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Workshop on guidelines and methods for the evaluation of rebuilding plans (WKREBUILD)

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WORKSHOP ON GUIDELINES AND METHODS FOR THE EVALUATION OF REBUILDING PLANS (WKREBUILD)

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WORKSHOP ON GUIDELINES AND METHODS FOR THE EVALUATION OF REBUILDING PLANS (WKREBUILD)

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Contents

i Executive summary

The Workshop on guidelines and methods for the evaluation of rebuilding plans (WKREBUILD) chaired by Vanessa Trijoulet (Denmark) and Martin Pastoors (Netherlands) met from 24 to 28 February 2020. The workshop attracted 27 participants from the US, Canada, Europe and FAO.

When stocks are estimated to be below B_{lim}[1] and there is no perceived possibility of rebuilding above B_{lim} within the time-frame of a short-term forecast, ICES has regularly recommended zero catch in combination with the development of a rebuilding plan.

A review was carried out on the international experience on the development, evaluation and implementation of rebuilding plans for fisheries management in the Northeast Atlantic and in other fora around the world. In the Northeast Atlantic, rebuilding plans have been implemented in the past (e.g. the cod recovery plans of the early 2000s) but ICES has played a limited role in evaluating the performance of such recovery plans and does not have the tools or criteria to evaluate such plans. Recently, when a rebuilding plan for herring in 6.a 7.bc was submitted to ICES for evaluation, ICES refrained from providing such an evaluation. In the US and Canadian approaches, the legal framework determines the triggering and required elements of rebuilding plans. Such a legal imperative does not exist in the Northeast Atlantic. Nevertheless, the US and Canadian experiences provided useful elements that could be included in establishing ICES approach to rebuilding plans.

Several case studies were presented on potential tools for the evaluation of rebuilding plans. Particular attention was given to evaluating options for harvest control rule options of such a plan. The tools focused mostly on short to medium term explorations of the probability of achieving a rebuilding of stocks. Because rebuilding plan evaluations need to be ready and available at short-notice when required, it was concluded that relatively standardized tools (i.e. packages or compiled code) to carry out such evaluations would be preferable over custom-made evaluation tools. In addition, certain modelling considerations were highlighted as important such as realistic assumptions of productivity, uncertainty, bias in assessments and implementation error and the possibility of estimating the probability of achieving a rebuilding of stocks.

Criteria for the acceptability of rebuilding plans will require an agreed Limit Reference Point (LRP) for initiating a rebuilding plan, definition of targets for fishing mortality or stock biomass, time-frames and the acceptable probabilities whether the rebuilding targets have been achieved. All of these should take into account realistic levels of uncertainty and being consistent with international best (scientific) practices. Although it was recognized that B_{lim} would be the most likely candidate LRP triggering a rebuilding plan, the current approach in ICES for the determination of B_{lim} was questioned during the workshop because it requires a more or less subjective classification of the stock-recruitment pairs into different types. In other regions, the LRP is often set as a certain proportion of the SSB at maximum sustainable yield (B_{MSY}), e.g. 40% B_{MSY}. If changes in productivity have been experienced in recent years at these are taken into account when estimating MSY reference points, the proportion of B_{MSY} approach would likely lead to greater changes in the estimated value of LRP than the current ICES procedures used to estimate B_{lim}, which rely on stock-recruitment pairs or definition of the lowest observed biomass (B_{loss}). This could have a large impact on the rebuilding target for stocks that experience changes in productivity regimes. Some concerns were raised regarding the often small distance between B_{lim} and MSY $B_{trigger}$[2] reference points for ICES stocks in comparison to

[1] Limit reference point for spawning stock biomass (SSB) below which a stock is considered to have reduced reproductive capacity.

[2] Trigger reference point for SSB. The point at which F is reduced when applying the ICES MSY advice rule (AR).

the distance between trigger and limit in other jurisdictions. MSY $B_{trigger}$ could therefore represent a late trigger to start decreasing fishing mortality when SSB is decreasing. The workshop recommended a future workshop on the revision of the procedure to estimate reference points within the ICES framework.

An estimate of the minimum time (T_{MIN}) by which rebuilding may be expected to be achieved, could be calculated by assuming zero catch and should be used as baseline for comparison with other rebuilding scenarios. The maximum time for rebuilding in the US and New Zealand is set to $T_{MAX} = 2 * T_{MIN}$ or to T_{MIN} plus one generation time[1] (average length of time between when an individual is born and the birth of its offspring NRC (2014)). While the workshop did not arrive at an overall agreement on a default value for T_{MAX}, it was suggested that $T_{MAX} = 2 * T_{MIN}$ could be explored as a potential bounding on the rebuilding period, even though this should be subject to scientific analysis of potential effects on the stock in question.

The workshop generated a guidance table summarizing the best practices for evaluation of rebuilding plans against the potential criteria of acceptability. The guidance table includes elements such as estimation of reference points, time-frames for rebuilding, rebuilding targets, handling uncertainties and bias, probability of achieving rebuilding targets and visualizing results. The workshop recommended that a follow-up workshop (WKREBUILD2) be organized for testing the guidelines with actual test cases, with the aim of defining more specific criteria and guidelines, i.e. learning by doing.

Some of the elements that were discussed in the workshop but that have not (yet) entered the guidelines for evaluation of rebuilding plans are socio-economic trade-offs (e.g. between fast and slow rebuilding), mixed fisheries aspects (e.g. unavoidable bycatch due to mixed fisheries) and elements in rebuilding plans other than the HCR part (e.g. monitoring to improve the knowledge base).

Most of the discussion at WKREBUILD was centred on stocks with analytical assessments (Category 1+2). Identifying when a data limited stock is in need of rebuilding (or has rebuilt) and how to evaluate rebuilding plan options for such stocks would likely require a separate process.

[1] Please note various definitions of generation time exist in the literature. When generation time is mentioned in the report, please refer to the reference given to get its specific definition.

ii Expert group information

Expert group name	Workshop on guidelines and methods for the evaluation of rebuilding plans (WKREBUILD)
Expert group cycle	Annual
Year cycle started	2020
Reporting year in cycle	1/1
Chair(s)	Vanessa Trijoulet, Denmark
	Martin Pastoors, The Netherlands
Meeting venue(s) and dates	24-28 February 2020, Copenhagen, Denmark (27 participants)

1 Introduction

The Workshop on Guidelines and Methods for the Evaluation of Rebuilding plans (WKREBUILD) took place at the ICES Headquarters in Copenhagen, Denmark from 24 February (13:00) until 28 February (13:00) 2020.

Background

ICES regularly recommends rebuilding plans in combination with zero TACs for the next year, especially when stocks are estimated to be below B_{lim} and there is no perceived possibility of rebuilding above B_{lim} within the time frame of a short-term forecast (2 years). While there has been ample attention in ICES to the guidelines and methods for carrying out Management Strategy Evaluations that are applicable in the long-term (e.g. WKGMSE2 2019), there are no agreed methods or guidelines on evaluating rebuilding plans.

Recently, rebuilding plans have been recommended by ICES for a number of herring stocks (Celtic Sea herring, western Baltic spring-spawning herring, herring in 6.a and 7.b-c). This poses a challenge for ICES given the requirement to evaluate such plans and their potential to achieve a form of rebuilding that would be consistent with the precautionary approach.

The ICES WKGMSE2 guidelines (2019) touched on the issue of rebuilding plans but did not address the technical and advisory implications. The specific feature of evaluation of rebuilding plans is that they tend to focus on the short-term perspectives, and thereby the starting conditions, while MSEs tend to focus on the longer term.

Rebuilding plans can be considered as a special case of the more generic management plans or management strategies. Rebuilding plans are applicable in cases when a stock or stocks are perceived to be in a poor state, which would require remedial actions to recover the stock to some predefined state or at least to take actions to reduce the negative impacts on the stock. A rebuilding plan could be developed by the relevant management authorities or affected stakeholders, or a combination of the two.

ICES recommendations for zero TACs when stocks fall below B_{lim}, possibly in combination with the recommendations to develop a rebuilding plan, take place within the realm of scientific advice. The ICES MSY advice rule (AR), that is often used as the basis for single stock advice and is accepted by recipients of the advice, is a kind of a hybrid between a management plan and an advisory product because it defines specific management actions based on scientifically defined reference points. Since the introduction of the AR in 2011, ICES has indicated that additional conservation measures may be recommended to prevent further stock decline for stocks that are estimated to be below B_{lim}. In 2013 ACOM has added a specific interpretation of the MSY advice "*If the stock is below B_{lim}, ICES advice is based on bringing the stock above B_{lim} in the short-term. This may result in advice of zero catch*". In 2018 this was modified to "*If the F following from applying rule 2 [ICES AR] is insufficient to bring the stock above B_{lim} in the short-term ICES advice will be based on bringing the stock above B_{lim} in the short-term. This may result in advice of zero catch*". In such situations ICES will recommend a zero-TAC for the next year.

Terms of reference (ToR)

a) Review the history of scientific advice, evaluation and implementation of rebuilding plans for fisheries management in the Northeast Atlantic and in other fora around the world.

b) Evaluate technical tools that are available or could be developed for evaluating the performance of different types of rebuilding plans. Take into account the work of WKGMSE2 (2019) on characterizing relevant uncertainties and bias.

c) Develop guidelines for the evaluation of rebuilding plans that take into account the precautionary approach, the species life history (incl. longevity), changes in productivity and rebuilding potential.

d) Propose criteria for the acceptability of rebuilding plans including rebuilding target, time and probability that would be consistent with international best practices.

Structure of the report

The report is essentially structured around the four Terms of Reference that have been set for WKREBUILD.

Chapter 2 deals with the review of the history of scientific advice and evaluation and implementation of rebuilding plans (ToR a).

Chapter 3 deals with the technical tools available for the evaluation of rebuilding plans (ToR b).

Chapter 4 deals with the criteria for acceptability of rebuilding plans (ToR d)

Chapter 5 deals with the guidelines for evaluation of rebuilding plans (ToR c), taking into account all the previous chapters.

Chapters 6 and 7 deal with the recommendations and references.

The list of participants and Annexes can be found at the end of the report.

2 Review of rebuilding plans in different jurisdictions

ToR a) Review the history of scientific advice, evaluation and implementation of rebuilding plans for fisheries management in the Northeast Atlantic and in other fora around the world.

2.1 Summaries of presentations

2.1.1 ICES experience with rebuilding plans

Colm Lordan, ICES

ICES gives advice consistent with recipients' needs and various international agreements as outlined in the introduction to the advice (ICES, 2019). ICES gives zero catch advice on two categories of stocks; depleted commercial exploited stocks and stock in need of conservation (these are often very data limited and may not have assessments). The basis for B_{lim} was discussed and the ICES Advice Rule was explained. ACOM reviewed its procedures when a stock is below B_{lim} in 2018. This review concluded that unless a stock can be rebuild above B_{lim} by the end of the short-term forecast (typically 2 years) then ACOM should recommend zero catch. However, ACOM recognises that:

- **Stocks may decline below B_{lim} through overfishing, or unfavourable environmental conditions, or a combination of both.**
- **Removals from stocks below B_{lim} can be advised but require greater caution.**
- **Recovery potential should be fully examined through stochastic projections**

Below B_{lim}, risk of irreversible harm is increased and the dynamics of populations at very low stock levels are not well understood. ICES has advised zero catch for around 14 "commercial stocks" since 2007 including several cod stocks, herring, hake, whiting, *Nephrops*, plaice, sole and sandeels. Often ICES will recommend rebuilding plans in the advice sheet. Rebuilding plans need to involve scientists as risk assessors, managers as risk managers and require an interactive engagement and information exchange about the known and unknown risks. While ICES has given recent advice on a rebuilding plan for Bay of Biscay sardines (cf. part 3.1.5) there are few cases where ICES has given advice on rebuilding plans and in the past this has been problematic due to the lack of evaluation criteria (e.g. 6.a herring).

There are a number of examples of successful rebuilding plans in the ICES area, notably for Northern Hake. The cod recovery plan and long-term management plans did reduce fishing mortality for North Sea, Irish Sea and West of Scotland cod stocks although F is estimated to have increased in recent years again. In recent years, ICES has received few special requests on rebuilding plans and has struggled to evaluate these due to the lack of agreed guidelines e.g. 6.a herring. There has been a number of special requests for "monitoring TACs" and also request on "unavoidable bycatch" levels for zero TAC stocks. It is important to consider the policy and legal context and obligations when a stock falls below B_{lim} (e.g. Common Fisheries Policy (CFP) regulation and EU Multi-Annual management Plans (EU-MAPs)). Post recovery procedures are also needed, typically once a stock is above B_{lim} ICES will use its advice rule as the basis of the advice. We have seen examples of where stocks like Irish Sea cod have declined after a short lived rebuild.

2.1.2 Historical overview of ICES advice on rebuilding plans

Martin Pastoors, PFA

A short text analysis has been carried out on the individual ICES advice documents from 1999 until 2019, searching for the keywords "rebuilding plan" or "recovery plan". The analysis was carried out in R using the package Pdfsearch. All individual pdf files were read into R, all line feeds were replaced by a space and then the position of the "history of the advice" table was identified and a search was carried out for one of the two key words. This resulted in the following number of documents in which the keywords had been used (Figure 2.1):

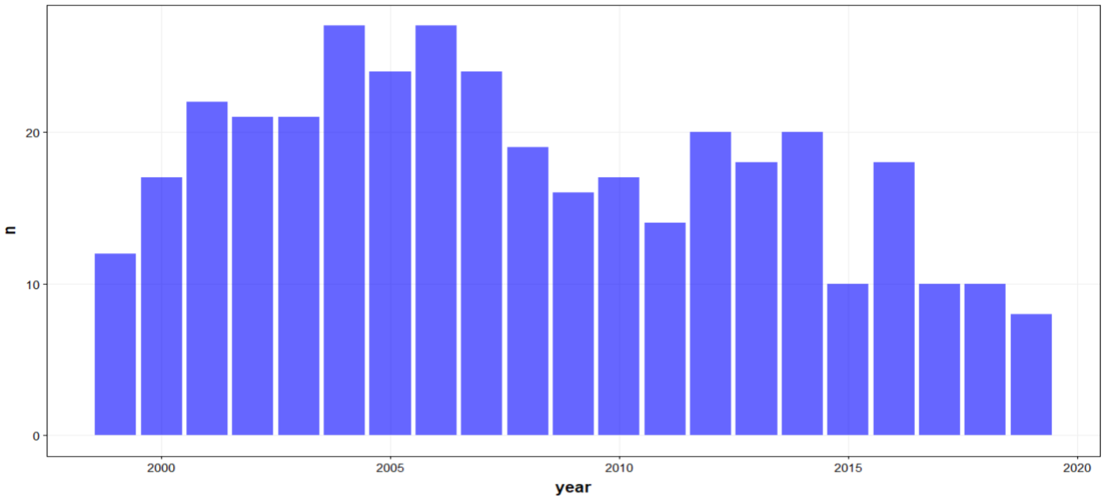

Figure 2.1: Number of ICES advice mentioning "rebuilding plan" or "recovery plan" in 1999-2019.

