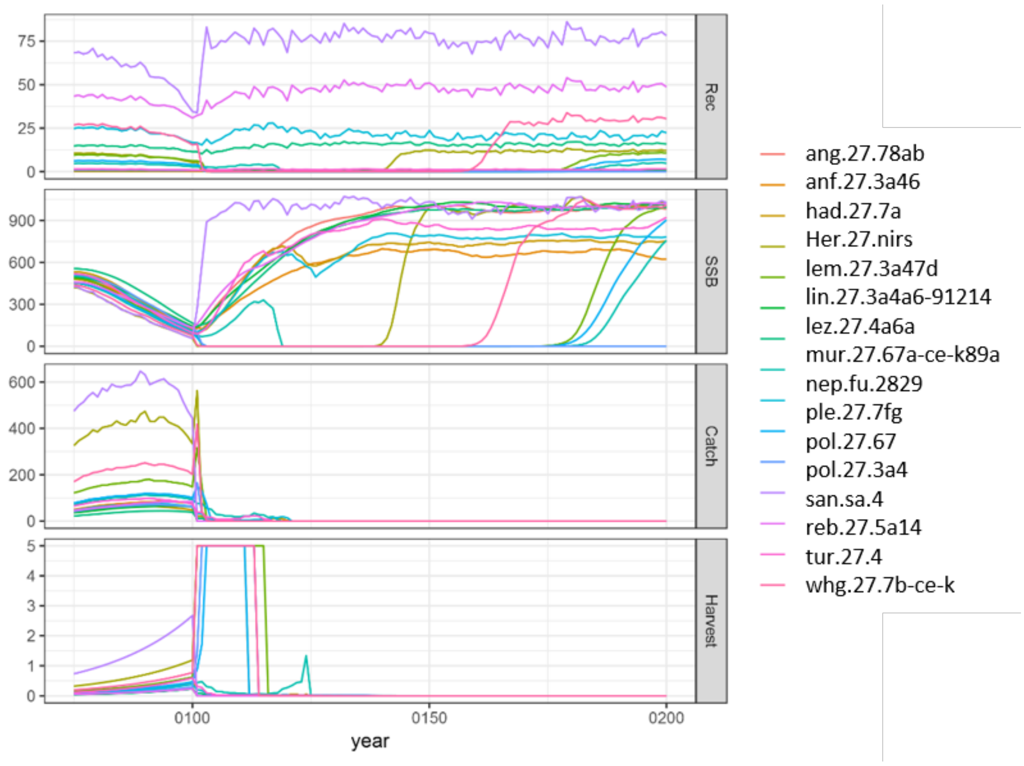

Figure A3.24. Stock plot with MSE results for component f option c (Gedamke & Hoenig model, with F_{MSY} in numerator) of catch rule 3.2.1 for the one-way trip.

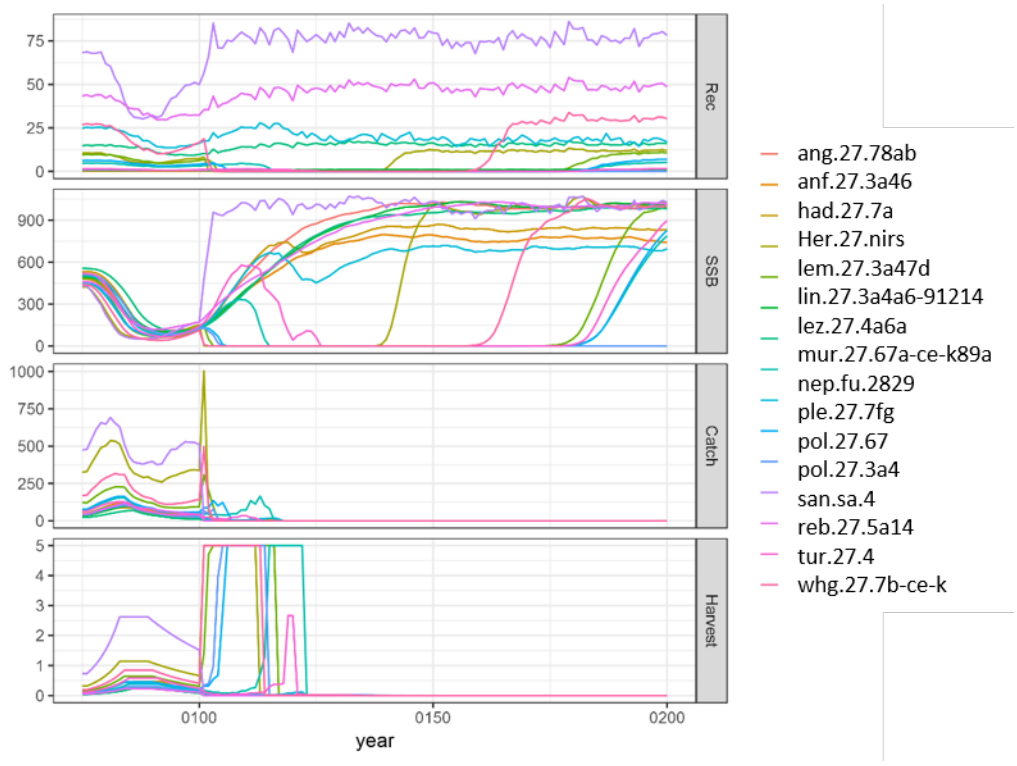

Figure A3.25. Stock plot with MSE results for component f option c (Gedamke & Hoenig model, with F_{MSY} in numerator) of catch rule 3.2.1 for the roller-coaster trip.

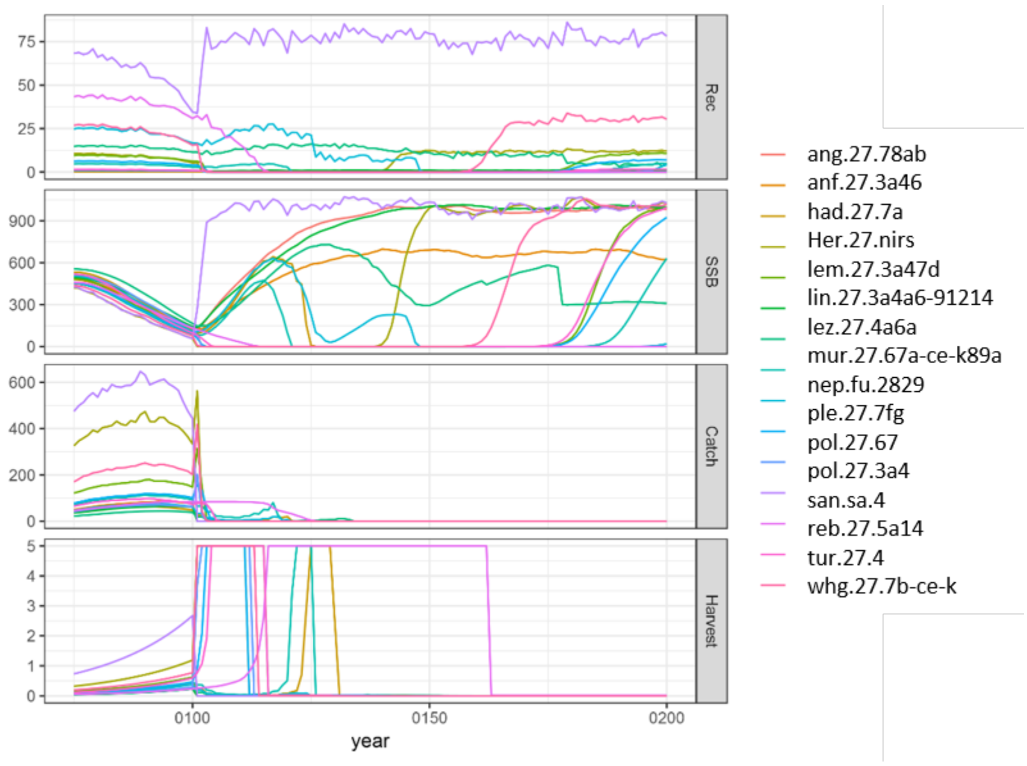

Figure A3.26. Stock plot with MSE results for component f option c (Gedamke & Hoenig model) of catch rule 3.2.1 for the one-way trip.

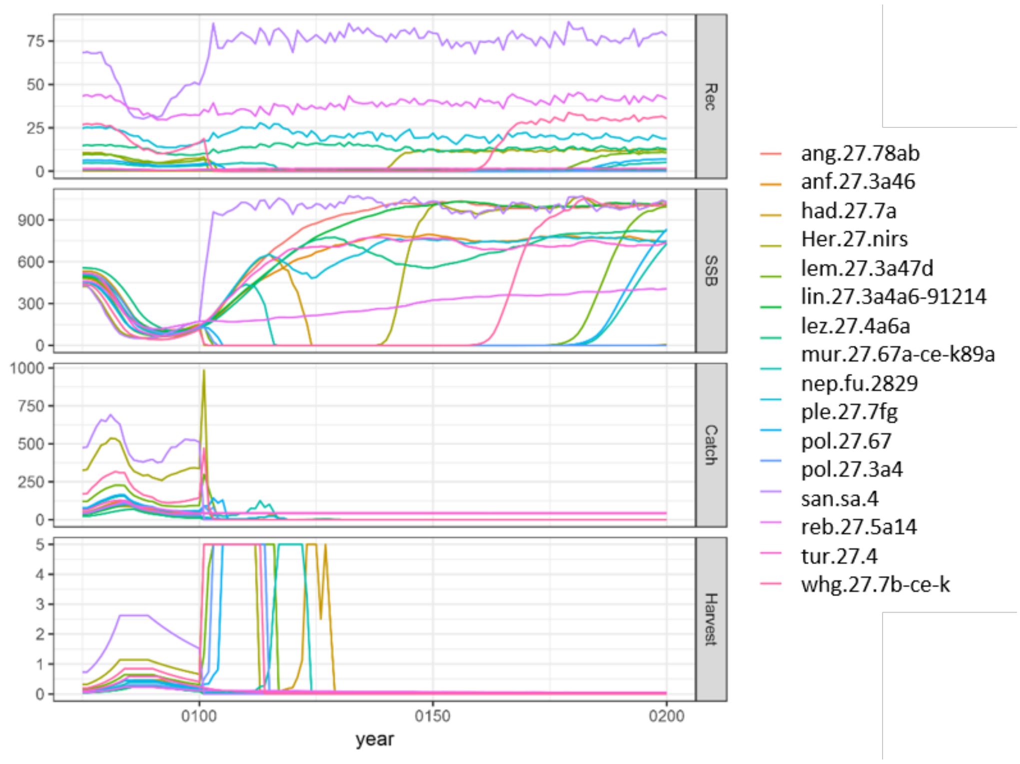

Figure A3.27. Stock plot with MSE results for component f option c (Gedamke & Hoenig model) of catch rule 3.2.1 for the roller-coaster trip.

A3.5.1.2.3 Component b

Component *b* of catch rule 3.2.1 is a stock size safeguard that reduces the catch if the stock is below a certain threshold.

WKMSYCat34 proposed two options. The option a is for category 3 stocks and is defined as

$b = \min\left\{1, \frac{I_{current}}{I_{trigger}}\right\}$, with $I_{trigger} = w \times I_{lim}$ and the default is $w = 1.4$.

In the absence of better values for $I_{current}$ or $I_{trigger}$, $I_{trigger}$ is set to the lowest observed index value.

Option b is proposed for category 4 stocks and is simply $b = 0.8$, applied every e.g. four years.

Only option a has been tested here, with default settings. The results for the two fishing histories are shown in Figure A3.28 and Figure A3.29. The results must be treated with caution as this catch rule, when applied on its own, is only able to reduce catches while there is no mechanism to increase them again. But this seemed to work quite well and all stocks apart from the two pelagics (her.27.nirs, san.sa.4) recovered. The final biomass depended on the fishing history with higher levels for the roller-coaster scenario.

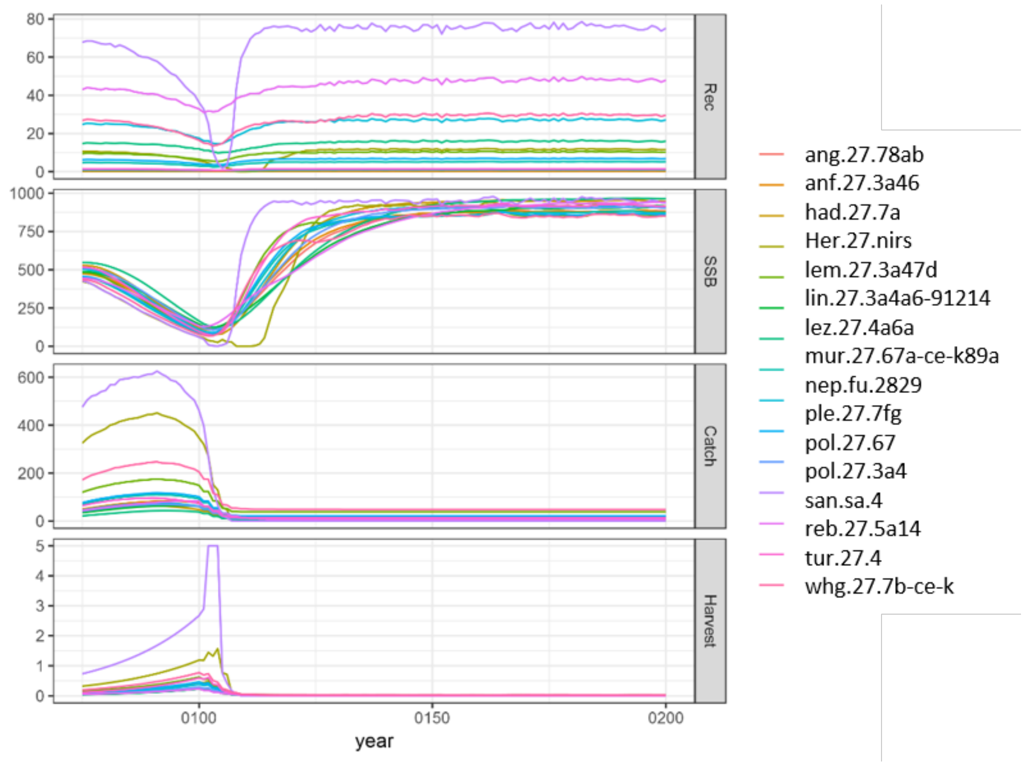

Figure A3.28. Stock plot with MSE results for component b option a of catch rule 3.2.1 for the one-way trip.

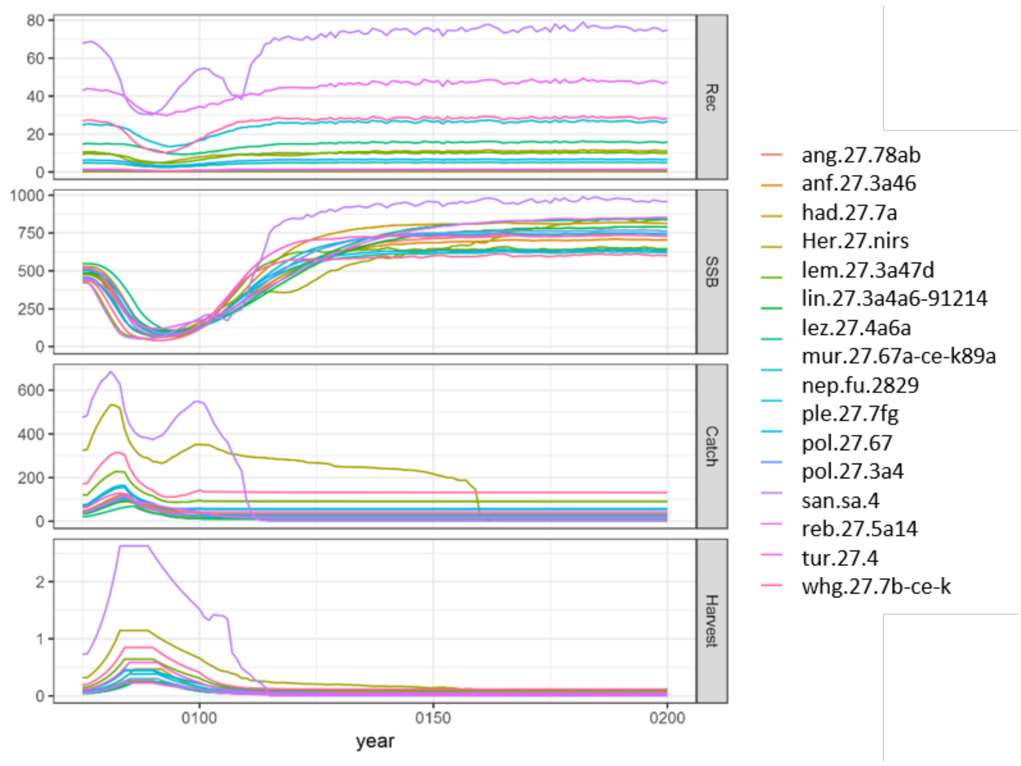

Figure A3.29. Stock plot with MSE results for component b option a of catch rule 3.2.1 for the roller-coaster trip.

A3.5.1.3 Combinations

In the simulations for catch rule 3.2.1 the individual components have been tested individually but not in combination as intended for the catch rule:

$$C_{y+1} = C_{current} \times r \times f \times b$$

Not all possible combinations have been tested. The following options were considered:

Component r: option a & b

Component f: options a & b (option c, the Gedamke & Hoenig method, was not tested as it was the slowest and showed the poorest performance when tested on its own)

Component b: option a (the default option for category 3 stocks)

This resulted in four combinations for each of the two fishing histories and 15 stocks, i.e. a total of 120 simulation scenarios.

The results for the combinations r:a & f:a & b:a (option a for component r, option a for component f and option a for component b) are shown in Figure A3.30 and Figure A3.31, combination r:b & f:a & b:a in Figure A3.32 and Figure A3.33, combination r:a & f:b & b:a in Figure A3.34 and Figure A3.35, and combination r:b & f:b & b:a in Figure A3.36 and Figure A3.37.

The management simulations for all combinations using option b for component f (using the slope of the stock trend) failed. Most stocks recovered quickly towards virgin biomass because the catches were drastically reduced towards zero at the beginning. A few stocks did not reach virgin conditions but stayed slightly below, i.e. had very low catches. Other stocks collapsed.

For the combinations with option a from component f, most stocks (9-12 of the 15 tested stocks, depending on the fishing history and option for component r) moved towards MSY levels. It did not work well for the pelagic stocks (her.27.nirs, san.sa.4) as they always approached virgin biomass levels because of zero or very low catches either because of an earlier stock collapse or because the catch rule advised very low catches. In general, the combination r:b & f:a & b:a caused much stronger and longer lasting oscillations. For the combination r:a & f:a & b:a the stocks approach MSY levels quicker and with small oscillations (apart from three stocks for the one-way trip and six stocks for the roller-coaster scenario, for which the catch rule did not work).

Figure A3.38 shows the results for one stock (pol.27.3a4) for combination r:a & f:a & b:a for the one-way trip. At the beginning of the simulation all three components were below 1 (i.e. mean length was below length at MSY, there was a negative stock trend and the index value was below the trigger) and the catches were reduced. This led to an increase in SSB and a few years later the catches increased again. The SSB peaked around 20 years into the simulation at around double B_{MSY} and declined from there. Eventually the stock reached equilibrium at levels around MSY.

In conclusion, the combination r:a & f:a b:a seemed to work best, with most stocks approaching MSY levels and smallest oscillations. Nevertheless, even under this perfect knowledge assumptions without adding any observation noise, the catch rule did not work for some stocks.

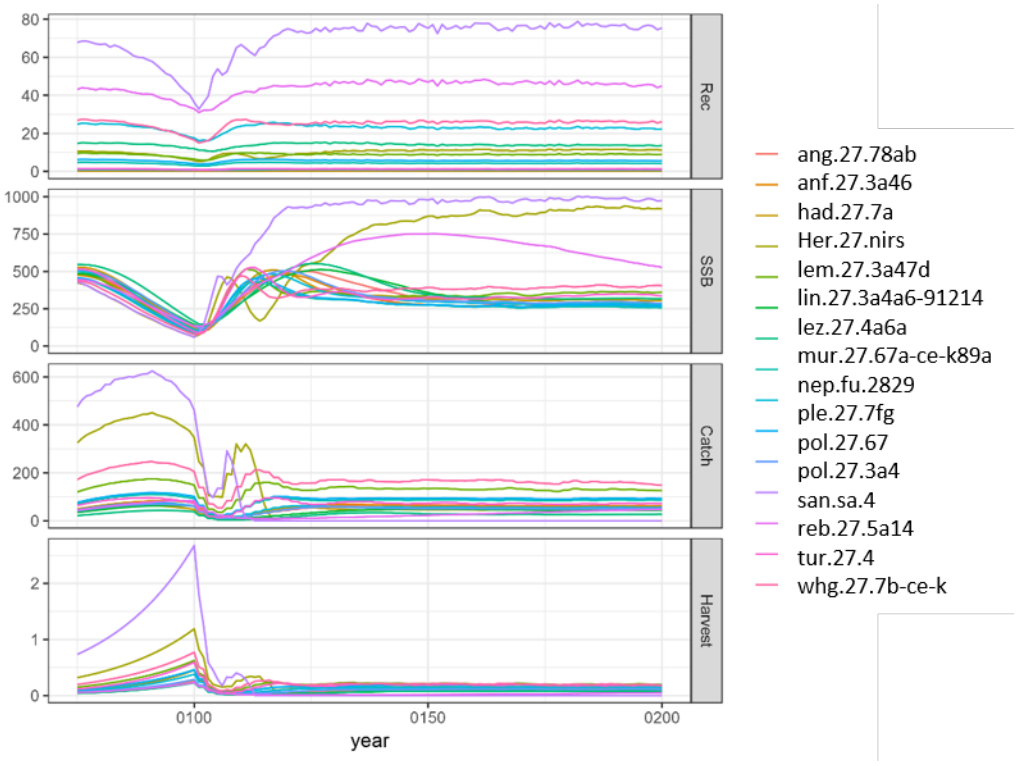

Figure A3.30.Stock plot with MSE results for combination r:a & f:a & b:a of catch rule 3.2.1 for the one-way trip.

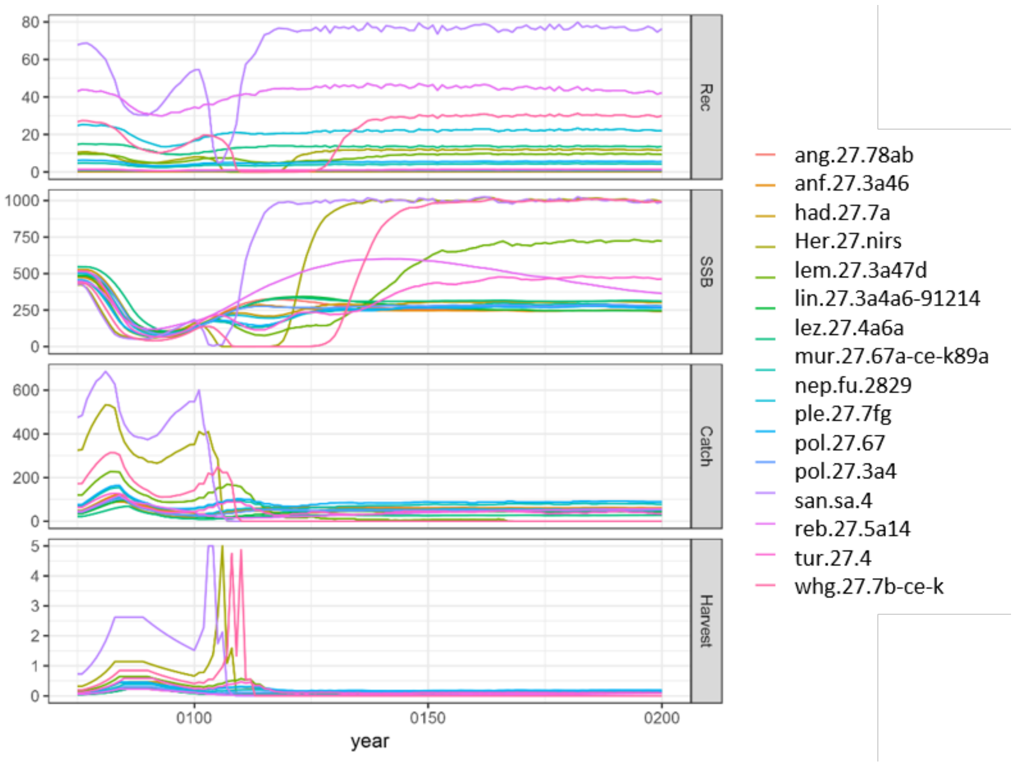

Figure A3.31.Stock plot with MSE results for combination r:a & f:a & b:a of catch rule 3.2.1 for the roller-coaster trip.

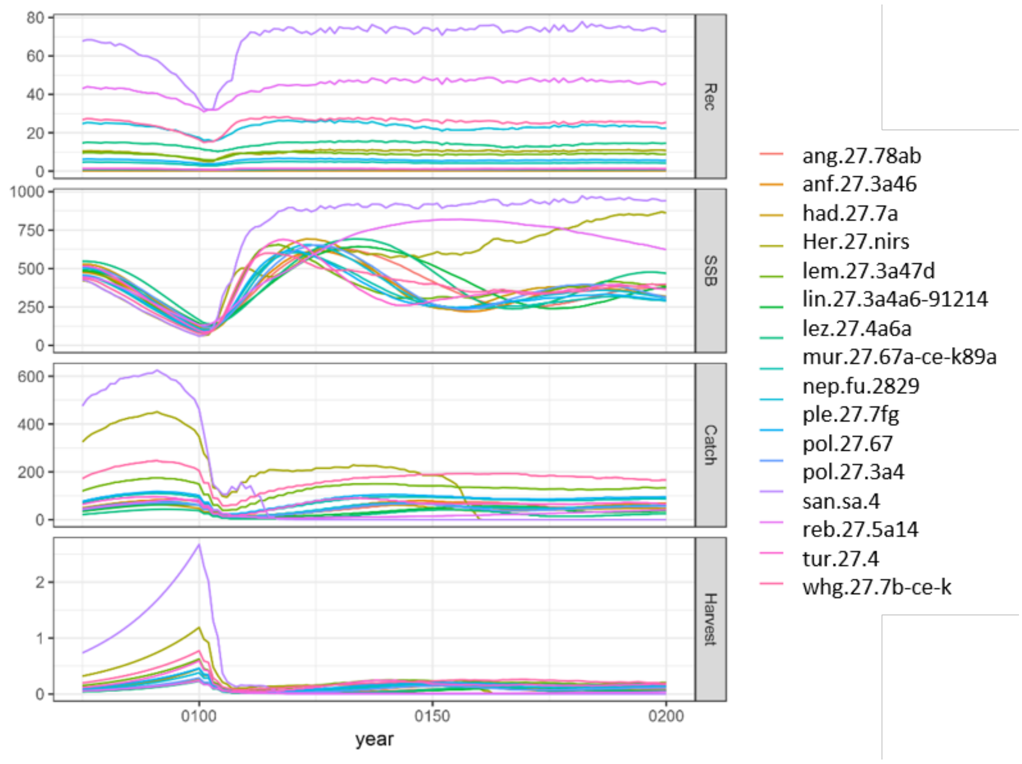

Figure A3.32.Stock plot with MSE results for combination r:b & f:a & b:a of catch rule 3.2.1 for the one-way trip.

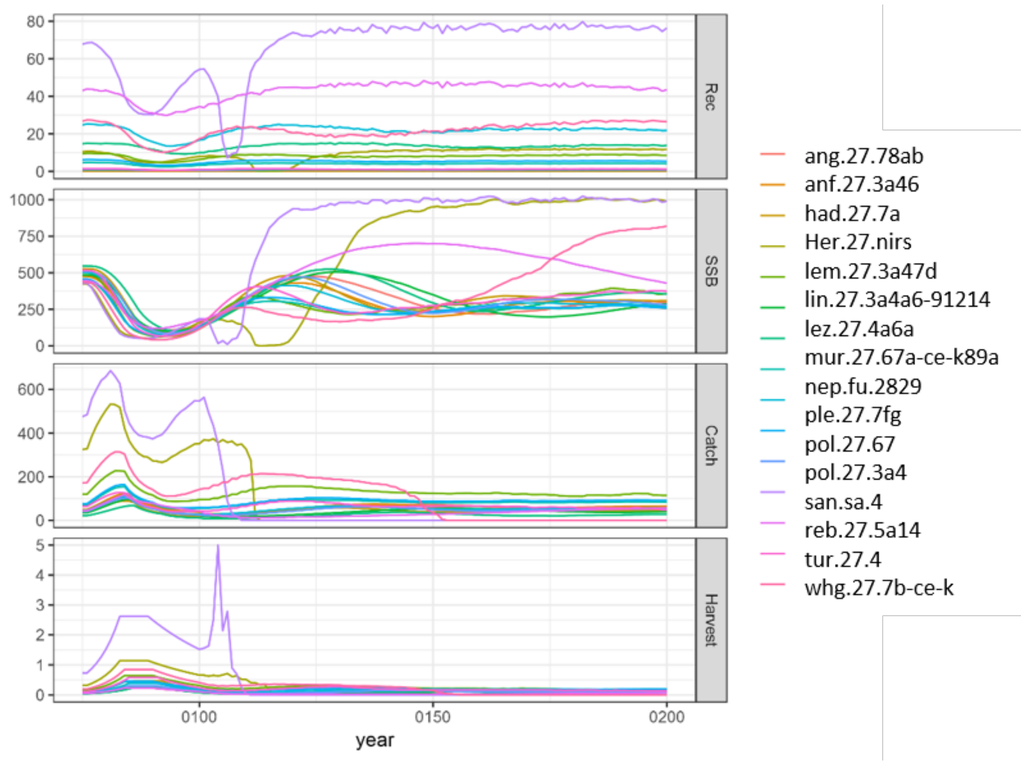

Figure A3.33.Stock plot with MSE results for combination r:b & f:a & b:a of catch rule 3.2.1 for the roller-coaster trip.

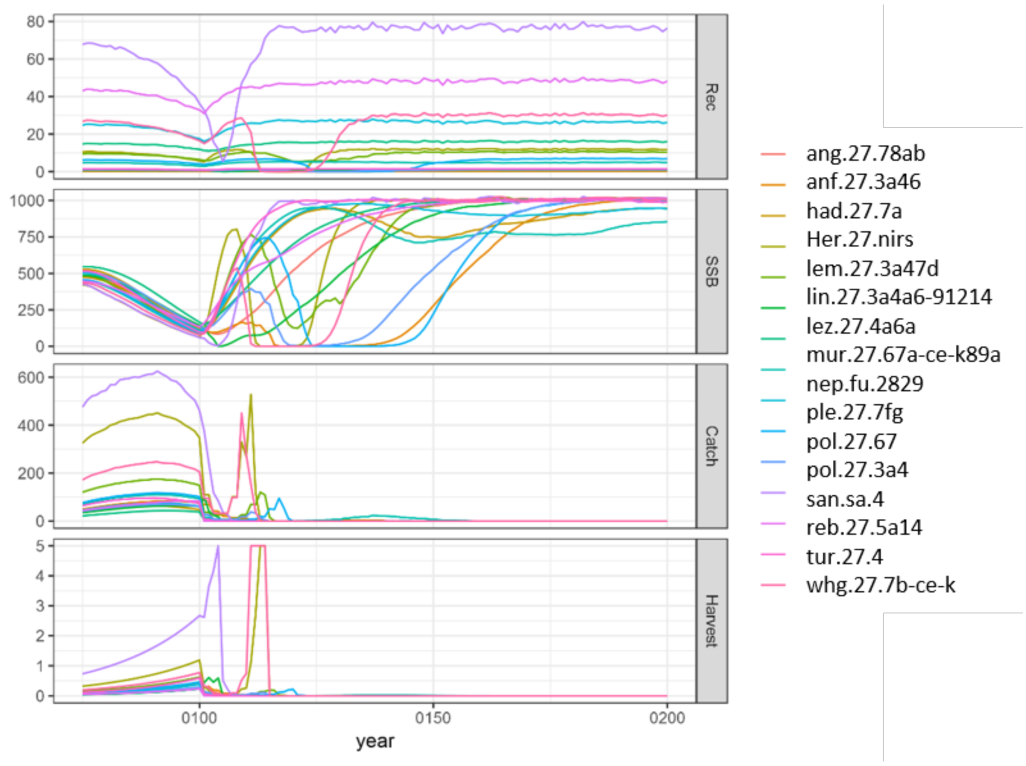

Figure A3.34.Stock plot with MSE results for combination r:a & f:b & b:a of catch rule 3.2.1 for the one-way trip.