A subdivision into number of mentions by species (and document) is in Figure 2.2, indicating that recovery plans are mostly mentioned in connection with cod, haddock, herring, *Nephrops*, plaice, sole and whiting. The specific mentions to rebuilding plans or recovery plans changed over time, from generic statements in the late 1990s (e.g. Irish Sea cod, 1999: "a recovery plan should be developed and implemented in order to rebuild SSB above B_{pa} (stock status reference point above which the stock is considered to have full reproductive capacity, having accounted for estimation uncertainty) as soon as practical"), to more specific language in the early 2000 (e.g. Irish Sea cod, 2003: "Such a recovery plan should include a provision for zero catch until the estimate of SSB is above B_{lim} or other strong evidence of recovery is observed"). Since 2018, there is a new interpretation of the ICES advice rule that specifies that if the stock is estimated to be below B_{lim} and where the stock cannot be rebuilt to B_{lim} in the time period of the short-term forecast, that a zero catch will be recommended.

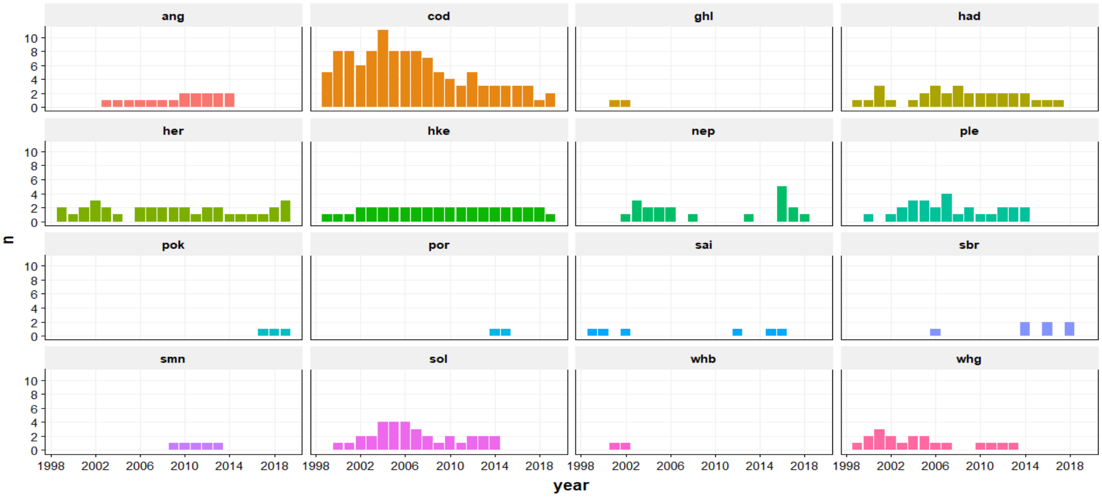

Figure 2.2: Number of ICES advice mentioning "rebuilding plan" or "recovery plan" in 1999-2019 by species.

2.1.3 WKGMSE2 Guidance relevant to rebuilding plans

David Miller, ICES

ICES regularly evaluates management strategies and gives advice on their performance. The "Study Group on Management Strategies" (SGMAS) prepared a set of guidelines in 2008 (ICES, 2013a), which were reviewed and updated by the "Workshop on Guidelines for Management Strategy Evaluations" (WKGMSE) in 2013 (ICES, 2013b). ICES set up the "second Workshop on Guidelines for Management Strategy Evaluations" (WKGMSE 2; ICES, 2020a) in 2019 which further developed this guidance and produced some Condensed MSE guidelines (WKGMSE2 Condensed Guidelines). The guidelines are intended to guide the decisions based on best practice throughout the evaluation. Following or deviating from the guidelines should be appropriately motivated.

The term "Management Strategy" here is used to refer to the combination of monitoring, assessment, harvest control rule and management action designed to meet the stated objectives of a fishery. In this sense, many of the items considered are relevant for the evaluation of rebuilding strategies, though criteria to measure performance would be different.

In its role as a 'reviewer' of HCR options (whether for rebuilding or otherwise), ICES needs both:

1. Criteria for how to evaluate their appropriateness i.e. what are the performance objectives? (TOR (d) of WKREBUILD)
2. Guidance on best practice for how to simulate (or qualitatively) evaluate performance against these criteria (TOR (c) of WKREBUILD)

In addition to this, some guidelines on the ICES MSE process were considered in WKGMSE2.

Guidance on performance criteria

The ICES Technical Guidelines on Criteria for defining multi-annual plans as precautionary (ICES, 2016a) is used as the basis for determining whether or not evaluated HCRs could be considered precautionary. In general the probability that SSB is less than B_{lim}, P(SSB < B_{lim}), should be no more than 5% over all years included in the management strategy (short- and long-terms). There are currently no agreed criteria specific to establishing rebuilding plan recovery time. Since a rebuilding plan starts from a non-precautionary situation by definition, it does not pass this precautionary standard. In these situations it is more logical to judge a recovery plan according to its ability to deliver SSB recovery within a certain time frame (pre-specified year) that is appropriate for that stock (e.g. for a stock with around 5-10 cohorts in the fishery 5 years from the start of the plan). In such cases, the precautionary requirement can be evaluated for the period after the recovery phase and different options to recover the stock can be evaluated as well.

When stocks are already below B_{lim} a dialogue is required between scientists, as risk assessors, and policy makers, who have the competency for risk management. The trade-off between the level of acceptable risk and the time frame to recovery above B_{lim} is a management decision.

The WKGMSE2 guidelines (Section 4) discusses various definitions of risk, and time frames to consider. But in the case of rebuilding plans, the focus will tend to be on looking at annual probabilities of SSB< B_{lim} (during recovery and at a pre-specified recovery year), rather than averaging over time periods, so these different definitions are not relevant. However, there is guidance on the number of iterations needed in simulations to provide adequate estimates of P(SSB < B_{lim}) (Section 4.3). It is recommended that the relevant risk measure used in the analysis be plotted against iteration number to get an understanding of how many iterations are required for the computation to stabilize in an area where conclusions can confidently be drawn.

Guidance on simulation testing of management plans

Section 3 of WKGMSE2 provides guidelines for simulation studies evaluating HCRs.

ICES is attempting to reconcile terminology used in simulation testing harvest strategies that currently varies between regions. WKGMSE2 suggested using a glossary of terms commonly used in MSE that was compiled by the Joint Tuna RFMO Management Strategy Evaluation Working Group to improve consistency and clarity of communication in MSE processes (Anon, 2018). The term 'Management Strategy' refers to the combination of monitoring, assessment, harvest control rule and management action designed to meet the stated objectives of a fishery. A 'Management Strategy' may be designed for optimal performance for healthy stocks, or for recovery of stocks in poor condition.

A Management Strategy Evaluation (MSE) simulation procedure is composed of different components (Figure 2.3). These different components of simulation evaluations are equally applicable to MSEs for rebuilding stocks as they are for healthy stocks. Simulations may include full feedback loops where the annual assessment and forecasts procedures are simulated or may follow a quicker short-cut form where assessment/forecast error is estimated at each step. Advantages of the shortcut approach compared to the full MSE are that it is faster, simpler, and more robust in certain circumstances. This can facilitate stakeholder interaction when time to make decisions is important, as is the case for rebuilding plan evaluations. However, WKGMSE2 recommends full MSE to be preferable to the shortcut approach when there is a need to evaluate if the management procedure can handle mismatches between the biological and assessment models. If the shortcut approach is considered to be necessary in order to facilitate investigation of a range of plausible stock and fishery scenarios, then simulation studies as described by Weidenmann et al. (2015) can help to match the patterns of errors of the actual assessment model. Such an approach could provide evidence that the shortcut method provides an acceptable approximation to the behaviour of the actual stock assessment model.

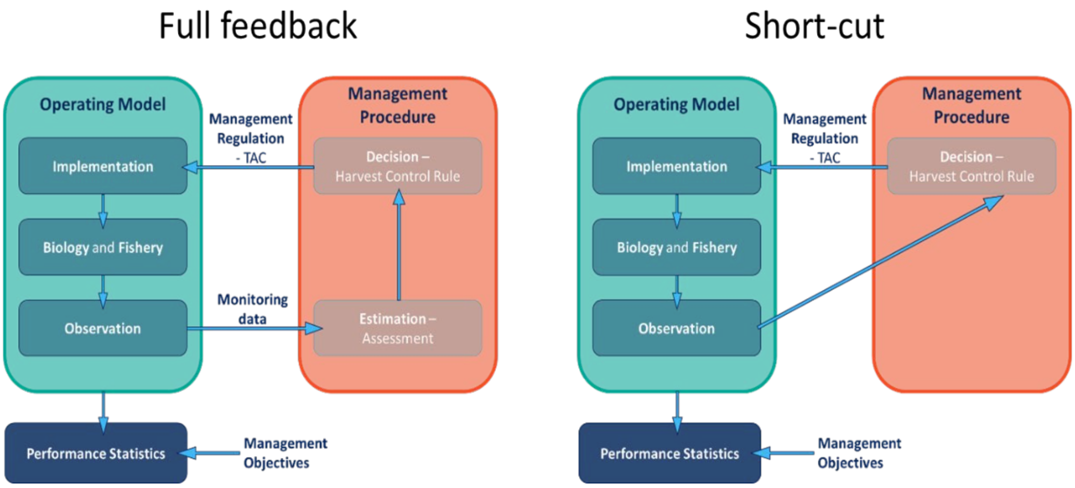

Figure 2.3: A conceptual overview of the MSE modelling process (following Punt et al., 2016).

MSE simulations are normally parameterized based on the current (or historically observed) ecosystem, biological and fishery state, and results are only valid under the conditions simulated in the operating models. Care should be taken with extrapolating into stock states beyond what has been observed recently or in the historical data. This is often the case in rebuilding evaluations, since stocks may have never been at such low levels in the past. The risk of unquantified errors in such situations increases. When a stock is estimated to have biomass levels below B_{lim}, specification of this region of the harvest control rule should be better explored. This would include taking account that there is a high risk of recruitment impairment below B_{lim}. The reliability of MSE results is dependent on having properly characterised the existing uncertainty.

Key elements of this are growth, recruitment, natural mortality and sexual maturation, as well as fisheries selectivity (covered in Section 3.3 of WKGMSE2). Key uncertainties in the conditioning process can be explored using a number of alternative operating models, which can be developed to evaluate the effects of deviations from the baseline model.

For rebuilding plan evaluations, recruitment (choice of SRR, temporal dynamics, regime shifts) is a key consideration. The minimum standard is a single stochastic stock-recruit model to reflect potential variability. Accounting for temporal dynamics (e.g. autocorrelation, periodicity and occasional extreme values) is also important, and metrics to show the appropriateness of the modelled dynamics to those historically observed should be presented. The issue of regime shifts is related to the classic dilemma between having a long time series of data and a large dynamic range, versus considering a (fairly) constant ecosystem regime existing only for a shorter time. For the purpose of evaluating management strategies, one guideline may be that the strategy should work well under a plausible range of future productivity regimes, and that it should cope with the kind of changes in productivity regimes that have been encountered in the past.

MSEs are generally run contingent on the current situation in terms of fishery selection at age e.g. based on recent stable representative periods (e.g. recent 3, 5 or 10 years). Fishery dynamics change over time and it may be unlikely that such changes are reversed. However, simulating changes in fishery selectivity may require more consideration when a stock is at very low levels. Fishery behaviour (e.g. timing/duration/location of fishing) may change as fewer vessels or only a certain component of the fishery continues to operate.

The guidelines also cover important validation checks that should be conducted to ensure that the model describes the real system realistically enough for the intended purpose (Section 3.7

of WKGMSE2). The available tools are very diverse, from informal tools based on consultations with experts to formal tools based on mathematical methods like inference or induction. Balci (1997) provides an exhaustive list of the methods available to validate models. Global sensitivity analysis (Saltelli et al., 2008), for example, is a useful tool to validate models and it is a recommendation by the European Commission in the implementation of impact assessment of management plans. Reality checks are also very important to increase confidence in the suitability and plausibility of the assumptions made in the MSE. It is good practice to run the MSE with perfect knowledge, and compare this with the management decision model including observation and assessment error to check the impact of the errors. It may be that the management strategy is not precautionary even under perfect knowledge.

An implementation model (Section 3.6 of WKGMSE2) should account for the effects of differences between the intended pattern of removals derived from the harvest rule and the actual removals. Such differences can be caused by variable discarding practices, misreported catch, the implementation of different catch share management systems, bycatch in other fisheries not regulated by the TAC, or un-modelled fleet behaviour. In the case of rebuilding stocks, implementation error could take on a form that is not easily explained by random or unbiased variation. There could be numerous stock/fishery specific implementation error scenarios that could be examined if a more 'realistic' fishing fleet behaviour needs to be simulated e.g. for stocks caught as bycatch in mixed fisheries there may a minimum F (or catch) that could be expected, or for stocks where fleets may have alternative target species TACs that are too low may not be caught at all as they are economically unviable and the fleet switches to another fishery. The extent to which assumptions shall be made about over-fishing (or under-fishing) of quotas is an open question that may have to be clarified with the managers.

The WKGMSE2 guidelines also contain some considerations for confounding between variables or correlated processes, and ecosystem, biological and technical interactions (Sections 3.3.7 and 3.3.8).

Guidance on decision model components

The decision model uses the assessment results, or directly the generated data, to produce the management action to be taken in response to the perceived status of the stock and fishery, according to a pre-determined process. Generally, a harvest control rule (HCR) will be applied to establish a level of removals (TAC) from the population. HCRs may simply be constant F or catch F regimes, or may specify F or catch to be applied at a given stock biomass. They may include stabilizing terms, which modify the 'primary' TAC by constraining the change in TAC from year to year, and other modifying terms, for example a fixed maximum and/or minimum TAC.

The duration of the decision/advice is most often one year, but it can be longer (or shorter). Long intervals between decisions may be combined with a gradual change of the TAC during the interval. This can be relevant in for example, rebuilding situations, where a very large reduction of the TAC is seen as necessary but hard to implement in a single year.

Guidance on process

WKGMSE2 guidelines (Section 5) state that involving all the players (Advisory Councils (ACs), managers, policy makers, scientists etc.) in the MSE process from the earliest stage is important to underpin the legitimacy and saliency of the result. It is important that there is a common and detailed understanding of what the request from managers actually means and what should be done by those scientists trying to answer the questions asked. The process should encourage representative participation from the stakeholders to ensure that all affected and interested parties are represented across relevant ethnic, cultural and social groups.