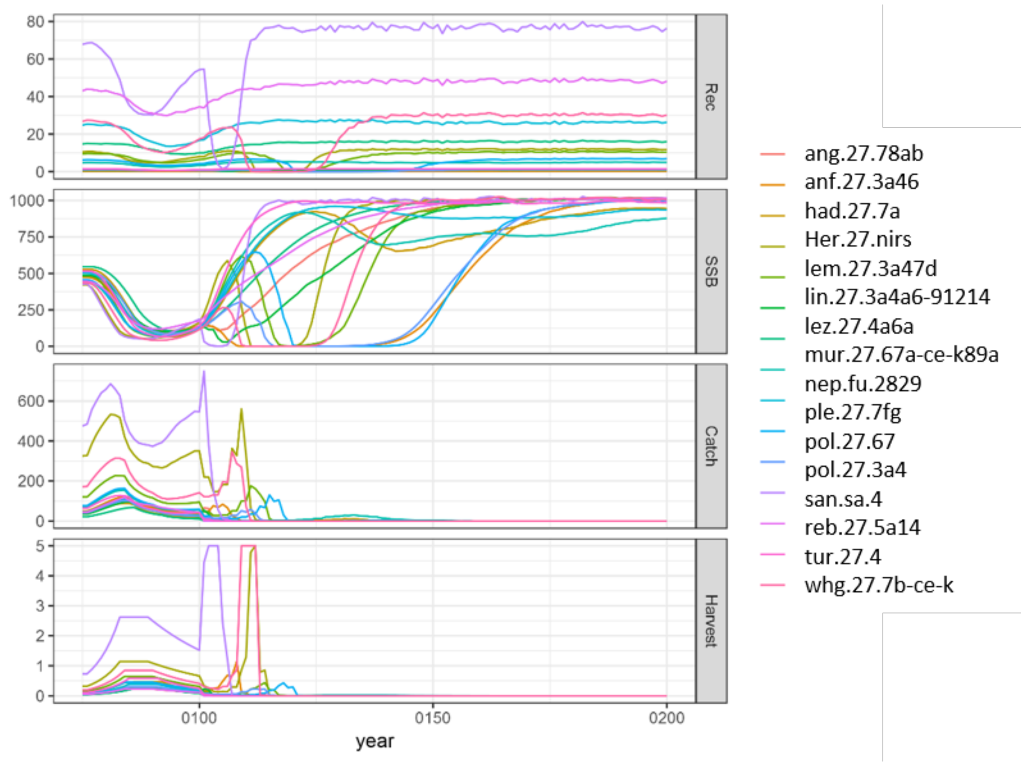

Figure A3.35.Stock plot with MSE results for combination r:a & f:b & b:a of catch rule 3.2.1 for the roller-coaster trip.

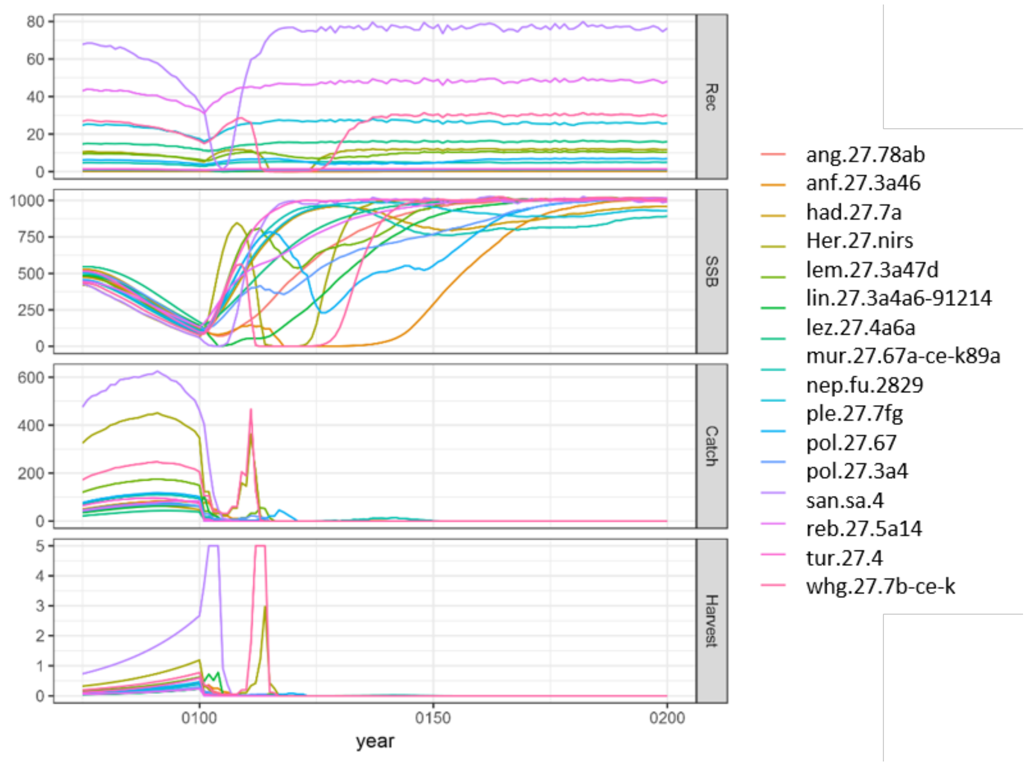

Figure A3.36.Stock plot with MSE results for combination r:b & f:b & b:a of catch rule 3.2.1 for the one-way trip.

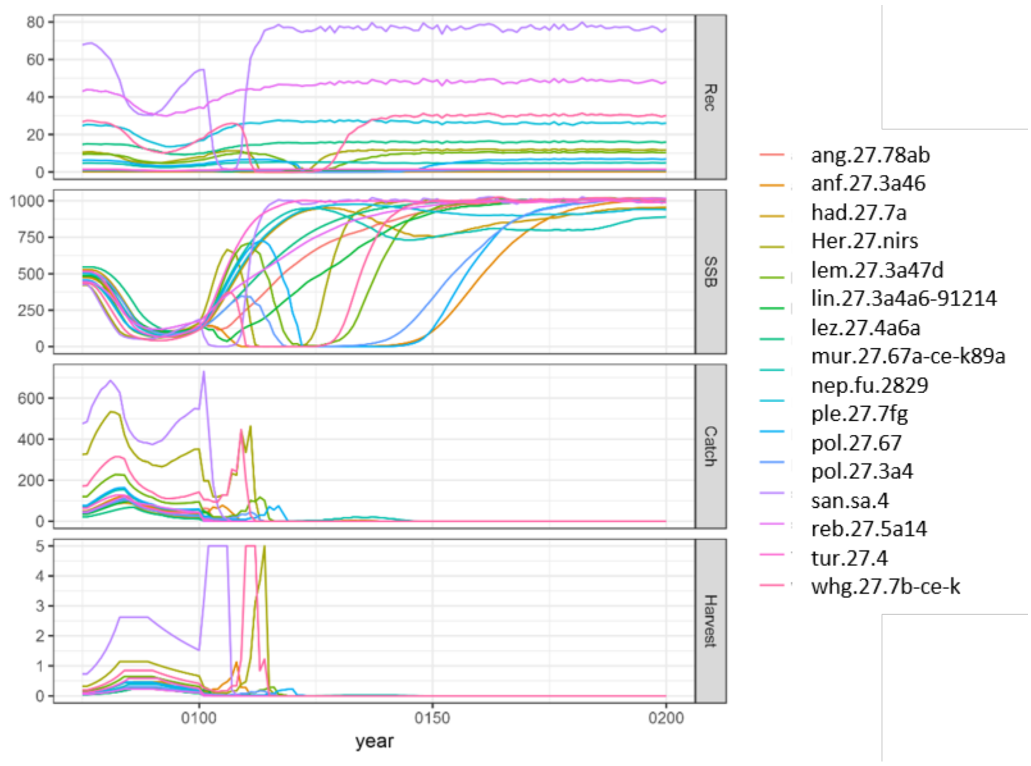

Figure A3.37.Stock plot with MSE results for combination r:b & f:b & b:a of catch rule 3.2.1 for the roller-coaster trip.

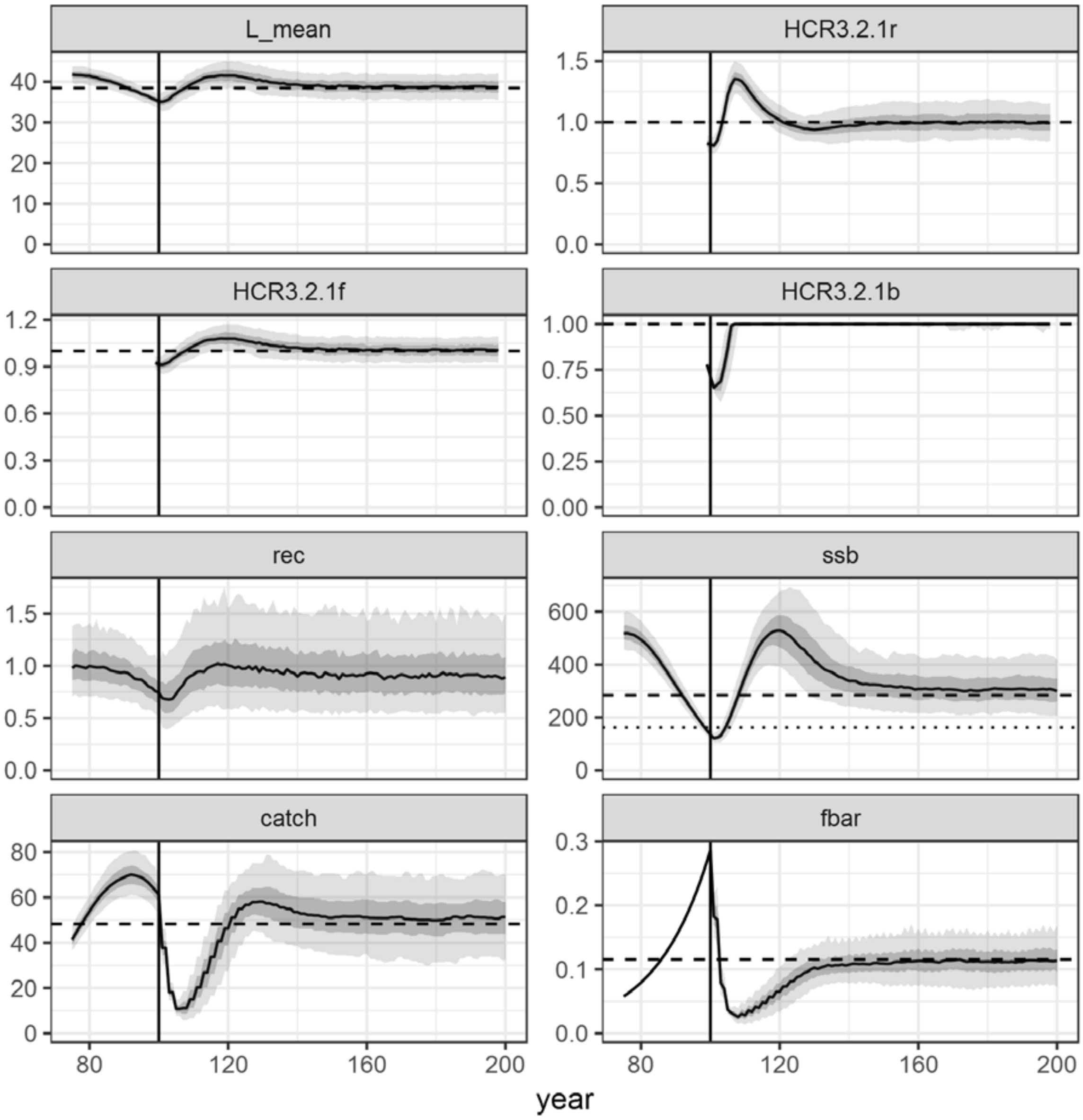

Figure A3.38. MSE results for combination r:a & f:a & b:a (assuming perfect knowledge and including only recruitment uncertainty) of catch rule 3.2.1 for one stock (pol.27.3a4) for the one-way trip.

A3.5.1.4 Stochastic runs

The simulation runs testing combinations of catch rule 3.2.1 from the previous section did not include any uncertainty or noise apart from the default recruitment variability.

Stochastic runs including observation error were conducted for two combinations: r:a & f:a & b:a and r:b & f:a & b:a. Combinations with option b for component *f* were not conducted, as the performance was poor even assuming perfect knowledge (as presented in the previous section).

For the stochastic simulations, observation error was included with a lognormal distribution. The following observation errors were added:

- Stock size index: 0.2 CV (uncertainty added to each age class, before the index was summed over all ages to obtain the total biomass index)
- Catch length frequencies: 0.2 CV (added to the catch numbers at each length class)
- Implementation error: 0.1 CV (deviation of the implemented catches from advised catch)
- Life-history parameters: 0.1 CV (only used in the management procedure, not for creating the stocks before the simulation)

Furthermore, the real-life application assumption of $M/K = 1.5$ was made.

The resulting stock trends for combination r:a & f:a & b:a are shown in Figure A3.39 and Figure A3.40 and the results for combination r:b & f:a & b:a in Figure A3.41 and Figure A3.42.

Compared to the previous runs, the stock trends were much more unstable and more stocks collapsed. As before, using option a of component r (2 over 3 rule) resulted in more stability and smaller oscillations.

Figure A3.43 shows a comparison of the combination r:a & f:a & b:a with and without observation error for one stock (pol.27.3a4). Including observation error led to much higher uncertainty and poorer performance. At the end of the simulation, the 90% confidence interval for SSB spans the entire range of possible values, from zero (total collapse) to virgin biomass. At the beginning of the simulation period the mean length in the catch was below the length at MSY. Nevertheless, for the stochastic run, component f of the catch rule was slightly above 1, as the calculated reference length from the Beverton–Holt equilibrium formula under the assumption of $M/K = 1.5$ was lower (less conservative) than the real length at MSY (see Figure A3.19). This means that f did not detect the overfishing at the beginning of the simulation. Nonetheless, the catch decreased initially because of the remaining two components of the catch rule (r detected a decreasing stock trend from the index and b detected that the index is below its trigger value). Compared to the run without observation error, the catch did not decrease as strongly, started to increase earlier and showed more variability. The SSB oscillated around B_{MSY} and after approaching B_{MSY} after around 50 years, the SSB did not settle down but kept increasing until the end of the simulation period. The catch reached a more or less stable phase at the end of the simulation at a level of around ½MSY.

Figure A3.44 shows the performance statistics for the stochastic runs. For most stocks using option a of component r resulted in lower risks and higher yields, i.e. the combination r:a & f:a & b:a seemed to perform better. Nevertheless, the risk of stock collapse was unacceptably high for many stocks. For some stocks the risk was very low but this optimistic result is sometimes negated by corresponding low catches, i.e. the catch rule did not work well.

In conclusion it might be stated that of the tested combinations, the combination r:a & f:a & b:a performed best but displayed an unacceptable high risk for many stocks or did not work well and should not be used without stock specific simulation testing and fine tuning.

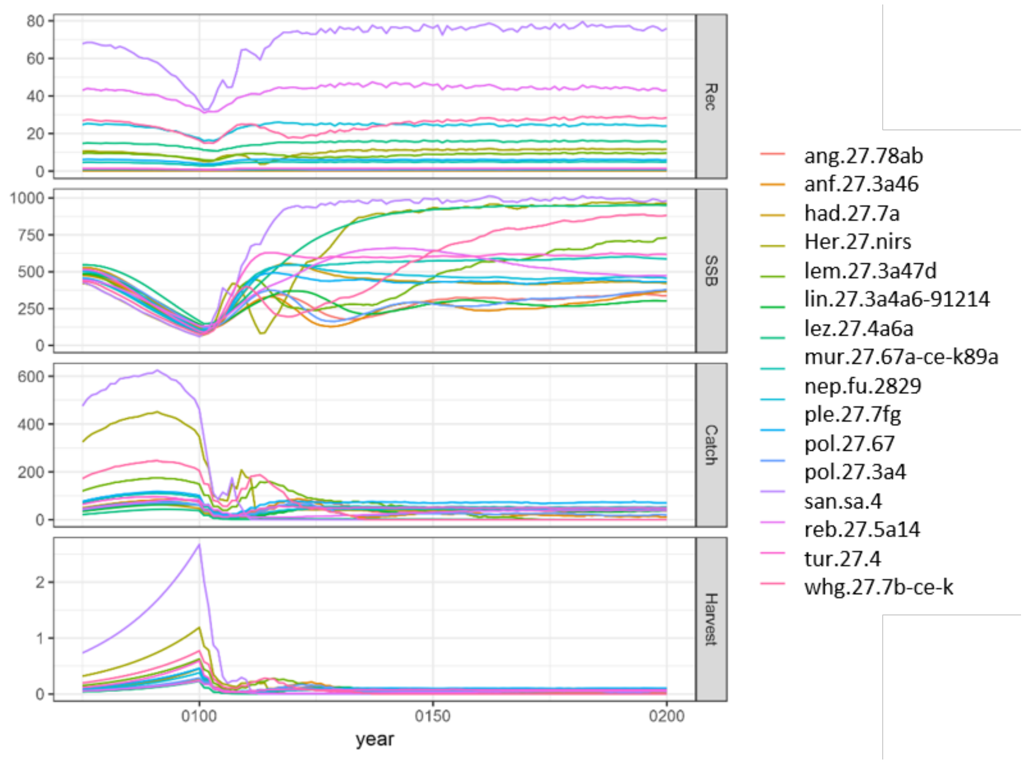

Figure A3.39.Stock plot with MSE results for combination r:a & f:a & b:a of catch rule 3.2.1 including observation noise for the one-way trip.

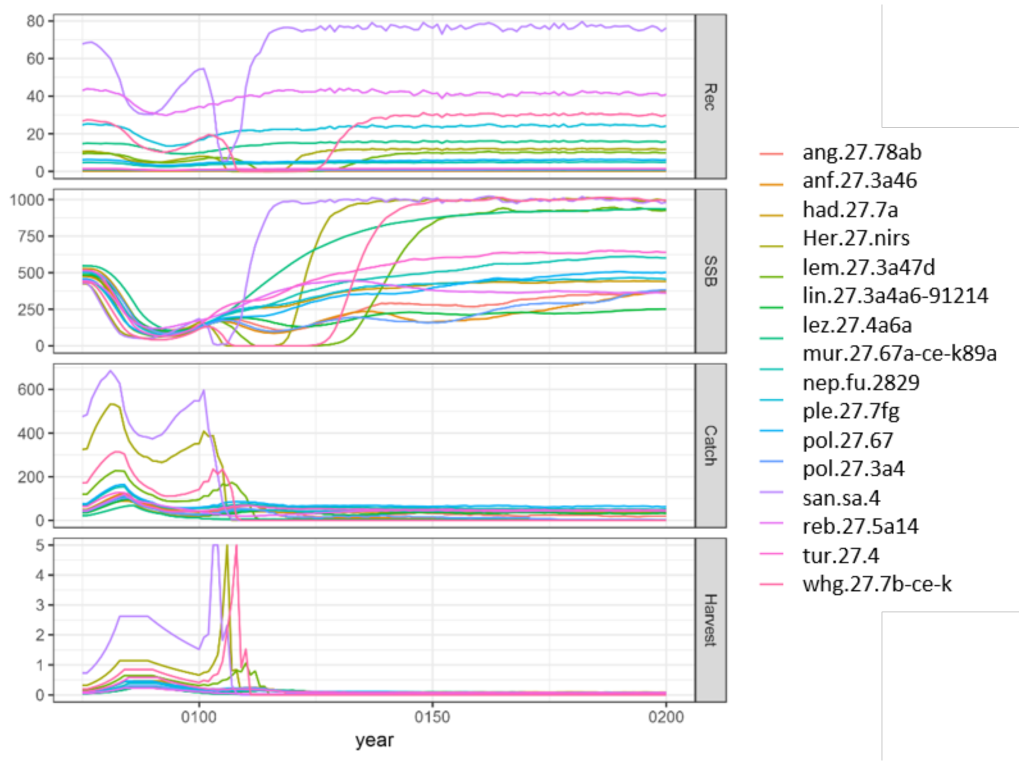

Figure A3.40.Stock plot with MSE results for combination r:a & f:a & b:a of catch rule 3.2.1 including observation noise for the roller-coaster trip.

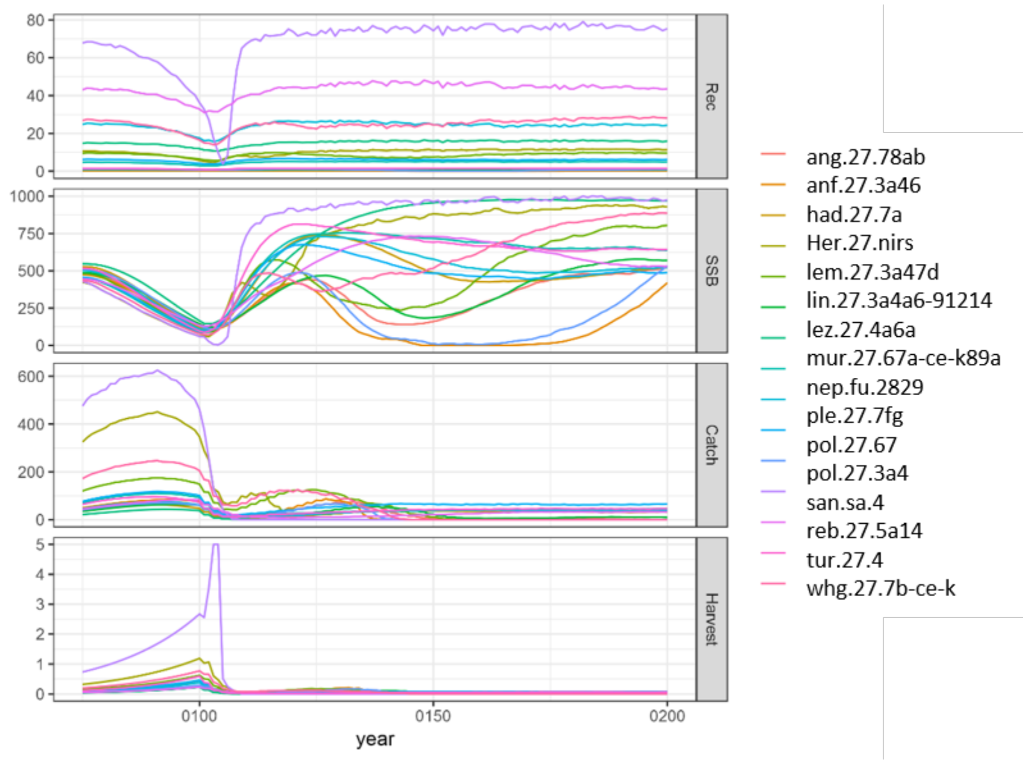

Figure A3.41.Stock plot with MSE results for combination r:b & f:a & b:a of catch rule 3.2.1 including observation noise for the one-way trip.

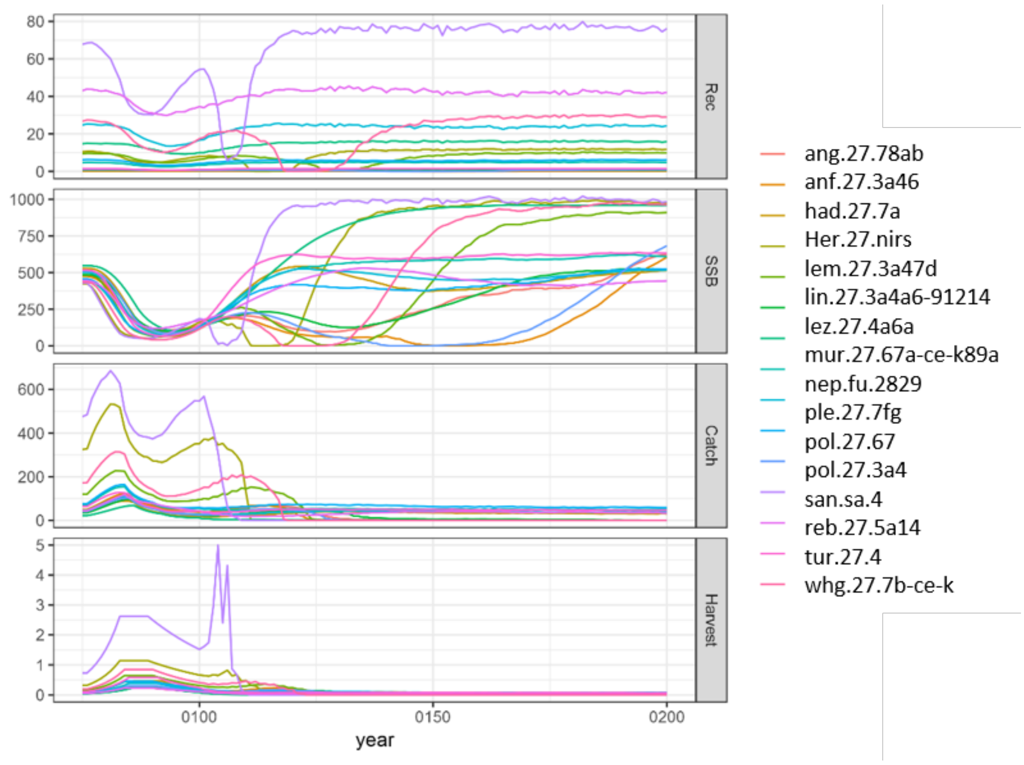

Figure A3.42.Stock plot with MSE results for combination r:b & f:a & b:a of catch rule 3.2.1 including observation noise for the roller-coaster trip.

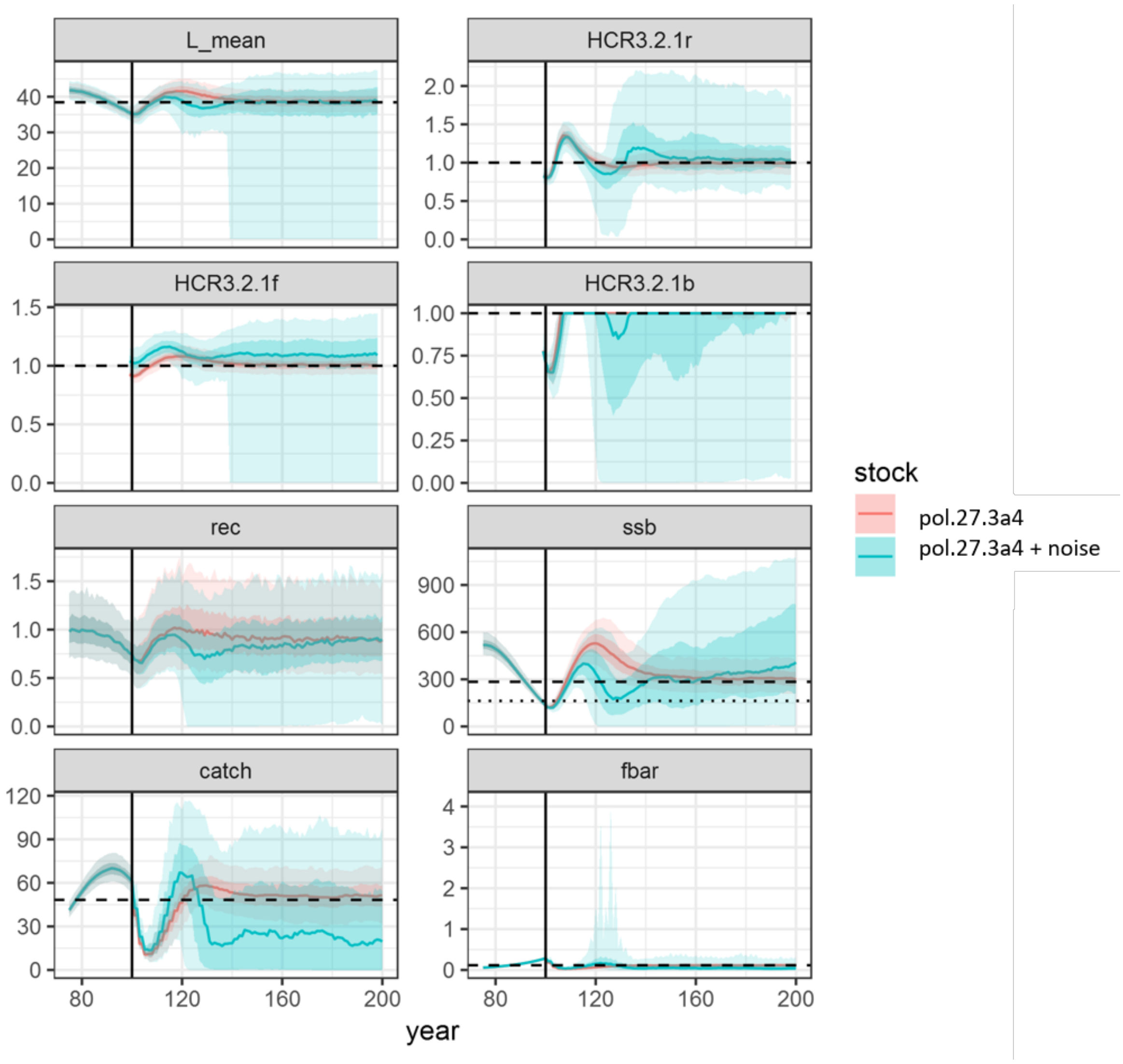

Figure A3.43. Stock plot with MSE results for one example stock (pol.27.3a4) for the combination r:a & f:a & b:a of catch rule 3.2.1. The plot shows a comparison of the deterministic runs (red) with the same scenario but including observation error (blue).

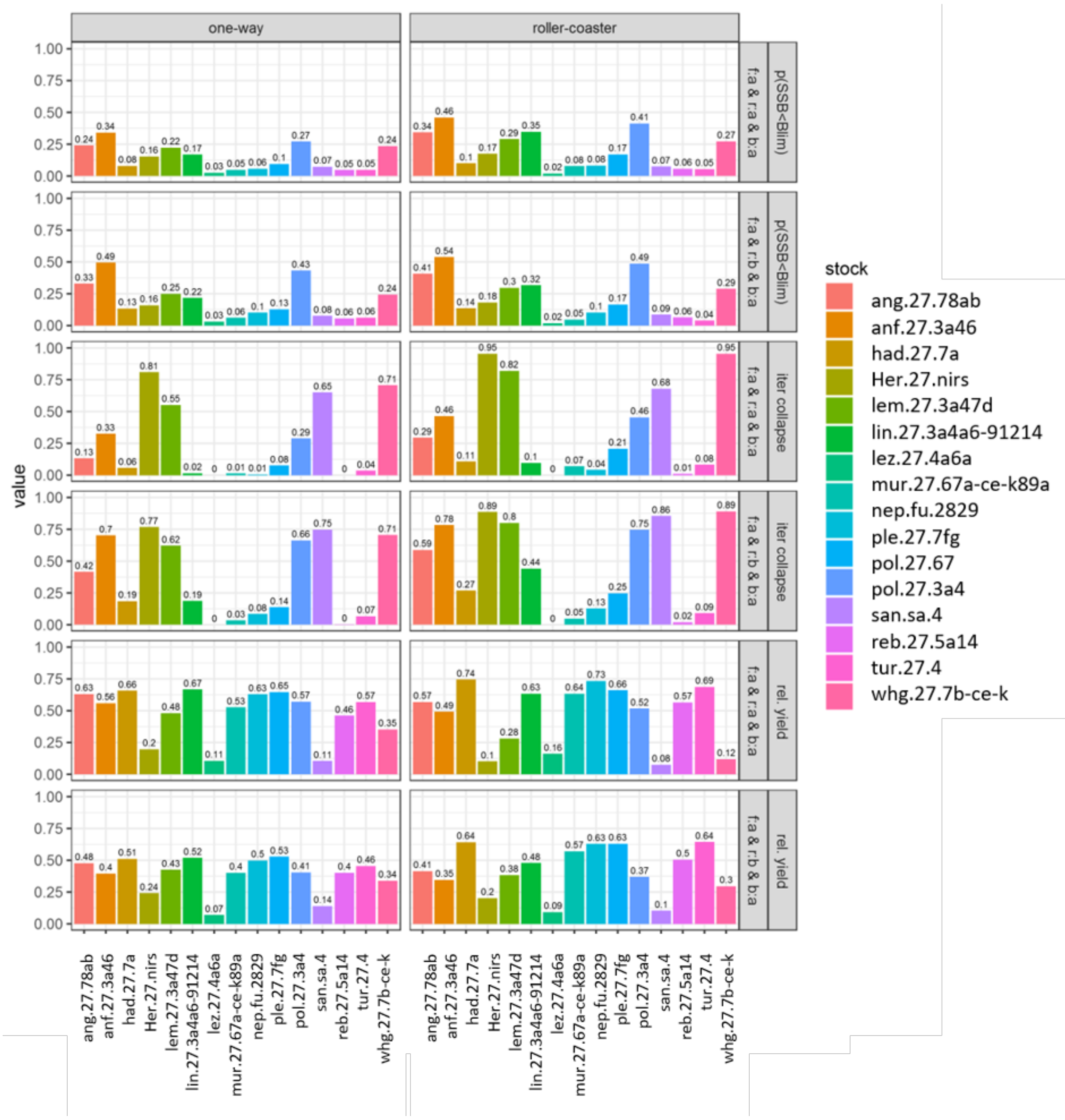

Figure A3.44. Performance statistics for the stochastic runs for combinations of catch rule 3.2.1. The first two rows show the risk of the stocks falling below B_{lim}, the middle two rows show the proportion of collapsed iterations during the simulation and the last two rows the average yield during the simulation compared to the average yield in the historic fishing period.

A3.5.1.5 Adding a catch multiplier for pol.27.3a4

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WKMSYCat34 proposed to add a multiplier to catch rule in case it did not perform precautionarily. The resulting catch rule would then be:

$$C_{y+1} = C_{current} \times r \times f \times b \times multiplier$$

This was trialled for pol.27.3a4. Multipliers in the range of 0.5-1 in 0.05 steps were tested in simulations including observation error. Figure A3.45 and Figure A3.46 show

the results for combination r:a & f:a & b:a, Figure A3.47 and Figure A3.48 for combination r:b & f:a & b:a and Figure A3.49 the performance statistics for these runs.

Implementing a catch advice multiplier reduced the catch at the beginning of the simulation period but could result in higher long-term catches for a certain range of multipliers. Decreasing the multiplier slightly from 1 (default, i.e. no multiplier effect) had a considerable impact on the risks but this effect slowed down when the multiplier was further decreased. Initially, implementing a multiplier even increased the long-term yield, i.e. led to better performance of the catch rule. Reducing the multiplier further, below approximately 0.8-0.9, had little effect on the risk but reduced the yield considerably.