However, in practice ICES often receives already developed management plans (potential designed based on ICES assessments and advice) and is simply asked to evaluate the proposed HCR(s) (Figure 2.4). To ensure the MSE process can accommodate and respond to information that comes from managers and identified stakeholders, workshops are open to a range of participants and the ICES secretariat maintains contact with the requesters of advice (managers). In the case of rebuilding plans, a thorough discussion and agreement of recovery targets would be necessary to evaluate the performance of candidate recovery HCRs.

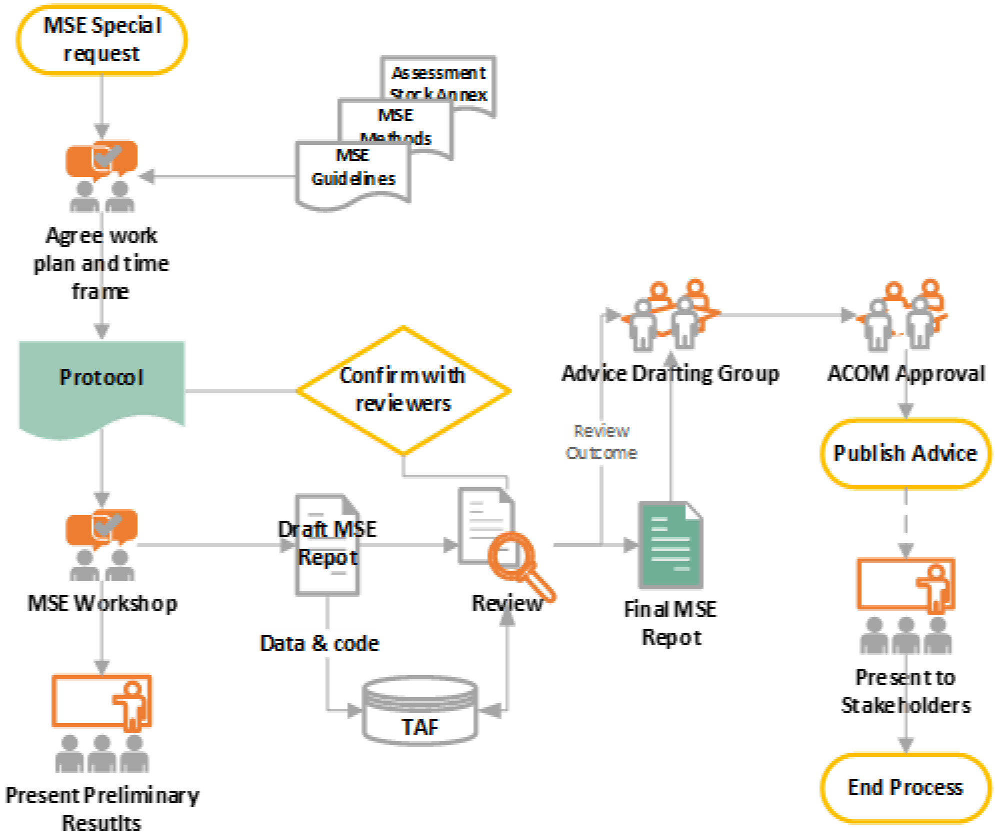

Figure 2.4: Workflow for standard ICES MSE process.

Future work

The third Workshop on guidelines for management strategy evaluations (WKGMSE3) will meet in 2020. This group will seek to provide further guidance on, amongst other items:

- When and how reference points should be extracted from an MSE when one is conducted, i.e. address the situation where there is a mismatch between reference point and current assumed stock productivity.
- How to use the results from alternative operating models in the reference set examined.
- Explore the relationship between the estimated P(SSB< B_{lim}) and assumed levels of uncertainty included in the MSE including the impacts of
    - The number of replicates and length of projection period used in the MSE;
    - The stationarity of MSE projections, from which risk metrics are calculated;

    - The risk metric itself (e.g. several definitions are given in the WKGMSE report of 2019).
- Providing guidelines for use of short-cut or full MSE approaches.

The Workshop on MSE development (WKMSEDEV) will also be held in 2020 to address more technical issues in the simulation evaluation of HCRs. The WK aims to allow developers to compare the different MSE tools under development in different regions around the world and identify areas where collaboration between development teams could be beneficial. They will produce a catalogue of different MSE tools available, with the different areas of emphasis described for each.

2.1.4 FAO Rebuilding plan review

Yimin Ye, FAO

See section 2.6

2.1.5 The US approach to rebuilding plans

Rick Methot, NOAA

See section 2.3

2.1.6 The Canadian approach to rebuilding plans

Brittany Beauchamp, DFO

See section 2.4

2.1.7 The experience with rebuilding plans in NAFO

Neil Campbell, Marine Scotland Science

See section 2.5

2.1.8 The struggle with Western horse mackerel evaluations

Martin Pastoors, PFA

An overview is presented of the attempt to develop a management plan for Western horse mackerel in the ICES area. After an initial egg-survey based management rule had been agreed and evaluated in 2008, the management plan was called into question in 2011 which lead to the statement by ICES in 2014 that the plan was no longer precautionary. In the years 2014-2015, CEFAS and the Marine Institute were commissioned by the Pelagic Regional Advisory Committee to evaluate potential new management plans. The SAD assessment that was used to assess the stock in those years, and that underpinned the MSEs for Western horse mackerel, was so uncertain, that the results were that in the case of no-fishing, the stock was expected to increase, but the uncertainty in the stock was also increasing, to the effect that **the probability of being below B_{lim} was larger than 5% for the next 40 years to come**. Apparently, the framing of those MSEs could not resolve to a meaningful and acceptable management plan.

A second iteration occurred after the stock had been benchmarked in 2017 and was using the Stock synthesis model for the assessment. A proof-of-concept full-feedback MSE was commissioned with Landmark Fisheries Research, Canada using the methods described by Cox et al. (2013). The evaluations were directed at different fishing strategies, also when the biomass would fall below B_{lim}. The results of the analysis (Cox et al., 2018) demonstrated a clear recovery potential of the stock under different fishing scenarios, mostly dependent on the recruitment assumptions and the target fishing mortality. However, the starting conditions of the simulated populations did not include uncertainty, and therefore the behaviour of the MSE may have been estimated too positively.

For a final iteration of the management plan, it was anticipated to use the guidelines from WKGMSE2 and WKREBUILD to plan for the next step in the development of the management plan. This will be carried out in the near future.

2.1.9 Review of some key concepts of Fishery rebuilding

Ashleen Benson, Landmark Fisheries Canada

Uncertainty and variability in definitions of stock status

Policies such as Canada's Sustainable Fisheries Framework (SFF; DFO PA Framework; DFO, 2009a, 2013) and the Magnuson-Stevens Act in the US treat concepts such as the Limit Reference Point (LRP), the maximum sustainable yield (MSY) as clearly defined, measurable quantities. In reality, they are theoretical constructs used to identify average harvest rates and stock sizes that a population can sustain, and vary based on the type of fishery, state of the environment, background of the scientists and managers, and goals of those involved in the fishery (Beamish et al., 2006; Cox et al., 2013; Kronlund et al., in press; NRC, 2014). These concepts were designed for and work best in data-rich fisheries. Rudimentary reference points and proxies such as trends in CPUE indices or average length are used in data-poor fisheries (NRC, 2014). Proxies are similarly used to define depletion and overfishing in data- poor stocks. Examples include declines in growth and recruitment, truncated age structure, and loss of economic value (Beamish et al., 2006). The operational definitions of "overfishing" and "overfished" can thus vary substantially and lead to inconsistent application of rebuilding policies and management plans by nation, region, and species (NRC, 2014).

In additional to variable definitions of stock status, a review of US rebuilding plans found a high probability of error in the designation of stocks as overfished, resulting from both uncertainty in the specification of a threshold for action and the determination of whether the stock has dropped below the threshold (NRC, 2014). Such scientific uncertainty can lead to stocks incorrectly being declared overfished (e.g. Pacific widow rockfish in the US; Milazzo, 2012). Error in specification of stock status can lead to abrupt, often disjointed changes in management that can amplify errors in subsequent assessments of status (Benson et al., 2016; NRC, 2014). This is a particular problem in fisheries managed using rigid rebuilding frameworks. **Management approaches that are based on a smooth response to changes in stock biomass (gradual reduction in fishing mortality when the stock is depleted) have proven to be more robust to errors in stock assessment and calculation of thresholds and LRPs** (NRC, 2014).

Approaches to rebuilding:

a. Rebuilding via a schedule of biomass

The National Marine Fisheries Service (NMFS) uses a pre-specified framework to ensure that overfished stocks are rebuilt to biomass levels consistent with MSY in 'as short a time as possible". Under this approach, populations that are estimated to be able to rebuild in 10 years in the absence of fishing are required to do so. Populations that cannot meet this time frame must rebuild within a period of time no longer than the rebuilding time with no fishing (T_{MIN}) plus one generation (Wetzel and Punt, 2016). The NMFS system has created discrepancies in rebuilding plans for short and long-lived species that is viewed by many to be unfair and arbitrary (Benson et al., 2016). For example, a population predicted to rebuild in 9 years is required to do so, potentially requiring a moratorium on fishing, while a population predicted to rebuild in 11 years must rebuild within 11 years + 1 generation time (T_{MAX}).

Consideration of additional factors beyond life history are recommended, and commonly incorporated, when specifying fishery rebuilding times (NRC, 2014). For example, the Pacific Fishery Management Council (PFMC) modified the target rebuilding time ($T_{MIN} \leq T_{target} \leq T_{MAX}$) for seven rockfish species to accommodate the social-economic requirements of the groundfish fishery (Punt and Ralston, 2007). Finally, it is important to consider natural ecological variability when developing rebuilding schedules. Lower than expected recruitment, ecological shifts, and increased predation pressure can all impact rebuilding timelines (Ben-Hasan et al., 2017; Harvey et al., 2008). **It is therefore critical to ensure flexibility in the rebuilding plan, to revise plans as necessary, and to ensure ongoing monitoring and assessment during the rebuilding period** (Punt and Ralston, 2007).

b. Alternative rebuilding plans

Benson et al. (2016) evaluated Harvest Control Rules (HCR) as alternative policies to rebuilding planning. They contrasted rebuilding outcomes achieved using HCRs (best practices in fisheries management) with 'active' rebuilding policies. The HCRs evaluated included the $0.75F_{MSY}$ constant-F strategy and the 40-10 rule. The latter rule implies that if the stock is estimated to be above 40% of its unfished size (B_0) the target catch is the population size multiplied by F_{MSY}. If the stock is below 10% of its unfished size no catch is permitted. Between 10–40% of B_0 the fishing mortality rate increases from 0 to F_{MSY} (Benson et al., 2016). Constant-F policies are considered viable alternatives to rebuilding plans (Patrick and Cope, 2014), and 40-10 and similar rules are generally accepted procedures for managing fisheries and their impacts across a range of stock sizes. Simulation testing found that the NMFS rebuilding policy and the 40-10 rule achieved the best rebuilding outcomes (Benson et al., 2016). The 40-10 rule closed fisheries on severely depleted stocks (6-12% unfished B), and allowed some fishing on moderately depleted stocks (20-22% unfished B) while the NMFS plan kept fisheries closed in both cases. This study points to a need to consider the value of rigid rebuilding schedules versus establishing HCRs for management of any species, regardless of stock status.

c. Data-poor strategies

Lack of adequate data for calculating robust MSY- and biomass-based quantities requires alternative paradigms of rebuilding and management. One option is to use spatial management (MPAs) designed to protect essential fish habitat as an alternative approach to rebuilding. MPAs have proven to help rebuild biomass of some species within well- enforced MPAs (Aburto-Oropeza et al., 2011), and to promote emigration and larval export (Harrison et al., 2012). However, their contribution to rebuilding entire fish stocks is difficult to assess (NRC, 2014).

What determines success in rebuilding plans?

Rebuilding plans fail for two general reasons: (1) ineffective or incomplete control of fishing mortality, and (2) adverse biological and environmental factors (Milazzo, 2012). The first problem arises from use of inappropriate rebuilding plans (discussed above), non-compliance, and bycatch (Milazzo, 2012). The latter issues contribute to a problem of partial controllability (Williams, 1997) – the fact that managers do not have the ability to keep catch at or below the target across all fisheries and sectors. Patrick et al. (2013) evaluated the degree of controllability in US fisheries and found that it varies by management regime. Quota-based commercial fisheries had the highest controllability (lower implementation error) compared to any fishery (commercial or recreational) managed using in-season and post-season management. Furthermore, commercial fisheries showed higher controllability than recreational fisheries, regardless of the management regime (i.e. if both are managed using in-season or post-season management; quotas are not typically used in recreational fisheries). This result supports the observation that measures to limit fishing mortality have been generally unsuccessful in rebuilding fisheries comprised of large commercial and recreational sectors such as red snapper and black sea bass (Milazzo, 2012).

The second broad category of factors contributing to rebuilding failures relates to the variable responses of fish stocks to environmental change. Biological 'resilience' is the capacity of a stock to be impacted and recover from the effects of fishing (Milazzo, 2012 and references therein). Recent rebuilding failures indicate that certain groups of fish exhibit low resilience, including cod, certain flatfish (Yellowtail flounder), and rockfish species such as Bocaccio and Canary and other long-lived members of the Pacific groundfish complex (Milazzo, 2012). Atlantic cod is a well-known example of a species that remains at low abundance despite fishing moratoria. Pacific Herring off the west coast of Vancouver Island and Haida Gwaii appear to be local examples of the same phenomenon. Management options for such species are highly uncertain but may include stock enhancement and habitat protection (Milazzo, 2012).

Social and economic aspects of rebuilding

Rebuilding objectives should be flexible and explicitly address the social and economic requirements of the fishery (NRC, 2014). The economic costs of stock depletion are not borne equally among all stakeholders, and it is generally suggested that a key social objective of rebuilding is to ensure equity in the apportionment of reforms (fishery losses) to promote stock rebuilding (Brown et al., 2017). This social objective is often paired with an economic promise of high profits at some future time (Costello et al., 2016). However, a recent simulation study of stock rebuilding on the Great Barrier Reef found that the most equitable policies are also the least profitable (Brown et al., 2017). Furthermore, the trade- offs between equity and profit (e.g. remove the least efficient participants via buy-backs or ensure broad participation in the fishery by providing increased access) determine the efficacy of rebuilding plans (Brown et al., 2017).

2.1.10 Reflections on development of a rebuilding plan for herring in 6.a 7.b-c

Steve Mackinson, Scottish Pelagic Fishermen's Association

During the ICES benchmark workshop on herring west of the British Isles (ICES, 2015), the stock assessments of 6.aN herring and 6.aS/7.b-c herring were merged into one combined assessment. The reason for this was that the baseline morphometric information used to separate the two components was found to be unreliable due to evidence of changes over time. The consequence is that since 2015, ICES has advised a zero TAC, and recommended that a rebuilding plan be developed (ICES, 2019a).

Using guidance provided by ICES on a scientific monitoring fishery aimed at obtaining relevant data for assessment (ICES, 2016b), this situation catalysed fishing industry associations (under the auspices of the Pelagic Advisory Council) to instigate scientific surveys to collect data required to establish reliable stock assessments for the separate stocks, and to develop a rebuilding plan.

The first proposed rebuilding plan was reviewed by ICES Herring Assessment Working Group (HAWG) in June 2017. The review concluded that when the combined stocks were forecast to be above B_{lim}, the proposed plan was more precautionary than the ICES MSY advice rule, and that the plan was able to provide a framework for recovery of the combined stocks, but not by 2020 given recent poor recruitments. However, at low stock size well below B_{lim}, the plan implied mortality rates that would be above the ICES MSY rule, and hence not considered precautionary. Full details can be found in ICES HAWG report 2018. The special request advice was issued in November 2017.

After addressing the issues raised by the review, the Pelagic Advisory Council submitted a revised plan, which was reviewed by HAWG in March 2018, using the same basis as the review of the original proposal. HAWG concluded that the revised plan had successfully addressed the previous concerns, finding the plan to be consistent with the ICES MSY advice rule and even more conservative in parts (decreasing F as the stock rebuilds) (Figure 2.5).

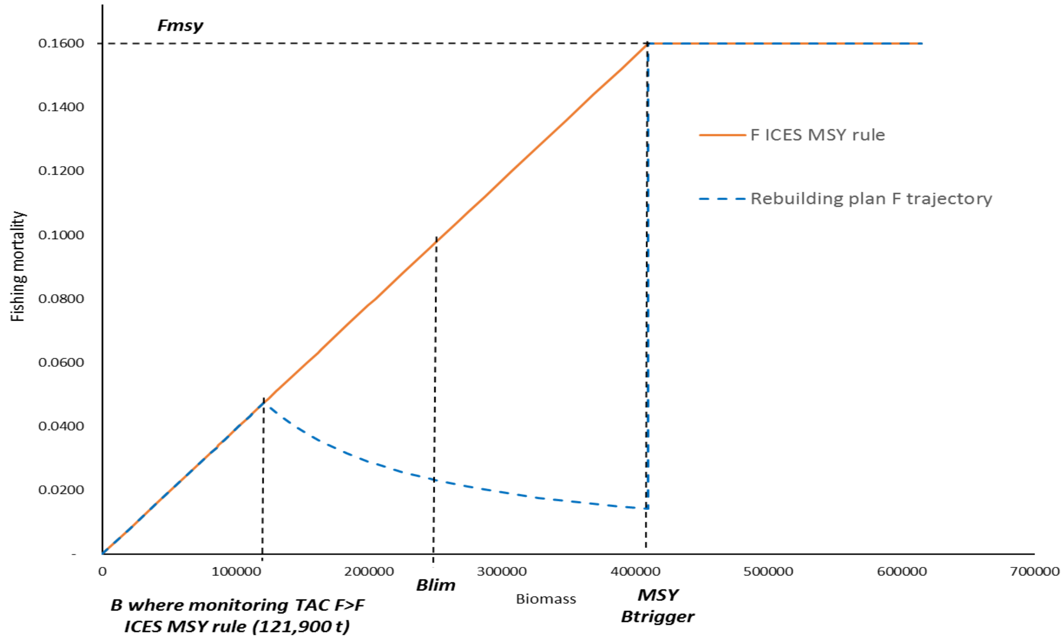

Figure 2.5: Trajectory of the 6.a 7.b-c rebuilding plan HCR and ICES MSY Rule

However, at the ACOM WebEx on 8 May 2018, it was decided that the basis for the evaluation of the HCR in the rebuilding plan (comparison to the ICES MSY advice rule formula following the sliding scale below B_{lim} to the origin) was not valid and would not automatically make the plan precautionary unless it could be demonstrated that the stock would not decline further, and because the plan did not imply the possibility of a zero catch advice below B_{lim}. At this point it was suggested that a Management Strategy Evaluation (MSE) exercise was carried out to support the evaluation of the plan.

At the present time, issues with the stock assessment (ICES, 2019b), and in particular the lack of information on stock discrimination means that it is not possible to carry out a meaningful MSE and therefore not possible to address ACOM's decision regarding evaluation of the proposed rebuilding plan. The outcome is that further development of the rebuilding plan is in limbo, with ICES advising on zero catch and monitoring TAC being set higher than that which would have been calculated by the proposed plan. However, with an apparent worsening state of the stock, industry have taken voluntary actions to reduce catches to a very low level, with the intention in 2020 for catches to be restricted to only those required to undertake the scientific surveys.

Finally, ICES advice in 2019, notes *'ICES still considers it important to develop a stock recovery plan for herring in divisions 6.a and 7.b–c, but given the large changes in perception of the stock, fishing pressure and recruitment together with the continued uncertainty in the quality of the assessment, the requirement for a rebuilding plan (or plans) are considered to be better addressed during a full benchmark, anticipated for 2021'*.

2.2 Rebuilding plans in the Northeast Atlantic

Legal framework

The ICES introduction to advice (ICES, 2019c) describes the key international agreements and policies as well as the national and regional legislation that provide the legal framework for management of fisheries resources in the Northeast Atlantic.

International agreements and policies:

- UN Convention on the Law of the Sea (UNCLOS, UN, 1982) -MSY
- UN Conference on Environment and Development (UNCED, UN, 1992a) - precautionary approach
- UN Straddling Fish Stocks Agreement of 1995 (UNFSA, UN, 1995) - precautionary approach
- Convention on Biological Diversity (UNCBD, UN, 1992b) - ecosystem approach
- Johannesburg Declaration of the World Summit on Sustainable Development (WSSD, UN, 2002)- ecosystem approach & MSY

National and regional legislation:
including EC CFP, EC MSFD, Norwegian Marine Resources Act, Russian Federal Law on Fisheries, Icelandic Fisheries Management Act, Faroe Islands Fisheries Management Act.

As a signatory to the World Summit on Sustainable Development (WSSD), the European Union (EU) and other countries in the North East Atlantic have made a commitment to maintain or restore fish stocks above levels that can produce the maximum sustainable yield (MSY). Based on this commitment ICES has developed its ICES MSY framework to support the implementation of this policy with its advice on fishing opportunities (ICES, 2016a, 2017). Next to the ICES MSY framework ICES is giving advice based on management plans if these plans have been evaluated to be precautionary (less than 5% probability to fall below B_{lim}) and have been agreed by all relevant parties. For data-limited stocks, a precautionary approach has been developed inside ICES (ICES, 2018a).

Within the EU, some management/rebuilding plans are established at a national/regional level (e.g. sardine MP is Portuguese/Spanish), while others are management plans at EU level (e.g. regional Multi-annual Plans; MAPs).

Rebuilding in the context of the Common Fisheries Policy (CFP)

The CFP sets the legal and policy framework for fisheries management for EU countries in the North Eastern Atlantic. The 2013 reform introduced a number of new articles and management changes that are relevant to rebuilding (EU, 2013). Article 2 sets out one of the key objectives of the CFP:

"In order to reach the objective of progressively restoring and maintaining populations of fish stocks above biomass levels capable of producing maximum sustainable yield, the maximum sustainable yield exploitation rate shall be achieved by 2015 where possible and, on a progressive, incremental basis at the latest by 2020 for all stocks."

Article 8 states that the EU will endeavour to establish protected areas to promote fish stock recovery. The CFP also define 'safe biological limits' as a high probability that its estimated spawning biomass at the end of the previous year is higher than the limit biomass reference point (B_{lim}) and its estimated fishing mortality rate for the previous year is less than the limit fishing mortality rate reference point (F_{lim}).

Member states are also required to co-operate on conservation measures through regional groups and with third countries for shared stocks. In additional conservation measures need to be compatible with the objectives of Multi-annual plans or MAPs a number of which have been established (e.g. ICES, 2016a). Target species are defined in the MAPs and for these "Fishing opportunities shall in any event be fixed in such a way as to ensure that there is less than a 5 % probability of the spawning stock biomass falling below B_{lim}." The MAPs also include "safe-guards" when a stock is below the B_{lim}. This include further remedial measures to ensure rapid return of the stock concerned to levels above the level capable of producing MSY. Those remedial measures may include; suspending the targeted fishery and the adequate reduction of fishing opportunities. The choice of safe-guarding measures shall be made in accordance with the nature, seriousness, duration and repetition of the situation where the spawning stock biomass is below MSY $B_{trigger}$ and B_{lim}. The plans also take account of mixed fisheries technical interactions and may involve emergency and technical measures.

Throughout the CPF and MAPs ICES standard reference points are specified and there is a requirement for decisions to be based on "based on the best available scientific advice".

Rebuilding in the context of NEAFC

ICES is the primary advisory body for NEAFC and the convention sets out that contracting parties should "ensure that such recommendations are based on the best scientific evidence available" and should "apply the precautionary approach".

Advisory framework; notably the ICES MSY rule and the zero-catch advice

ICES advice responds to the policy and legal needs of ICES Member Countries (including all countries with international waters in the Northeast Atlantic) as well as to multinational and intergovernmental organizations that use the advice as the scientific basis to manage human activities that affect, and are affected by, marine ecosystems. An important part of ICES advice regards the management of the exploitation of living marine resources. The ICES approach to advice on fishing opportunities integrates ecosystem-based management with the objective of achieving maximum sustainable yield (MSY), unless otherwise requested.

The advice rule applied by ICES in developing the advice on fishing opportunities depends on management strategies agreed by relevant management parties, and the information and knowledge available for the concerned stocks. For stocks with analytical assessments and defined reference points (see Figure 2.6 for an illustration of biomass reference points), the advice rule (ICES 2019c) leads to catch advice corresponding to a fishing mortality of:

1. $F = F_{MSY}$ when the spawning-stock biomass is at or above MSY $B_{trigger}$; and

2. $F = F_{MSY} \times SSB / MSY\ B_{trigger}$ when the stock is below MSY $B_{trigger}$ and above B_{lim};

3. If the F following from applying rule 2 is insufficient to bring the stock above B_{lim} in the short-term, ICES advice will be based on bringing the stock above B_{lim} in the short-term (at the

end of the forecast year). This may result in advice of zero catch. ICES interprets short-term as the end of the projection year.

An overview of number of stocks (excluding *Nephrops*, deepwater species and elasmobranchs) by year for which zero advice has been given by ICES is presented in Figure 2.7, including the number of cases where the subsequent TAC decisions and catches were equal to zero. This demonstrates that the zero-catch advice has not been regularly followed up in the management system.

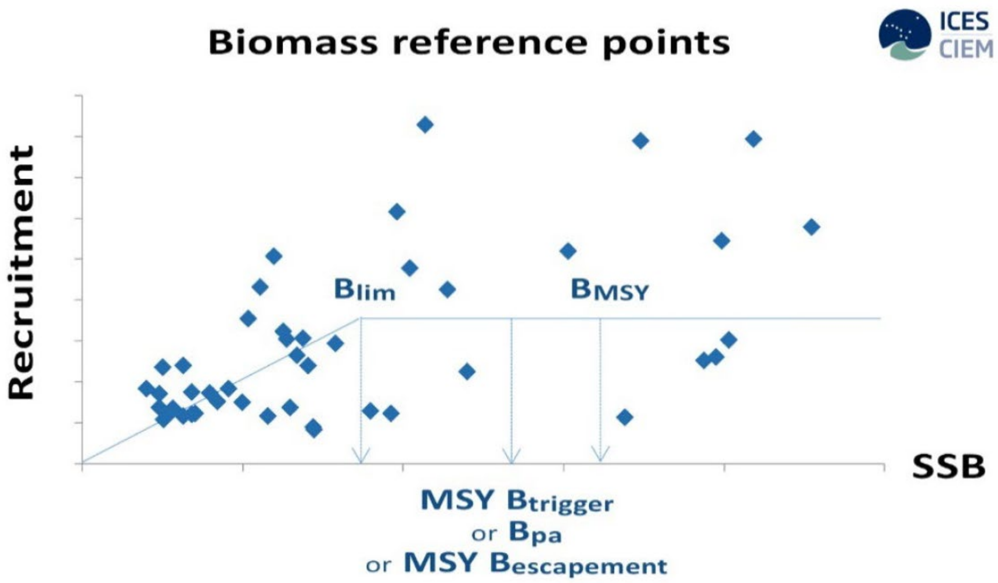

Figure 2.6: Illustration of biomass-based biological reference points. B_{lim} and B_{pa} are precautionary reference points related to the risk of impaired reproductive capacity, while MSY $B_{escapement}$ (for short-lived species, a deterministic biomass limit below which a stock is considered to have reduced reproductive capacity, including any identified additional biomass need (ICES 2017); often equal to B_{pa}) is used in the advice framework for short-lived species. MSY $B_{trigger}$ (the lower bound, 5th percentile of spawning-stock biomass fluctuations to be expected when fishing at F_{MSY}) is the parameter in the ICES MSY framework, which triggers advice on a reduced fishing mortality relative to F_{MSY}. B_{MSY} is the expected average biomass if the stock is exploited at F_{MSY}. Diamonds show the variable recruitment versus SSB that have been observed over the years. Recruitment can be seen to be generally lower when SSB is below B_{lim}.

If all relevant management parties have agreed on a management plan or strategy, and the plan/strategy has been evaluated by ICES to be consistent with the precautionary approach (no more than 5% probability to fall below B_{lim}) , ICES will provide advice in accordance with the plan/strategy when requested. Current ICES criteria for evaluating management plans is not prescriptive for the case of rebuilding plans.

Key concepts, terminology

The ICES MSY approach does not use a B_{MSY} estimate. Instead, it focuses on the fishing mortality (F_{MSY}) that leads to B_{MSY} and can be influenced directly by fisheries management. B_{MSY} strongly depends on the interactions between the fish stock and the environment it lives in, including biological interactions between different species. Historical stock size trends may not be informative about B_{MSY} (e.g. when F has exceeded F_{MSY} for many years or when current ecosystem conditions and spatial stock structure are, or could be, substantially different from those in the past). Estimates of B_{MSY} are very sensitive to the assumption that all future factors that influence fisheries productivity remain unchanged in the future. Determination of MSY $B_{trigger}$ requires contemporary data that identify the normal range of fluctuations in biomass when stocks are fished at F_{MSY}. If the observation on fluctuation in biomass is insufficient to estimate MSY $B_{trigger}$, the reference point is normally set at B_{pa} (if this reference point is available). If sufficient observations of SSB fluctuations associated with fishing around F_{MSY} are available, the MSY $B_{trigger}$ should be re-estimated to correspond to the 5th percentile of B_{MSY} when fishing at F_{MSY}.