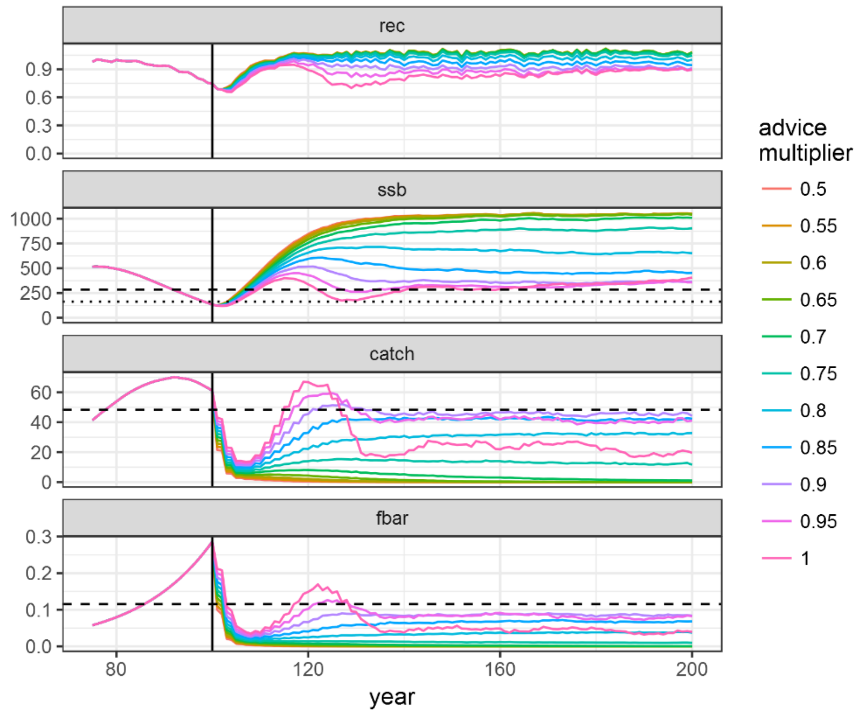

Figure A3.45. MSE results for pol.27.3a4 testing various advice multipliers on top of combination r:a & f:a & b:a of catch rule 3.2.1 for the one-way trip including observation error.

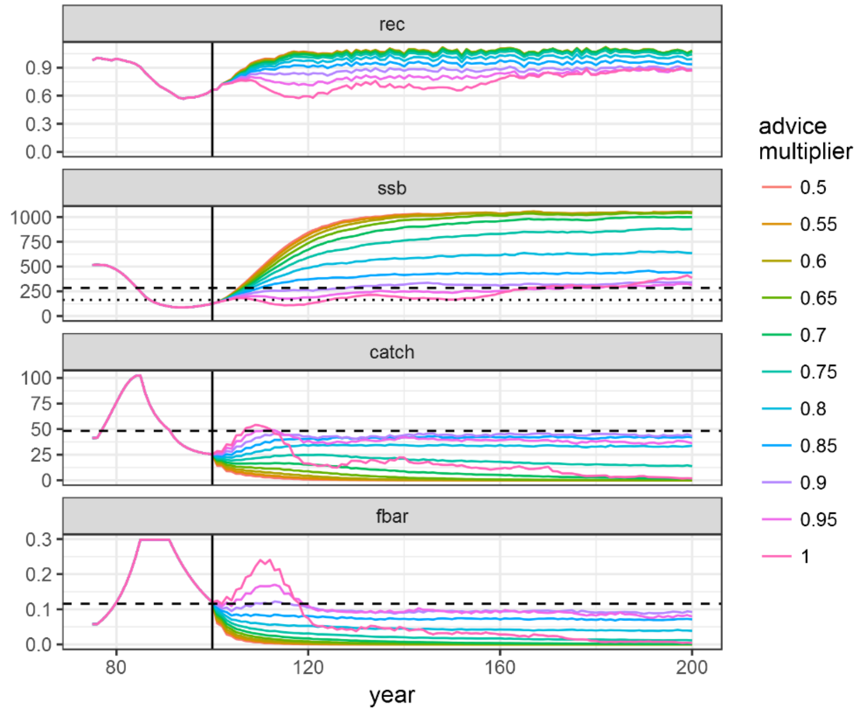

Figure A3.46. MSE results for pol.27.3a4 testing various advice multipliers on top of combination r:a & f:a & b:a of catch rule 3.2.1 for the roller-coaster trip including observation error.

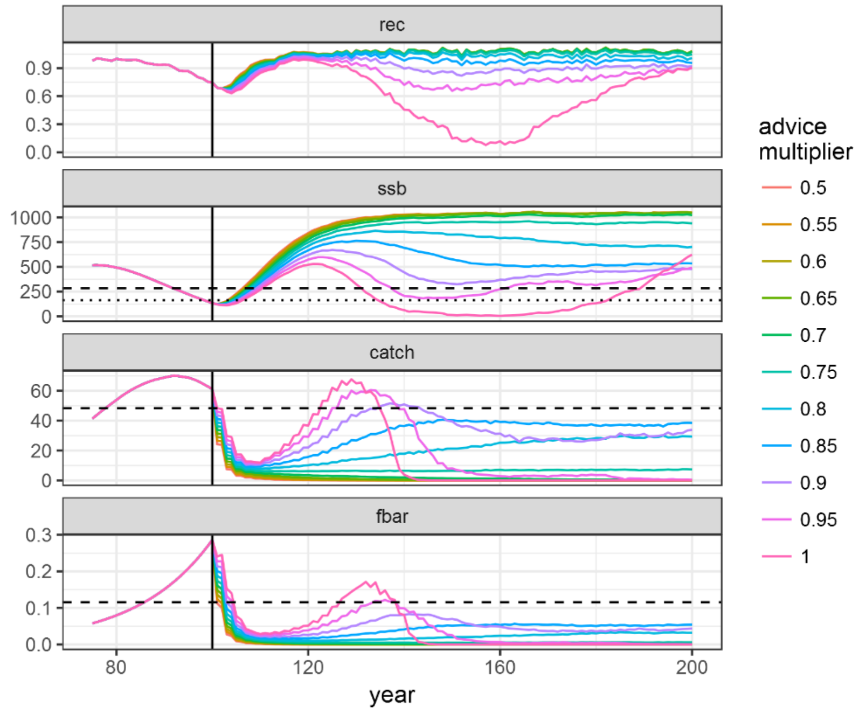

Figure A3.47. MSE results for pol.27.3a4 testing various advice multipliers on top of combination r:b & f:a & b:a of catch rule 3.2.1 for the one-way trip including observation error.

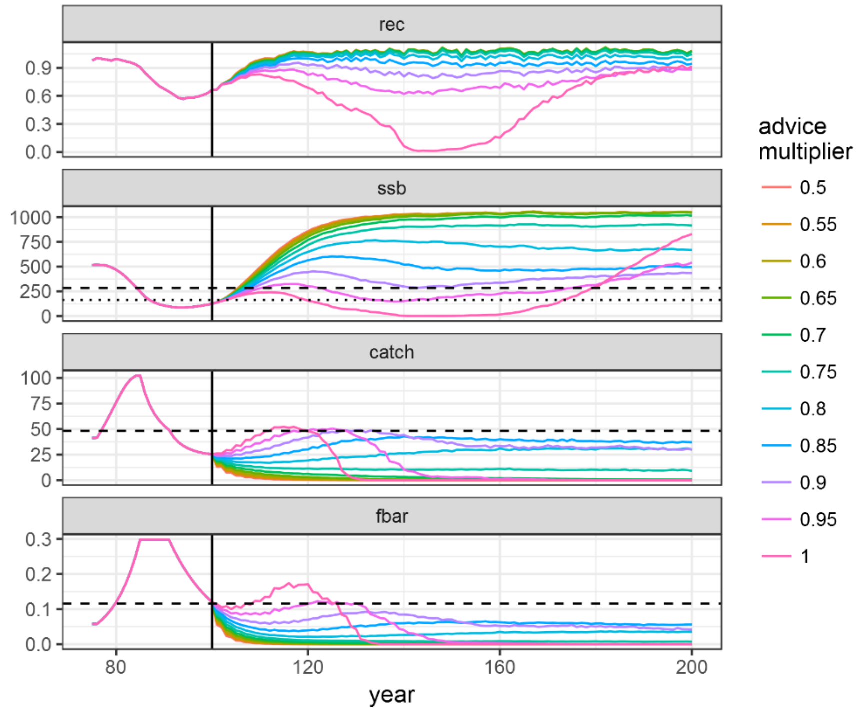

Figure A3.48. MSE results for pol.27.3a4 testing various advice multipliers on top of combinations r:b & f:a & b:a of catch rule 3.2.1 for the roller-coaster trip including observation error.

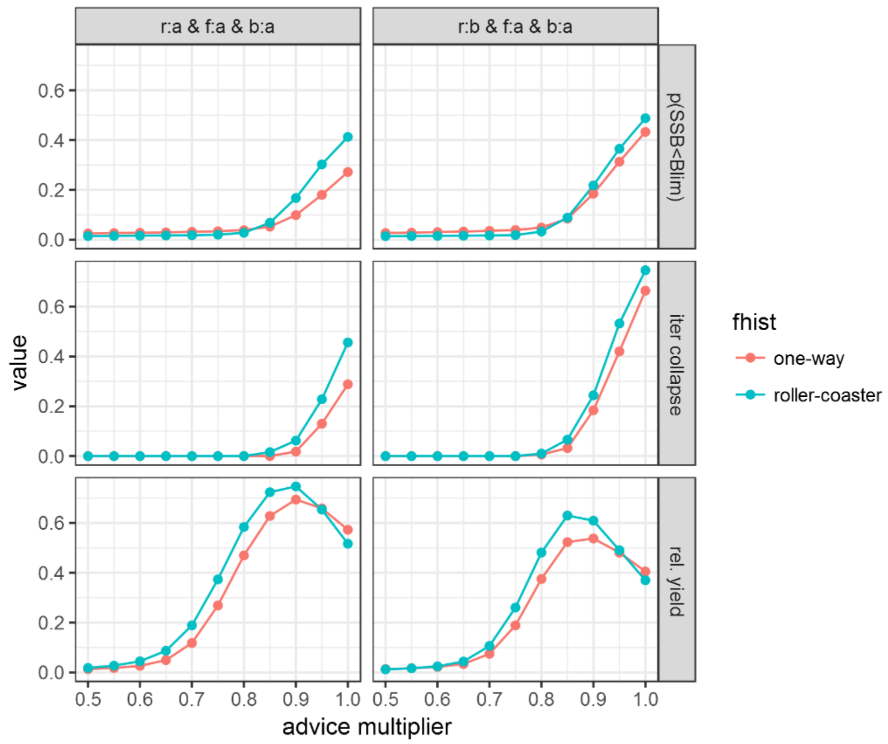

Figure A3.49. Performance statistics for various catch advice multipliers on top of combinations r:b & f:a & b:a of catch rule 3.2.1 for pol.27.3a4.

A3.5.1.6 Modifying the calculation of $I_{trigger}$ for pol.27.3a4

Another possibility to tweak catch rule 3.2.1 is to change the calculation of the index trigger value below which component b of the catch rule reduces the catch. The default calculation is:

$b = min\left\{1, \frac{I_{current}}{I_{trigger}}\right\}$ with $I_{trigger} = w \times I_{lim}$ and by default $w = 1.4$

Simulation runs for pol.27.3a4 including uncertainty were conducted for w values of 1.4, 1.6, 1.8, 2, 3, 4 and 5. By increasing w, the $I_{trigger}$ is set higher and component b is activated at lower stock levels (more precautionary).

Figure A3.50 and Figure A3.51 show the results for combination r:a & f:a & b:a, Figure A3.52 and Figure A3.53 for combination r:b & f:a & b:a and Figure A3.54 the performance statistics.

Small changes in w had only little impact on the results. In order to markedly reduce the risk, w had to be very large (≥ 3). If w is that large, this leads to a very large value of $I_{trigger}$ and component b of catch rule 3.2.1 reduces the catch even at very high stock sizes. The conclusion from this is that in order for w to work, it has to be so high that is acts more like a multiplier on the catch.

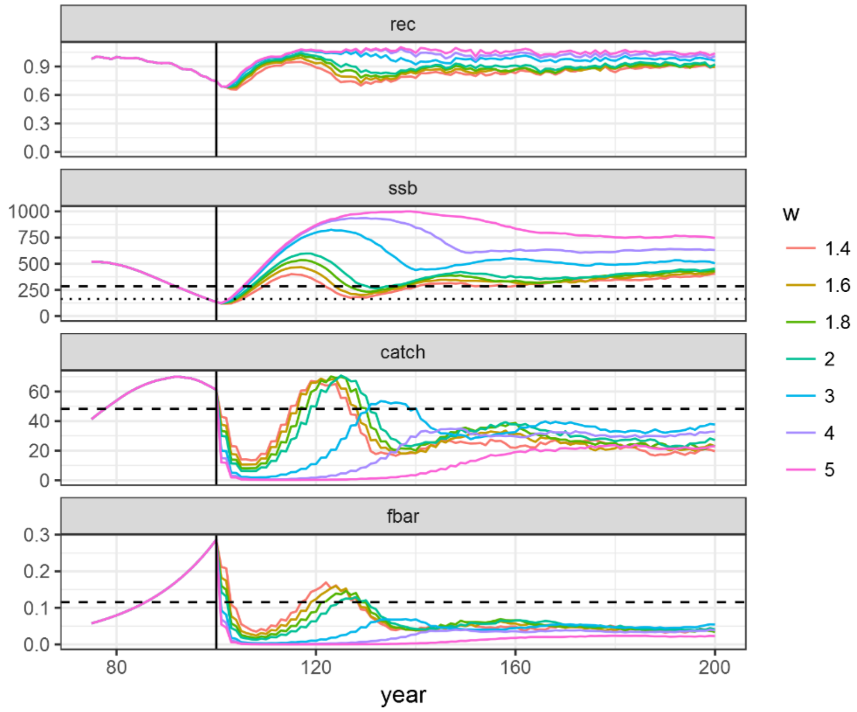

Figure A3.50. MSE results for pol.27.3a4 testing various values for w in the calculation of $I_{trigger}$ on top of combination r:a & f:a & b:a of catch rule 3.2.1 for the one-way trip including observation error.

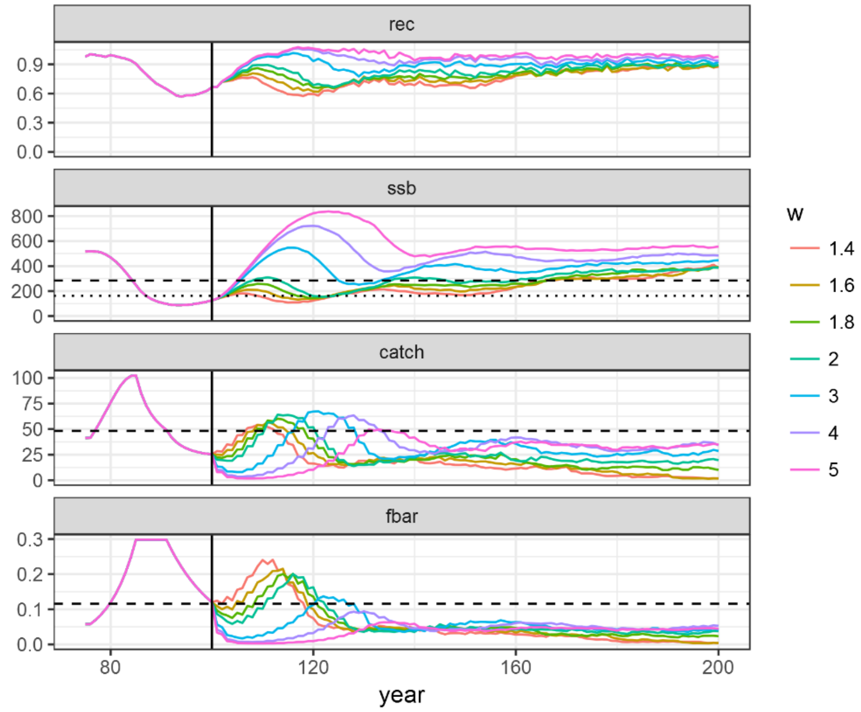

Figure A3.51. MSE results for pol.27.3a4 testing various values for w in the calculation of $I_{trigger}$ on top of combination r:a & f:a & b:a of catch rule 3.2.1 for the roller-coaster trip including observation error.

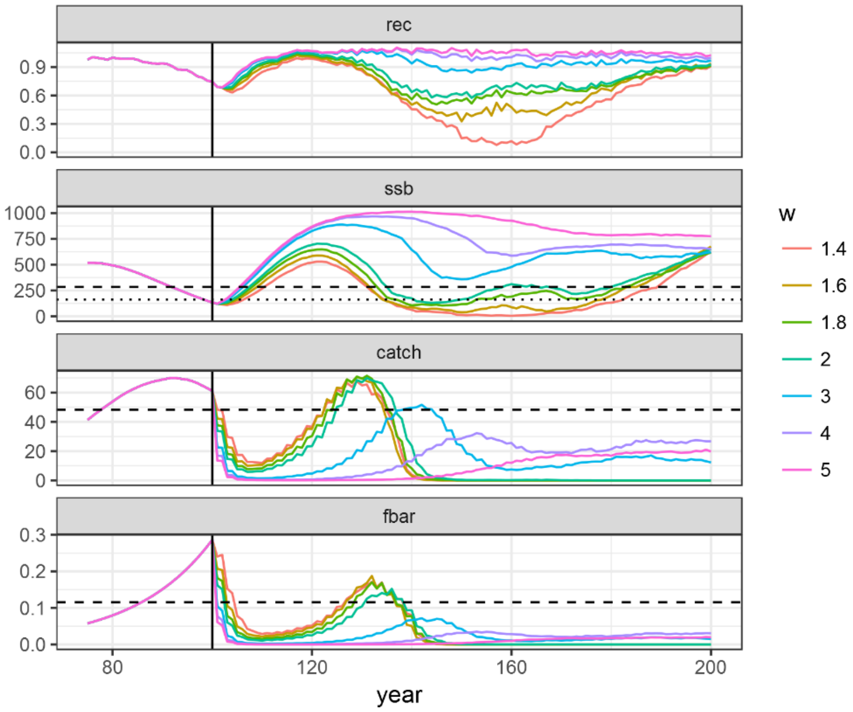

Figure A3.52. MSE results for pol.27.3a4 testing various values for w in the calculation of $I_{trigger}$ on top of combination r:b & f:a & b:a of catch rule 3.2.1 for the one-way trip including observation error.

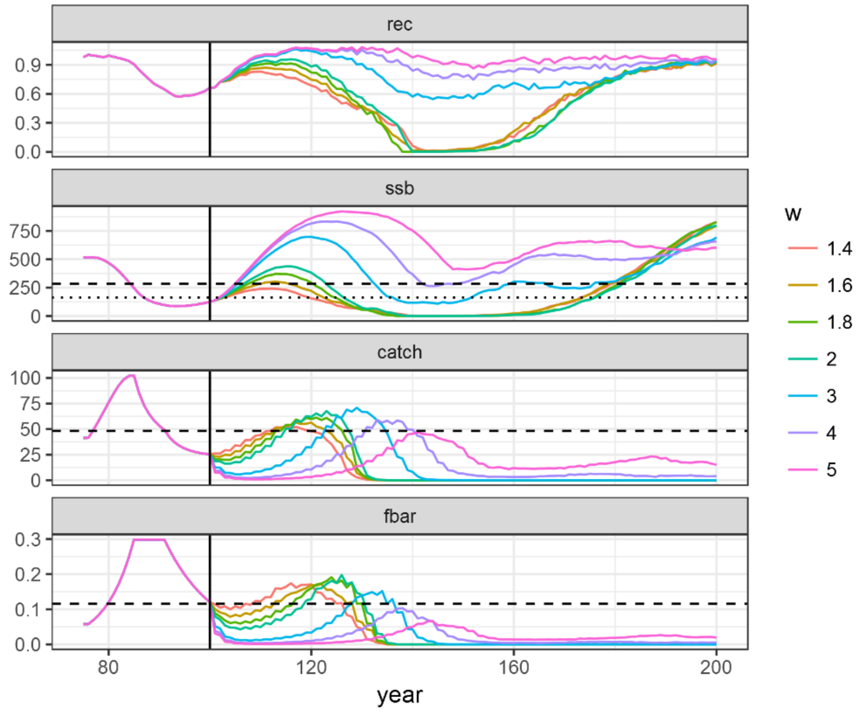

Figure A3.53. MSE results for pol.27.3a4 testing various values for w in the calculation of $I_{trigger}$ on top of combination r:b & f:a & b:a of catch rule 3.2.1 for the roller-coaster trip including observation error.

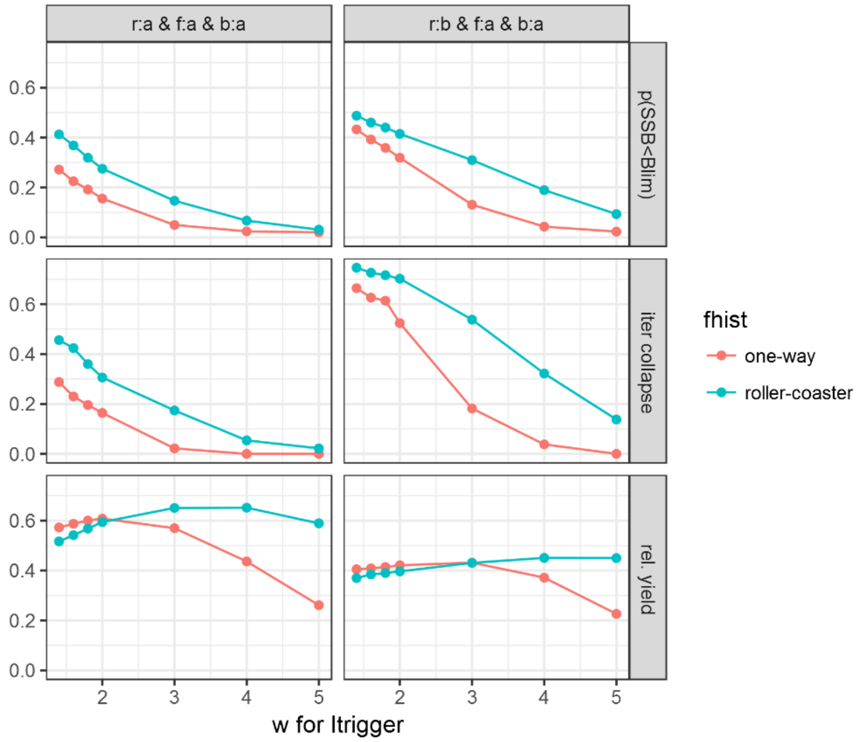

Figure A3.54. Performance statistics for various values of w in the calculation of $I_{trigger}$ on top of combinations of catch rule 3.2.1.

A3.5.1.7 Conclusions

The simulations described in this working document provide only a first set of generic simulations for ICES WKMSYCat34 catch rule 3.2.1. The simulation conditions were reasonably harsh with a high depletion at the beginning of the simulation and early onset of fisheries selectivity before full maturation.

General conclusions that can be made from the simulations so far include:

- The individual components of the catch rule showed a poor performance when implemented on their own
  - From the three tested options for component f, option a seemed to perform best. The resulting value for f showed its potential to track general stock trends but the interpretation of the absolute values is questionable as it depends on the definition of the reference length. The calculation of the reference length depends crucially on the assumptions and can deviate substantially from the real length at MSY in both directions. This can cause major issues as this might lead to a misspecification of the target.
  - There can be a massive time-lag between the peaks in SSB and f.
- Using the catch rule as intended by WKMSYCat34, i.e. multiplying all individual components could alleviate some of the issues.
- Option a from component r (2 over 3 rule) seemed to perform best with more stable trends and smaller oscillations.
- Combinations with options b or c for component f showed a very poor performance.
- From the tested combinations of the individual options for the components, the combination r:a & f:a & b:a seemed to work best but still failed entirely for some stocks.
  - Under perfect knowledge assumptions the catch rule worked reasonably for some stocks but not at all for others.
- Including observation error and making real life assumptions (M/K ratio) caused a worryingly high uncertainty (collapse <-> virgin biomass), led to less stability and for some stocks a misspecification of the MSY target.
- The advised catch is the product of several factors (the components of the catch rule). If only one factor failed (i.e. very large or very low/zero), the entire catch rule failed.
- The new catch is always based on the last catch. This causes some serious issues:
  - If the catch is zero at any point, either because of a zero advice or due to a stock collapse, the catch can never(!) recover as it is always a factor of zero, i.e. zero.
  - There is always a time-lag between the stock dynamic and the catch advice.
  - As the advice does not have an absolute target, the advised catch oscillates around its target until it reaches this value. This might be reasonable for some stocks but others are less resilient and these oscillations can cause stock collapses.

- Preliminary tuning of catch rule described in this working document showed that the catch rule can be improved.
  - o An advised catch multiplier could improve the performance, reduce the risk (both in term of falling below B_{lim} and the risk of stock collapses) and even lead to higher yield
  - o Modifying the calculation of $I_{trigger}$ did not satisfactorily improve the performance.
- None of the catch rules worked for the two pelagic/short-live stocks (her.27.nirs, san.sa.4).

More generic testing of the catch rules and assumptions is crucial. Before the catch rule is applied it should be thoroughly tested and fine-tuned with stock-specific MSE simulations.

A3.5.2 Catch rule 3.2.2

A3.5.2.1 Introduction

Catch rule 3.2.2 (equation 3.2.2.1 from WKMSYCat34, ICES, 2017), also known as Fproxy rule or Icelandic rule was tested in an MSE simulation with the 15 stocks and two fishing histories. The catch advice from this rule is calculated with the following equation:

$$C_{y+1} = I_{current} F_{proxy,MSY} \min \left\{ \frac{I_{current}}{I_{trigger}} \right\}$$

I is a stock size indicator and $F_{proxy,MSY}$ is a harvest rate (C/I) which is used as a target. This harvest rate should correspond to a rate at or around MSY. The last part of the equation is a biomass safeguard that reduces the advised catch if the stock size is below a trigger value. In the case of no knowledge of a reasonable value, this value is calculated as $I_{trigger} = w \times I_{lim}$, where $I_{lim}$is the lowest observed value and the default is $w = 1.4$.

A3.5.2.2 Catch rule parametrization

For the first set of simulations for catch rule 3.2.2 the default parametrizations as suggested by WKMSYCat34 was used. This included a biennial TAC and the trigger value was set to $I_{trigger} = 1.4 \times I_{loss}$. $F_{proxy,MSY}$ was derived outside the actual simulation loop by fishing the stock at F_{MSY} for 100 years and then using the obtained harvest rate. $I_{current}$ was always the stock size index in year-1, corresponding to the usual ICES procedure.

A3.5.2.3 Simulations without observation error

In the first set of simulations no additional uncertainty was added to the simulation apart from recruitment variability. $F_{proxy,MSY}$, $I_{current}$ and $I_{trigger}$ were perfectly known.

Catch rule 3.2.2 performed reasonably well for 13 out of the 15 tested stocks for both fishing histories. Simulated stock dynamics are shown in Figure A3.55 and Figure A3.56. For most stocks, the catch was reduced at the beginning of the simulation period, the stocks subsequently recovered and eventually reached equilibrium at levels around MSY. The example for one stock (pol.27.3a4) is shown in Figure A3.57. The catch rule failed for the two pelagic stocks, her.27.nirs and san.sa.4. For both stocks, catches were reduced initially and the stocks recovered, but a few years later, the stocks

collapsed. Several years after the stock collapse, the stocks could recover again, but collapsed again and this cycle was repeated until the end of the simulation period (Figure A3.58).

The catch rule seems to be overly reactive for the two pelagic stocks. Changing the biennial TAC to an annual TAC did not improve the performance or avoid the stock collapse (**Error! Reference source not found.**, Figure A3.59 and Figure A3.60).

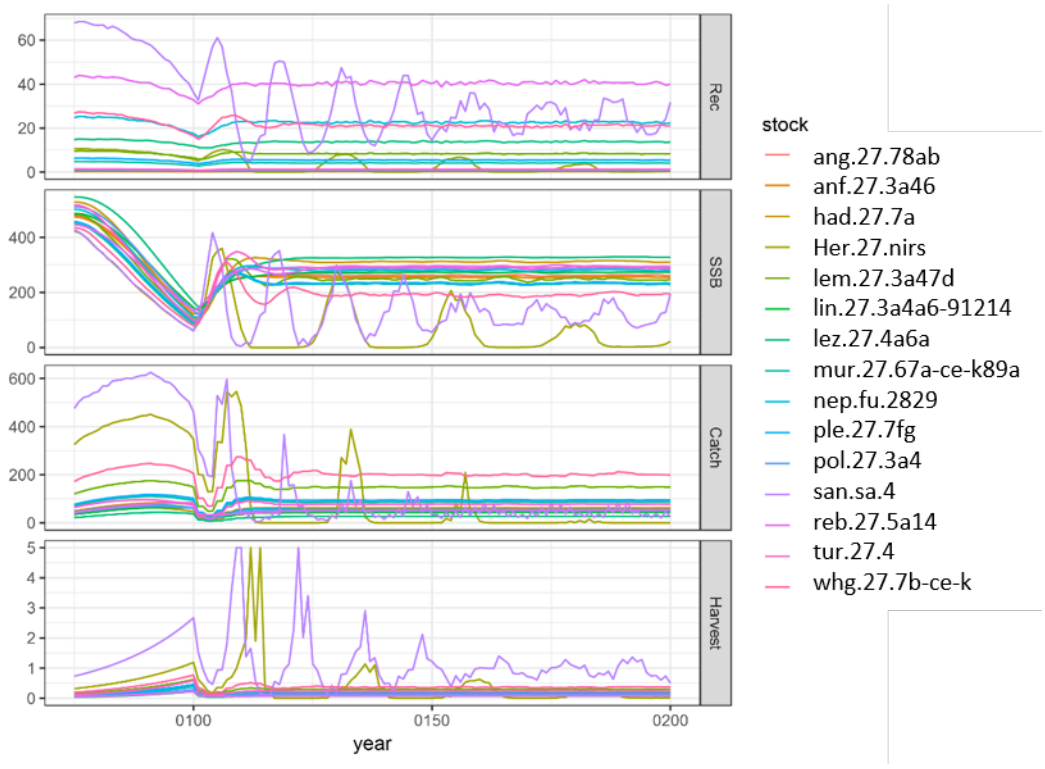

Figure A3.55. Stock results for catch rule 3.2.2 without observation uncertainty for the one-way trip fishing histories. Shown are the medians from 500 iterations for each stock.

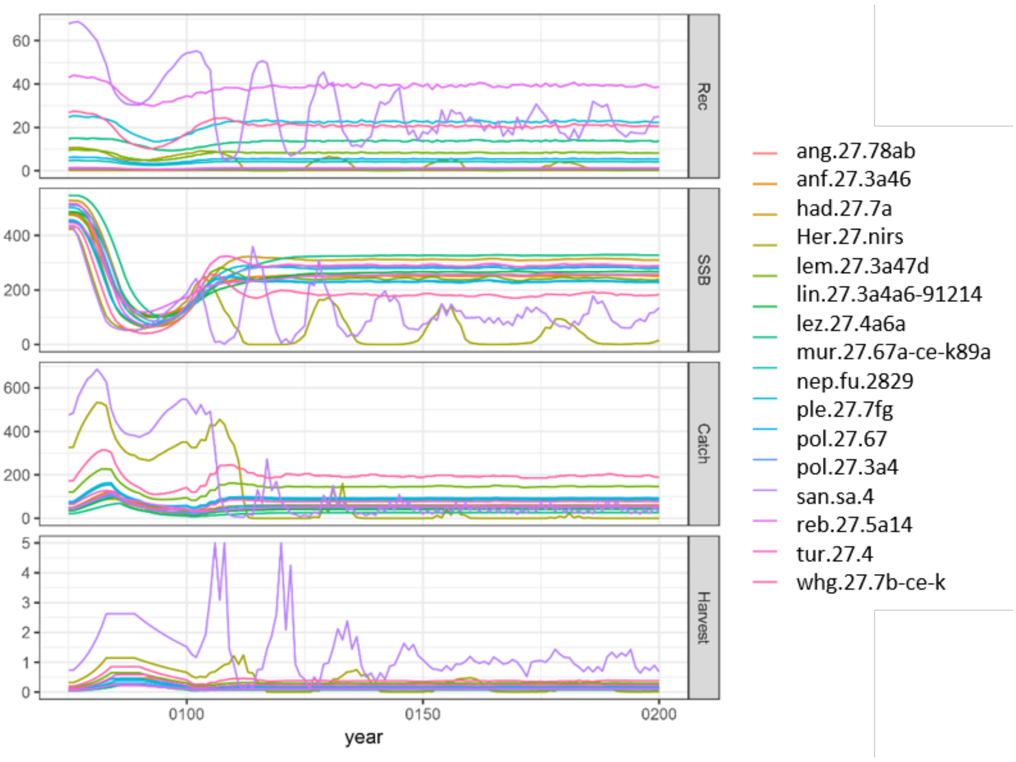

Figure A3.56.Stock results for catch rule 3.2.2 without observation uncertainty for the one-way trip fishing histories. Shown are the medians from 500 iterations for each stock.

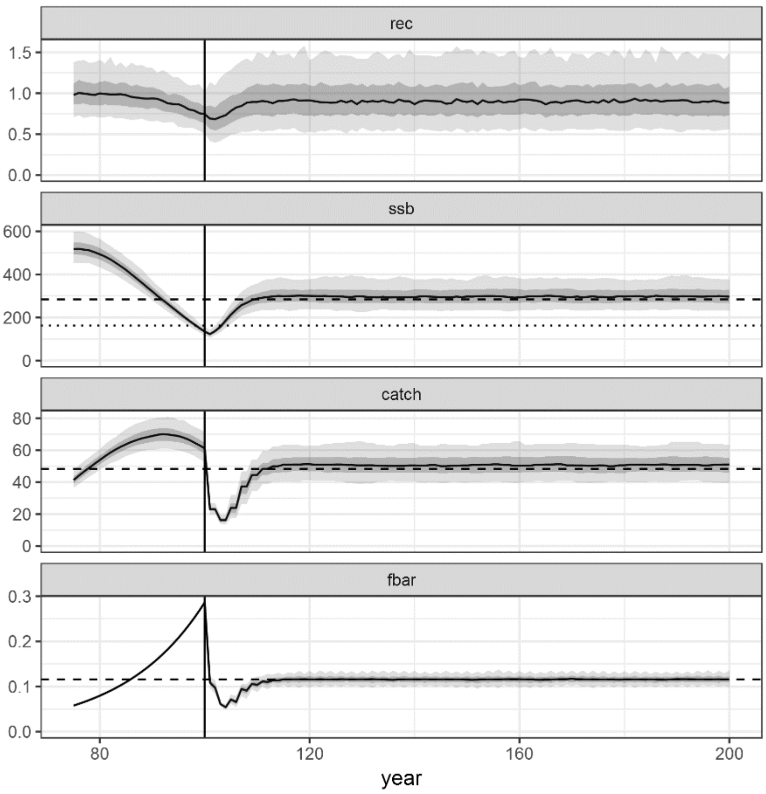

Figure A3.57. Stock results for catch rule 3.2.2 without observation uncertainty for the one-way trip for pol.27.3a4. The solid line indicates the median, the shaded areas

around mark the 50% and 90% confidence intervals. The dashed lines indicate MSY levels and the dotted line B_{lim}.

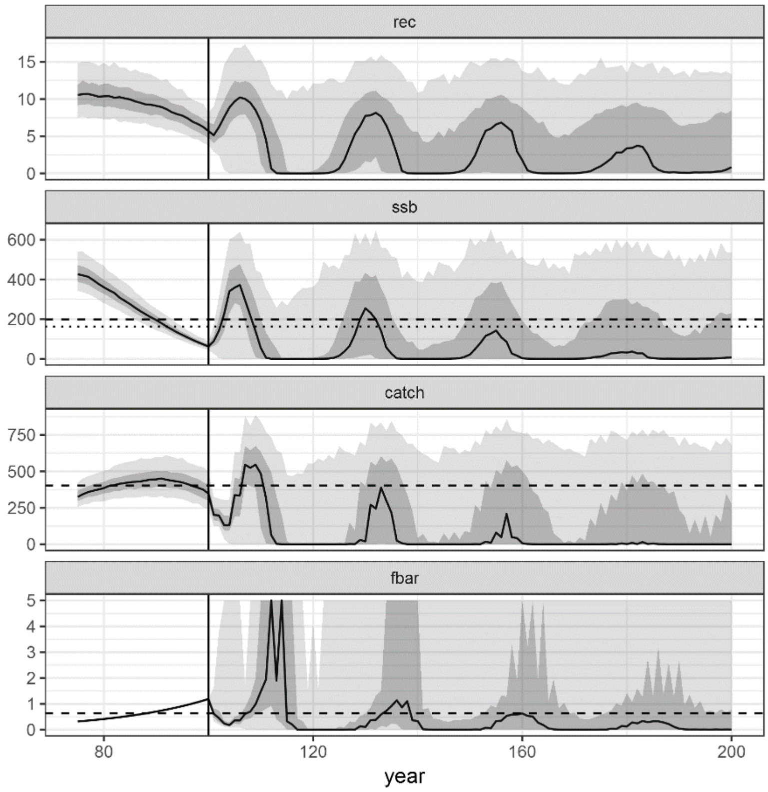

Figure A3.58. Stock results for catch rule 3.2.2 without observation uncertainty for the one-way trip for her.27.nirs.

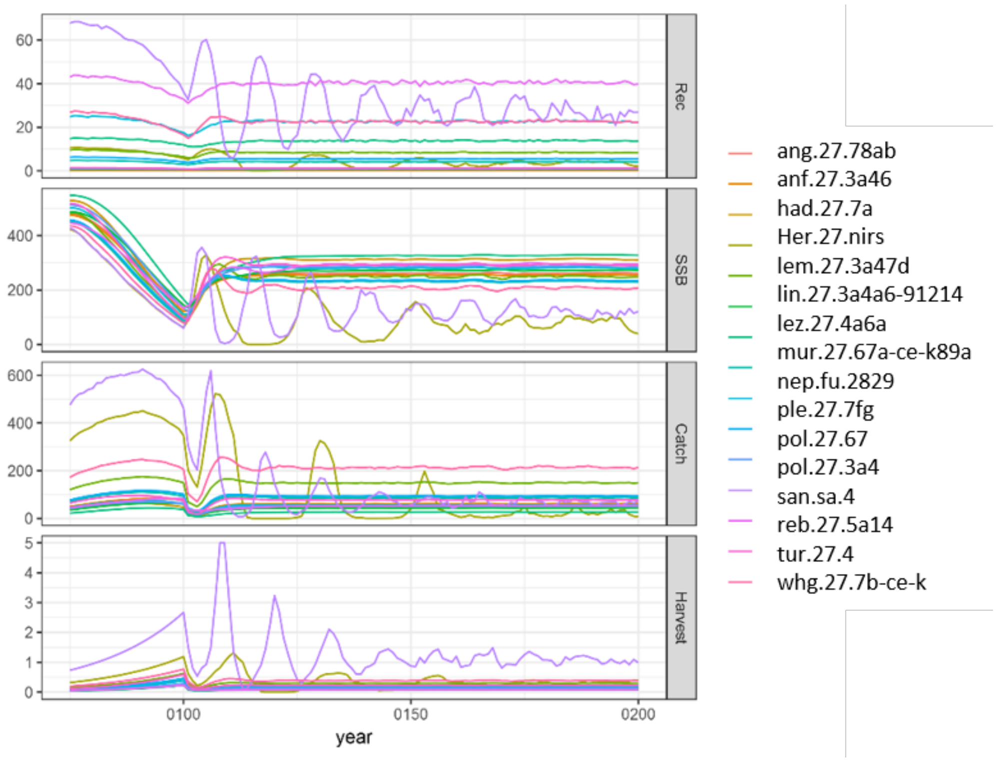

Figure A3.59. Stock results for catch rule 3.2.2 with annual TAC and without observation uncertainty for the roller-coaster trip fishing histories.

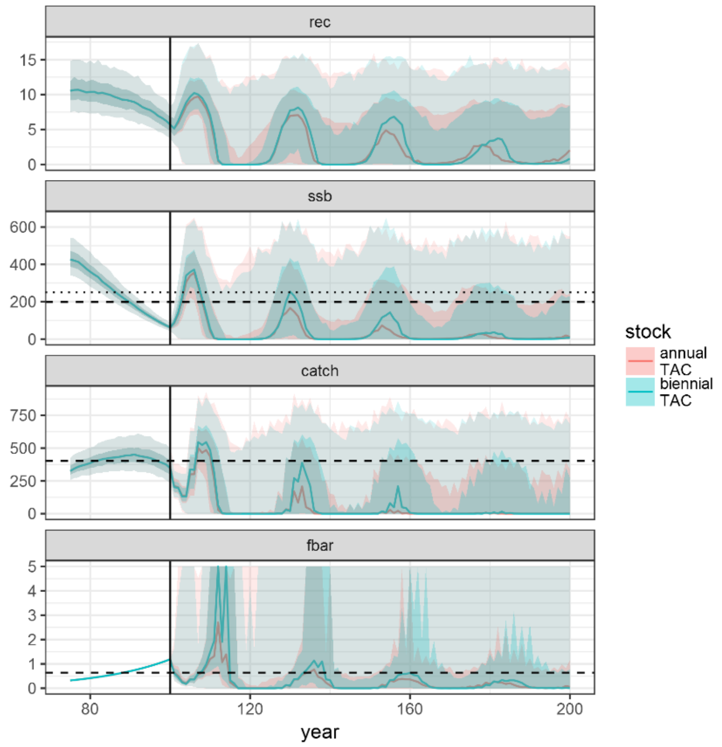

Figure A3.60. Stock results for catch rule 3.2.2 without observation uncertainty for the one-way trip for her.27.nirs, comparing the results from an annual and biennial setting of the TAC.

A3.5.2.4 Simulations with observation error

A3.5.2.4.1 Default parametrization

As the simulations of catch rule 3.2.2 without observations error led to promising results, the same catch rule was subsequently tested with observation error. The uncertainty was implemented with a lognormal noise and a cv of 0.2 for the index and cv of 0.1 for $F_{proxy,MSY}$. No additional noise was added to $I_{trigger}$ as it was derived from the survey index which already included noise.

The first set of simulations for catch rule 3.2.2 including observation error were conducted with default parametrizations. The results for all 15 stocks and the two fishing histories are shown in Figure A3.61 and Figure A3.62 and the performance statistics in Figure A3.63. The stock dynamics results are very similar to the ones obtained without observation error. The catch rule worked well for most stocks, apart from the two pelagics (her.27.nirs and san.sa.4). The risk for stock collapse is very low or zero for most stocks, apart from her.27.nirs, san.sa.4 and whg.27.7b-ce-k and the relative yields are relatively high.

On average all stocks apart from the pelagics (her.27.nirs, san.sa.4) reached levels around MSY (SSB, fishing mortality, catch) after 5-20 years and remained there for the rest of the simulation period. Smn-con reached SSB levels slightly higher than B_{MSY} and whg.27.7b-ce-k levels slightly lower than B_{MSY} at around B_{lim}. The likely reason for the poorer performance for whg.27.7b-ce-k is that some stock collapses occurred for some iterations during the simulation shifting the median to a lower level. For the remaining non-pelagic stocks, the levels reached were very close to MSY levels.

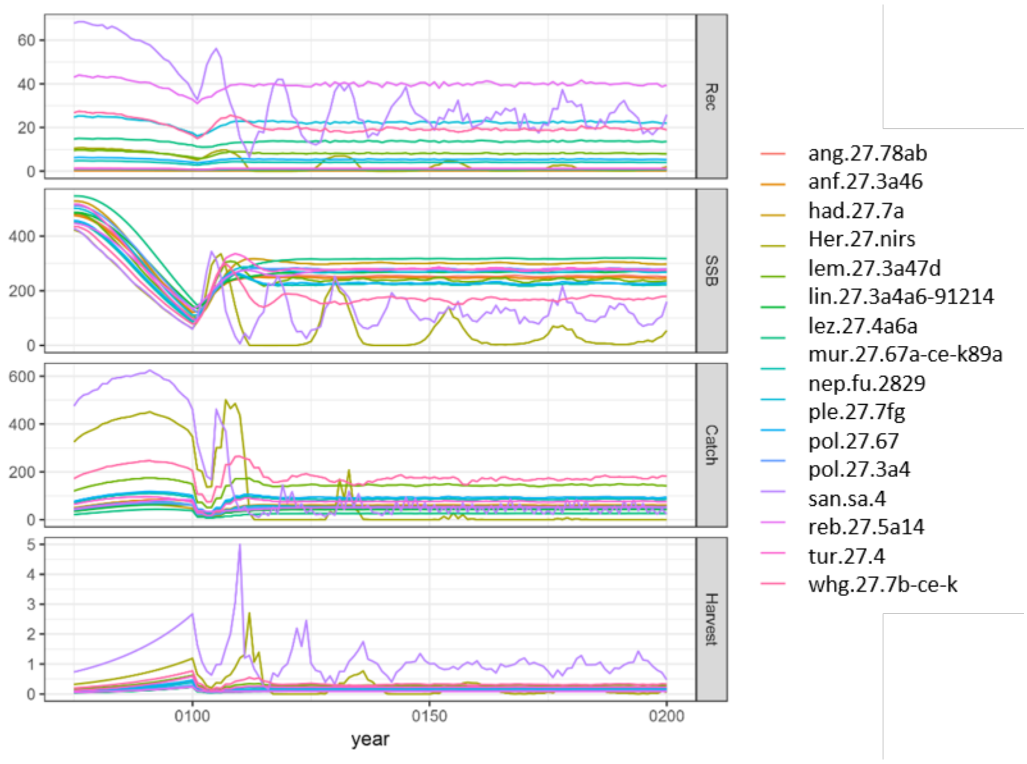

Figure A3.61. Stock results for catch rule 3.2.2 including observation uncertainty for the one-way trip fishing histories. Shown are the medians from 500 iterations for each stock.

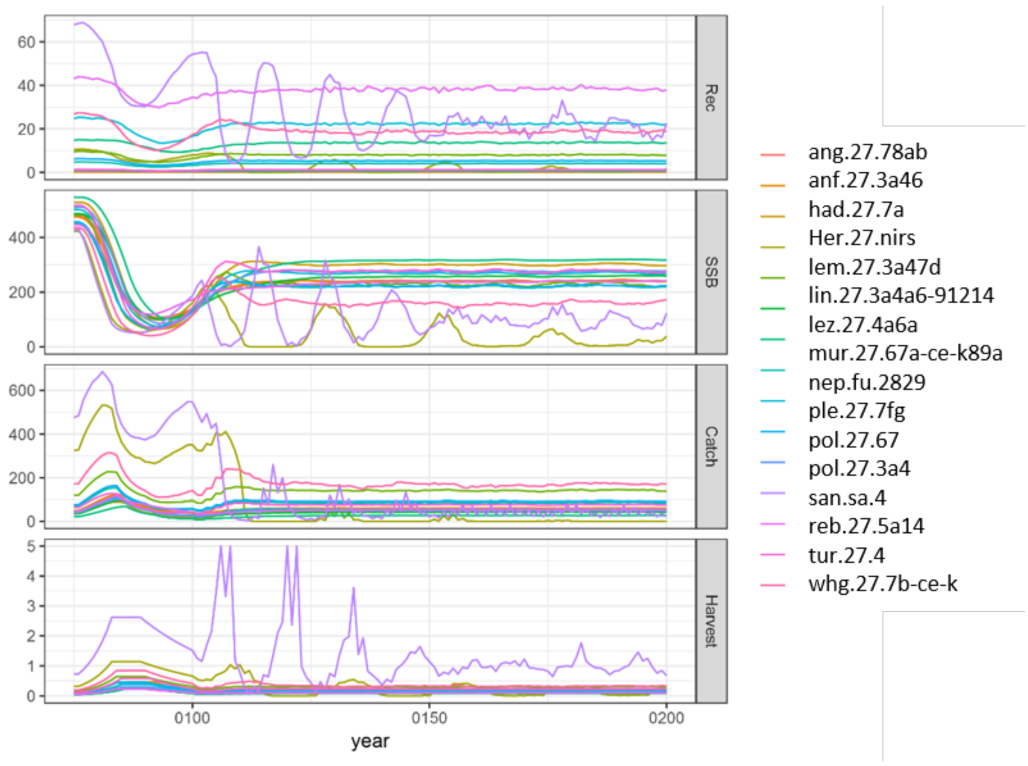

Figure A3.62. Stock results for catch rule 3.2.2 including observation uncertainty for the roller-coaster fishing history. Shown are the medians from 500 iterations for each stock.

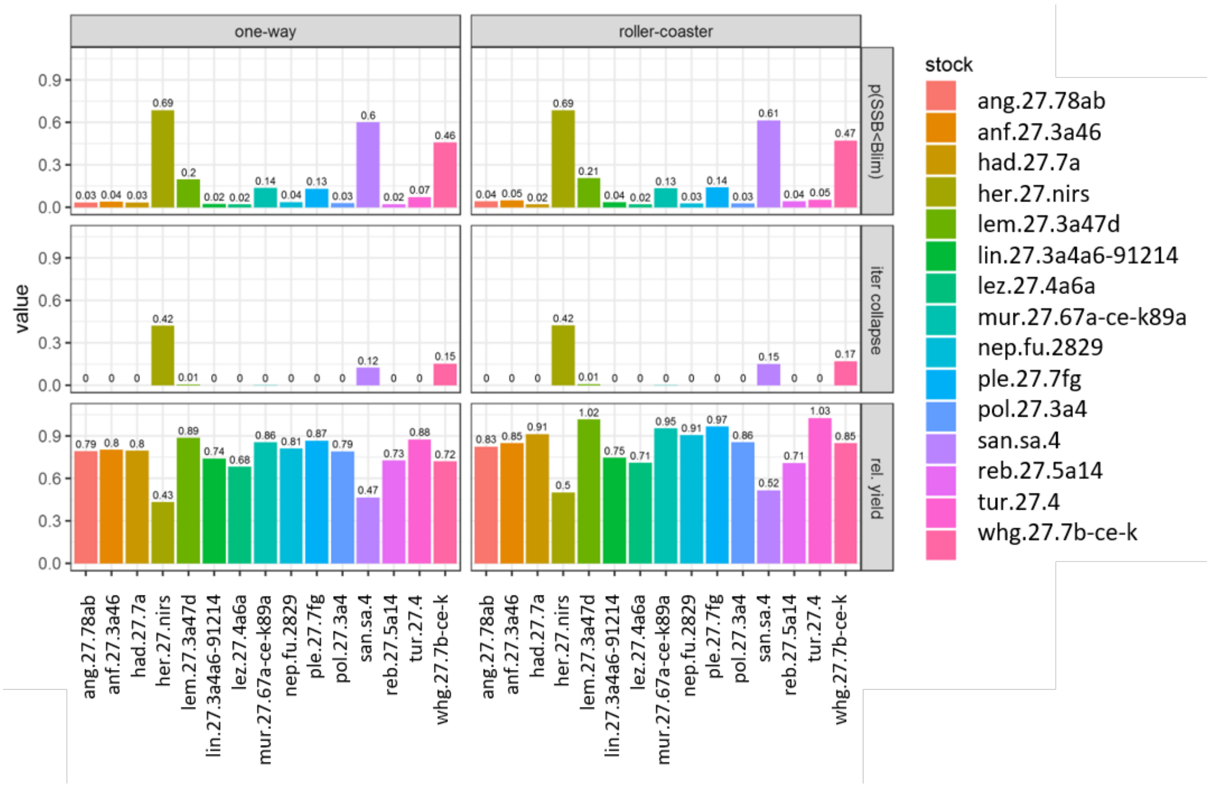

Figure A3.63. Performance statistics of the stochastic MSE runs for catch rule 3.2.2. Shown are the risks of dropping below B_{lim} during the 100-year simulation period (first row), the proportion of the 500 iterations that collapsed, i.e. dropped below 0.1% of B_0 (second row) and the relative yield (mean yield in the projection period compared to the yield before the implementation of the catch rule, third row).

A3.5.2.4.2 Adding a catch advice multiplier

One management option proposed by WKMSYCat34 is to add an advice multiplier to the catch rule in case it does not perform precautionarily. A trial set of simulations for all stocks with a multiplier of 0.5 was carried out. This multiplier basically reduces the targeted catch by 50%. The results for these runs are shown in Figure A3.64 and Figure A3.65. Using this multiplier resulted in SSB levels well above B_{MSY} for all stocks, but with catches below MSY. Furthermore, this modification of the catch rule stopped the cyclic collapsing of the pelagic stocks.

As implementing a multiplier seemed to work for the two pelagic stocks, further simulation runs were conducted to determine appropriate levels of the multiplier. Multipliers in the range of 0.5-1 in 0.05 steps were tested (Figure A3.66 and Figure A3.67 for her.27.nirs and Figure A3.68 and Figure A3.69 for san.sa.4). Implementing multipliers < 1 increasingly removed the cyclic behaviour of collapses and resulted in more stable long-term behaviour. Smaller multipliers led to smaller catches at the beginning of the simulation period, but as they avoided the frequent stock collapses, they even lead to higher long-term catches and lower risks (Figure A3.70). For san.sa.4 the highest long-term catches were achieved with the lowest tested multiplier (0.5), for her.27.nirs, the peak appeared at 0.55.

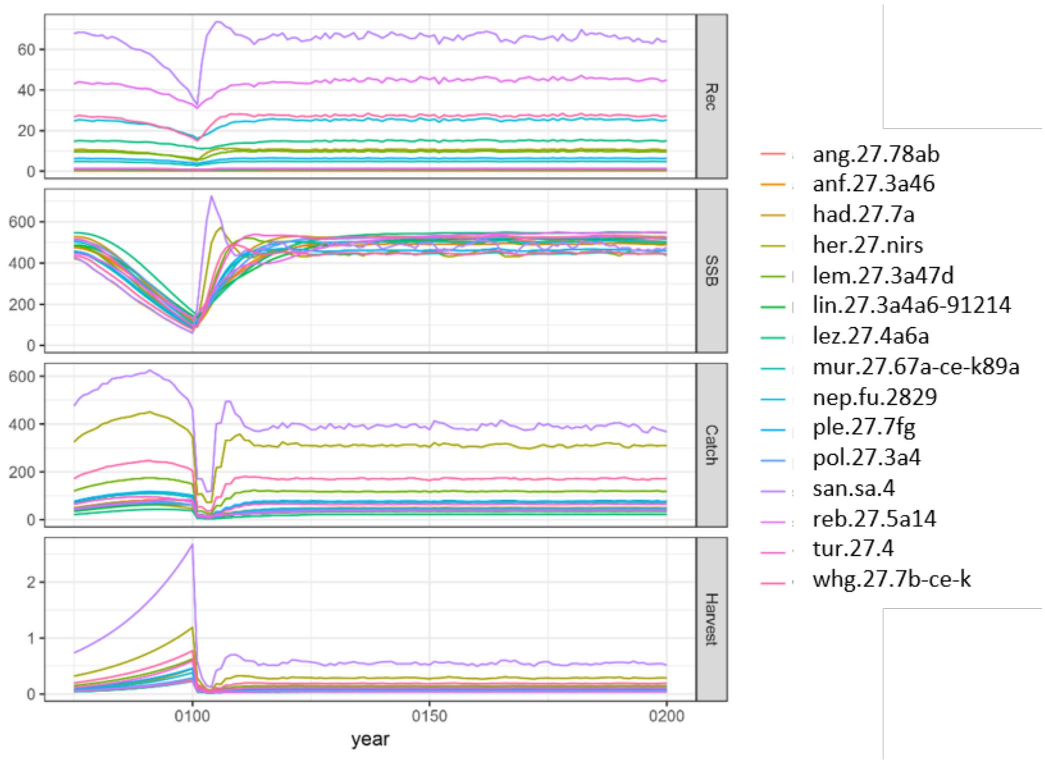

Figure A3.64. Stock projections for catch rule 3.2.2 and an advice multiplier of 0.5, including observation uncertainty for the one-way trip fishing history. Shown are the medians from 500 iterations for each stock.

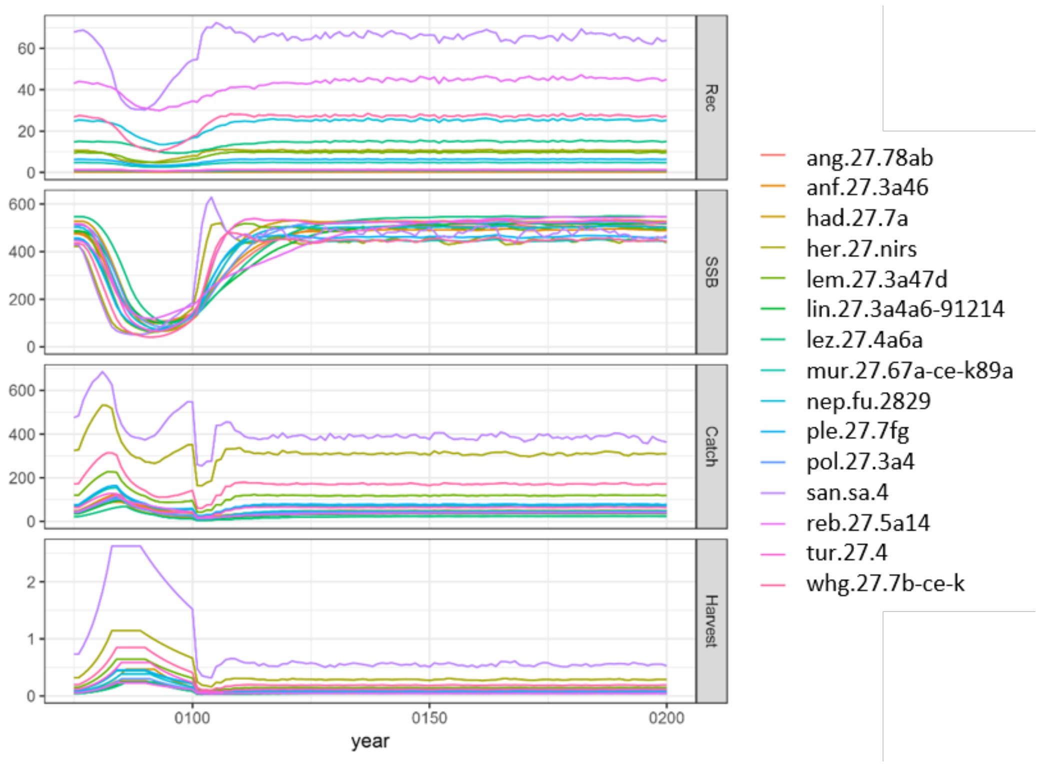

Figure A3.65. Stock projections for catch rule 3.2.2 and an advice multiplier of 0.5, including observation uncertainty for the roller-coaster fishing history. Shown are the medians from 500 iterations for each stock.

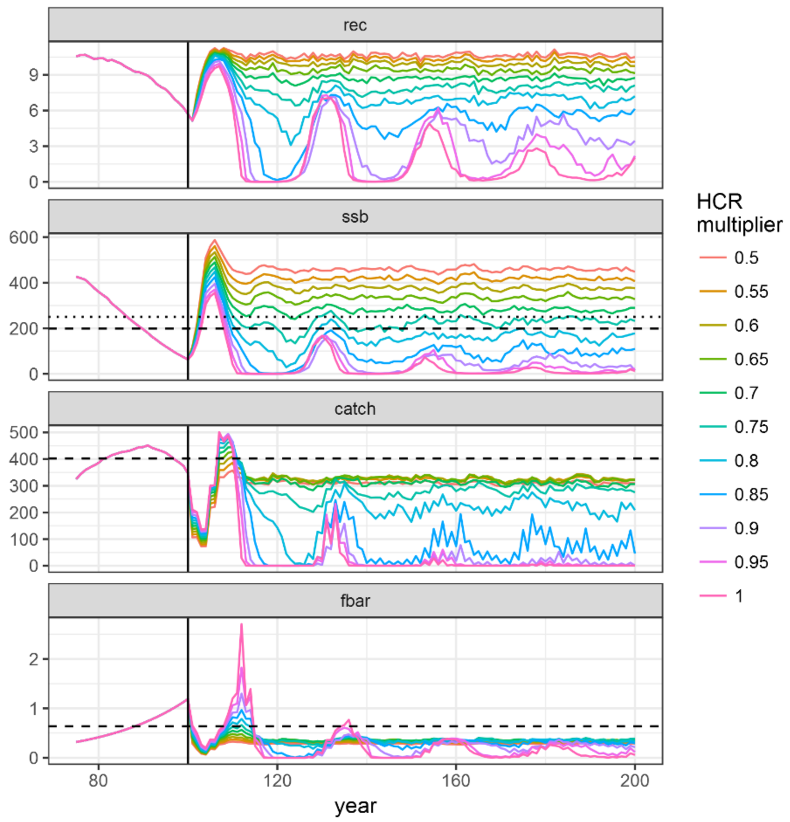

Figure A3.66. Stock projections for catch rule 3.2.2 for her.27.nirs (one-way trip) testing different catch advice multipliers.

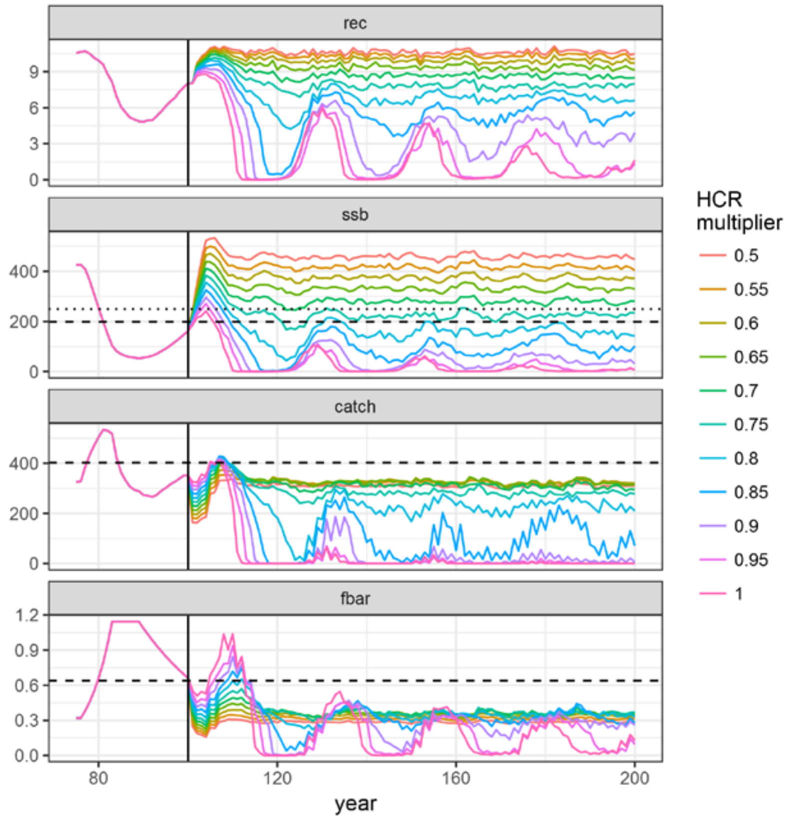

Figure A3.67. Stock projections for catch rule 3.2.2 for her.27.nirs (roller-coaster trip) testing different catch advice multipliers.

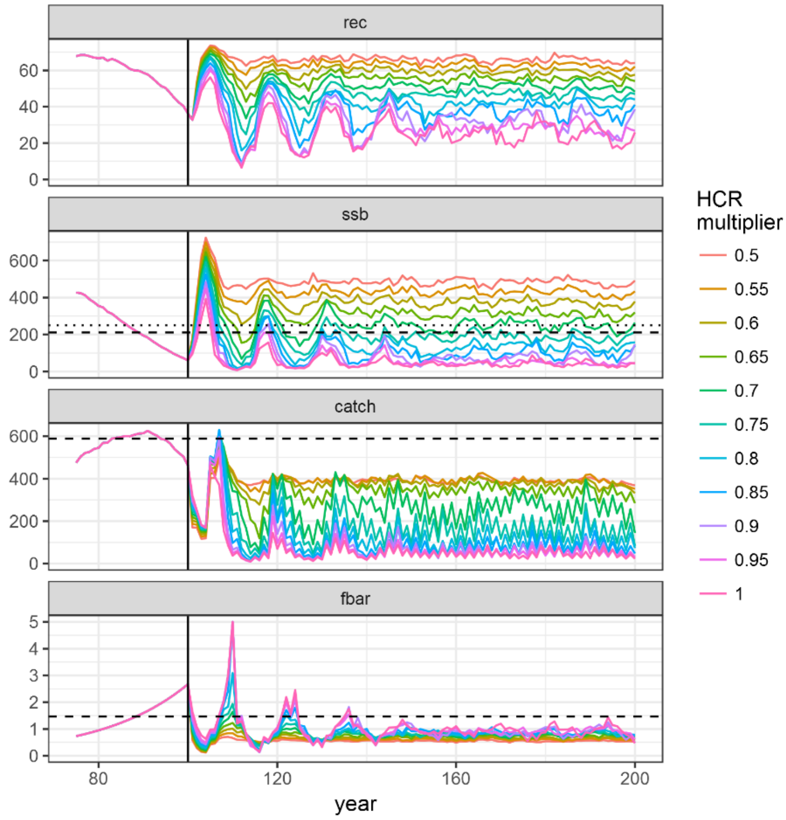

Figure A3.68. Stock projections for catch rule 3.2.2 for san.sa.4 (one-way trip) testing different catch advice multipliers.

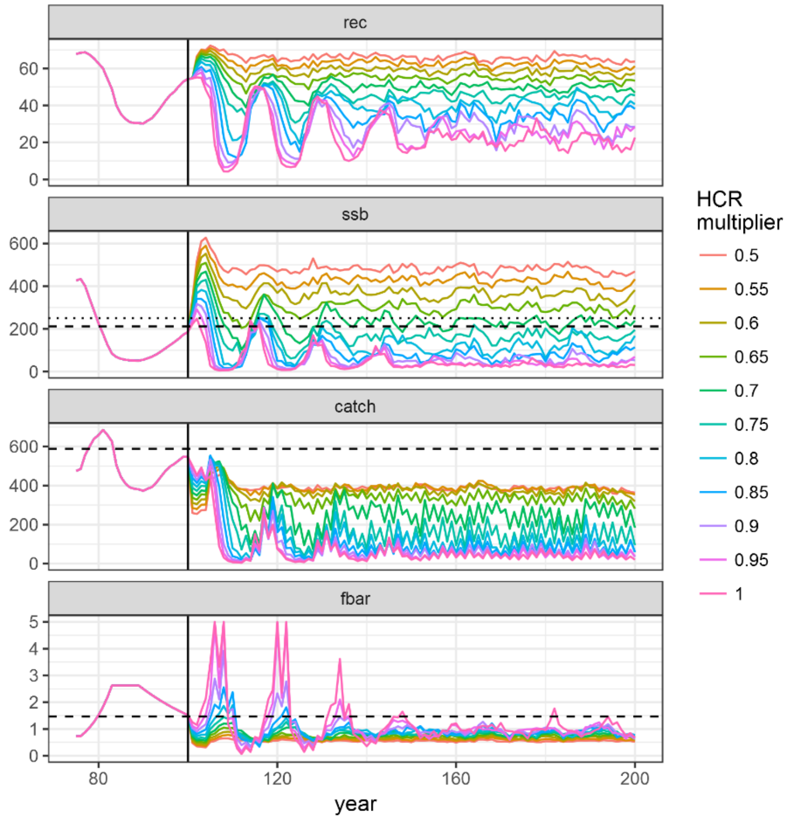

Figure A3.69. Stock projections for catch rule 3.2.2 for san.sa.4 (roller-coaster trip) testing different catch advice multipliers.