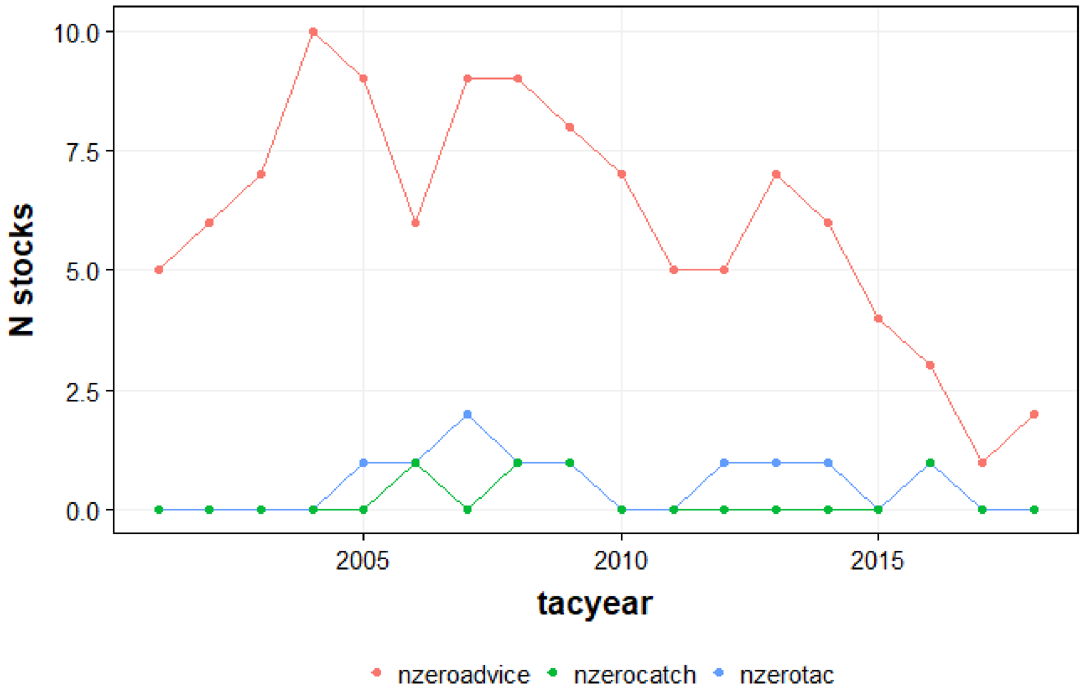

Figure 2.7: Overview of number of stocks for which zero advice has been given (nzeroadvice, red line), number of stocks for which zero TACs were agreed (nzerotac, blue line) and zero catches were recorded (nzerocatch, green line). Based on the ICES history of advice tables. Does not include deep-water species, elasmobranch species or *Nephrops*.

Targets for rebuilding and risk tolerances for avoiding overfished condition or achieving rebuilt state

The ICES criteria for defining multi-annual plans as precautionary is that the maximum probability that SSB is below B_{lim} is 5% (ICES, 2016a). The maximum probability is determined from the annual probabilities is taken over the all years evaluated (short- and long-terms).

A rebuilding plan cannot be judged using the same criterion for precautionarity (e.g. a stock's SSB may currently be below B_{lim}). Rebuilding plans should be judged according to their ability to deliver SSB recovery within a certain time frame that is appropriate for that stock. In that case, the requirement for considering the recovery plan as precautionary would be that the probability of SSB < B_{lim} in a pre-specified year is no more than 5%. Current ICES criteria are not specific with regards to what year may be considered appropriate. However, the current ICES MSY framework interprets the precautionary principle to be met if stocks are rebuilt above B_{lim} as fast as possible (i.e. a 50% chance to be above B_{lim} after the TAC year according to short-term forecasts or a zero TAC advice is given if this cannot be achieved).

Evaluation methods and treatment of uncertainty

MSEs are the standard tool in ICES to carry out impact assessments and to evaluate whether a certain management plan or management strategy leads to a less than 5% probability to fall below B_{lim}. Detailed guidelines how to set up MSE simulations have been developed during workshops in ICES (e.g., WKGMSE, ICES, 2019c). For more details, see section 2.1.3. No specific guidelines are so far available for the evaluation and impact assessment of rebuilding plans.

2.3 Rebuilding plans in the US context

The revisions to the U.S. national fishery legislation in 1996 created the requirement to rebuild overfished fish stocks in as short a time as possible, but not to exceed 10 years unless biology of the stock or other contingencies required a longer plan. National guidelines for implementation were in place by 1998 and rebuilding plans started to be implemented by 1999 for stocks below a defined Minimum Stock Size Threshold (B_{lim}), e.g. overfished. These plans typically were based on stochastic simulations of the probability that the stock would be rebuilt to B_{MSY} before the maximum allowable time to rebuild.

A review by the U.S. National Academy of Science in 2013 (NRC, 2014) of the effectiveness of these plans found that plans starting with the greatest probability of success (greatest reduction of F below F_{MSY}) were most likely to succeed. Some of the review's main messages were: (1) proactive reductions in F below F_{MSY} when stock abundance falls below B_{MSY} can prevent stocks becoming overfished and requiring rebuilding; (2) fishing mortality reference points are estimated with greater robustness than biomass reference points; (3) rebuilding plans that focus more on meeting selected fishing mortality targets than on exact schedules for attaining biomass targets may be more robust to assessment uncertainties, natural variability and ecosystem considerations, and may have lower social and economic impact; and (4) retrospective reviews of the socioeconomic impacts of rebuilding plans are recommended but are rare, in part due to data availability. A subsequent revision to the national guidelines for rebuilding plans allowed the maximum time to rebuild to be based on expectations from fishing at 75% of F_{MSY}. A MSE for the success of rebuilding plans (Wetzel and Punt, 2016) found that rebuilding plans that implemented a higher initial rebuilding probability (≥60%) generally resulted in fewer changes to the rebuilding plans and better achieved rebuilt status by the target rebuilding year. Overall in the U.S. at the end of 2018, there are 479 stocks and stock complexes, 321 of which have a known overfishing status and 244 have a known overfished status. Of these known status stocks, there were 9% experiencing overfishing, 18% on the overfished list, and 18% rebuilt after previously being on the overfished list.

Main conclusions:

- **The hard rebuilding deadlines and strict annual quota management in the U.S. have been successful in reducing number of fish stocks experiencing overfishing and successful in rebuilding 45 fish stocks from an overfished state to B_{MSY}.**
- **Implementation has been challenging in multi-stock fisheries**
- **Not all plans have succeeded in rebuilding in expected time frame, principally due to unanticipated reductions in stock productivity**
- **On other hand, several west coast groundfish stocks rebuilt faster than expected due to increases in productivity**
- **Rebuilding plans that focus on sufficient reductions in F below F_{MSY} can achieve rebuilding in realistic time frames and can then smoothly transition into long-term plans for optimum yield**

2.4 Rebuilding plans in Canadian context

Canada's *Fisheries Act* was recently revised to include Fish Stocks Provisions that introduce legal obligations to manage stocks at levels necessary to promote sustainability, avoid limit reference points, and institute plans to rebuild depleted fish stocks (*Fisheries Act* R.S.C., 1985, c. F-14. As amended by Bill C-68, June 21 2019). Under the modernized *Act*, the Minister of Fisheries and Oceans Canada (DFO) is required to develop and implement rebuilding plans for major stocks listed in regulation that decline below their limit reference point, taking into account the biology of the fish and the environmental conditions affecting the stock.

Prior to the *Fisheries Act* revisions, DFO did not have a legal requirement to implement rebuilding plans however the need to do so was outlined in policy and guidelines. In 2009, DFO published the Fishery Decision-Making Framework Incorporating the Precautionary Approach (DFO, 2009b). This policy indicates that once a stock is below its limit reference point (LRP) rebuilding plans must be in place with the aim of having a high probability of growing the stock above the LRP within a reasonable time frame. The Policy also states that below the LRP management actions must promote stock growth, removals from all sources must be kept to the lowest possible level, there should be no tolerance for preventable decline and that biological considerations prevail. Guidelines were also developed in the Guidance for the Development of Rebuilding Plans under the Precautionary Approach (DFO, 2013).

To support the new Fish Stocks Provisions, regulations are being developed which will outline the minimum requirements for the contents of rebuilding plans. The proposed regulations indicate that a rebuilding plan must contain (DFO, 2018):

- A description of stock status, and stock trends,
- Reasons for the stock's decline,
- Measurable objectives aimed at rebuilding the stock,
- Timelines for achieving the objectives,
- Rebuilt target,
- Management measures aimed at achieving the objectives,
- A method to track progress to achieve the rebuilding plan's objectives, and
- An approach to review the objectives and adjust them if the objectives are not being achieved.

In January 2020, DFO held a Canadian Science Advisory Secretariat peer-review meeting on Science guidelines to support development of rebuilding plans for Canadian fish stocks. At this meeting, DFO and two invited external experts reviewed existing guidance and policies, in Canada and internationally, related to science components of rebuilding plans and developed recommendations for Science guidelines for rebuilding plans. A summary of some of the findings and recommendations from this meeting were discussed at the ICES workshop on guidelines and methods for the evaluation of rebuilding plans (WKREBUILD). See Annex 2 for recommendations for development of guidelines in Canada. The recommendations were developed to support the development of rebuilding plans that are expected meet the legal requirements of the legislation and proposed regulations and policy requirements in Canada.

2.5 Rebuilding plans in the Northwest Atlantic Fisheries Organisation (NAFO) context

The Northwest Atlantic Fisheries Management Organisation (NAFO) is the regional fisheries management organisation (RFMO) responsible for coordinating the management of fisheries on high seas- and straddling stocks of demersal fish and crustaceans in the North West Atlantic. Although the seabed in much of this area is beyond the depths of commercial fisheries, the regulatory area includes a significant portion of the Grand Banks of Newfoundland (Div.2J, 3KLMNO), as well as the entirety of the Flemish Cap (Div. 3M). NAFO was formed from its precursor, the International Commission for Northwest Atlantic Fisheries, in 1979 in response to the extension of exclusive economic zones out to 200nm. It has thirteen contracting parties, of which four are coastal states - Canada, the US, Denmark in respect of Greenland and St Pierre and Miquelon. The major fishing states in the regulatory area are the EU, Norway, Faroes and Iceland.

Following the adoption of its revised convention in 2017, NAFO has a bicameral structure whereby it consists of an advisory body, the Scientific Council, who provide advice to the Commission - the body responsible for discussing and adopting management measures, which are then implemented at national levels. NAFO's guiding principles also differ from the MSY based approach used as the basis of advice in ICES, in that it uses the precautionary approach as the framework which defines limit reference points for fishing mortality and biomass, and buffer reference points, scaled relative to the limit reference points in proportion to the degree of uncertainty in the estimation of these. NAFO's management framework describes guidelines for what action to take when a stock is in each of these numbered parts of the phase plot.

Following the extension of EEZs to 200nm in 1979, there has been general decline in the status of stocks managed through NAFO. There was a brief increase in landings from the regulatory area in the late 1980s, and then again in the early 2000s, and thereafter, landings have settled to a low state, around 40kt per year.

NAFO has been considering issues around the adoption of rebuilding plans since at least 2004. Work can be summarised by considering work on four stocks over three stages of development; Greenland halibut, American Plaice and southern Grand Banks cod, and Flemish Cap cod.

Greenland Halibut (SA2 + Divs. 3KLMNO)

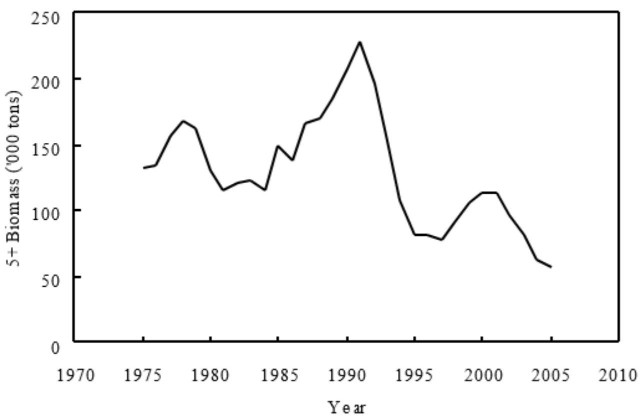

Figure 2.8: Estimates of Greenland halibut biomass (5+) in NAFO SA2 and Divs. 3JKLMNO, 1975 - 2005.

Estimates of Greenland halibut biomass in NAFO Subarea 2 + Divisions 3KLMNO declined from 230 000 t in 1990 to 60 000 t in 2005 (Figure 2.8). Cognisant of this decline NAFO Fisheries Commission adopted in place a 15 year rebuilding plan for Greenland halibut in September 2003, which involved a step-wise reduction in TAC commencing in 2004. Preliminary analysis showed that this rebuilding plan was not robust to uncertainty in the strength of recent year classes or to the assessment approach taken, and was considered by Scientific Council as unlikely to lead to successful rebuilding. Following this, a management strategy evaluation exercise was conducted between 2007 and 2010, involving a number of external contractors. A harvest control rule whereby the TAC was adjusted annually in response to an average of trends in several survey indices was adopted by the Fisheries Commission. An "Exceptional Circumstances Protocol" was also instigated whereby managers could intervene in the implementation of the plan if parameters outside of the ranges tested in the operating models were observed. The management strategy assumed that implementation would be perfect, however there were considerable discrepancies between official catches and scientific catch estimates used for assessment purposes. These differences crystallised into a refusal by several states to provide estimated catches, drastically altering the basis on which the stock assessment was conducted, and resulting in no assessment being carried out to assess the quality of management decisions being implemented as a result of the harvest control rule for several years. This stock provides an example of a "top down" recovery plan imposed with little scientific input. There has been scant evidence of rebuilding of the Greenland halibut stock since the plan was adopted.