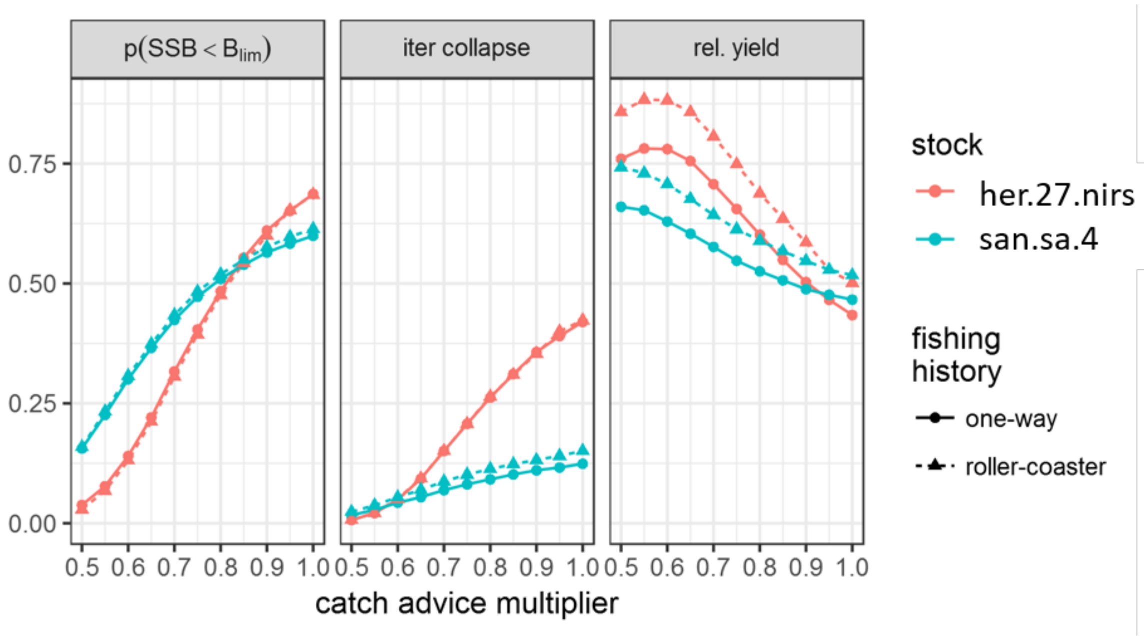

Figure A3.70. Performance statistics for catch rule 3.2.2 for pelagic stocks and different catch advice multipliers. Shown is the risk of dropping below B_{lim} during the 100 years simulation period, the proportion of collapsed iterations during the simulation and the yield relative to the yield before the management implementation.

A3.5.2.5 Modifying w in the calculation of $I_{trigger}$

Another option to fine-tune catch rule 3.2.2 proposed by WKMSYCat34 is to change w in the calculation of $I_{trigger}$. By default, $I_{trigger} = w \times I_{lim}$, with $w = 1.4$ and I_{lim} is the lowest observed historical index value. For the two pelagic stocks, w values of 1.4, 2, 3, 4, 5 and 10 were tested.

The results for these simulations are shown in Figure A3.71, Figure A3.72, Figure A3.73 and Figure A3.74 and the performance statistics in Figure A3.75. Regarding the stock trends, substantial improvements in the performance could only be observed when w became very large (≥5). This leads to the conclusion that modifying w does not work well for these two stocks. The reason is that if w is very large, $I_{trigger}$ becomes very large as well and can even be larger than B_0. In that case, the stock is always below $I_{trigger}$ and to be effective w has to become so large that it acts as a catch multiplier.

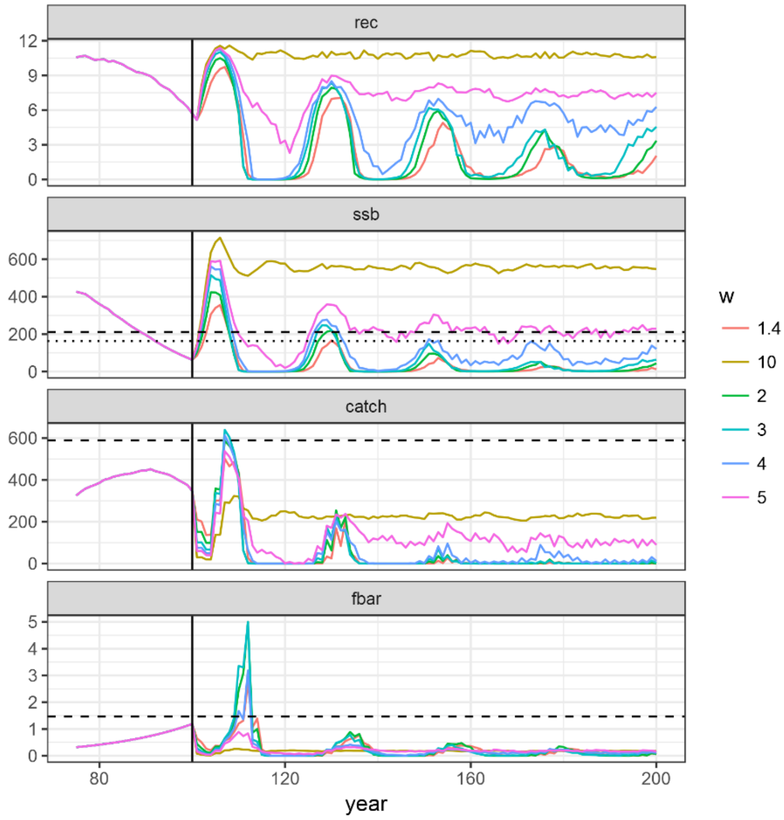

Figure A3.71. Stock projections for catch rule 3.2.2 for her.27.nirs (one-way trip) testing different values for w in the calculation of $I_{trigger}$.

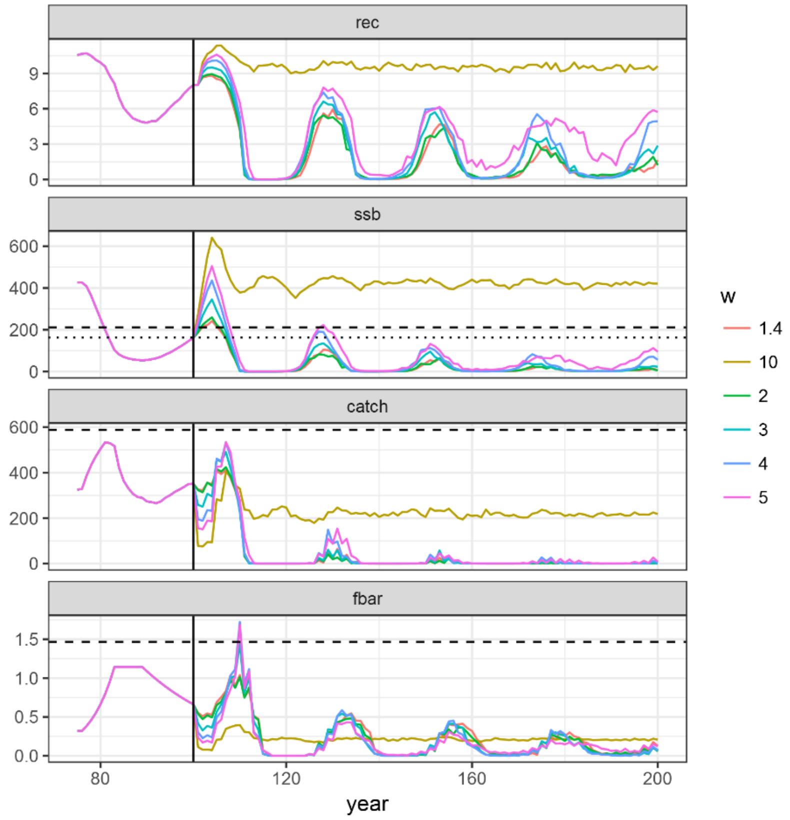

Figure A3.72. Stock projections for catch rule 3.2.2 for her.27.nirs (roller-coaster trip) testing different values for *w* in the calculation of $I_{trigger}$.

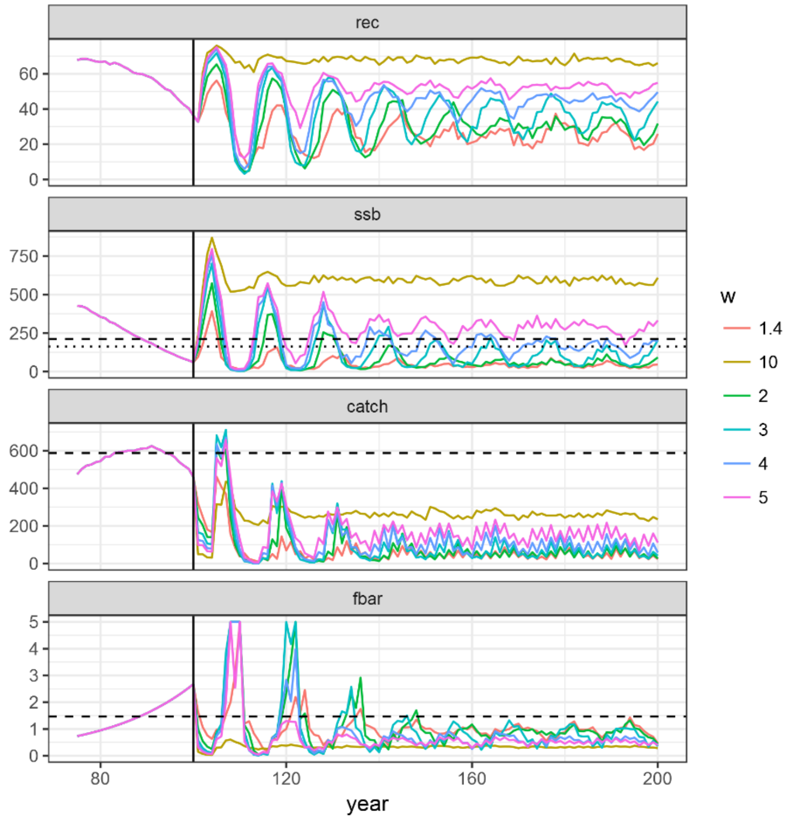

Figure A3.73. Stock projections for catch rule 3.2.2 for san.sa.4 (one-way trip) testing different values for w in the calculation of $I_{trigger}$.

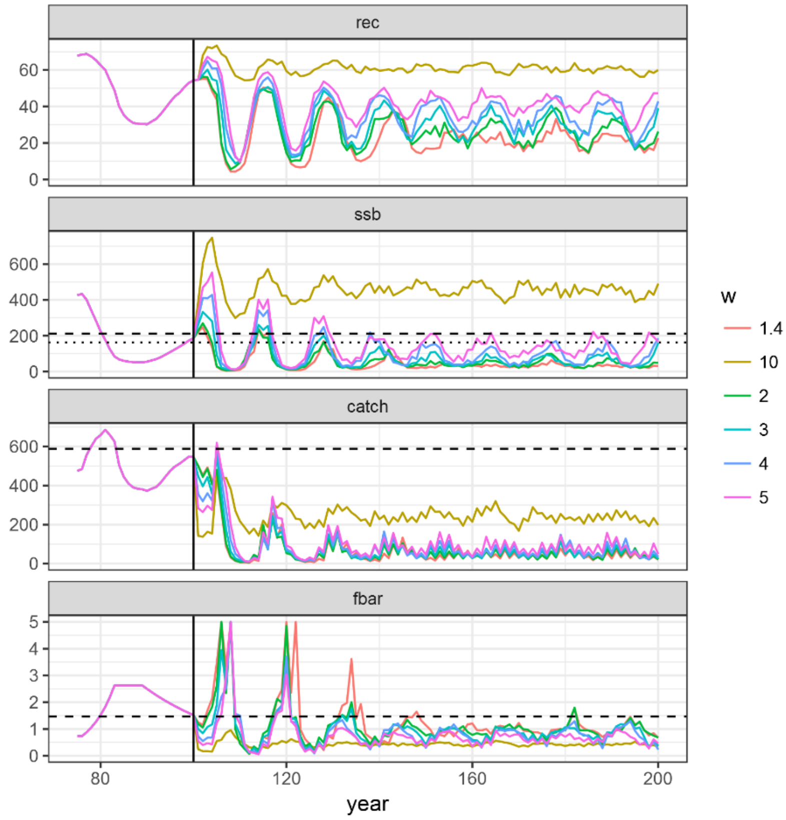

Figure A3.74. Stock projections for catch rule 3.2.2 for san.sa.4 (roller-coaster trip) testing different values for w in the calculation of $I_{trigger}$.

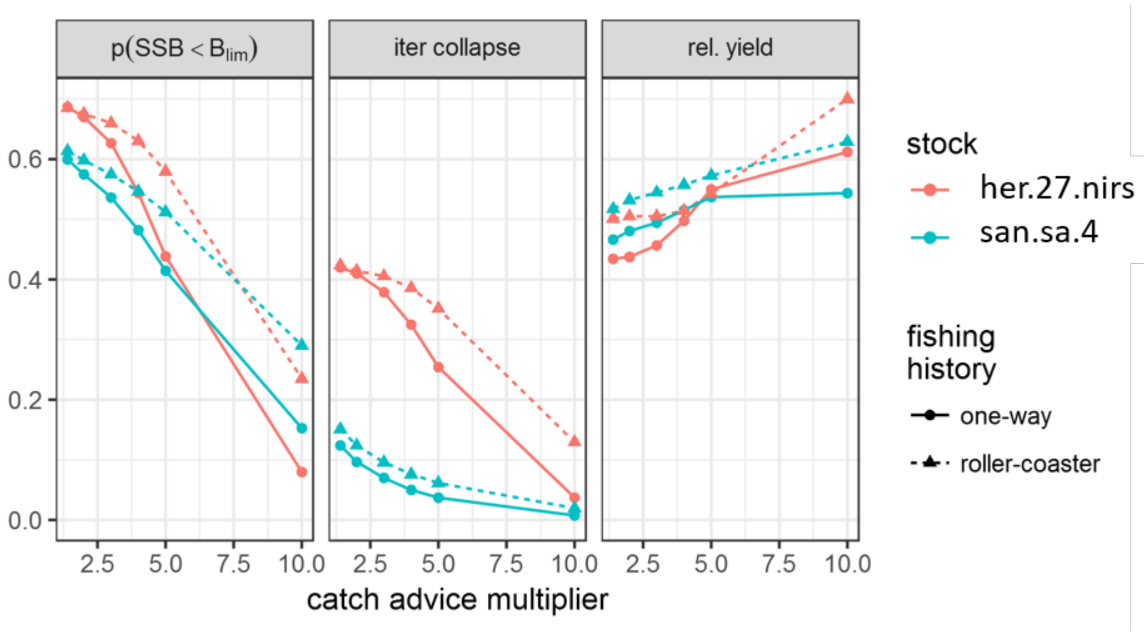

Figure A3.75. Performance statistics for catch rule 3.2.2 for pelagic stocks and different values for w in the calculation of $I_{trigger}$. Shown is the risk of dropping below B_{lim} during the 100 years simulation period, the proportion of collapsed iterations during the simulation and the yield relative to the yield before the management implementation.

A3.5.3 Conclusions

Catch rule 3.2.2 worked very well for 12 out of the 15 tested stocks, even using the default parametrization and including uncertainty. On average, the catch rule also performed reasonably well for whg.27.7b-ce-k but with a high uncertainty and higher risk compared to the other stocks.

The catch rule failed to manage the two pelagic stocks (her.27.nirs and san.sa.4) sustainably and induced a cyclic behaviour of collapse and recovery. This could be averted by implementing a catch multiplier, but for a marked improvement in the performance the multiplier had to be quite low (~ < 0.75).

A3.6 Catch rule 3.1

Catch rule 3.1 from the WKMSYCat34 report proposes a catch advice, based on a SPiCT (Surplus Production in Continuous Time, Pedersen & Berg, 2017) assessment and forecast. For the intermediate year (y) the proposal is to use the last fishing mortality from the assessment (y-1). For the forecast year, the target is F_{MSY}, reduced if the stock is below $MSYB_{trigger}$ (=$1/2B_{MSY}$):

$$F_{y+1} = F_{MSY} \times min\left\{1, median\left[\frac{B_{y+1}}{MSYB_{trigger}}\right]\right\},$$

or expressed as a factor of the fishing mortality in the intermediate year:

$$F_{y+1} = \frac{F_y \times min\left\{1, median\left[\frac{B_{y+1}}{MSYB_{trigger}}\right]\right\}}{median\left[\frac{F_y}{F_{MSY}}\right]}$$

One trial run was carried out for this management procedure in the FLR MSE framework. For this trial run, pol.27.3a4 with the roller-coaster fishing mortality was selected. The simulation was conducted with a biennial TAC, 500 iterations, recruitment uncertainty and an observation error in the survey index with a cv of 0.2. The results are shown in Figure A3. Although just one example was run, the results look promising. As the catch rule directly manipulates the fishing mortality, strong oscillations as observed in the previous catch rules did not appear and the SSB smoothly transitioned towards B_{MSY}. There are however drawbacks in this preliminary management procedure. There was no rule implemented in case the SPiCT assessment did not converge. In the example presented, the fishing history (roller-coaster) provided enough contrast for a good SPiCT fit and in fact in every of the assessment years and for every iteration SPiCT did successfully converge. Additionally, in each assessment and forecast year, the reference points were calculated independently from previous years and then used as a target. From Figure A3. it is evident that the SSB reached B_{MSY} after around 30 years, but then slightly overshot this value and kept increasing until the end of the simulation period. This behaviour is likely due to a slight downwards trend in the calculated F_{MSY} reference point from SPiCT and slightly reduced the targeted fishing mortality over time.

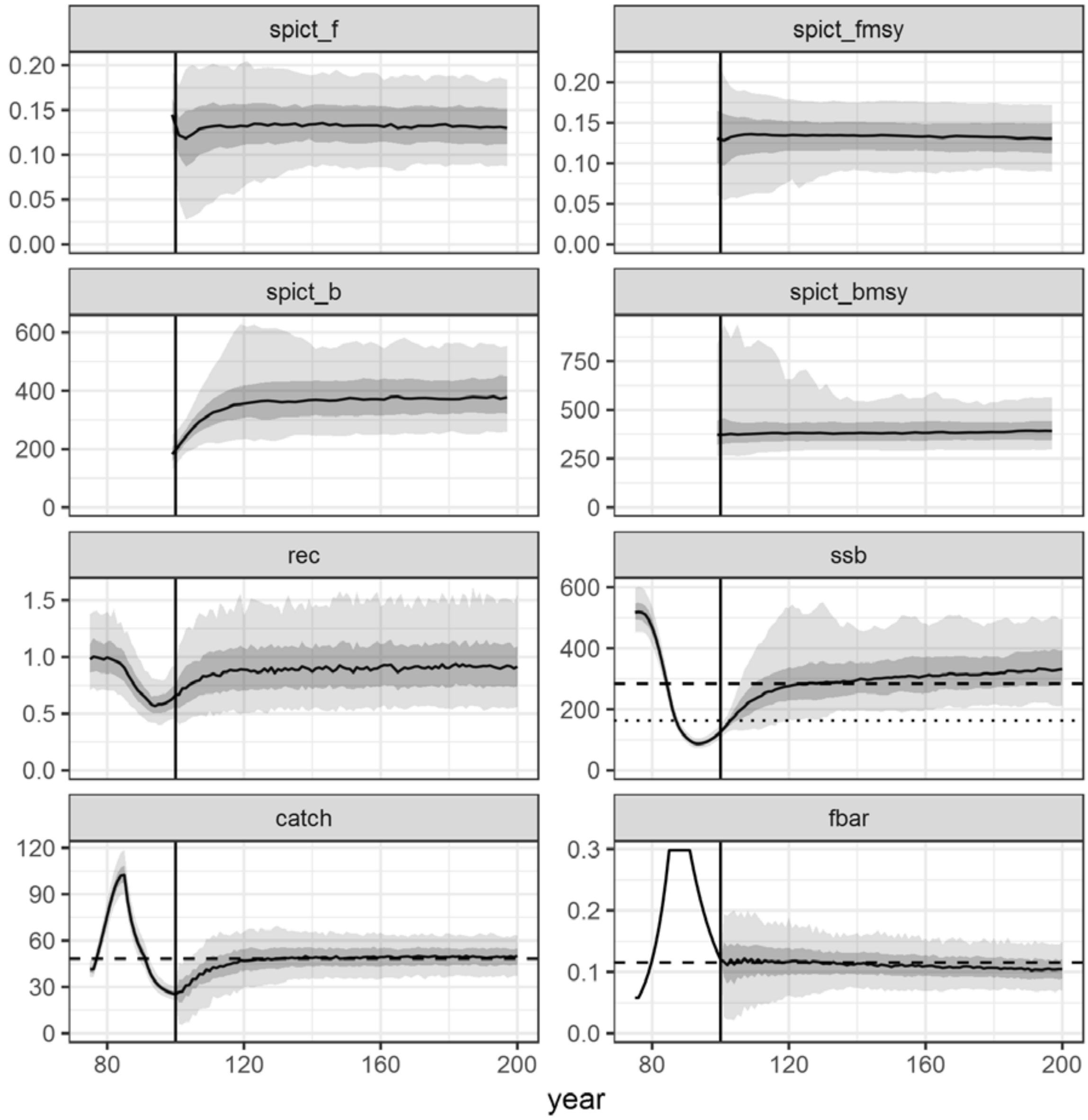

Figure A3.7. Results for a trial run for the SPiCT based catch rule 3.1 for pol.27.3a4. spict_f and spict_b are the fishing mortality and biomass estimates from SPiCT. spict_fmsy and spict_bmsy are the MSY reference points estimated by SPiCT. The solid black lines indicate the median of 500 iterations, surrounded by the 50% (dark grey) and 90% (light grey) confidence intervals. The dashed lines are MSY levels, the dotted line shows B_{lim}.

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Annex 4: Working document: Generic operating models in DLMtool

Generic operating models for DLMtool were created based on the life-history data for the 15 stocks available from FLife. The pre-simulation fishing history length was 100 years.Twoscenarios for the operating models were created: 2) stochastic with low starting depletion ($B_{current}/B_0$ = 0.1), and 2) stochastic with moderate starting depletion ($B_{current}/B_0$= 0.2). All operating models assumed perfect information in the *Observation* class and perfect implementation in the *Implementation* class.

For a single parameter, two values are usually given as the bounds that DLMtool samples for within assuming a uniform distribution. The bounds for the two stochastic simulations were generally 0.9 times the mean and 1.1 times the mean parameter value unless otherwise indicated.

Specific parameters for the*Stock* and *Fleet* classes were input into the operating models as in the following table. Note that grey shading means that these values are default settings.There were three correlated parameters: Linf, K, and L50 (the length at 50% maturity). Correlated samples were obtained using the *ForceCor* function in DLMtool.

Table A.4.1. DLMtool operating model parameters for the management strategy evaluation in Section 4.X. 'FLife' in the third column indicates values were obtained from FLife.

Parameter	Description	Bounds or Values
K	Von Bertalanffy growth parameter	FLife * (0.9, 1.1) †
Linf	Von Bertalanffy mean asymptotic length parameter	FLife * (0.9, 1.1) †
t0	Von Bertalanffy theoretical age at length 0	FLife * (0.9, 1.1)
Maxage	Maximum age of simulated individuals	1.5 * age at length (Linf – 1)
R0	Virgin recruitment (arbitrary value)	0
M	Natural mortality-at-age	M at length calculated based on Gislason et al. 2010, then converted to M at age (Figure A.4.1) $M_L = \exp(0.55 + 1.44\log(L_\infty) + \log(k) - 1.61\log(L))$ M at age * (0.9, 1.1)
Msd	Interannual variability of M (CV)	(0, 0.05)
Mgrad	Mean temporal trend in M	0
Mexp	Exponent of Lorenzen function for exponential decline in M	NA
Fdisc	Fraction of discarded fish that die	0
h	Steepness of stock-recruit relationship	(0.7, 0.9)
SRrel	Type of stock-recruit relationship	1 (Beverton-Holt)
LenCV	CV of length-at-age	(0.08, 0.12)
Ksd	Interannual variability of K	(0, 0.025)
Kgrad	Mean temporal trend in K	0
Linfsd	Interannual variability of Linf	(0, 0.025)
Linfgrad	Mean temporal trend in Linf	0

Parameter	Description	Bounds or Values
Recgrad	Mean temporal trend in recruitment deviation	0
AC	Autocorrelation in recruitment deviations	(0.3, 0.5)
a	Length-weight parameter a	FLife
b	Length-weight parameter b	FLife
D	Depletion: biomass at the end of the historical period relative to virgin biomass	Two scenarios: Mean = 0.1 Mean = 0.2 Bounds calculated as 0.9-1.1 times mean.
Perr	Process error, CV of lognormal recruitment deviations	(0.3, 0.6)
Period	Period for cyclical recruitment pattern	NA
Amplitude	Amplitude in deviation from mean recruitment during recruitment cycle	NA
Size_area_1	Size of area 1 relative to area 2	0.1 * (0.9, 1.1)
Frac_area_1	Fraction of unfished biomass in stock 1	0.5 * (0.9, 1.1)
Prob_staying	Probability of individuals in area 1 staying in area 1 in one year	0.5 * (0.9, 1.1)
L50	Length at 50% maturity	FLife * (0.9, 1.1) †
L50_95	Length increment between 50% and 95% maturity	(L95 – L50) * (0.9, 1.1) where L95 comes from A95, which is calculated via the inverse of the logistic function: $Mat_a = \frac{1}{1+19^{a_{50}-a}}$
Nyears	Number of historical years	100
Spat_targ	Distribution of fishing in relation to spatial biomass	(1, 1)
Esd	Interannual variability of historical effort	0.15 * (0.9, 1.1)
Qinc	Mean percent change in fishing efficiency	(-0.2, 0.2)
Qcv	Interannual variability of fishing efficiency	(0.05, 0.30)
EffYears	Year index for historical fishing effort	(1, 2, 75, 80, 85, 100)
Effort	Relative fishing effort in historical period	"Roller coaster" Effort is low and stable until year 75, increases linearly in years 75-80, stays high year 80-85, then decreases to Fmsy until year 100 (Figure A.4.4.) (0, 0.3, 0.3, 1, 1, 0.5) * (0.9, 1.1)
SelYears	Year index for historical selectivity	NA
AbsSelYears	Years for historical selectivity	NA
L5	Length at 5% fishery selection	Age at 5% calculated as the inverse of the double-normal function: $Sel_a = 2^{-\left(\frac{a-a_{50}}{2}\right)^2}$ Age converted to length via von Bertalanffy parameters L_5% * (0.9, 1.1)
LFS	Length at full selection	L50 * (0.9, 1.1)

Parameter	Description	Bounds or Values
Vmaxlen	Vulnerability of largest size individuals	1 (i.e. asymptotic selectivity)
LR5	Length at 5% retention	NA
LFR	Length at full retention	NA
RMaxlen	Retention of largest fish	NA
DR	Discard rate	NA
L5Lower	Lower limits of 5% selectivity	NA
L5Upper	Upper limits of 5% selectivity	NA
LFSLower	Lower limits of length at full selection	NA
LFSUpper	Upper limits of length at full selection	NA
VmaxLower	Lower limits of vulnerability of largest fish	NA
VmaxUpper	Upper limits of vulnerability of largest fish	NA
isRel	Are selectivity parameters relative to size-of-maturity?	FALSE

† Linf, K, and L50 were input as correlated parameters.

Table A.4.2. FLife stock parameters for the DLMtool operating models. L50 and a50 are the length-at-age at 50% maturity, respectively.

Stock	a	b	Linf	L50	a50	t0	k
haddock	0.0113	2.96	80	30	2	-0.4	0.20
herring	0.0048	3.198	33	23	1.9	-0.1	0.61
lemonsole	0.0123	2.971	37	27	3.0	-0.1	0.42
ling	0.0036	3.108	119	74	7.2	-0.1	0.14
lobster	0.0006	3.029	65	30	9.4	-0.1	0.07
megrim	0.0022	3.343	54	23	4.5	-0.1	0.12
plaice	0.0110	2.958	48	23	2.7	-0.1	0.23
pollack	0.0076	3.069	86	47	4.1	-0.1	0.19
redmullet	0.0057	3.243	48	17	2.0	-0.1	0.21
rosefish	0.0178	2.972	50	40	14.8	0.1	0.11
turbot	0.0149	3.079	67	34	2.2	0.3	0.32
whiteanglerfishC	0.0198	2.895	106	73	6.2	-0.4	0.18
whiteanglerfishN	0.0297	2.841	106	61	4.7	-0.1	0.18
whiting	0.0103	2.395	38	28	2.5	-1.0	0.38

Table A.4.3. Derived DLMtool operating model parameters. Lsel is the length of 50% selectivity.

Stock	maxage	Lsel	Mmature	M/k	L50/Linf	Lsel/L50
haddock	32	2.29	0.20	0.99	0.38	0.08
herring	9	-0.60	0.54	0.89	0.70	-0.03
lemonsole	13	12.34	0.35	0.83	0.73	0.46
ling	51	16.49	0.11	0.76	0.62	0.22
lobster	96	12.76	0.06	0.96	0.46	0.43
megrim	50	8.92	0.12	1.02	0.43	0.39
plaice	25	5.66	0.23	1.00	0.48	0.25
pollack	35	11.30	0.16	0.84	0.55	0.24
redmullet	27	0.64	0.24	1.12	0.36	0.04
rosefish	54	24.89	0.08	0.71	0.80	0.62
turbot	20	2.51	0.29	0.90	0.51	0.07
whiteanglerfishC	38	18.41	0.13	0.73	0.69	0.25
whiteanglerfishN	39	12.92	0.14	0.80	0.58	0.21
whiting	13	14.43	0.33	0.87	0.74	0.52

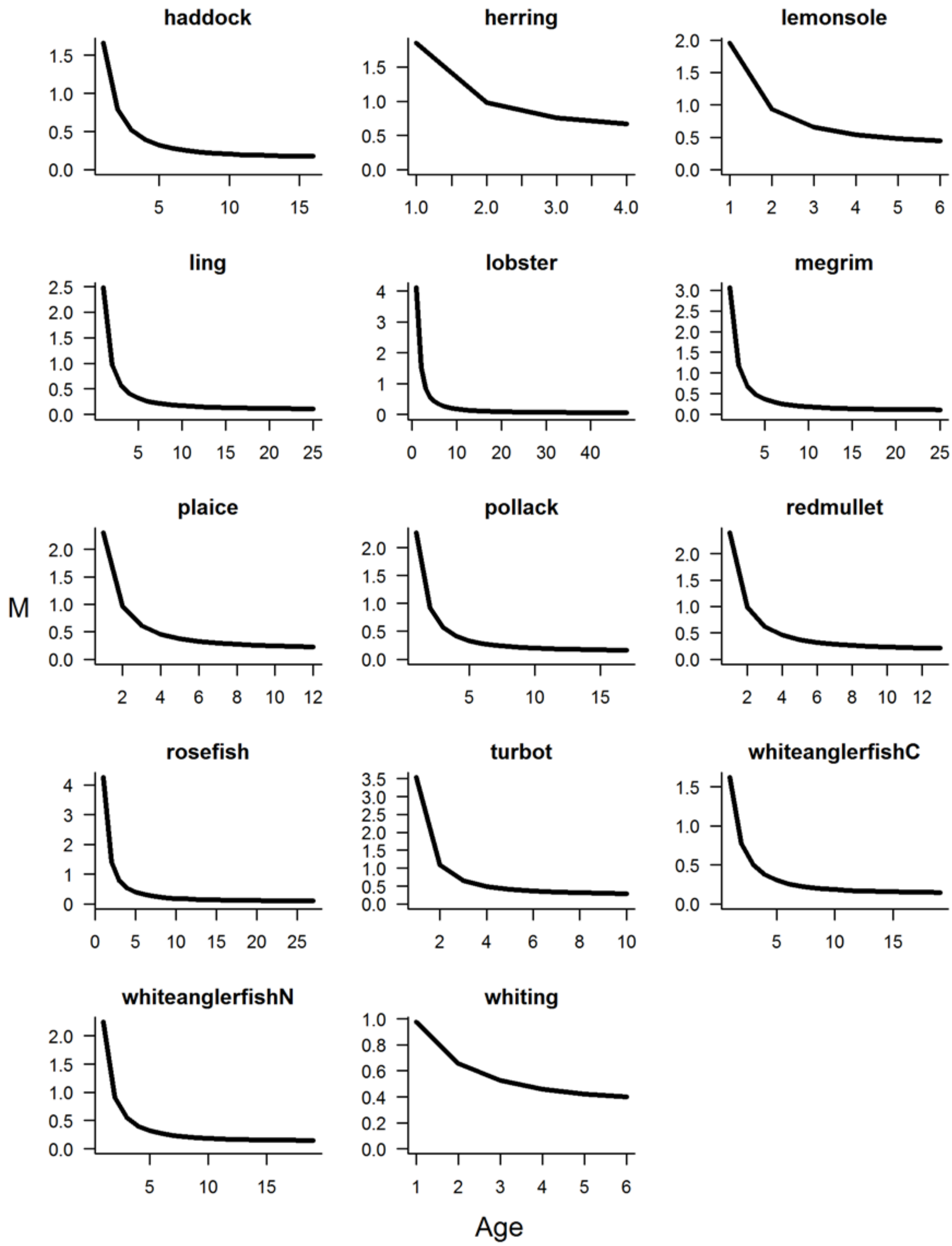

Figure A.4.1. Age-specific natural mortality (M) for the DLMtool operating models.Length-specific M was first obtained through the Gislason et al. (2010) estimator, and subsequently converted age-specific M through von Bertanlffy parameters.