American plaice (Div. 3LMNO) and Southern Grand Banks Cod (Div. 3NO)

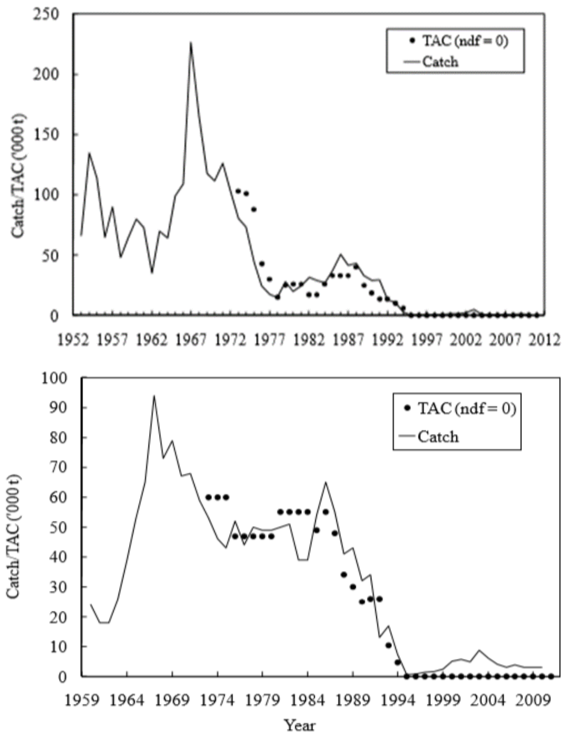

Figure 2.9: Catch and TAC for American plaice (L) and Cod (R) on the Grand Bank (Div. 3LNO) and southern part of the Grand Bank (Div. 3NO) respectively.

Cod and American plaice are two species, which have both formerly supported large fisheries on the Grand Bank. They are now primarily caught as bycatch in the redfish and yellowtail flounder fisheries. A moratorium on both stocks has remained in place since its declaration in 1995. During 2010, assessments suggested some recovery in stock status, and conscious of commitments under international law and the performance assessments being carried out on RFMO's to improve governance and transparency, NAFO began developing rebuilding plans for these stocks.

In 2011, it established a new Working Group on Conservation Plans and Rebuilding Strategies (WGCPRS), which was innovative in that it was made up of both managers and scientists, facilitating robust discussion of nuanced points in assessment uncertainty and management objectives. The group was mandated to produce recommendations to both managerial and scientific bodies. The group was given two standing terms of reference; in the short-term, to produce a comprehensive review of the interim 3LNO American plaice and 3NO Cod rebuilding plan, and in the longer term, to consider risk management approaches, review, update and development of future plans for other stocks. The Fisheries Commission specified that in a rebuilding plan it wished to see consideration of limit and buffer reference points, timelines, conditions at which directed fishery might occur, harvest control rules and implementation strategy. Guidance provided to the group in formulating plans specified that when a stock had recovered beyond B_{lim}, initial TAC levels should be set at conservative levels to allow for continued recovery and growth; bycatch should be kept to the lowest possible level and restricted to unavoidable bycatch in fisheries directing for other species; interim targets could be set to allow for further growth in the stock prior to re-opening; harvest control rules which imply a low risk of falling below the long-term rebuilding target (e.g. B_{MSY}) over a specified time frames, and to develop a monitoring and review process for each rebuilding plan to enable Fisheries Commission to assess and revise plans as necessary to ensure rebuilding plan targets are achieved.

Rebuilding plans for both stocks were drafted by this group and adopted for management by Fisheries Commission. The agreed text was incorporated into NAFO's Conservation and Enforcement Measures, and can be seen in Annex 3. The features to highlight from this plan include:

- Square bracketing of a number of reference points. The absolute values of these could not be agreed amongst the contracting parties on the basis of the current scientific evidence, however it was felt more important to agree a plan first and refine the details later, therefore these reference points can be revised as the stock recovers and their value becomes less uncertain.
- The adoption of an intermediate stock reference point, B_{isr}, which sits between B_{lim} and B_{target}, and which allows a more conservative approach to be taken when the stock has "recovered" to a level above, but still near to, B_{lim}.
- Text agreeing at what point in the recovery process a fishery can be reopened, and guiding the decision making in the years immediately afterwards, and establishing a set of harvest control rules which apply through recovery and beyond.
- The recovery plan for cod also recognised the importance of forage fish as a food source for cod, and consequently prohibited fishing for capelin in the stock area until the recovery has taken place.

Flemish Cap Cod (Div. 3M)

Cod on the Flemish Cap declined to very low levels from the mid-1990s to the mid-2000s, and the fishery was placed under a moratorium. During the late-2000's the stock showed strong recovery and the fishery was reopened. Like the Greenland halibut, this fishery also raised concerns around misreporting of catches, and there were indications for several years that F was well above F_{MSY}.

In 2015, NAFO's Fisheries Commission and Scientific Council requested the joint working group, which by this time had been renamed the Working Group on Risk-Based Management Strategies, reflecting a broadening of the scope of the group, to begin developing a conservation plan which could maintain stock size and guide rebuilding efforts should it decline below B_{lim} once again.

The group took from managers a list of objectives they would wish to see in a management plan. This included a very low risk of breaching B_{lim}, a low risk of overfishing, a low risk of "steep decline", maximum averages catch, and limited annual catch variation. They then conducted a prioritisation exercise with managers, before asking Scientific Council to evaluate a harvest control rule which satisfied the first two of these objectives (low risk of breaching B_{lim}, low risk of overfishing) over five and ten years.

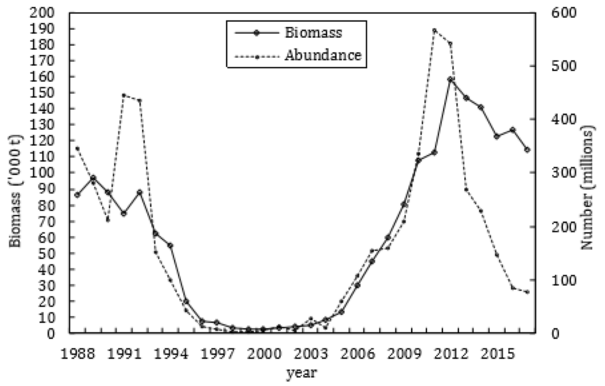

Figure 2.10: Trends in biomass and abundance of cod on the Flemish Cap (Div. 3M), 1988 - 2017.

Conclusions

The road to developing and implementing meaningful rebuilding plans in NAFO has been long and met with mixed results. None of the stocks for which plans have been developed could be said to have substantially recovered, while those stocks, which have recovered have done so of their own accord, under the protection of a fishing moratorium. Nevertheless, the process has provided a number of lessons in what works and what does not.

- Institutions
  NAFO has created a specific group to address the drafting of rebuilding plans, and structured it such that managers and scientists can sit down at the same table and discuss their findings and requirements. This sets it apart from other RFMO's and science-management relationships such as the ones ICES has with its clients, in that **two-way dialogue** can take place, helping scientists to understand the thinking of policymakers and why they want certain elements to be included, as well as helping managers understand the implications and limitations of the advice they are being provided with.

- Frameworks
  NAFO has adopted a **precautionary approach framework**, which guides management decisions at all points of a stock's recovery. This helps establish ground rules for quota setting out with the rebuilding plan, taking much of the political "heat" out of the decision making process.

- Flexibility
  The rebuilding plans for 3LNO American plaice and 3NO Cod show remarkable **flexibility** and pragmatism, in that the plan has been adopted, bringing into force all the restrictions on bycatch, ecosystem elements and targets, while at the same time recognising that there is uncertainty in the specific reference points, and that the current stock status is so far from these that the disagreement over them becomes academic.

- Prioritisation
  As shown in the Div. 3M Cod exercise, **prioritisation is the key to getting a workable rebuilding plan**. In order to do this, the "right" questions need to be posed to managers to ensure everybody fully understands what is being asked for in the process of developing a rebuilding plan.

2.6 Rebuilding of fisheries in FAO context

Fisheries make significant contributions to food security, economy and livelihoods of coastal communities. The international community and the United Nations have initiated a number of initiatives to ensure the sustainable use and conservation of fishery resources. The latest is the UN Sustainable Developed Goals, which set a global target of zero overfishing by 2020. However, based on FAO's assessment, the fraction of fish stocks that are within biologically sustainable levels has decreased from 90 percent in 1974 to 65.8 percent in 2017. In contrast, the percentage of stocks fished at biologically unsustainable levels has increased, especially in the late 1970s and 1980s, from 10 percent in 1974 to 34.2 percent in 2017.

There are great variations among regions. In 2017, among the 16 major FAO statistical areas, the Mediterranean and Black Sea had the highest percentage (62.5%) of unsustainable stocks, followed by the Southeast Pacific 54.5% and Southwest Atlantic 53.3%. In contrast, the Eastern Central Pacific, Southwest Pacific, Northeast Pacific, and Western Central Pacific had the lowest proportion of fish stocks at biologically unsustainable levels. The Other areas varied between 21% and 44% in 2017.

However, the ever-decreasing trend in the proportion of sustainable fish stocks does not mean fisheries have made no progress at all. A recent paper (Hilborn et al., 2020) shows that, in the case of "assessed" stocks, the average fishing pressure increased and fish biomass declined on average until 1995 when fishing pressure began to decrease. By 2005, average biomass had started to increase and reached a level of biomass higher than expected to deliver maximum sustainable yields (MSY) in 2016. At the same time, fishing pressure has declined to levels below that which is expected to deliver MSY. These results demonstrate that fisheries are being managed sustainably in some places and that fisheries management works when implemented, allowing fish stocks to recover.

While developed countries are improving the way they manage their fisheries, developing countries face a worsening situation in terms of overcapacity, production per unit of effort and stock status (Ye and Gutierrez, 2017). Compared with regions that are intensively managed, regions with less strict fisheries management have, on average, threefold greater harvest rates, and their stocks have half the abundance of assessed stocks and are in poor shape (Hilborn et al., 2020). The less-intense management is common in many developing nations, and the situation is fuelled by economic interdependences coupled with limited management and governance capacities (Ye and Gutierrez, 2017). The current successes accomplished in some countries and regions are not sufficient to reverse the global declining trend of overfished stocks. This uneven progress highlights an urgent need to replicate and re-adapt successful policies and measures in the light of the realities of specific fisheries, and to focus on creating mechanisms that can effectively implement policy and management regulations for sustainable fisheries and ecosystems.

Rebuilding overfished stocks is required by many international instruments and has been practiced in many fisheries and countries. **A global review shows** (FAO, 2018) **that (i) not all rebuilding plans are successful, (ii) controlling F is the most critical measure for rebuilding either through TAC or fleet size control, (iii) rebuilding single species fisheries is easier than multispecies fisheries, (iv) environmental factors often make rebuilding difficult, and (v) socioeconomic benefits are foreseeable in the long-term, though not always obvious in the short-term**.

3 Technical tools for evaluation of rebuilding plans

ToR b) Evaluate technical tools that are available or could be developed for evaluating the performance of different types of rebuilding plans. Take into account the work of WKGMSE2 (2019) on characterizing relevant uncertainties and bias.

3.1 Summaries of presentations

3.1.1 A rebuilding plan for Mediterranean demersal stocks?

Cecilia Pinto, Joint Research Centre

Mediterranean stocks (here referred to as stocks shared only between geographical sub-areas of the European Union (EU) member states on which a management evaluation has been done) are typically characterized by short time series. The official Data Collection Framework (DCF), funded by the EU started in 2002, which means that most time series cover a period shorter than 20 years. For some of the stocks of the Eastern Mediterranean, time series can be shorter, or present gaps both in the commercial and in the survey time series. When longer time series are made available, length frequencies distributions (LFDs) are often lacking, making it necessary to assume constant LFDs structure through time. Short time series and data gaps limit the parameterization of complex analytical stock assessment models, producing unstable results which cannot be used for management advice. To face this issue the Joint Research Centre (JRC) developed, tested and distributed the **a4a Initiative** (Jardim et al., 2014). This project produced methods to develop analytical stock assessments and management strategy evaluations (MSEs) also on data limited stocks, giving advice to policy makers in a short operational time frame.

Of the Mediterranean stocks assessed within EU waters, 90% resulted in a state of overfishing in the last few years assessments (https://stecf.jrc.ec.europa.eu/dd/medbs/sambs), therefore multiannual management plans (MAPs) for the western Mediterranean (STECF 16-21) and the Adriatic Sea (STECF 19-02) were developed by the EU and Mediterranean member states. To evaluate such MAPs, full feedback MSEs were developed during STECF working groups using the modelling framework developed at the JRC (Jardim et al., to be submitted). The mse package developed within the FLR framework (http://www.flr-project.org/) has a modular structure in order to help modellers in the process to properly distinguish between the different modules of an MSE feedback loop: the operating model, the observation error, the management procedure and the implementation error. The modelling framework is built so that the output of each module is the input for the next module, easing the understanding of the feedback loop structure.

Results from MSEs ran over Mediterranean stocks suggest that effort regimes prevail over TAC ones, but a number of issues remain unsolved in the implementation process, such as hyper stability (lack of a linear relationship between effort and fishing mortality) and the application of single stock assessments to mixed fisheries fleets. Uncertainty surrounding MSEs outputs remains one of the main issues to account for, with cases where fishing mortality and spawning stock biomass show ranges which are outside of the historical ones. The time frames within which MSEs are developed are restricted at the moment, which further limits the investigation of uncertainties characterizing Mediterranean assessments. Time lags between the assessments publication, the evaluation process and the implementation of management decisions is variable depending on the advisory body, creating delays in the future evaluation of management implementations which is fundamental specifically considering the uncertainty levels of Mediterranean stocks and assessments.

3.1.2 Celtic Sea herring monitoring TAC

Michael Gras, Marine Institute

The Celtic Sea Herring stock (CSH) occurs to the South of Ireland in ICES sub–divisions 7.aS, 7.g–h and 7.j–k (ICES, 2019a). That stock is primarily fished by Irish fishers. The Celtic Sea Herring Management Advisory Committee (CSHMAC) represents the fishers and provides input to the Irish managers of this stock.

Two fleets exploit the stock, the main fleet that generally fish early Q4 primarily in 7.g and the sentinel fleet that is confined to 7.aS and fish between mid–November and mid–December. A 3–week survey is conducted by the Irish Marine Institute every year in October, concurrently to the fishing season that occurs in Q4. A number of plans have been developed for the CSH, including two rebuilding plans. One was a ban of fishing at the end of the 1970s. The second one was developed in 2008–2009 following the second period of low abundance (Marine Institute, 2012). That plan led to the recovery of the stock that reached its last peak in abundance in 2011 (Clarke and Egan, 2017). Following that recovery, the abundance followed a decreasing trend until 2017 (ICES, 2019a).