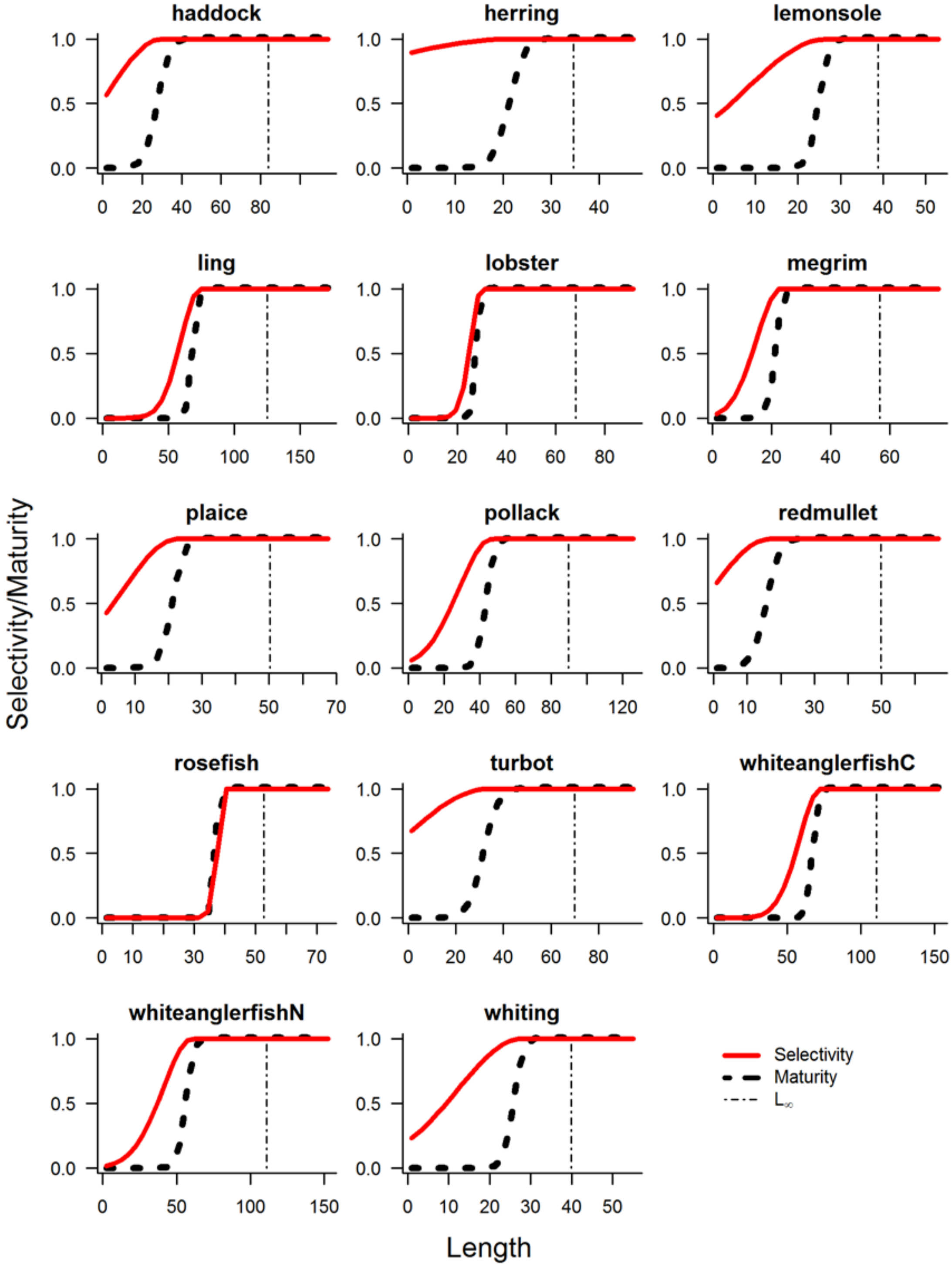

Figure A.4.2. Selectivity and maturity at length for the 14 operating models as input parameters into the DLMtool software.

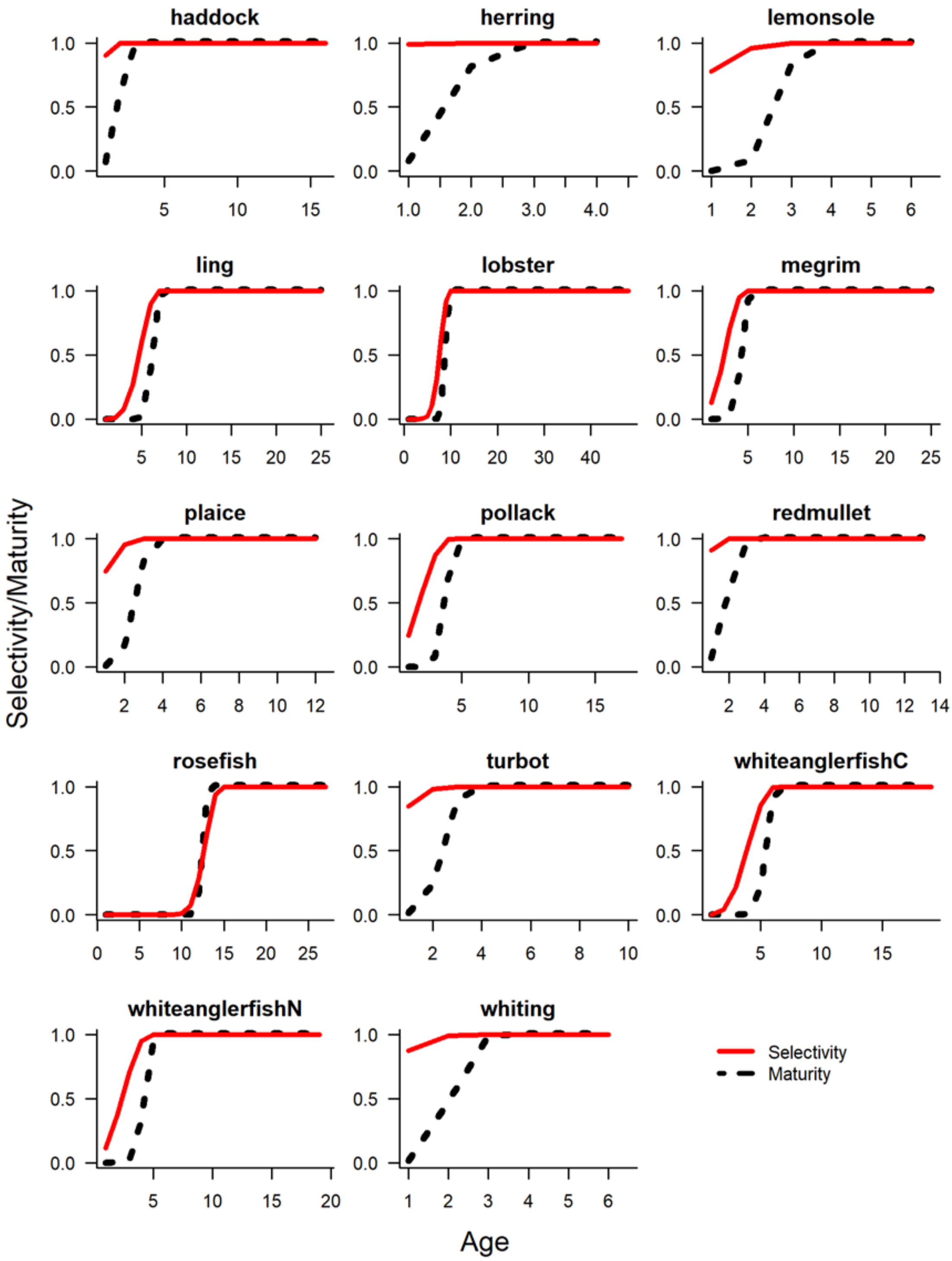

Figure A.4.3. Selectivity and maturity-at-age in DLMtool for the 14 operating models. Input selectivity and maturity functions are length-based (Figura A.4.2) and subsequently converted to age-based functions for the age-structured operating model. Selectivity is converted from lengths to ages using an age–length transition matrix while maturity is converted via von Bertalanffy parameters.

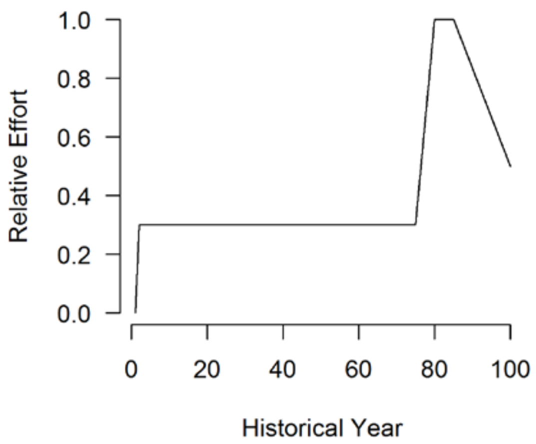

Figure A.4.4. Relative effort in the historical period of the management strategy evaluation. In DLMtool, the relative effort is scaled in order to obtain the fishing mortality needed to obtain the depletion at the beginning of the projection period (specified in the operating model).

Annex 5: Working document: Reference points for length-based indicator Lmax5%

Working Document for ICES WKLIFE VII, 2 – 6 October 2017, Lisbon, Portugal

Reference points for length-based indicator $L_{max5\%}$ to support assessment of data-limited stocks and fisheries

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A.5.1 Abstract

In the absence of scientific surveys to support a stock assessment, reliable commercial catch data together with length frequency data of sampled catches can be used to support an indirect assessment of stock status. Length-based indicators are a simple tool to describe the length frequency distributions of catches. Indicators and appropriately selected reference points help to evaluate the presence of very large individuals in the catches and exploitation level. Using analytical per recruit models, we derive reference points with respect to a spawning potential ratio (SPR) of 40% for the length-based indicator $L_{max5\%}$, the mean length of the largest 5% in the catch. The reference points depend on parameters for growth, natural mortality and maturity (L_∞, k, b, M, L_{mat}) and can be applied for species with various life histories.

Keywords: Bertalanffy, LBSR, management, selectivity

A.5.2 Introduction

Changes in the fishing regime overtime affect not only the total stock abundance but also the length distribution of populations. As a cohort grows and ages, the effects of mortality accumulate, and the abundance of a cohort decreases over time. A population which is subject to a high level of mortality will contain fewer large and old individuals than a population with low mortality even when all other life-history parameters are the same. Size-selective fishing mortality targeting large individuals further truncates the size distribution. A lack of large individuals in a population can indicate overexploitation, if such individuals would be expected to occur given knowledge of life-history parameters, such as individual growth parameters (k, asymptotic growth L_∞) and natural mortality. Many life-history processes such as maturation, fecundity and reproductive success are size-dependent, such that a change in size structure can affect reproductive potential of stocks, sustainability and recovery potential (Berkeley *et al.*, 2004; Walsh *et al.*, 2006; Wright and Trippel, 2009; Moland *et al.*, 2010).

A range of length-based indicators are available to assess fisheries selectivity, monitor stock dynamics and infer stock status (Blanchard *et al.*, 2005; Shin *et al.*, 2005; ICES, 2015; Miethe *et al.*, 2016). Length-based indicators are easily understood, sensitive to fisheries impacts and can be derived from commercial catch sampling data (Shin *et al.*,

2005). The mean length is a simple length frequency summary statistics, which typically decreases at high exploitation rate (Trenkel *et al.*, 2007). However, the mean length is sensitive to recruitment variability and in fast growing species, is less sensitive to fishing mortality and may not adequately reflect exploitation status. Jardim *et al.* (2015) found that the performance of mean length and the respective reference point was poor for stocks with late maturity and when length at first capture, L_c, was well below the length at first maturity, L_{mat}.

As an alternative indicator, the mean length of the largest 5% of individuals in the catch, $L_{max5\%}$ was introduced by Probst *et al.* (2013). As this indicator is derived from data in the right hand tail of the length distribution, it is assumed to be less affected by recruitment variability than the mean length in the catch. Compared with the mean length, $L_{max5\%}$ is predicted to be less sensitive to changes in the length at first capture, L_c, but more sensitive to changes in fishing mortality (ICES, 2016). For the length-based indicator $L_{max5\%}$, suitable reference points have yet to be developed. Reference points can be derived with consideration of the spawning–stock biomass (SSB) per recruit (Clark, 1991; Ault *et al.*, 2008; Prince *et al.*, 2011; Hordyk *et al.*, 2015a). $F_{40\%}$, the fishing mortality which results in a spawning potential ratio (SPR) of 40%, when SSB per recruit that is 40 % of that with no fishing (SSB_0), has been suggested as a good target for risk-averse fishing. The calculation of SPR takes into account the maturation schedule of a species. It minimizes both the risk of yield to fall below MSY and the risk of stock collapse, in particular with uncertainty in recruitment (Mace, 1994).

Reference points for length-based indicators are sensitive to M/k, as the ratio of natural mortality M and the von Bertalanffy growth constant k determines the shape of the length distribution of both population and catch (Hordyk *et al.*, 2015a; ICES, 2016). The M/k ratio is known as a life-history invariant as it has been found to be relatively constant among closely related species (Beverton, 1992). Prince *et al.* (2015) distinguished different life-history types according to the ratio of M/k. Unfished stocks with indeterminate growth and a ratio of M/k above 1 are dominated by juveniles (known as type I stocks). Other species with M/k ratios below 1 were considered to be of type II with unfished populations being dominated by adult individuals. This type includes for example fast-growing and early maturing species of clupeids but also late-maturing elasmobranchs (Prince *et al.*, 2015).

In this paper, we combine age-structured per recruit models with the von Bertalanffy growth equation to derive reference point the length-based indicator $L_{max5\%}$(Beverton and Holt, 1957; Quinn II and Deriso, 1999; Hordyk *et al.*, 2015a).We propose general guidelines for the definition of the reference point $L_{max5\%}^{F40\%}$, which may be used in a length-based data-limited assessment. Example reference points are calculated for three species with different life histories, including type I and type II (early and late maturing) stocks. We compare reference points based on SPR=0.4 to the maximum yield reference points derived from the same analytical models. The sensitivity of the reference point with regard to L_c, L_{mat} and M/k are explored.

A.5.3 Model

A.5.3.1 Age-structured per recruit model

The abundance of a cohort decreases exponentially as it ages (Quinn II and Deriso, 1999). The total number per recruit $\tilde{N}_t$ at age t depends on the natural mortality (M) and is written as:

$$\tilde{N}_t = e^{-Mt} \tag{1}$$

The cohort dynamics are modified for the fished population to include mortality which differs below and above length at first capture L_c (with corresponding age t_c) assuming knife-edge fishery selectivity. The total number per recruit $\tilde{N}_t$ at age t depends on natural mortality (M) and, at and above t_c, also on fishing mortality (F):

$$\tilde{N}_t = \begin{cases} e^{-Mt} & t < t_c \\ e^{Ft_c} e^{-(F+M)t} & t \geq t_c \end{cases} \tag{2}$$

To apply the age-structured model length-based approach, we assume individuals follow von Bertalanffy growth. With standardized length $\tilde{L}_t = \frac{L_t}{L_\infty}$ and t_0=0, this is written as:

$$\tilde{L}_t = 1 - e^{-kt} \tag{3}$$

According to equation 3, the age at standardized length is:

$$t = \frac{-\ln(1-\tilde{L}_t)}{k} \tag{4}$$

Main assumptions of these models are equilibrium conditions, constant recruitment, no variability of growth ($CV_{L_\infty} = 0$), constant natural mortality and constant asymptotic fishing mortality at length (above L_c).

A.5.3.2 Estimation of $F_{40\%}$ using SPR

To calculate $F_{40\%}$ for different values of L_c we calculate the SPR, the ratio of SSB in the fished and unfished state. Unfished SSB is calculated by integrating the mature biomass, using equation 1 and 3, age at maturity t_{mat} (knife-edge) and a standardized length-weight relationship, $\tilde{W} = \tilde{L}^b$:

$$SSB_0 = \int_{t_{mat}}^{\infty} e^{-Mt} \tilde{L}_t^{\,b} dt \tag{5}$$

The calculation of fished SSB depends on the relation of length at maturity, L_{mat}, and length at first capture, L_c:

$$SSB_{fished} = \begin{cases} \int_{t_{mat}}^{\infty} e^{Ft_c} e^{-(F+M)t} \tilde{L}_t^{\,b} dt & t_{mat} \geq t_c \\ \int_{t_{mat}}^{t_c} e^{-Mt} \tilde{L}_t^{\,b} dt + \int_{t_c}^{\infty} e^{Ft_c} e^{-(F+M)t} \tilde{L}_t^{\,b} dt & t_{mat} < t_c \end{cases} \tag{6}$$

where t_{mat} and t_c are determined from L_{mat} and L_c (equation 4), and $\tilde{L}_t$ is replaced by equation 3.

The SPR is defined as the ratio of fished and unfished SSB:

$$SPR = \frac{SSB_{fished}}{SSB_0} = 0.4 \tag{7}$$

By setting SPR=0.4 and substituting equations 5 and 6, we solve the equation 7 numerically for F, given the respective life-history parameters. The resulting $F_{40\%}$ is used to calculate the reference point $L_{max5\%}^{F_{40\%}}$ (equation 12).

A.5.3.3 Estimation of FMAX

The rate of increase of increase in yield is given by $\mathrm{F}d\left(N_t\tilde{L}_t^{\ b}\right)$(Quinn II and Deriso, 1999). The standardized yield-per-recruit over a life time of a cohort, $\tilde{Y}_\infty$, is then calculated as:

$$\tilde{Y}_\infty = F\int_{t_c}^{\infty} e^{Ft_c} e^{-(F+M)t}\, \tilde{L}_t^{\ b} dt \tag{8}$$

We maximize the integral (equation 8) numerically with respect to F, which gives the fishing mortality at maximum yield (F_{max}). The respective length-based reference point, $L_{max5\%}^{F_{max}}$ follows from equation 12.

A.5.4 Reference point $\mathbf{L_{max5\%}^{F}}$

To calculate the mean size of the largest 5% in the catch at a particular value of F, we require the standardized minimum length of the largest 5% in the catch, $\tilde{L}_*$ (with corresponding age t_*).This value can vary depending on the population dynamics and fishing selectivity. For this purpose, the proportion of individuals larger than $\tilde{L}_*$ in the catch needs to equal 0.05:

$$P_{\tilde{L}_*} = \frac{F\int_{t_*}^{\infty} e^{Ft_c} e^{-(F+M)t} dt}{F\int_{t_c}^{\infty} e^{Ft_c} e^{-(F+M)t} dt} = \frac{e^{-(F+M)t_*}}{e^{-(F+M)t_c}} = 0.05 \tag{9}$$

Equation 9 is solved for t_* and transformed to standardized length $\tilde{L}_*$ (substituting equation 4):

$$t_* = -\frac{1}{F+M}\ln(0.05) + t_c \tag{10}$$

$$\tilde{L}_* = 1 - 0.05^{k/(F+M)}\left(1 - \tilde{L}_c\right) \tag{11}$$

From the numbers-at-age in the catch at fishing mortality F and standardized length-at-age, $\tilde{L}_t$, an analytical expression for the mean length of the largest 5% in the catch, $L_{max5\%}^{F}$, is derived:

$$L_{max5\%}^{F} = \frac{F\int_{t_*}^{\infty} e^{-(F+M)t}\left(1-e^{-kt}\right)dt}{F\int_{t_*}^{\infty} e^{-(F+M)t}dt} L_\infty = \frac{\left[-\frac{e^{-(F+M)t}}{(F+M)} + \frac{e^{-(F+M+k)t}}{(F+M+k)}\right]_{t_*}^{\infty}}{\left[-\frac{e^{-(F+M)t}}{(F+M)}\right]_{t_*}^{\infty}} L_\infty,$$

$$= \left(1 - \frac{(F+M)e^{-kt_*}}{(F+M+k)}\right) L_\infty = \left(1 - \frac{1}{1+k/(F+M)} 0.05^{\frac{k}{F+M}}\left(1 - \tilde{L}_c\right)\right) L_\infty \tag{12}$$

For the unfished population the expected mean length of the largest 5% above $\tilde{L}_c$ is calculated with F=0:

$$L_{max5\%}^{0} = \left(1 - \frac{1}{1+k/M} 0.05^{\frac{k}{M}}\left(1 - \tilde{L}_c\right)\right) L_\infty \tag{13}$$

Equation 13 and the value of $F_{40\%}$, derived from numerical calculation (section 2.2), are used to calculate the reference point $L_{max5\%}^{F_{40\%}}$.

A.5.4.1 Example life histories

We calculate reference points for three stocks representing different life histories, including a type I stock and type II stocks, with either maturation late or early in life (Prince *et al.*, 2015). European lobster *Homarus gammarus* is a crustacean species, which

includes a number of data-limited stocks with no available scientific survey data or ageing method. Using life-history parameters from the North Sea, lobster is categorized as type I, having an M/k above 1 with populations dominated by juveniles (Chapman, 1994; Mesquita *et al.*, 2016). Lobster males, the larger sex with regard to L_∞, mature at an L_{mat}/L_∞ of 0.46 (Table A.5.1). Elasmobranchs are cartilaginous fish most of which are k-selected species with relatively slow growth, late maturity, long-lived, large adult size, and few developed juveniles (Smith *et al.*, 1998; Dulvy *et al.*, 2000). Cuckoo ray *Leucoraja naevus*, a member of the Rajidae family, in the Irish Sea exhibits a M/k of 0.69 and is classified as type II with populations dominated by adults (Gallagher *et al.*, 2005; Prince *et al.*, 2015). Female rays are typically the larger sex with higher value of L_∞. Maturation occurs late in life and at relatively large size, with L_{mat}/L_∞ of 0.67 for females.

In contrast, Atlantic herring *Clupea harengus* grow fast and mature at young age. Herring in the Celtic Sea have an M/k of 0.78 and are also classified a type II stock (Jennings *et al.*, 1998). While herring grow fast and mature early in life, they are also relatively short lived with a small adult size and L_{mat}/L_∞ of 0.75.

Life-history parameter values are taken from available literature for these three stocks in the North Sea, Irish Sea and Celtic Sea, respectively (Table A.5.1). Natural mortality for the stocks was estimated using the length-based updated Pauly estimator recommended by Then *et al.* (2015):

$$M = 4.118k^{0.73}L_\infty^{\ -0.33} \qquad (14)$$

A.5.4.2 Calculating a reference point with variability of growth ($CV_{L\infty}$) using length-based SPR

Reference points for $L_{max5\%}$ taking into account variability of L_∞ ($CV_{L\infty}$) can be calculated using the R-package LBSPR (Hordyk *et al.*, 2016). The package provides a function to simulate a population distribution and its SPR given a set of life-history and exploitation parameters. However, if SPR is provided instead of F/M, the function estimates by optimization the ratio F/M leading to the respective SPR at equilibrium given the life-history characteristics. It is therefore possible to approximate the size distribution at equilibrium for a population exploited at MSY using the proxy SPR=0.4 and calculate the $L_{max5\%}$ at SPR=0.4. This allows a calculation of a reference point not only for different values of M/k and L_c but also for $CV_{L\infty}$>0 and age/length dependent natural mortality. The model extends previous versions of the length-based SPR (Hordyk *et al.*, 2015a; Hordyk *et al.*, 2015b; Prince *et al.*, 2015) by accounting for size dependent natural mortality ($M_L = M_{L\infty}\left(\frac{L_\infty}{L}\right)^c$). We use LBSPR package to test for sensitivities over a wide range of M/k and L_c.

A.5.6 Results

In a previously unexploited lobster stock with a type I life history, $L^0_{max5\%}$ increases with L_c (Figure A.6.1). This reflects the selectivity effect not a change in the underlying length structure of the stock. As less individuals are included in the calculation, the mean size of the largest 5% increases slightly (Figure A.6.1a). The maximum yield reference point $L^{F_{max}}_{max5\%}$ represents the expected indicator value when fishing mortality is equal to F_{max}. With increasing value of L_c, less size classes are available to the fishery, and F_{max} increases causing $L^{F_{max}}_{max5\%}$ to decrease. To maximize yield at high values of L_c, F_{max} increases indefinitely (here limited at value 2), but yield and $L^{F_{max}}_{max5\%}$ are restricted

by L_c (Figure A.5.1b, c). At this point the yield cannot increase any further and starts to decreases for higher values of L_c. For calculation of the maximum yield reference point the maturation schedule and state of SSB are not considered. Alternatively, fishing mortality at SPR=0.4 used to calculate the reference points $L_{max5\%}^{F40\%}$ depends on L_{mat}. As L_c approaches L_{mat}, $L_{max5\%}^{F40\%}$ increases with L_c parallel with the value in the unexploited case (Figure A.5.1a). When $L_c>L_{mat}$, immature are not targeted by the fishery and also mature individuals are increasingly protected. The level of fishing mortality is allowed to increase and causes a reduction in $L_{max5\%}^{F40\%}$. As L_c increases further the majority of SSB is protected, $F_{40\%}$ increases indefinitely and $L_{max5\%}^{F40\%}$ becomes equal to L_c. At high values of L_c, the reference point $L_{max5\%}^{F40\%}$ may therefore represent SPR>0.4. The reference point where SPR=0.4 is at maximum around $L_c=L_{mat}$. To support risk-averse fishing in the face of uncertainty in recruitment and fisheries selectivity, the constant reference point of $L_{max5\%}^{F40\%}$ at $L_c=L_{mat}$ can be proposed, which becomes independent of L_c. This reference point is more precautionary when $L_c<L_{mat}$, as not only all mature but also immature individuals are targeted which could impair recruitment. The value is also precautionary at high L_c by preventing high fishing mortality and stronger truncation in the length distribution which may lead to overexploitation if L_c is uncertain.

We investigate the reference points for species of life-history type II (Figure A.5.2). Due to slow-growth and long lifespan, cuckoo ray stocks are dominated by adults. Therefore, in the unexploited stock $L_{max5\%}^{0}$ is relatively constant and close to L_∞ for different values of L_c (Figure A.5.2a). The reference point $L_{max5\%}^{F40\%}$ is also constant over a wide range of values of L_c and declines only for $L_c>L_{mat}$.

Atlantic herring are fast-growing and short-lived, maturation occurs at large size relative to L_∞. Similar to the results for Cuckoo rays, $L_{max5\%}^{0}$ is relatively constant across values of L_c. The maximum yield reference point appears to be particularly unsuitable for herring, because fishing mortality may increase indefinitely at $L_c<L_{mat}$ (Figure A.5.2c). The assumption of constant recruitment to ensure high yield in a fast-growing stock may not be appropriate, when mature individuals are fully exploited. While the analytical model assumes constant recruitment,$L_{max5\%}^{F40\%}$ is calculated with reference to mature biomass and therefore is more restrictive on fishing mortality. High fishing mortality and a strong truncation in length structure is discouraged to ensure sufficient SSB at $L_c<L_{mat}$.

For both type II stocks we expect to see only a small degree of truncation in the length distribution when exploited sustainably ensuring SPR of 40%. For both life-history types the constant reference point $L_{max5\%}^{F40\%}$ at $L_c=L_{mat}$ is appropriate to a wide range of values of L_c. To optimize yield L_c should ideally be above L_{mat}, where $L_{max5\%}^{F40\%}$ is close to the constant $L_{max5\%}^{F40\%}$ at $L_c=L_{mat}$ and yield is high.

When testing a wide range of M/k ratios (Figure A.5.3), we can confirm a general low sensitivity of $L_{max5\%}^{F40\%}$ to L_c. The reference point is sensitive to values of L_{mat}, taking into account maturation schedule of the stock (Figure A.5.4). At low values of M/k the contrast in reference point at SPR=0.4 to the theoretical $L_{max5\%}^{F=0}$ decreases, also reducing the effect of L_{mat} on the reference value. Due to low contrast for type II life histories, with uncertainty in life-history parameters and observation error, it may be difficult to evaluate exploitation status using $L_{max5\%}$.

A.5.7 Discussion

Overexploitation of stocks can lead to long-term decline in SSB, recruitment, yield, catch per unit of effort and even stock collapse. Without knowledge of stock status and depletion level, it is difficult to determine the most appropriate management action to prevent overexploitation. For data-limited stocks, sampling data from commercial catches are often available. Size-based indicators facilitate the monitoring of truncation in sampled size distribution and have been suggested as an alternative or supporting tool in data-limited stock assessment (Froese, 2004; Blanchard *et al.*, 2005; Jennings and Dulvy, 2005; ICES, 2014; ICES, 2015).

We derive reference points based on SPR=0.4 for the mean length of the largest 5% of individuals in the catch ($L_{max5\%}$), a length-based indicator introduced by Probst *et al.* (2013). Using analytical models, we compare reference points based on SPR for different life-history types. The SPR approach incorporates the maturation schedule. The constant reference point using the value of $L_{max5\%}^{F_{40\%}}$ at L_c=L_{mat}ensures robustness to uncertainty in L_c by preventing stronger truncation in the length distribution predicted for extreme values of L_c. Furthermore, this reference point creates the initiative to fish with an L_c slightly above L_{mat} to optimize yield (Kirkwood *et al.*, 1994).

It is often assumed that fast-growing, productive stocks are less vulnerable to overfishing (Dulvy *et al.*, 2003; Olden *et al.*, 2007). However, a greater number of unfished age classes in longer-lived species can act as a buffer against recruitment failure and support recovery (Kirkwood *et al.*, 1994). In elasmobranchs, recruitment is closely linked to the number of mature females, which limit the potential to recover from overfishing and the abundance of new incoming cohorts (Cailliet *et al.*, 2005). Instead of maximizing yield, the focus of management for elasmobranch stocks should therefore be the protection of the reproductive potential. The indicator $L_{max5\%}$ and the reference point appear to be less suitable for stocks of life-history type II. For populations dominated by individuals at adult sizes even at high exploitation level, the truncation in size structure in response to fishing is limited. Growth variability of L_∞ accounts for the fact that individuals may never reach L_∞ (even at low mortality) or reach sizes larger than L_∞, leading to longer tails in the stock length distribution. However, the difference between the reference point at SPR=0.4 and the theoretical indicator from catches from a previously unexploited stock F=0 remains low. Stocks with very low M/k (<0.5), with population and catches dominated by adults, will have $L_{max5\%}^{F_{40\%}}$ reference points identical with L_∞(Hordyk *et al.*, 2015b). Generally, for type II (M/k<1) stocks a truncation in the length distribution may not be detectable even at high fishing mortality. Conclusion on the exploitation status for stocks of type II life history may therefore be difficult when considering only the right tail of the length distribution. Considering also uncertainty in the indicator estimate due to observation error, the difference between $L_{max5\%}^{0}$ and $L_{max5\%}^{F_{40\%}}$ may be too small to infer exploitation status relative to SPR correctly.

At dome-shaped selectivity, larger individuals are exempted from fishing mortality and do not appear in catches. This affects indicators and can lead to type I and type II errors, when a truncation or change in the length distribution remains unobserved or a truncation is falsely assumed due to the lack of large individuals in the catch. Estimates of M are often difficult to obtain for data-limited stocks. In our study, natural mortality is estimated using the updated Pauly estimator as recommended by Then *et al.* (2015). In some cases, a rough estimate of M/k can be derived from other stocks or closely related species (Prince *et al.*, 2015). Alternatively, marine protected areas implemented on relatively sedentary stocks for a sufficient amount of time can allow for a recovery of the size distribution to near unexploited level allowing for an estimation of

asymptotic size and natural mortality (Wilson *et al.*, 2010; Moland *et al.*, 2013; Hordyk *et al.*, 2015a; ICES, 2016; Howarth *et al.*, 2017).

In the models, we assume equilibrium conditions, constant recruitment and constant natural mortality. The model can be modified by using age or length-dependent mortality. The effect of non-equilibrium conditions and non-constant recruitment relationship on SPR have been investigated by Hordyk *et al.* (2015b). Their length-based SPR (LBSPR) model aims to estimate SPR and fishing mortality by fitting an expected length distribution to the observed catch length distribution making it sensitive to the observed L_c, non-equilibrium conditions and recruitment variability (Hordyk *et al.*, 2015b). The reference point $L_{max5\%}^{F_{40\%}}$ is calculated using basic life-history characteristics, the reference point calculation from the observed catch then only depends on the tail of the length distribution making it less sensitive to L_c, non-equilibrium conditions and recruitment variability. The extension of the LBSPR to include variability of growth and size-dependent mortality allow an even better approximation of the reference point when the respective parameters are known (Hordyk *et al.*, 2016).

We apply simple age-per-recruit models in combination with a growth equation to derive length-based reference points for $L_{max5\%}$. Basic life-history information L_{mat}, M, k, b and L_∞ are used to parameterize the models. For various life-history strategies (in particular type I stocks) we can determine reference points that are robust to uncertainty in L_c and risk-averse by considering the state of SSB and L_{mat}. Instead of giving a direct estimate of fishing mortality, the state of the stock can be assessed directly by comparing the observed indicator value to the length reference point based on$F_{40\%}$. The suitability of the reference point for a stock can be tested by comparing $L_{max5\%}^{F_{40\%}}$ to the indicator value in a previously unexploited stock $L_{max5\%}^{F=0}$. With larger the contrast between these two values and good knowledge of M/k and L_{mat}, the performance of reference point to represent SPR=0.4 is expected to improve.

A.5.9 Table and Figures

Table A.5.1. Life-history parameter values for three example stocks. European lobster (type I), Cuckoo ray (type II, late-maturing, slow-growing), Atlantic herring (type II, early maturing, fast-growing).

Species	sex	M^{+}	k^{*}	L_{∞}^{*} (mm)	b^{**}	L_{mat}^{***} (mm)	references
European lobster (*Homarus gammarus*) North Sea	male	0.15	0.11	173	3.360	80	*Chapman (1994), **Mesquita *et. al* (2016), ***Lizarraga-Cubedo *et al.*(2003) +Then et al. 2015
Cuckoo ray (*Leucoraja naevus*) Irish Sea	female	0.14	0.197	839	3.147	562	*,***Gallagher, 2005 **McCully *et al.* 2012 +Then et al. 2015
Atlantic herring (*Clupea harengus*) Celtic Sea	male	0.34	0.44	303	3.090	221	*,***Jennings et al 1998 **Coull et al. 1989 +Then et al. 2015

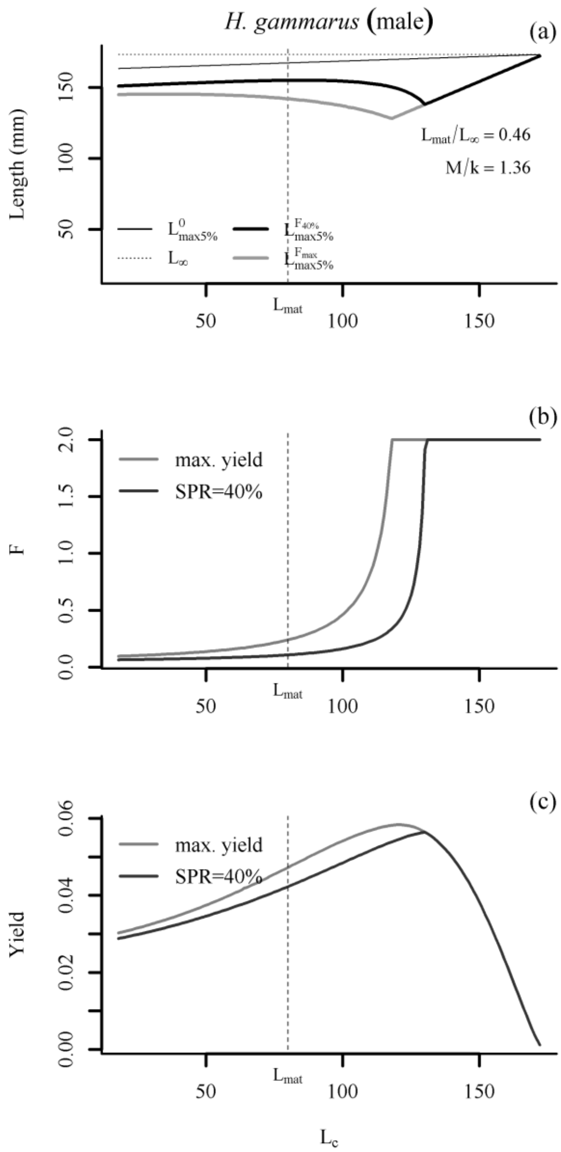

Figure A.5.1. Theoretical reference points for $L_{max5\%}$, type I life history, European lobster. (a) $L^{0}_{max5\%}$ from an unexploited stock, $L^{F40\%}_{max5\%}$exploited at SPR=0.4 (bold black), $L^{F_{max}}_{max5\%}$ from the stock exploited at F_{max} (bold grey), (b) $F_{40\%}$, fishing mortality for exploitation at 40% SPR, limited by value 2. (c) Corresponding standardized yield.

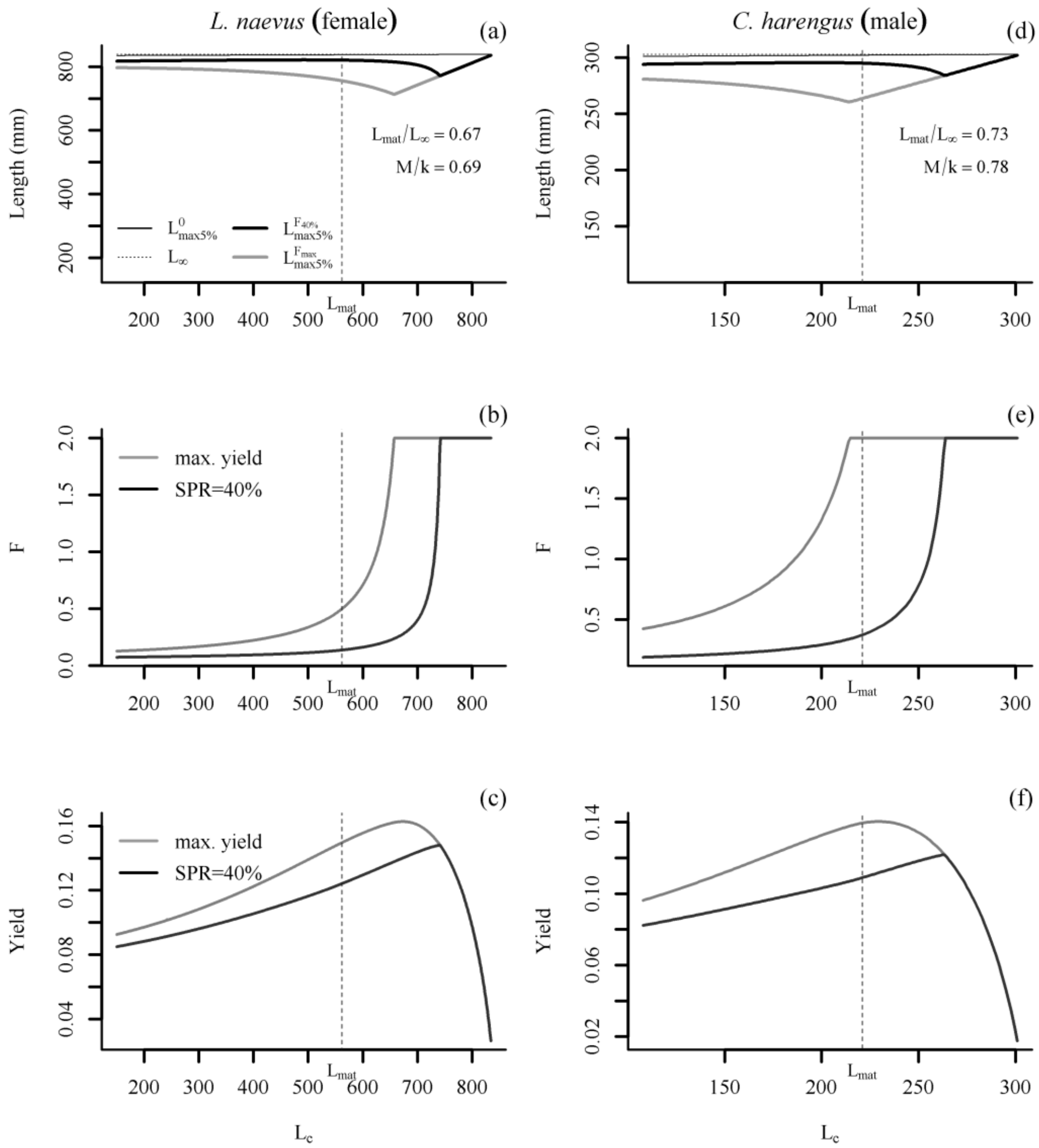

Figure A.5.2. Theoretical reference points for $L_{max5\%}$, type II life history, Cuckoo ray and Atlantic herring. (a) $L^{0}_{max5\%}$ from an unexploited stock, $L^{F40\%}_{max5\%}$ exploited at SPR=0.4 (bold black), $L^{F_{max}}_{max5\%}$ from the stock exploited at F_{max} (grey), (b) $F_{40\%}$, fishing mortality for exploitation at 40% SPR, limited by value 2. (c) Corresponding standardized yield.

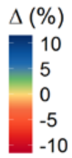

Figure A.5.3. Sensitivity of reference points to misspecification of L_C ($\pm 15\%$).

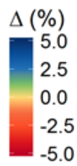

Figure A.5.4. Sensitivity of reference points to misspecification of L_{mat}($\pm 15\%$). The.

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Annex 6: Working document: Model for testing length-based indicators

Working Document for ICES WKLIFE VII, 2 – 6 October 2017, Lisbon, Portugal

Model for testing length-based indicators and reference points for stocks and fisheries

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A.6.1 Introduction

A range of empirical length-based indicators are available to assess fisheries selectivity, monitor stock dynamics and infer exploitation level (Blanchard *et al.*, 2005; Shin *et al.*, 2005; Cope and Punt, 2009; Babcock *et al.*, 2013; ICES, 2015; Miethe *et al.*, 2016). The mean length, $\bar{L}$, is a simple length frequency summary statistics, which typically decreases at high exploitation rate (Trenkel *et al.*, 2007). The expected mean length in the catch when fishing mortality is equal to natural mortality, $L_{F=M}$, is recognized as a proxy for the mean length at MSY (ICES WKLIFE, 2012; ICES, 2015; Jardim *et al.*, 2015). Jardim *et al.* (2015) derived a general expression for $\bar{L}$ based on M/k which enables the calculation reference points using basic life-history information.

As an alternative indicator, the mean length of the largest 5% of individuals in the catch, $L_{max5\%}$, was introduced by Probst *et al.* (2013). This indicator was suggested to be more sensitive to fishing mortality and less sensitive to the length at first capture, L_c, than$\bar{L}$. As this indicator is derived from data in the right hand tail of the length distribution, it is assumed to be less affected by recruitment variability than $\bar{L}$ For the length-based indicator $L_{max5\%}$ reference points have been developed by Miethe et al. (Working document) with consideration of the spawning–stock biomass (SSB) per recruit (Clark, 1991; Ault *et al.*, 2008; Prince *et al.*, 2011; Hordyk *et al.*, 2015). $F_{40\%}$, the fishing mortality which results in a spawning potential ratio (SPR) of 40%, when SSB per recruit is 40 % of that with no fishing (SSB_0), has been suggested as a good target for risk-averse fishing (Mace, 1994). It minimizes both the risk of yield to fall below MSY and the risk of stock collapse, in particular with uncertainty in recruitment. Using analytical per recruit models together with the von Bertalanffy growth equation, reference points can be calculated based on $F_{40\%}$ (WD Miethe *et al.*, Annex 5).

We use length-based sex-structured population model parameterized for European lobster, *Homarus gammarus*, and Cuckoo ray, *Leucoraja naevus*, to compare the two length-based indicators $L_{max5\%}$ and $\bar{L}$ for determining stock status relative to SPR=40% in different scenarios of fishery selectivity (L_c) under non-equilibrium dynamics, assuming recruitment variability and a Beverton–Holt spawning stock recruitment relationship. The two stocks differ in their life-history strategy with regard to M/k and L_{mat}/L_∞. Life-history parameters and model parameters are listed in Table 1 for European lobster and in Table 2 for Cuckoo ray. The results allow a direct comparison in the sensitivity of indicators to L_c and the contrast in indicator and reference point at fishing mortality $F_{40\%\ under}$ non-equilibrium conditions.

A.6.2 Methods

A.6.2.1 Population model

Discrete length-structured models often make use of size classes with constant bin width (Drouineau *et al.*, 2008). However, in our model we construct length classes with varying bin width such that individuals grow into the next length class within a single time-step as described by Andrews *et al.* (2006), Gurney *et al.* (2007) and Speirs *et al.* (2010). This results in a parsimonious number of length classes for each sex. The use of very small time-steps or many narrow length classes can thereby be avoided, improving computational efficiency.

Growth occurs instantaneously at the end of each time-step and is irreversible. To incorporate variability of growth into the model, we assume that only a fraction, p, of individuals in a length class grows to the next size class within any time-step and the remaining fraction, (1-p), of individuals stay at their current size for another time-step (Gurney *et al.*, 2007; Speirs *et al.*, 2010). We select a value of p=0.9, which limits the variability allowing only 10 % of individuals to remain in their current length class after one time-step while keeping the general growth pattern close to the respective von Bertalanffy growth equation.

In order to create the length bins, we first define for each sex a development index, q, which is a function of length L (Gurney *et al.*, 2007; Speirs *et al.*, 2010):

$$q \equiv -\ln\left(\frac{L_\infty - L}{L_\infty - L_{min}}\right) \quad (1)$$

where L_∞ is the respective asymptotic length. At the minimum length at which recruits are assumed to enter the population, L_{min}, q is zero. Following von Bertalanffy growth, q increases linearly with length and tends to infinity as the individual length approachesL_∞. We can calculate a finite q_{max}, for an arbitrary maximum length L_{max} which is slightly less than L_∞. All length classes are of fixed q width (Δq) but varying length bin width: classes are wider (in length) early in life when the individual growth rate is high and decrease as growth slows later in life, when individuals approach asymptotic size.

To ensure growth follows the von Bertalanffy growth equation, it can be shown that in the unexploited population, the increment Δq is set with respect to the growth rate k, growth variability coefficient p and the time-step Δt of the model (Speirs *et al.*, 2010):

$$\Delta q = \frac{k\Delta t}{p} \quad (2)$$

The number of length classes for each sex (n_m, n_f) can then be calculated using the respective sex-specific growth parameters:

$$n_{sex} = \frac{q_{max}}{\Delta q} \quad (3)$$

The total number of length classes in the model, n, is the sum of male, n_m, and female length classes, n_f. The left-hand (lower) boundary of each length class i in terms of the development index is:

$$L_i = L_\infty - (L_\infty - L_{min})\, e^{(-(i-1)\Delta q)} \quad (4)$$

using L_∞ and Δq for the respective sex. The midpoint of each length class, l_i, is calculated as the mean length of the lower boundary (Equation 4) and the lower boundary

of the next larger length class. For the maximum length class of each sex, the respective L_∞ is used as the upper boundary to calculate the midpoint. There is no variability of L_∞ individuals cannot grow larger than this size.

The length classes are constructed under the assumption of size-independent mortality. The approach is robust to size-dependent mortality, which directly affects the size distribution while the size distribution of a cohort at any age changes relatively little (Gurney *et al.*, 2007).

Using $N_{i,t}$ to denote the number of individual in length class i at time t, we can express the population model (equation 1) in difference equations for two sexes and n length classes:

$$N_{i,t+1} = \begin{cases} e^{-(M+F_{i,t})}(1-p)N_{i,t} + \frac{1}{2}R_{t+1} & \text{for } i = 1 \text{ and } i = (n_m + 1) \\ e^{-(M+F_{i-1,t})}pN_{i-1,t} + e^{-(M+F_{i,t})}(1-p)N_{i,t} & \text{for } 1 < i < n_m \text{ and } (n_m + 1) < i < n_f \\ e^{-(M+F_{i-1,t})}pN_{i-1,t} & \text{for } i = n_m \text{ and } i = n_f \end{cases} \quad (5)$$

where R_{t+1} is total recruitment at time t+1 and assumed to be split equally between males and females (entering only the smallest length class).

A.6.2.2 Mortality

The population is subject to both fishing and natural mortality, which occur simultaneously and continuously through time. Natural mortality is assumed to be constant over time, length and for both sexes. Natural mortality is estimated using the length-based updated Pauly estimator recommended by Then *et al.* (2015) using L_∞ of the larger sex:

$$M = 4.118k^{0.73}L_\infty^{-0.33} \quad (6)$$

Fishing mortality at time t and length class i, $F_{i,t}$, is assumed to be separable and can be written as the product of a length-dependent selectivity ogive (logistic curve) and a time-dependent component, f_t, related to the level of fishing effort in the fisheries:

$$F_{i,t} = f_t \frac{1}{1+e^{-v(l_i - L_{50\%})}} e^{\varepsilon_{i,t}} \quad (7)$$

where $L_{50\%}$ is the length at 50% retention, and v is a constant describing the steepness of the selectivity ogive. A lognormal error is included to allow for variability of fishing mortality, with $\varepsilon_{i,t}$ being normally distributed with $N(0, \sigma_F^2)$ (Figure 1).

Catch in numbers by length class i at time t are calculated according to the Baranov catch equation:

$$C_{i,t} = \frac{F_{i,t}}{M+F_{i,t}}\left(1 - e^{-(M+F_{i,t})}\right)N_{i,t} \quad (8)$$

and total yield (assuming zero discards) are given by:

$$Y_t = \sum_{i=1}^{n} w_i \, C_{i,t} \quad (9)$$

A.6.2.3 Reproduction

Mature individuals produce offspring at the beginning of the time-step and only in the following time-step do recruits enter the smallest length class of the population.

The maturity ogive is defined as a logistic function with an inflection point around the sex-specific length at 50% maturity, L_{mat} and calculated for the midpoint of each length class l_i (Figure 2):

$$\mathrm{Mat_i} = \frac{1}{1+e^{-u(l_i-L_{mat})}} \qquad (10)$$

Spawning–stock biomass is calculated as the sum of individual weights of all mature individuals in the stock:

$$\mathrm{SSB_t} = \sum_{i=1}^{n} \mathrm{Mat_i} N_{i,t} a l_i^b \qquad (11)$$

The individual weights at length are calculated using sex-specific exponential length–weight relationships with parameters a and b, which are constant over time.

Recruitment is related to SSB in the previous year and is assumed to follow the Beverton–Holt stock–recruitment relationship with multiplicative lognormal error (Figure 3a):

$$R_{t+1} = \frac{c\mathrm{SSB_t}}{1+d\mathrm{SSB_t}} e^{\left(\varepsilon_{t+1}-\frac{\sigma_R^2}{2}\right)} \qquad (12)$$

The error ε_{t+1} is normally distributed with N(0, σ_R^2) and is combined with a bias correction term (Thorson and Kristensen, 2016). In the basic scenario, the spawning–stock recruitment relationship is parameterized to generate an unexploited stable population equilibrium and a steepness that allows for a reduction of recruitment as SSB decreases low levels (Figure 3a). The stock-specific life-history parameters used in the model are listed in Table 1 and 2.

Each scenario is simulated 1000 times. Each simulation is initiated with a stock at the unexploited equilibrium and with stochastic recruitment. After 10 years without exploitation, the fishery is assumed to begin, initially with a constant catch (C_0 in tonnes) at a level which causes the stock to be overexploited. The simulations are run for a total of 100 years to allow observation of SPR=40%. All simulations are carried out in R (R Core Team, 2017).

Length-based indicators, $L_{max5\%}$ and $\bar{L}$, are calculated from the 'sampled' catch-at-length data. $\bar{L}$ is calculated as the mean length of individuals larger than L_c (the length at first capture), the length at which the frequency reaches 50 % of the mode on the left hand side of the distribution (Jennings *et al.*, 2001; ICES WKLIFE, 2012). L_c of the 'sampled' catches is then equivalent to the $L_{50\%}$of the selectivity ogive, and it corresponds to L_c in the analytical model with knife-edge selectivity to determine the reference points (Figure 1, 5).

A.6.3 Analytical reference points

Derivation of the reference point for $\bar{L}$, $L_{F=M}$, requires the assumptions that the population is at equilibrium with individuals following deterministic von Bertalanffy growth, natural mortality independent of size, fishing mortality with knife-edged selectivity. An analytical expression for the calculation of the reference point $L_{F=M}$was presented by Jardim *et al.* (2015), with $\theta = \frac{k}{M}$ and F=M:

$$L_{F=M,k=\theta M} = \frac{\theta L_\infty + 2L_c}{\theta+2} \qquad (15)$$

The reference point depends on L_c and biological parameters of L_∞, M, and k (for the larger sex, Table 1). The respective values of L_c are derived from the 'sampled' catch-at-length data generated with the simulation model.

We follow the approach by Miethe *et. al* (WD, Miethe et al. Annex 5) to derive reference points for $L_{max5\%}$based on the spawning potential ratio (SPR) using simple per recruit models. For that purpose, we calculate $F_{40\%}$ and the respective mean length of the largest 5% in the catch when SPR is 0.4. The standardized von Bertalanffy growth equation are used to calculate the expected non-dimensional length distribution in the stock and in the catch, under the assumptions that the population is at equilibrium with individuals following deterministic von Bertalanffy growth, natural mortality independent of size and fishing mortality with knife-edged fishery selectivity. An analytical expression for the mean length of the largest 5% in the catch, $L^F_{max5\%}$, at fishing mortality F can be derived:

$$L^F_{max5\%} = \left(1 - \frac{1}{1+k/(F+M)} 0.05^{\frac{k}{F+M}} \left(1 - \frac{L_c}{L_\infty}\right)\right) L_\infty \qquad (16)$$

The theoretical mean length of the largest 5% in the catch of an unexploited stock, $L^0_{max5\%}$, is calculated from equation 16 by setting F=0.

We calculate $L^{F_{40\%}}_{max5\%}$ by solving equation 17 numerically for $F_{40\%}$ which satisfies SPR=0.4:

$$SPR = 0.4 = \begin{cases} \dfrac{\int_{t_{mat}}^{\infty} e^{Ft_c} e^{-(F+M)t} \tilde{L}^b dt}{\int_{t_{mat}}^{\infty} e^{-Mt} \tilde{L}^b dt} & t_{mat} < t_c \\ \dfrac{\int_{t_{mat}}^{t_c} e^{-Mt} \tilde{L}^b dt + \int_{t_c}^{\infty} e^{Ft_c} e^{-(F+M)t} \tilde{L}^b dt}{\int_{t_{mat}}^{\infty} e^{-Mt} \tilde{L}^b dt} & t_{mat} \geq t_c \end{cases} \qquad (17)$$

where $\tilde{L} = \frac{L}{L_\infty}$ is the standardized length and t_c and t_{mat} are calculated from the respective lengths L_c an L_{mat}:

$$t = \frac{-\ln(1-\tilde{L})}{k} \qquad (18)$$

For both simulations and reference points, it is assumed that there is no variability of L_∞ and individuals cannot grow larger than L_∞.

A.6.4 Tables

Table A.6.1. Parameter values, in simulation model for lobster *Homarus gammarus* in the North Sea.

Description	parameter	value	unit	reference
Von Bertalanffy growth	K (male)	0.11		Chapman (1994)
	K (female)	0.13		
	L_∞ (male)	173.4	mm	
	L_∞ (female)	150.0	mm	
Maximum length to determine num-	L_{max} (male)	173.0	mm	
ber of classes	L_{max} (female)	149.5	mm	
Minimum modelled length	L_{min}	10	mm	
Growth variability constant	p	0.9		
Times step	Δt	1		
Natural mortality	M	0.15		Then *et al.* 2015
Length at 50% retention	$L_{50\%}$	70-110	mm	
Selectivity ogive constant	v	0.2		
Standard deviation of $\varepsilon_{t,i}$ (F)	σ_F	0.1		
Length-weight relationship	a (male)	0.000126	g mm^{-b}	Mesquita *et. al*
	a (female)	0.000919	g mm^{-b}	(2016)
	b (male)	3.360		
	b (female)	2.922		
Size at 50% maturity	L_{mat} (males)	80	mm	Lizarraga-Cubedo
	L_{mat} (females)	79	mm	*al.* (2003)
Maturity ogive constant	u	0.2		
Spawning stock recruitment relation-	c	0.02		
ship	d	1.66×10^{-10}		
Standard deviation of ε_{t+1} (R)	σ_R	0.2		

Table A.6.2. Parameters *L.naevus*, using life-history characteristics for Irish Sea stock

Description	parameter	value	unit	reference
Von Bertalanffy growth	K (male)	0.294		Gallagher *et al.*
	K (female)	0.197		(2005)
	L_∞ (male)	746	mm	
	L_∞ (female)	839	mm	
Maximum length to determine	L_{max} (male)	745.5	mm	0.5 below L_∞
number of classes	L_{max} (female)	838.5	mm	
Minimum modelled length	L_{min}	100	mm	ICES 2004
Growth variability constant	p	0.9		
Times step	Δt	1		
Natural mortality	M	0.136		Then *et al.* 2015
Length at 50% retention	$L_{50\%}$	300-700	mm	
Selectivity ogive constant	v	0.07		
Standard deviation of $\varepsilon_{t,i}$ (fishing mortality)	σ_F	0.1		
Length-weight relationship	a' (male)	0.0041	g cm^{-b}	McCully *et al.* (2012)
	a' (female)	0.0035	g cm^{-b}	to mm a=a'10^{-b}
	b (male)	3.105		
	b (female)	3.147		
Size at 50% maturity	L_{mat} (males)	568.7	mm	Gallagher *et al.*
	L_{mat} (females)	561.6	mm	(2005)
Maturity ogive constant	u	0.06		
Spawning stock recruitment rela-	c	4		
tionship	d	$4*10^{-6}$		
Standard deviation of ε_{t+1} (fecundity)	σ_{Rec}	0.1		

A.6.5 References

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Annex 7: ICES stocks by data category in 2017

Table A7.1 All stocks in 2017 by ICES data category.

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category	Advice Type
ank.27.8c9a	Black-bellied anglerfish (*Lophius budegassa*) in divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian waters)	WGBIE	1.00	MSY
bli.27.5b67	Blue ling (*Molva dypterygia*) in subareas 6-7 and Division 5.b (Celtic Seas, English Channel, and Faroes grounds)	WGDEEP	1.00	MSY
whb.27.1-91214	Blue whiting (*Micromesistius poutassou*) in subareas 1-9, 12, and 14 (Northeast Atlantic and adjacent waters)	WGWIDE	1.00	MP
cod.27.5a	Cod (*Gadus morhua*) in Division 5.a (Iceland grounds)	NWWG	1.00	MP
cod.27.7a	Cod (*Gadus morhua*) in Division 7.a (Irish Sea)	WGCSE	1.00	MSY
cod.27.7e-k	Cod (*Gadus morhua*) in divisions 7.e-k (eastern English Channel and southern Celtic Seas)	WGCSE	1.00	MSY
cod.21.1	Cod (*Gadus morhua*) in NAFO Subarea 1, inshore (West Greenland cod)	NWWG	1.00	MSY
cod.27.47d20	Cod (*Gadus morhua*) in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, eastern English Channel, Skagerrak)	WGNSSK	1.00	MSY
cod.27.1-2	Cod (*Gadus morhua*) in subareas 1 and 2 (Northeast Arctic)	AFWG	1.00	MP
cod.27.22-24	Cod (*Gadus morhua*) in subdivisions 22-24, western Baltic stock (western Baltic Sea)	WGBFAS	1.00	MP
ldb.27.8c9a	Four-spot megrim (*Lepidorhombus boscii*) in divisions 8.c and 9.a (southern Bay of Biscay and Atlantic Iberian waters East)	WGBIE	1.00	MSY
reg.27.561214	Golden redfish (*Sebastes norvegicus*) in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)	NWWG	1.00	MP
ghl.27.561214	Greenland halibut (*Reinhardtius hippoglossoides*) in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)	NWWG	1.00	MSY
had.27.5a	Haddock (*Melanogrammus aeglefinus*) in Division 5.a (Iceland grounds)	NWWG	1.00	MP
had.27.6b	Haddock (*Melanogrammus aeglefinus*) in Division 6.b (Rockall)	WGCSE	1.00	MSY
had.27.7a	Haddock (*Melanogrammus aeglefinus*) in Division7.a (Irish Sea)	WGCSE	1.00	MSY
had.27.7b–k	Haddock (*Melanogrammus aeglefinus*) in Divisions 7.b-k (southern Celtic Seas and English Channel)	WGCSE	1.00	MSY
had.27.46a20	Haddock (*Melanogrammus aeglefinus*) in Subarea 4, Division 6.a, and Subdivision 20 (North Sea, West of Scotland, Skagerrak)	WGNSSK	1.00	MSY
had.27.1-2	Haddock (*Melanogrammus aeglefinus*) in subareas 1 and 2 (Northeast Arctic)	AFWG	1.00	MP
hke.27.8c9a	Hake (*Merluccius merluccius*) in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and Atlantic Iberian waters)	WGBIE	1.00	MSY
hke.27.3a46-8abd	Hake (*Merluccius merluccius*) in Subareas 4, 6, and 7, and Divisions 3.a, 8.a-b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay)	WGBIE	1.00	MSY
her.27.5a	Herring (*Clupea harengus*) in Division 5.a, summer-spawning herring (Iceland grounds)	NWWG	1.00	MP
her.27.nirs	Herring (*Clupea harengus*) in Division 7.a North of 52°30’N (Irish Sea)	HAWG	1.00	MSY

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category	Advice Type
her.27.irls	Herring (*Clupea harengus*) in divisions 7.a South of 52°30'N, 7.g-h, and 7.j-k (Irish Sea, Celtic Sea, and southwest of Ireland)	HAWG	1.00	MSY
her.27.3a47d	Herring (*Clupea harengus*) in Subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, Skagerrak and Kattegat, eastern English Channel)	HAWG	1.00	MP
her.27.1-24a514a	Herring (*Clupea harengus*) in subareas 1, 2, 5 and divisions 4.a and 14.a, Norwegian spring-spawning herring (the Northeast Atlantic and Arctic Ocean)	WGWIDE	1.00	MP
her.27.28	Herring (*Clupea harengus*) in Subdivision 28.1 (Gulf of Riga)	WGBFAS	1.00	MP
her.27.20-24	Herring (*Clupea harengus*) in subdivisions 20-24, spring spawners (Skagerrak, Kattegat, and western Baltic)	HAWG	1.00	MSY
her.27.25-2932	Herring (*Clupea harengus*) in subdivisions 25-29 and 32, excluding the Gulf of Riga (central Baltic Sea)	WGBFAS	1.00	MP
her.27.3031	Herring (*Clupea harengus*) in subdivisions 30 and 31 (Gulf of Bothnia)		1.00	MSY
hom.27.9a	Horse mackerel (*Trachurus trachurus*) in Division 9.a (Atlantic Iberian waters)	WGHANSA	1.00	MSY
hom.27.2a4a5b6a7a-ce-k8	Horse mackerel (*Trachurus trachurus*) in Subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a-c,e-k (the Northeast Atlantic)	WGWIDE	1.00	MSY
lin.27.5a	Ling (*Molva molva*) in Division 5.a (Iceland grounds)	WGDEEP	1.00	MP
mac.27.nea	Mackerel (*Scomber scombrus*) in subareas 1-8 and 14 and division 9.a (the Northeast Atlantic and adjacent waters)	WGWIDE	1.00	MSY
lez.27.4a6a	Megrim (*Lepidorhombus* spp.) in divisions 4.a and 6.a (northern North Sea, West of Scotland)	WGCSE	1.00	MSY
meg.27.7b-k8abd	Megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k, 8.a-b, and 8.d (west and southwest of Ireland, Bay of Biscay)	WGBIE	1.00	MSY
meg.27.8c9a	Megrim (*Lepidorhombus whiffiagonis*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	WGBIE	1.00	MSY
pra.27.4a20	Northern shrimp (*Pandalus borealis*) in Division 4.a (northern North Sea, Fladen Ground)		1.00	MSY
pra.27.3a4a	Northern shrimp (*Pandalus borealis*) in divisions 3.a and 4.a East (Skagerrak and Kattegat and northern North Sea in the Norwegian Deep)	NIPAG	1.00	MSY
nep.fu.3-4	Norway lobster (*Nephrops norvegicus*) in Division 3.a, Functional units 3 and 4 (Skagerrak and Kattegat)	WGNSSK	1.00	MSY
nep.fu.7	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 7 (northern North Sea, Fladen Ground)	WGNSSK	1.00	MSY
nep.fu.6	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 6 (central North Sea, Farn Deeps)	WGNSSK	1.00	MSY
nep.fu.8	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 8 (central North Sea, Firth of Forth)	WGNSSK	1.00	MSY
nep.fu.9	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 9 (central North Sea, Moray Firth)	WGNSSK	1.00	MSY
nep.fu.11	Norway lobster (*Nephrops norvegicus*) in Division 6.a, Functional Unit 11 (West of Scotland, North Minch)	WGCSE	1.00	MSY
nep.fu.12	Norway lobster (*Nephrops norvegicus*) in Division 6.a, Functional Unit 12 (West of Scotland, South Minch)	WGCSE	1.00	MSY
nep.fu.13	Norway lobster (*Nephrops norvegicus*) in Division 6.a, Functional Unit 13 (West of Scotland, the Firth of Clyde and Sound of Jura)	WGCSE	1.00	MSY
nep.fu.14	Norway lobster (*Nephrops norvegicus*) in Division 7.a, Functional Unit 14 (Irish Sea, East)	WGCSE	1.00	MSY