In 2018, the HAWG estimated the CSH to be just above B_{lim} (ICES, 2018b). As a result of this update assessment, a collaboration between the fishing industry and the MI scientists was initiated to develop a rebuilding plan. The proposal was a modified MSY rule (with a low F_{target}), identical $B_{trigger}$ and a minimum TAC that would be set at 3,000 t if the calculated TAC would be < 3,000 t. When the assessment was updated by the HAWG 2019 (ICES, 2019a), a revision of the perception of the stock showed that the stock was significantly below B_{lim} since 2017. As a result, the industry perspective changed and the recovery of the stock was considered to be too long if the rebuilding plan was implemented. The objective subsequently changed from maintaining a commercial fishery while rebuilding the stock to stop the commercial fishing but help supporting the assessment with a monitoring TAC. To reach such objectives, the minimum level of catches required was estimated using the same method as for the 6.a herring (Campbell, 2016). First, the minimum number of samples to maintain a precision level ranging from 2.5–12.5% was estimated. Assuming that 100% of the hauls would be sampled and using the average size of a haul for each fleet, the minimum level of catches required to help support the assessment was calculated to be 869 t (ICES, 2019a).

In order to evaluate the impact of the rebuilding plan on the stock and the proposal for a monitoring fishery, a management strategy evaluation (MSE) was developed and used by ICES to give advice. Simple Simulation (**SimpSim**), a software that enables the undertaking of shortcut MSE was chosen. That software is derived from EqSim (the software used by ICES to calculate reference points) and was used to work at non–equilibrium with complex harvest control rules in the short to medium-term. SimpSim was used to evaluate the long-term management strategy of blue whiting (ICES, 2016c). The report includes a more comprehensive description of the software. SimpSim showed that, if 869 t were to be caught annually, the recovery of the stock would be delayed by one year compared to a base case scenario where no fishing would occur.

This work led to a number of discussion points. The ICES advice process might consider to give advice on a regular basis on the minimum level of catches that is required to help support assessments. The evaluation approach was discussed, especially regarding the choice of the assessment model that conditioned the use of a shortcut or full feedback MSE to evaluate the HCR. Finally, that work has shown that all the stakeholders (industry, managers, NGOs and scientists) should be part of the development process to be successful.

3.1.3 Stochastic forecasts with harvest control rules in SAM

Vanessa Trijoulet, DTU Aqua (National Institute of Aquatic Resources, Technical University of Denmark)

A generic **stochastic forecast with harvest control rules** (HCRs) was developed in the stock-assessment package in R (SAM model). The forecast is available for both the single fleet and the multi fleet version of the package. It can be download directly from GitHub (https://github.com/vtrijoulet/SAM) with reference to the branch "master2" for the single fleet forecast and "multi2" for the multifleet forecast. See forecast2 function to run the HCR forecast (?forecast2 in R).

The forecast considers different types of uncertainty:

1. Uncertainty in the current perception of the stock. This is done by simulating the initial population given the estimated SSB in the final year of the assessment and its confidence interval for a certain number of replicates (n). Similarly, fishing mortality is simulated. The uncertainty in the current stock perception is a proxy of the uncertainty in the assessment model (e.g. retrospective patterns).
2. Uncertainty in the future dynamics of the stock. This is done by assuming random recruitment and survival of the stock.

After the intermediate year, an HCR is applied such as F in year y is a function of SSB in year y-1. The same HCR is applied to all replicates but these are treated independently.

Currently, five HCRs are built in the forecast (Figure 3.1). F_{target}, B_{lim}, MSY $B_{trigger}$ and low F have to be specified for each forecast run. Simple forecast scenarios such as F=0 and constant catch can also be run with similar code than with the original forecast function in SAM.

The forecast allows for four recruitment assumptions:

1. Recruitment is randomly sampled from the assessment estimates in a specified year range (assumption currently used for short-term advice).
2. Recruitment follows a random walk assuming the variance estimates in SAM.
3. Log recruitment follows a random walk with drift (drift * variance) where the drift (drift > 0) has to be specified. If drift > 1 then the recruitment increases in the future, if drift < 1 then recruitment decreases in the future.
4. Recruitment follows a stock recruitment relationship (segmented regression or hockey-stick) that is fitted given chosen SSB and recruitment pairs.

The forecast is easy to implement for stocks with a SAM assessment since the user just needs to specify the assumptions to be chosen for recruitment, the HCR number and the different targets that define the HCRs. The forecast is easy to run and can be modified to add options fairly simply. Figure 3.2 summarises the method used in the forecast years.

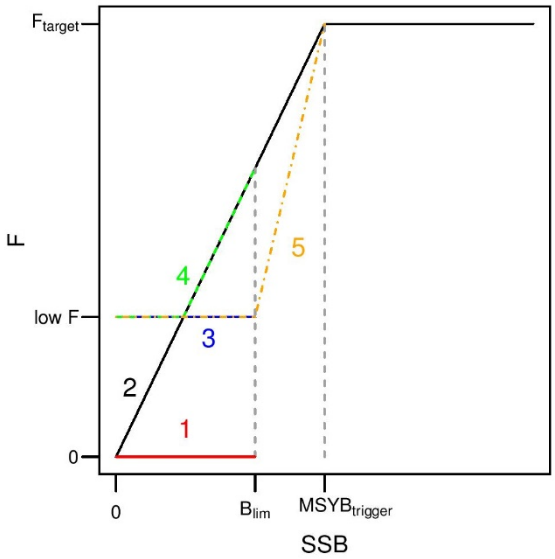

Figure 3.1: Harvest control rules currently built in the forecast. The numbers (1-5) correspond to different HCR shapes. HCR 1 is the MSY approach where F=0 when SSB< B_{lim} at the end of the short-term forecast. HCR 2 is a simple hockey-stick shape where F decreases linearly from F_{MSY} to 0 below MSY $B_{trigger}$. HCR 3 is the scenario where F=low F when SSB< B_{lim}. HCR 4 has the same shape than HCR 2 except that F cannot decrease below low F. HCRs 1-4 have the same shape above B_{lim} (black line). HCR 5 is the case where F=low F when SSB< B_{lim} but when B_{lim} <SSB<MSY $B_{trigger}$ F decreases from F_{MSY} to low F linearly.

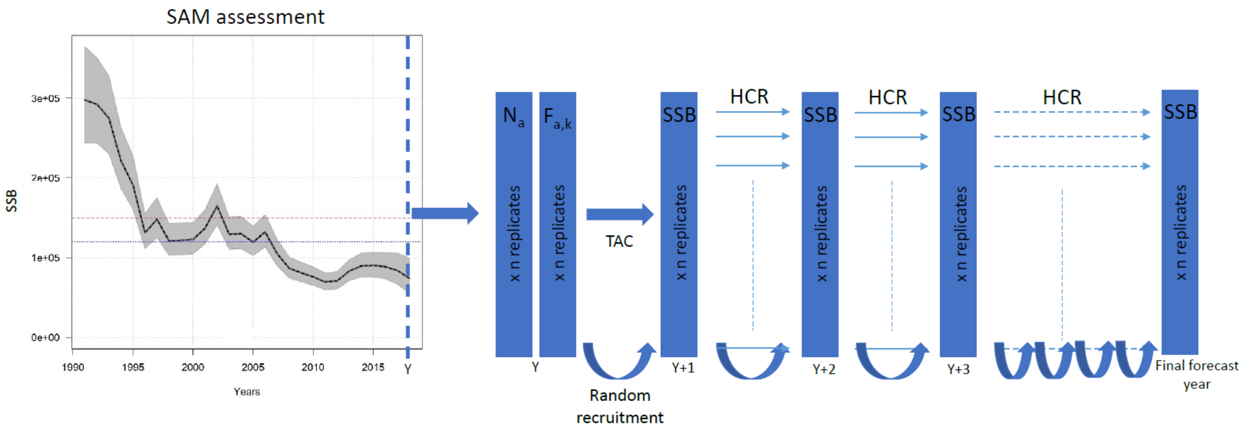

Figure 3.2: Example of the forecast method with uncertainty in stock perception and recruitment and the implementation of the HCR.

3.1.4 Simple HCR forecasting methods in FLR

Martin Pastoors, PFA

The ICES zero-catch advice for Western Baltic Spring-spawning herring (WBSS) in 2018 prompted the development of a simple stochastic medium-term HCR-based forecasting tool to evaluate potential effects of different management rules for when stocks would go below B_{lim}. The forecasting tool has been developed in FLR and reads in the final results of the SAM stock assessment into an FLStock forecast object. Different forms of HCR can be generated with the different biomasses where F is set to be zero (here explored with SSB = 0, 40000, 80000 or B_{lim}). The two main conclusion from the analysis are similar to the results presented in section 3.1.3: rebuilding depends on the assumed recruitment regime (Figure 3.4) and on the (associated) target fishing mortality (Figure 3.5).

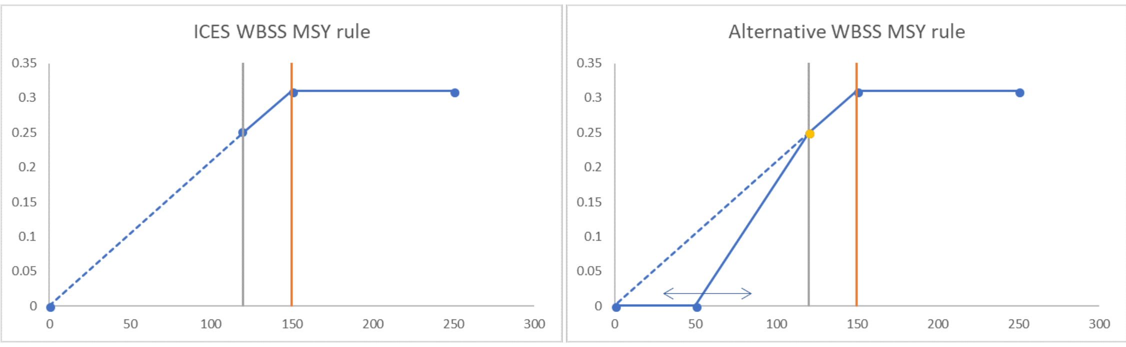

Figure 3.3: ICES WBSS MSY rule (left) and the alternative WBSS MSY rules explored in this analysis (right)

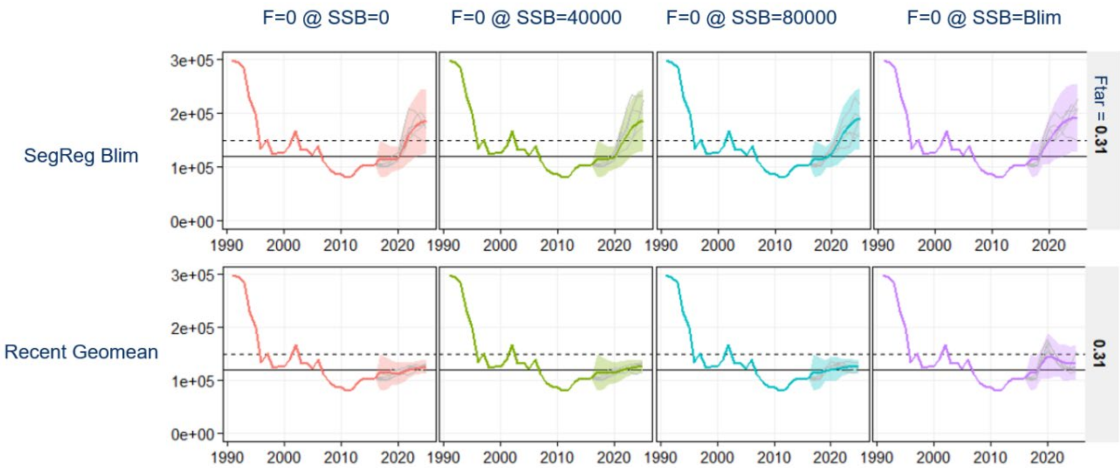

Figure 3.4: Comparison of two different recruitment regimes (segmented regression through B_{lim} (top) and recent geometric mean resampled (bottom)) with F_{target} 0.31 (=F_{MSY}) for four different SSBs where F is set to zero.

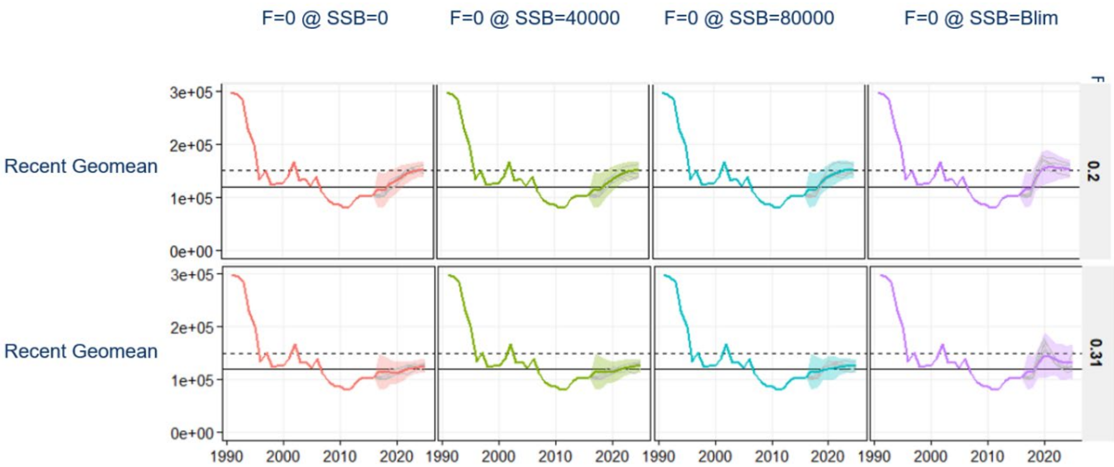

Figure 3.5: Comparison of two different target fishing mortalities (F=0.2 (top) and F=0.31 (bottom)) with recent geometric mean recruitment (resampled) for four different SSBs where F is set to zero.

3.1.5 MSE for the Iberian sardine stock

Laura Wise, Portuguese Institute for the Sea and the Atmosphere

A multi-annual management plan for the Iberian sardine (*Sardine pilchardus*) stock was developed by the two Member States Portugal and Spain. ICES was requested to evaluate if the two harvest control rules (HCRs) within that plan were seen as precautionary. A full-feedback Management Strategy Evaluation framework was implemented in FLBEIA (García et al., 2017) using R-FLR packages (Kell et al., 2007) to test the performance of the proposed and alternative HCRs against a set of performance statistics and quantify the achievement of management objectives and compliance with ICES precautionary criterion (risk type 3).

The conditioning of the operating model was based on the 2018 stock assessment, following the stock benchmark in early 2017, and with recruitment stochasticity. Several scenarios with different Operating Models (i.e., four different Hockey-stick stock-recruitment models according to four scenarios of productivity: low, medium productivity and two scenarios with a persistent or non-persistent transition between the low and medium productivity dependent on the biomass level) and different Management Procedure (i.e. advice assumptions on the Biological Reference Points or 'perceived' BRPs) were simulated for 1000 populations in a period of thirty years (2019-2023). Estimated BRP's were used to set the biomass and fishing mortality reference levels of the catch rules and, following the ICES guidelines for the evaluation of management plans, the basis to compute performance statistics of the management strategy evaluation under each operating model.