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category	Advice Type
nep.fu.15	Norway lobster (*Nephrops norvegicus*) in Division 7.a, Functional Unit 15 (Irish Sea, West)	WGCSE	1.00	MSY
nep.fu.17	Norway lobster (*Nephrops norvegicus*) in Division 7.b, Functional Unit 17 (west of Ireland, Aran grounds)	WGCSE	1.00	MSY
nep.fu.19	Norway lobster (*Nephrops norvegicus*) in divisions 7.a, 7.g, and 7.j, Functional Unit 19 (Irish Sea, Celtic Sea, eastern part of southwest of Ireland)	WGCSE	1.00	MSY
nep.fu.16	Norway lobster (*Nephrops norvegicus*) in divisions 7.b-c and 7.j-k, Functional Unit 16 (west and southwest of Ireland, Porcupine Bank)	WGCSE	1.00	MSY
nep.fu.22	Norway lobster (*Nephrops norvegicus*) in divisions 7.g and 7.f, Functional Unit 22 (Celtic Sea, Bristol Channel)	WGCSE	1.00	MSY
nep.fu.2021	Norway lobster (*Nephrops norvegicus*) in divisions 7.g and 7.h, functional units 20 and 21 (Celtic Sea)	WGCSE	1.00	MSY
nep.fu.2324	Norway lobster (*Nephrops norvegicus*) in divisions 8.a and 8.b, functional units 23-24 (northern and central Bay of Biscay)	WGBIE	1.00	MSY
nop.27.3a4	Norway pout (*Trisopterus esmarkii*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGNSSK	1.00	MSY
ple.27.7a	Plaice (*Pleuronectes platessa*) in Division 7.a (Irish Sea)	WGCSE	1.00	MSY
ple.27.7d	Plaice (*Pleuronectes platessa*) in Division 7.d (eastern English Channel)	WGNSSK	1.00	MSY
ple.27.420	Plaice (*Pleuronectes platessa*) in Subarea 4 (North Sea) and Subdivision 20 (Skagerrak)	WGNSSK	1.00	MSY
ple.27.21-23	Plaice (*Pleuronectes platessa*) in subdivisions 21-23 (Kattegat, Belt Seas, and the Sound)	WGBFAS	1.00	MSY
rng.27.5b6712b	Roundnose grenadier (*Coryphaenoides rupestris*) in subareas 6-7, and in Divisions 5.b and 12.b (Celtic Seas and the English Channel, Faroes grounds, and western Hatton Bank)	WGDEEP	1.00	MSY
pok.27.5a	Saithe (*Pollachius virens*) in Division 5.a (Iceland grounds)	NWWG	1.00	MP
pok.27.1-2	Saithe (*Pollachius virens*) in subareas 1 and 2 (Northeast Arctic)	AFWG	1.00	MP
pok.27.3a46	Saithe (*Pollachius virens*) in Subareas 4, 6 and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)	WGNSSK	1.00	MSY
sal.27.22-31	Salmon (*Salmo salar*) in subdivisions 22-31 (Baltic Sea, excluding the Gulf of Finland)	WGBAST	1.00	MSY
san.sa.3r	Sandeel (*Ammodytes* spp.) in Divisions 4.a and 4.b, and Subdivision 20, Sandeel Area 3r (Skagerrak, northern and central North Sea)	HAWG	1.00	MSY
san.sa.4	Sandeel (*Ammodytes* spp.) in divisions 4.a and 4.b, Sandeel Area 4 (northern and central North Sea)	HAWG	1.00	MSY
san.sa.2r	Sandeel (*Ammodytes* spp.) in Divisions 4.b and 4.c, and Subdivision 20, Sandeel Area 2r (Skagerrak, central and southern North Sea)	HAWG	1.00	MSY
san.sa.1r	Sandeel (*Ammodytes* spp.) in Divisions 4.b and 4.c, Sandeel Area 1r (central and southern North Sea, Dogger Bank)	HAWG	1.00	MSY
bss.27.4bc7ad–h	Sea bass (*Dicentrarchus labrax*) in Divisions 4.b-c, 7.a, and 7.d-h (central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea)	WGCSE	1.00	MSY
sol.27.7d	Sole (*Solea solea*) in Division 7.d (eastern English Channel)	WGNSSK	1.00	MSY
sol.27.7e	Sole (*Solea solea*) in Division 7.e (western English Channel)	WGCSE	1.00	MSY

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sol.27.7fg	Sole (*Solea solea*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)	WGCSE	1.00	MSY
sol.27.8ab	Sole (*Solea solea*) in divisions 8.a-b (northern and central Bay of Biscay)	WGBIE	1.00	MSY
sol.27.4	Sole (*Solea solea*) in Subarea 4 (North Sea)	WGNSSK	1.00	MP
sol.27.20-24	Sole (*Solea solea*) in subdivisions 20-24 (Skagerrak and Kattegat, western Baltic Sea)	WGBFAS	1.00	MSY
spr.27.4	Sprat (*Sprattus sprattus*) in Subarea 4 (North Sea)	HAWG	1.00	MSY
spr.27.22–32	Sprat (*Sprattus sprattus*) in Subdivisions 22-32 (Baltic Sea)	WGBFAS	1.00	MP
usk.27.5a14	Tusk (*Brosme brosme*) in Subarea 14 and Division 5.a (East Greenland, and Iceland grounds)	WGDEEP	1.00	MP
mon.27.8c9a	White anglerfish (*Lophius piscatorius*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	WGBIE	1.00	MSY
whg.27.6a	Whiting (*Merlangius merlangus*) in Division 6.a (West of Scotland)	WGCSE	1.00	MSY
whg.27.7b-ce-k	Whiting (*Merlangius merlangus*) in divisions 7.b -c and 7.e-k (southern Celtic Seas and eastern English Channel)	WGCSE	1.00	MSY
whg.27.47d	Whiting (*Merlangius merlangus*) in Subarea 4 and Division 7.d (North Sea and eastern English Channel)	WGNSSK	1.00	MSY
cod.27.6a	Cod (*Gadus morhua*) in Division 6.a (West of Scotland)	WGCSE	1.20	MSY
her.27.6a7bc	Herring (*Clupea harengus*) in divisions 6.a and 7.b-c (West of Scotland, West of Ireland)	HAWG	1.20	MSY
pil.27.8c9a	Sardine (*Sardina pilchardus*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	WGHAN SA	1.20	MSY
sol.27.7a	Sole (*Solea solea*) in Division 7.a (Irish Sea)	WGCSE	1.20	MSY
dgs.27.nea	Spurdog (*Squalus acanthias*) in Subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	1.20	PA
whg.27.7a	Whiting (*Merlangius merlangus*) in Division 7.a (Irish Sea)	WGCSE	1.20	MSY
pra.27.1-2	Northern shrimp (*Pandalus borealis*) in subareas 1 and 2 (Northeast Arctic)	NIPAG	1.60	MSY
cod.27.5b1	Cod (*Gadus morhua*) in Subdivision 5.b.1 (Faroe Plateau)	NWWG	1.70	MSY
had.27.5b	Haddock (*Melanogrammus aeglefinus*) in Division 5.b (Faroes grounds)	NWWG	1.70	MSY
pok.27.5b	Saithe (*Pollachius virens*) in Division 5.b (Faroes grounds)	NWWG	1.70	MSY
ane.27.8	Anchovy (*Engraulis encrasicolus*) in Subarea 8 (Bay of Biscay)	WGHAN SA	1.80	MP
cap.27.1-2	Capelin (*Mallotus villosus*) in subareas 1 and 2 (Northeast Arctic), excluding Division 2.a west of 5°W (Barents Sea capelin)	AFWG	1.80	MP
cap.27.2a514	Capelin (*Mallotus villosus*) in subareas 5 and 14 and Division 2.a west of 5°W (Iceland and Faroes grounds, East Greenland, Jan Mayen area)	NWWG	1.80	MP
reb.27.1-2	Beaked redfish (*Sebastes mentella*) in subareas 1 and 2 (Northeast Arctic)	AFWG	1.85	PA
ghl.27.1-2	Greenland halibut (*Reinhardtius hippoglossoides*) in subareas 1 and 2 (Northeast Arctic)	AFWG	1.87	PA
sal.27.neac	Atlantic salmon (*Salmo salar*) from the Northeast Atlantic	WGNAS	1.90	NA
sal.2127.wgc	Atlantic salmon from West Greenland	WGNAS	1.90	NA
sal.21.2-5	Salmon (Salmo salar) from North America	WGNAS	1.90	NA
pil.27.8abd	Sardine (*Sardina pilchardus*) in divisions 8.a-b and 8.d (Bay of Biscay)	HANSA	2.11	MSY

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reb.2127.dp	Beaked redfish (*Sebastes mentella*) in ICES subareas 5, 12, and 14 (Iceland and Faroe grounds, North of Azores, East of Greenland) and NAFO subareas 1 and 2 (deep pelagic stock > 500 m)	NWWG	2.13	MSY
reg.27.1-2	Golden redfish (*Sebastes norvegicus*) in subareas 1 and 2 (Northeast Arctic)	AFWG	2.13	PA
reb.2127.sp	Beaked redfish (*Sebastes mentella*) in ICES subareas 5, 12, and 14 (Iceland and Faroe grounds, North of Azores, East of Greenland) and NAFO subareas 1 and 2 (shallow pelagic stock < 500 m)	NWWG	3.14	PA
cod.21.1a-e	Cod (*Gadus morhua*) in NAFO divisions 1.A-E, offshore (West Greenland)	NWWG	3.14	PA
cod.27.5b2	Cod (*Gadus morhua*) in Subdivision 5.b.2 (Faroe Bank)	NWWG	3.14	PA
ele.2737.nea	European eel (*Anguilla anguilla*) throughout its natural range	WGEEL	3.14	PA
nep.fu.25	Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 25 (southern Bay of Biscay and northern Galicia)	WGBIE	3.14	PA
nep.fu.31	Norway lobster (*Nephrops norvegicus*) in Division 8.c, Functional Unit 31 (southern Bay of Biscay and Cantabrian Sea)	WGBIE	3.14	PA
nep.fu.2627	Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 26-27 (Atlantic Iberian waters East, western Galicia, and northern Portugal)	WGBIE	3.14	PA
ple.27.7h–k	Plaice (*Pleuronectes platessa*) in Divisions 7h-k (Celtic Sea South, southwest of Ireland)	WGCSE	3.14	PA
rjr.27.23a4	Starry ray (*Amblyraja radiata*) in Subareas 2 and 4, and Division 3.a (Norwegian Sea, North Sea, Skagerrak and Kattegat)	WGEF	3.14	PA
anf.27.3a46	Anglerfish (*Lophius budegassa, Lophius piscatorius*) in Subareas 4 and 6, and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)	WGCSE	3.20	PA
reb.27.14b	Beaked redfish (*Sebastes mentella*) in Division 14.b, demersal (Southeast Greenland)	NWWG	3.20	PA
reb.27.5a14	Beaked redfish (*Sebastes mentella*) in Subarea 14 and Division 5.a, Icelandic slope stock (East of Greenland, Iceland grounds)	NWWG	3.20	PA
bsf.27.nea	Black scabbardfish (*Aphanopus carbo*) in Subareas 1, 2, 4-8, 10, and 14, and Divisions 3.a, 9.a, and 12.b (Northeast Atlantic and Arctic Ocean)	WGDEEP	3.20	PA
ank.27.78ab	Black-bellied anglerfish (*Lophius budegassa*) in divisions 7.b-k, 8.a-b, and 8.d (west and southwest of Ireland, Bay of Biscay)	WGBIE	3.20	PA
sho.27.89a	Black-mouth dogfish (*Galeus melastomus*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGEF	3.20	PA
sbr.27.10	Blackspot sea bream (*Pagellus bogaraveo*) in Subarea 10 (Azores grounds)	WGDEEP	3.20	PA
sbr.27.9	Blackspot sea bream (*Pagellus bogaraveo*) in Subarea 9 (Atlantic Iberian waters)	WGDEEP	3.20	PA
rjh.27.9a	Blonde ray (*Raja brachyura*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20	PA
rjh.27.4c7d	Blonde ray (Raja brachyura) in divisions 4.c and 7.d (southern North Sea and eastern English Channel)	WGEF	3.20	PA
jaa.27.10a2	Blue jack mackerel (*Trachurus picturatus)* in Subdivision 10.a.2 (Azores grounds)	WGHANSA	3.20	PA
boc.27.6-8	Boarfish (*Capros aper*) in subareas 6-8 (Celtic Seas, English Channel, and Bay of Biscay)	WGWIDE	3.20	PA

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bll.27.3a47de	Brill (*Scophthalmus rhombus*) in Subarea 4 and divisions 3.a and 7.d-e (North Sea, Skagerrak and Kattegat, English Channel)	WGNSSK	3.20	PA
bll.27.22-32	Brill (*Scophthalmus rhombus*) in subdivisions 22-32 (Baltic Sea)	WGBFAS	3.20	PA
cod.27.21	Cod (*Gadus morhua*) in Subdivision 21 (Kattegat)	WGBFAS	3.20	PA
cod.27.25-32	Cod (*Gadus morhua*) in subdivisions 25-32, eastern Baltic stock (eastern Baltic Sea)	WGBFAS	3.20	PA
rjn.27.8c	Cuckoo ray (*Leucoraja naevus*) in Division 8.c (Cantabrian Sea)	WGEF	3.20	PA
rjn.27.9a	Cuckoo ray (*Leucoraja naevus*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20	PA
rjn.27.3a4	Cuckoo ray (*Leucoraja naevus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGEF	3.20	PA
rjn-678abd	Cuckoo ray (*Leucoraja naevus*) in subareas 6 and 7 and divisions 8.ab and 8.d	WGEF	3.20	PA
dab.27.3a4	Dab (*Limanda limanda*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGNSSK	3.20	PA
dab.27.22-32	Dab (*Limanda limanda*) in subdivisions 22-32 (Baltic Sea)	WGBFAS	3.20	PA
fle.27.3a4	Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGNSSK	3.20	PA
fle.27.2223	Flounder (*Platichthys flesus*) in subdivisions 22 and 23 (Belt Seas and the Sound)	WGBFAS	3.20	PA
fle.27.2425	Flounder (*Platichthys flesus*) in subdivisions 24 and 25 (west of Bornholm and southwestern central Baltic)	WGBFAS	3.20	PA
fle.27.2628	Flounder (*Platichthys flesus*) in subdivisions 26 and 28 (east of Gotland and Gulf of Gdańsk)	WGBFAS	3.20	PA
fle.27.2729-32	Flounder (*Platichthys flesus*) in subdivisions 27 and 29-32 (northern central and northern Baltic Sea)	WGBFAS	3.20	PA
gfb.27.nea	Greater forkbeard (*Phycis blennoides*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGDEEP	3.20	PA
aru.27.5b6a	Greater silver smelt (*Argentina silus*) in divisions 5.b and 6.a (Faroes grounds and west of Scotland)	WGDEEP	3.20	PA
aru.27.123a4	Greater silver smelt (*Argentina silus*) in subareas 1, 2, and 4, and in Division 3.a (Northeast Arctic, North Sea, Skagerrak and Kattegat)	WGDEEP	3.20	PA
aru.27.6b7-1012	Greater silver smelt (*Argentina silus*) in Subareas 7-10 and 12, and Division 6.b (other areas)	WGDEEP	3.20	PA
gug.27.3a47d	Grey gurnard (*Eutrigla gurnardus*) in Subarea 4 and divisions 7.d and 3.a (North Sea, eastern English Channel, Skagerrak and Kattegat)	WGNSSK	3.20	PA
hom.27.3a4bc7d	Horse mackerel (*Trachurus trachurus*) in divisions 3.a, 4.b-c, and 7.d (Skagerrak and Kattegat, southern and central North Sea, eastern English Channel)	WGWIDE	3.20	PA
lem.27.3a47d	Lemon sole (*Microstomus kitt*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	WGNSSK	3.20	PA
syc.27.8abd	Lesser-spotted dogfish (*Scyliorhinus canicula*) in divisions 8.a-b and 8.d (Bay of Biscay)	WGEF	3.20	PA
syc.27.8c9a	Lesser-spotted dogfish (*Scyliorhinus canicula*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	WGEF	3.20	PA
syc.27.3a47d	Lesser-spotted dogfish (*Scyliorhinus canicula*) in Subarea 4 and Divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	WGEF	3.20	PA

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syc.27.67a-ce-j	Lesser-spotted dogfish (*Scyliorhinus canicula*) in Subarea 6 and divisions 7.a-c and 7.e-j (West of Scotland, Irish Sea, southern Celtic Seas)	WGEF	3.20	PA
lin.27.5b	Ling (*Molva molva*) in Division 5.b (Faroes grounds)	WGDEEP	3.20	PA
lin.27.1-2	Ling (*Molva molva*) in subareas 1 and 2 (Northeast Arctic)	WGDEEP	3.20	PA
lin.27.3a4a6-91214	Ling (*Molva molva*) in Subareas 6-9, 12, and 14, and Divisions 3.a and 4.a (Northeast Atlantic and Arctic Ocean)	WGDEEP	3.20	PA
lez.27.6b	Megrim (*Lepidorhombus* spp.) in Division 6.b (Rockall)	WGCSE	3.20	PA
nep.fu.2829	Norway lobster (*Nephrops norvegicus*) in Division 9.a, functional units 28-29 (Atlantic Iberian waters East and southwestern and southern Portugal)	WGBIE	3.20	PA
ple.27.7e	Plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel)	WGCSE	3.20	PA
ple.27.7fg	Plaice (*Pleuronectes platessa*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)	WGCSE	3.20	PA
ple.27.24-32	Plaice (Pleuronectes platessa) in subdivisions 24-32 (Baltic Sea, excluding the Sound and Belt Seas)	WGBFAS	3.20	PA
raj.27.1012	Rays and skates (*Rajidae*) (mainly thornback ray (*Raja clavata*)) in subareas 10 and 12 (Azores grounds and north of Azores)	WGEF	3.20	PA
bss.27.8ab	Sea bass (*Dicentrarchus labrax*) in divisions 8.a-b (northern and central Bay of Biscay)	WGBIE	3.20	PA
rje.27.7fg	Small-eyed ray (*Raja microocellata*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea North)	WGEF	3.20	PA
sdv.27.nea	Smooth-hound (*Mustelus* spp.) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	3.20	PA
sol.27.7h–k	Sole (*Solea solea*) in Divisions 7.h-k (Celtic Sea South, southwest of Ireland)	WGCSE	3.20	PA
rjm.27.8	Spotted ray (*Raja montagui*) in Subarea 8 (Bay of Biscay)	WGEF	3.20	PA
rjm.27.9a	Spotted ray (*Raja montagui*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20	PA
rjm.27.7ae-h	Spotted ray (*Raja montagui*) in divisions 7.a and 7.e-h (southern Celtic Seas and western English Channel)	WGEF	3.20	PA
rjm.27.3a47d	Spotted ray (*Raja montagui*) in Subarea 4 and Divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	WGEF	3.20	PA
rjm.27.67bj	Spotted ray (*Raja montagui*) in Subarea 6 and divisions 7.b and 7.j (West of Scotland, west and southwest of Ireland)	WGEF	3.20	PA
spr.27.3a	Sprat (*Sprattus sprattus*) in Division 3.a (Skagerrak and Kattegat)	HAWG	3.20	PA
spr.27.7de	Sprat (*Sprattus sprattus*) in divisions 7.d and 7.e (English Channel)	HAWG	3.20	PA
mur.27.3a47d	Striped red mullet (*Mullus surmuletus*) in Subarea 4 and divisions 7.d and 3.a (North Sea, eastern English Channel, Skagerrak and Kattegat)	WGNSSK	3.20	PA
rjc.27.9a	Thornback ray (*Raja clavata*) in Division 9.a (Atlantic Iberian waters)	WGEF	3.20	PA
rjc.27.7afg	Thornback ray (*Raja clavata*) in divisions 7.a and 7.f-g (Irish Sea, Bristol Channel, Celtic Sea North)	WGEF	3.20	PA
rjc.27.3a47d	Thornback ray (*Raja clavata*) in Subarea 4 and in divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	WGEF	3.20	PA
rjc.27.6	Thornback ray (*Raja clavata*) in Subarea 6 (West of Scotland)	WGEF	3.20	PA
rjc.27.8	Thornback ray (*Raja clavata*) in Subarea 8 (Bay of Biscay)	WGEF	3.20	PA
tur.27.3a	Turbot (*Scophthalmus maximus*) in Division 3.a (Skagerrak and Kattegat)	WGNSSK	3.20	PA

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tur.27.4	Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)	WGNSSK	3.20	PA
tur.27.22–32	Turbot (*Scophthalmus maximus*) in Subdivisions 22-32 (Baltic Sea)	WGBFAS	3.20	PA
usk.27.1-2	Tusk (*Brosme brosme*) in subareas 1 and 2 (Northeast Arctic)	WGDEEP	3.20	PA
usk.27.3a45b6a7-912b	Tusk (*Brosme brosme*) in Subareas 4 and 7-9, and Divisions 3.a, 5.b, 6.a, and 12.b (Northeast Atlantic)	WGDEEP	3.20	PA
rju.27.7de	Undulate ray (*Raja undulata*) in divisions 7.d and 7.e (English Channel)	WGEF	3.20	PA
mon.27.78abd	White anglerfish (*Lophius piscatorius*) in divisions 7.b-k, 8.a-b, and 8.d (southern Celtic Seas, Bay of Biscay)	WGBIE	3.20	PA
wit.27.3a47d	Witch (*Glyptocephalus cynoglossus*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	WGNSSK	3.20	PA
bli.27.5a14	Blue ling (*Molva dypterygia*) in Subarea 14 and Division 5.a (East Greenland and Iceland grounds)	WGDEEP	3.30	PA
cod.2127.1f14	Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland, South Greenland)	NWWG	3.30	PA
aru.27.5a14	Greater silver smelt (Argentina silus) in Subarea 14 and Division 5.a (East Greenland and Iceland grounds)	WGDEEP	3.30	PA
cod.27.1-2coast	Cod (*Gadus morhua*) in subareas 1 and 2 (Norwegian coastal waters cod)	AFWG	3.60	MP
syt.27.67	Greater-spotted dogfish (*Skyliorhinus stellaris*) in subareas 6 and 7 (West of Scotland, southern Celtic Sea, and the English Channel)	WGEF	3.70	PA
sal.27.32	Salmon (*Salmo salar*) in Subdivision 32 (Gulf of Finland)	WGBAST	3.80	PA
trs.27.22-32	Sea trout (*Salmo trutta*) in subdivisions 22-32 (Baltic Sea)	WGBAST	3.80	PA
ane.27.9a	Anchovy (*Engraulis encrasicolus*) in Division 9.a (Atlantic Iberian waters)	WGHAN SA	3.90	No advice
sho.27.67	Black-mouth dogfish (*Galeus melastomus*) in subareas 6 and 7 (West of Scotland, southern Celtic Seas, and English Channel)	WGEF	3.90	PA
pol.27.67	Pollack (*Pollachius pollachius*) in subareas 6-7 (Celtic Seas and the English Channel)	WGCSE	4.12	PA
nep.fu.10	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 10 (northern North Sea, Noup)	WGNSSK	4.14	PA
nep.fu.32	Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 32 (northern North Sea, Norway Deep)	WGNSSK	4.14	PA
nep.fu.33	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 33 (central North Sea, Horn's Reef)	WGNSSK	4.14	PA
nep.fu.34	Norway lobster (*Nephrops norvegicus*) in Division 4.b, Functional Unit 34 (central North Sea, Devil's Hole)	WGNSSK	4.14	PA
nep.fu.30	Norway lobster (*Nephrops norvegicus*) in Division 9.a, Functional Unit 30 (Atlantic Iberian waters East and Gulf of Cadiz)	WGBIE	4.14	PA
nep.fu.5	Norway lobster (*Nephrops norvegicus*) in divisions 4.b and 4.c, Functional Unit 5 (central and southern North Sea, Botney Gut-Silver Pit)	WGNSSK	4.14	PA
alf.27.nea	Alfonsinos (*Beryx* spp.) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGDEEP	5.20	PA
rjh.27.7e	Blonde ray (*Raja brachyura*) in Division 7.e (western English Channel)	WGEF	5.20	PA
rjh.27.7afg	Blonde ray (*Raja brachyura*) in divisions 7.a and 7.f-g (Irish Sea, Bristol Channel, Celtic Sea North)	WGEF	5.20	PA
rjh.27.4a6	Blonde ray (*Raja brachyura*) in Subarea 6 and Division 4.a (North Sea and West of Scotland)	WGEF	5.20	PA

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nep.27.6aoutFU	Norway lobster (*Nephrops norvegicus*) in Division 6.a, outside the functional units (West of Scotland)	WGCSE	5.20	PA
nep.27.4outFU	Norway lobster (*Nephrops norvegicus*) in Subarea 4, outside the functional units (North Sea)	WGNSSK	5.20	PA
nep.27.7outFU	Norway lobster (*Nephrops norvegicus*) in Subarea 7, outside the functional units (southern Celtic Seas, southwest of Ireland)	WGCSE	5.20	PA
ple.27.89a	Plaice (*Pleuronectes platessa*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20	PA
pol.27.3a4	Pollack (*Pollachius pollachius*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGNSSK	5.20	PA
pol.27.89a	Pollack (*Pollachius pollachius*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20	PA
rng.27.5a10b12ac14b	Roundnose grenadier (*Coryphaenoides rupestris*) in Divisions 10.b and 12.c, and Subdivisions 12.a.1, 14.b.1, and 5.a.1 (Oceanic Northeast Atlantic and northern Reykjanes Ridge)	WGDEEP	5.20	PA
san.sa.6	Sandeel (*Ammodytes* spp.) in subdivisions 20-22, Sandeel Area 6 (Kattegat)	HAWG	5.20	PA
rji.27.67	Sandy ray (*Leucoraja circularis*) in subareas 6-7 (West of Scotland, southern Celtic Seas, English Channel)	WGEF	5.20	PA
bss.27.8c9a	Sea bass (*Dicentrarchus labrax*) in divisions 8.c and 9.a (southern Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20	PA
rjf.27.67	Shagreen ray (*Leucoraja fullonica*) in subareas 6-7 (West of Scotland, southern Celtic Seas, English Channel)	WGEF	5.20	PA
rje.27.7de	Small-eyed ray (*Raja microocellata*) in divisions 7.d and 7.e (English Channel)	WGEF	5.20	PA
sol.27.8c9a	Sole (*Solea solea*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	WGBIE	5.20	PA
spr.27.67a–cf–k	Sprat (*Sprattus sprattus*) in Subarea 6 and Divisions 7.a-c and 7.f-k (West of Scotland, southern Celtic Seas)	HAWG	5.20	PA
mur.27.67a-ce-k89a	Striped red mullet (*Mullus surmuletus*) in subareas 6 and 8, and in divisions 7.a-c, 7.e-k, and 9.a (North Sea, Bay of Biscay, southern Celtic Seas, and Atlantic Iberian waters)	WGWIDE	5.20	PA
rjc.27.7e	Thornback ray (*Raja clavata*) in Division 7.e (western English Channel)	WGEF	5.20	PA
gag.27.nea	Tope (*Galeorhinus galeus*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	5.20	PA
usk.27.6b	Tusk (*Brosme brosme*) in Division 6.b (Rockall)	WGDEEP	5.20	PA
whg.27.3a	Whiting (*Merlangius merlangus*) in Division 3.a (Skagerrak and Kattegat)	WGNSSK	5.20	PA
whg.27.89a	Whiting (*Merlangius merlangus*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGBIE	5.20	PA
bli.27.nea	Blue ling (*Molva dypterygia*) in Subareas 1, 2, 8, 9, and 12, and Divisions 3.a and 4.a (other areas)	WGDEEP	5.30	PA
rjb.27.89a	Common skate (Dipturus batis-complex) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGEF	5.30	PA
san.sa.5r	Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 5r (northern North Sea, Viking and Bergen banks)	HAWG	5.30	PA
san.sa.7r	Sandeel (*Ammodytes* spp.) in Division 4.a, Sandeel Area 7 (northern North Sea, Shetland)	HAWG	5.30	PA
ldb.27.7b-k8abd	Four-spot megrim (*Lepidorhombus boscii*) in Divisions 7.b-k, 8.a-b, and 8.d (west and southwest of Ireland, Bay of Biscay)	WGBIE	5.90	PA
raj.27.89a	Rays and skates (*Rajidae*) in Subarea 8 and Division 9.a (Bay of Biscay and Atlantic Iberian waters)	WGEF	5.90	No advice
pil.27.7	Sardine (*Sardina pilchardus*) in Subarea 7 (Southern Celtic Seas, English Channel)	WGHANSA	5.90	PA

2017 Stock Key Label	2017 Stock Description	EG	2017 ICES Data Category	Advice Type
cod.27.6b	Cod (*Gadus morhua*) in Division 6.b (Rockall)	WGCSE	6.20	PA
ple.27.7bc	Plaice (*Pleuronectes platessa*) in divisions 7.b-c (West of Ireland)	WGCSE	6.20	PA
gur.27.3-8	Red gurnard (*Chelidonichthys cuculus*) in subareas 3-8 (Northeast Atlantic)	WGWIDE	6.20	PA
rng.27.1245a8914ab	Roundnose grenadier (*Coryphaenoides rupestris*) in subareas 1, 2, 4, 8, and 9, Division 14.a, and in subdivisions 14.b.2 and 5.a.2 (Northeast Atlantic and Arctic Ocean)	WGDEEP	6.20	PA
bss.27.6a7bj	Sea bass (*Dicentrarchus labrax*) in divisions 6.a, 7.b, and 7.j (West of Scotland, West of Ireland, eastern part of southwest of Ireland)	WGCSE	6.20	PA
sol.27.7bc	Sole (*Solea solea*) in divisions 7.b and 7.c (West of Ireland)	WGCSE	6.20	PA
whg.27.6b	Whiting (*Merlangius merlangus*) in Division 6.b (Rockall)	WGCSE	6.20	PA
agn.27.nea	Angel shark (*Squatina squatina*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
bsk.27.nea	Basking shark (*Cetorhinus maximus*) in Subareas 1-10, 12 and 14 (Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
sbr.27.6-8	Blackspot sea bream (*Pagellus bogaraveo*) in subareas 6-8 (Celtic Seas, the English Channel, and Bay of Biscay)	WGDEEP	6.30	PA
rjb.27.67a-ce-k	Common skate (*Dipturus batis*-complex flapper skate (*Dipturus* cf. *Flossada*) and blue skate (*Dipturus* cf. *intermedia*) in Subarea 6 and divisions 7.a-c and 7.e-k (Celtic Seas and western English Channel)	WGEF	6.30	PA
rjb.27.3a4	Common skate (*Dipturus batis*-complex) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	WGEF	6.30	PA
sck.27.nea	Kitefin shark (*Dalatias licha*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
guq.27.nea	Leafscale gulper shark (*Centrophorus squamosus*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
pra.27.4a	Northern shrimp (*Pandalus borealis*) in Division IVa (Northern North Sea, Fladen Ground)	NIPAG	6.30	PA
nop.27.6a	Norway pout (*Trisopterus esmarkii*) in Division 6.a		6.30	PA
ory.27.nea	Orange roughy (*Hoplostethus atlanticus*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGDEEP	6.30	PA
por.27.nea	Porbeagle (*Lamna nasus*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
cyo.27.nea	Portuguese dogfish (*Centroscymnus coelolepis, Centrophorus squamosus*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
rhg.27.nea	Roughhead grenadier (*Macrourus berglax*) in subareas 5-8, 10, 12 and 14 (Northeast Atlantic and Arctic Ocean)	WGDEEP	6.30	PA
tsu.27.nea	Roughsnout grenadier (*Trachyrincus scabrus*) in subareas 1-2, 4-8, 10, 12, 14 and Division 3a (Northeast Atlantic and Arctic Ocean)	WGDEEP	6.30	PA
rng.27.3a	Roundnose grenadier (*Coryphaenoides rupestris*) in Division 3.a (Skagerrak and Kattegat)	WGDEEP	6.30	PA
san.27.6a	Sandeel (*Ammodytes* spp.) in Division 6.a (West of Scotland)	HAWG	6.30	No advice
thr.27.nea	Thresher sharks (*Alopias* spp.) in Subareas 10, 12, Divisions 7.c-k, 8.d-e, and Subdivisions 5.b.1, 9.b.1, 14.b.1 (Northeast Atlantic)	WGEF	6.30	PA
usk.27.12ac	Tusk (*Brosme brosme*) in Subarea 12, excluding Division 12.b (southern Mid-Atlantic Ridge)	WGDEEP	6.30	PA
rju.27.8c	Undulate ray (*Raja undulata*) in Division 8.c (Cantabrian Sea)	WGEF	6.30	PA

2017 Stock Key Label	**2017 Stock Description**	**EG**	**2017 ICES Data Category**	**Advice Type**
rju.27.7bj	Undulate ray (*Raja undulata*) in divisions 7.b and 7.j (west and southwest of Ireland)	WGEF	6.30	PA
rja.27.nea	White skate (*Rostroraja alba*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	WGEF	6.30	PA
raj.27.3a47d	Rays and skates (*Rajidae*) in Subarea 4 and in divisions 3.a and 7.d (North Sea, Skagerrak, Kattegat, and eastern English Channel)	WGEF	6.90	PA
raj.27.67a-ce-h	Rays and skates (*Rajidae*) in Subarea 6 and divisions 7.a-c and 7.e-h (Rockall and West of Scotland, southern Celtic Seas, western English Channel)	WGEF	6.90	No advice
rju.27.9a	Undulate ray (*Raja undulata*) in Division 9.a (Atlantic Iberian waters)	WGEF	6.90	PA
rju.27.8ab	Undulate ray (*Raja undulata*) in divisions 8.a-b (northern and central Bay of Biscay)	WGEF	6.90	PA

Annex 8: Recommendations

Recommendation	For follow up by:
It is recommended by WKLIFE VII that there be an eighth meeting of WKLIFE in Lisbon, Portugal 8-12 October 2018whose ToRs should be discussedby ACOM at their November 2017 consultation meeting and agreed intersessionally.	ACOM
Early in 2018, convene an ICES Workshop on DLS short-lived species that addresses both assessment methods; e.g. seasonal SPiCT, and long-term management strategy evaluations; building on the work of WKLIFE VII. Two co-chairs are recommended (Rasmus Nielsen, Denmark and ANOTHER to be identified). It is suggested that the workshop focus on the five stocks identified by WKLIFE VII in Section 5.1 of their report. After WKLIFE VII it was decided that the best approach is to hold this in parallel with WKLIFE VIII in October 2018.	ACOM
The approaches to estimation of reference points for Nephrops stocks have evolved since their inception at the first Nephrops Benchmark group in 2010. This evolution has occurred, through necessity, mainly around the working groups (WGNSSK and WGCSE) but has not been subject to dedicated scrutiny. Attempts to determine reference points for stocks during the 2016 Nephrops Benchmark meeting highlighted some potential issues with the approach that could not be satisfactorily resolved, and it is now apposite to undertake a detailed review of the methods used to determine MSY reference points for Nephrops stocks. There are now multiple stocks with both UWTV surveys and reference point estimation covering several years and a wide geographic range within the ICES area, and a meta-analysis of the performance of the reference point setting would seem appropriate. In addition, the data situation; i.e. low confidence in reported landings, that occurred for many stocks prior to 2006 is now considered to have been resolved and therefore the scope for dynamic population assessment models may now have become more feasible. It is recommended that a workshop be convened early in 2018 at which the following are explored: a. The historical performance of the existing reference points, including detection of systematic bias. b. Data-limited and non-parametric reference points. c. Performance of dynamic assessment models.	ACOM