The stock assessment cycle, with observation error, was performed using the current assessment model (Stock Synthesis) in each simulation loop. Abundance indices are generated from the "true population" with lognormal distributed errors to simulate observation error. Observation error was also introduced in the numbers-at-age in the catch as a multiplicative lognormal error. The MSE was run without implementation error. Performance statistics for catch, spawning stock biomass and fishing mortality were estimated for three time periods: an initial time period starting in the first projection year 2019 and ending in 2023; a short time period from 2019 to 2028 (i.e. the first ten years of the projection period) and in the long-term (i.e. the last ten years of the projection period; 2039 to 2048) which corresponds to the period after recovery and when the 'true' stock has reached equilibrium.

After the evaluation, ICES considered that the stock is in a low productivity regime since 2006 and advised that HCR3 and HCR4 were precautionary (ICES, 2019d). These rules where alternative HCRs tested based on the two proposed ones but with biomass and fishing mortality triggers points corresponding to the low productivity regime, i.e., adopting the biological references points of the low productivity scenario. This prompted a new request by the two Member states to follow up the work done and evaluate alternative catch rules to HCR4 seeking the highest fishing mortality target that has a maximum risk3 of 5% in the long-term and that will give higher median catches in the short and long-term than with HCR4. The outcome of this evaluation was a new advice from ICES stating that HCR12 is considered to be precautionary and allows for higher catches in the initial, short and long-term when compared to HCR3 and HCR4 (ICES, 2019e).

For the purpose of this workshop and using the Iberian sardine stock as a case study, we evaluated what would be the time frame for the rebuilding of such stock using the definitions adopted in the US approach (Patrick & Cope, 2014) and if we considered another approach such as the mean generation time. If mean generation time is estimated following the approach described in Punt et al. (2012) or in Charlesworth (1994), mean generation time for the Iberian sardine stock is 4 years. This means that a possible time frame for the rebuilding of this stock could be two times its means generation time, i.e., 8 years. TMIN is defined as the expected amount of time a stock needs to rebuild to a biomass target in the absence of fishing mortality. From Figure 1 (left) we can see that, if we consider this biomass target to be BMSY and that the term "expected" refers to 50% probability, TMIN for the Iberian sardine stock in the current low productivity regime would be 5 years (T_{BMSY50} = 5 years). However, if we consider this biomass target to be B_{lim} with a 95% probability following ICES precautionary approach, TMIN for the Iberian sardine stock in the current low productivity regime would be 6 years ($T_{Blim\ 95}$ = 6 years). Therefore, TMAX would be 10 years with both biomass targets if we were to follow the guidelines of the US approach. However, if we were to follow one of the suggestions of Patrick & Cope (2014) that TMAX = 2 * TMIN, then TMAX could be extended to 12 years if the biomass target is B_{lim} with a 95% probability. In Figure 3.6 (right), we can see that from all the rules tested during the MSE for the Iberian sardine only HCR3 and HCR4 reach this objective by T_{MAX_Blim95}. HCR12 will reach this objective one year later.

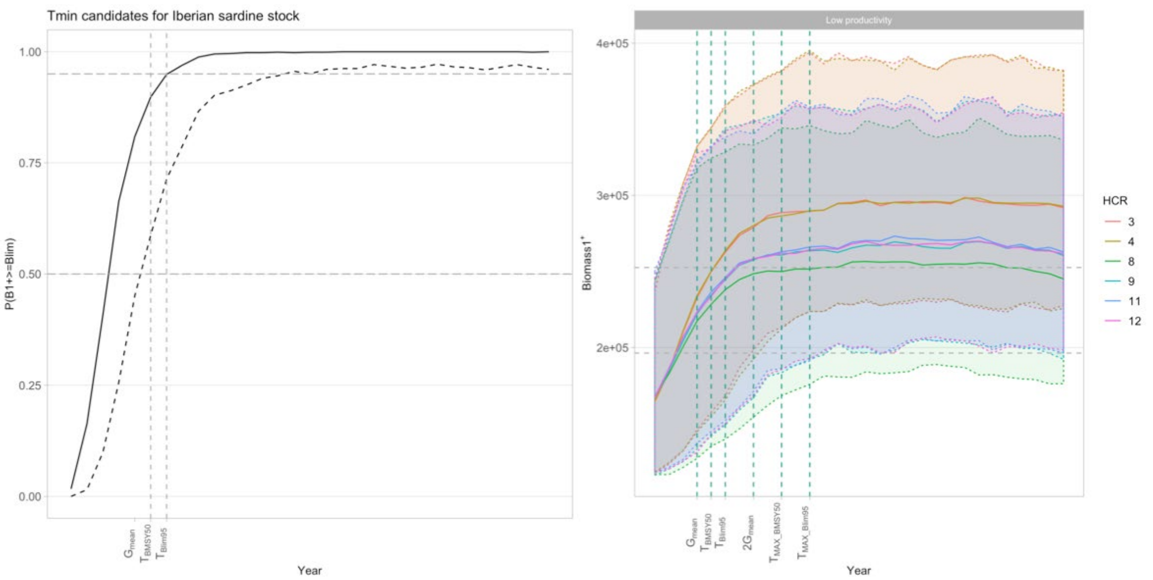

Figure 3.6: Probability profile of P(B1+ ≥ B_{lim}) in a no fishing scenario in the current low productivity regime of the Iberian sardine stock (8c9a from 2018 to 2048. Horizontal dashed lines represent 50% and 95% probability (left panel). Biomass of fish age 1 and older (B1+, thousand tonnes during the projected period (2019–2048) for harvest control rules tested under the low productivity regime (3, 4, 8, 9, 11 and 12. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} and B_{pa}. Vertical dashed lines represent different years in the projected period (right panel).

3.1.6 Communication and representation of risk

Polina Levontin, Imperial College London

The presentation summarised the recent multi-author publication *Visualising Uncertainty: a short introduction* (AU4DM, Levontin et al., 2020) that grew out of an extensive review of research on the role of the visual in decision-making under uncertainty across diverse domains. Visualisation is a factor in processing uncertainty regardless of whether it is presented graphically or only imagined by the person trying to understand uncertainty. Research shows conclusively that skilful representations of uncertainty can play a positive role in guiding decisions whenever risks are difficult to quantify or when large uncertainties remain unaccounted for once quantifications are done. This is precisely the situation of rebuilding scenarios, where the data and knowledge are often lacking but the need to understand and communicate uncertainty is greater since the evidence shows greater unpredictability of population dynamics once the stocks are depleted. The sensitivity to management decisions taken during the rebuilding phase is also higher.

The visual dimension is vital for the understanding of uncertainty, as well as representing it to other stakeholders. There is perhaps a need to distinguish visualisations used in presenting results of simulations in the rebuilding plans by using different graphical conventions to those employed in representing standard ICES advice, in order to draw attention to the presence of deep uncertainty and lower reliability of results. Often the challenge is to present visualisations in ways which allow the audience to intuitively perceive the uncertainty probabilistically, despite the many quirks of human psychology that bias our perception in somewhat predictable ways. There is no one optimal format or unifying theory of uncertainty visualisation, but there is a rich and growing body of research and best practice. The main conclusion of our extensive review is that there is a need for iterative process in designing visualisation and that testing with intended audiences is essential, see the recommended 12-step strategy for developing visualisations below.

Figure 3.7: The 12-step strategy for uncertainty visualisation design

3.1.7 What methods are available to assess the economic impacts of a rebuilding plan

Ralf Doering, Thuenen-Institute of Sea Fisheries

The basic regulation of the EU Common Fisheries Policy (Regulation (EU) No 1380/2013) includes in Articles 9 & 10 multiannual plans as a management measure. These plans could include a rebuilding/recovery period ('restore fish stocks'). Before adoption each new or revised management plan needs to go through an impact assessment to assess biological but also social and economic impacts of the plan and STECF has so far been requested to do the impact assessments. **Specific bio-economic models were developed to assess those impacts**. The main element of the models is the feedback loop between the biological and economic/management modules. The models include a biological stock assessment model feeding in an economic model part to assess the reaction of the fleet on a e.g. TAC proposal. A fleet reaction could be the fully or non-fully uptake of the quota, the redistribution of fishing effort to avoid e.g. juvenile bycatch, and the effects on profits. The results feed then back into the biological module for the stock assessment for the year +1. It is, therefore, possible to assess the effects of rebuilding plans for a time period of 3-5 years (longer time frames require a different type of model).

The main economic issue dealing with rebuilding plans is the perception of the fishers regarding future revenues. In case fishers are not sure to be the recipients of the gains of a recovered stock they may be in favour of the status quo where they are sure what they receive (instead of lower catch possibilities next year to rebuild the stock keep the quota at the current level).

The lack of social and economic objectives in the rebuilding plans is also a problem from a socio-economic viewpoint. There are usually no objectives regarding distributional effects ('who will gain from the recovery') or measures to ease the possible economic losses during the transition phase so that the current fishers gain from the recovery. Another important aspect is the assumption that a recovered stock will automatically improve the economic situation of the fishing companies. The plaice fishery in the North Sea is an example that this automatism is not always the case. Prices dropped when catches were low (there were substitutes for plaice on the market) and it took years to recover the market and observe an increase in prices. Although the stock is now on a record high catches have not increased over the last 10 years and the quota is not fished out due to the limited market for plaice.

3.1.8 Predicting productivity via climate services

Mark Payne, DTU Aqua

The inability to predict recruitment has long been a thorn in the side of marine science, and in spite of many years of effort, little progress has been made. Today, the accepted wisdom of the community, and also held by the majority of participants of the workshop, is that it can't be done. However, a quiet revolution is taking place in the field of climate science, where **it is now possible to reliably forecast the state of the ocean months and even years into the future**. This new technology represents both a tremendous opportunity and challenge for marine science: can we convert these forecasts of the physical environment into forecasts of biological responses? The ICES Working Group for Seasonal-to-Decadal Prediction of Marine Ecosystems (WGS2D) has developed forecast products based on top of this knowledge, and in particular recruitment predictions for four sandeel stocks in the North Sea. These predictions of the likelihood of high, medium or low recruitment are shown to be correct around 60-70% of the time, significantly outperforming random guessing. The question of how such knowledge can be used in harvest control rules was then discussed, using California Sardine as an example. Recent work has examined the incorporation of environmental forecasts into the management of this stock, and this has been shown to improve both the yield and sustainability of the fishery. The application of environmental predictions as a basis for predicting recruitment therefore is an exciting new opportunity to inform both the routine management and rebuilding of fish stocks.

3.1.9 Rebuilding plans in mixed fisheries – FLBEIA as tool for impact assessments

Alexander Kempf, Thuenen-Institute of Sea Fisheries

Rebuilding of stocks in mixed fisheries is often more complicated than rebuilding stocks in fisheries with low bycatch. For example, the SSB of North Sea cod is currently estimated to be below B_{lim}. This led to a strong drop in advice (-61% compared to TAC in 2019) to bring the stock back to B_{lim} in one year (according to the ICES MSY framework). Finally, a 50% reduction has been agreed by EU and Norway. However, mixed fisheries forecasts show that status quo fishing effort would lead to a substantial overshoot of cod quotas because cod is either a target or at least a valuable bycatch in most demersal fisheries in the North Sea. Therefore, typical single species HCRs are meaningless in this situation without further considerations.

The situation of cod shows that more thought is needed to ensure that either the TAC is not exceeded (i.e. by increasing selectivity through technical measures) or alternative HCRs are applied for setting TACs in such a situation (Figure 3.8).

A tool for impact assessments that is able to handle such mixed fisheries interactions must have certain features to be able to handle typical issues (not an exhaustive list here) in relation to the rebuilding of stocks in mixed fisheries:

- Bio-economic models (e.g., FLBEIA) need to be able to simulate changes in catchabilities when implementing e.g., new selective gears (often there is also a loss in catch from other target species and not only the stock in focus) and associated consequences including increasing effort and loss in revenue/profit.
- Bio-economic models like FLBEIA should at least be able to take into account changes in catchability due to closed areas.
- There must be an option to simulate the impact of effort reductions in certain fleets/métiers
- MSE type simulations (or at least stochastic forecasts) are needed to answer whether there is a x% probability to be above B_{lim} in year y (for all stocks).
- There is a need to predict how large the loss in revenue/profit caused by choke effects will be.
- Parameterization by fleet/métier is needed (complexity case specific) to understand which fleets/métiers are mainly impacted or which fleets/métiers have to change their selectivity patterns most.
- A possibility to simulate also data limited stocks next to stocks with analytical assessments is beneficial to answer questions like whether bycatch stocks are already protected by managing the target stocks.

FLBEIA (for a description and links to manuals etc. see WKGMSE2, ICES, 2020a) is a tool that has all these features, although i.e. the evaluation of spatial measures is a big challenge as there is currently no spatially explicit version. On top, it can simulate socio-economic consequences that may also be relevant for rebuilding plans. Therefore, it is an important tool for impact assessments of rebuilding plans and has been used already especially in STECF. It is recommended to use it at least next to traditional single species MSE simulations, although FLBEIA has all features needed to apply it as only model.

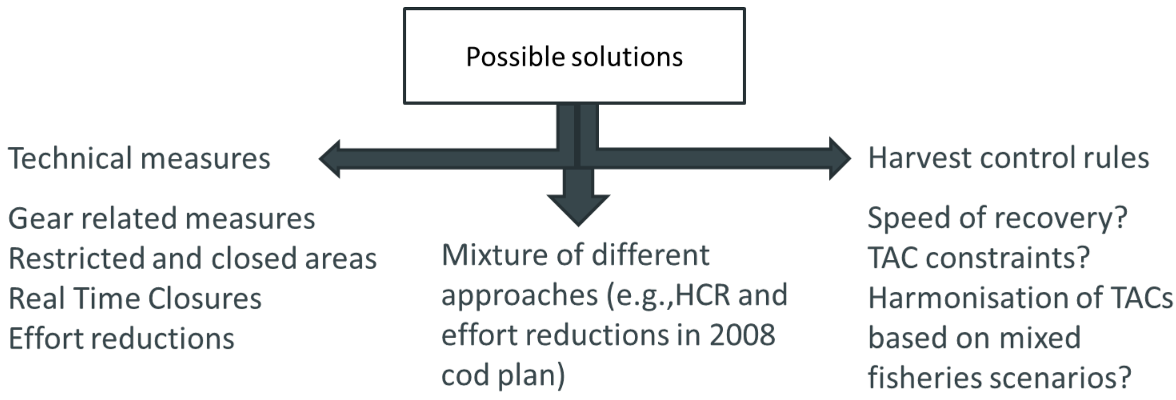

Figure 3.8: Possible solutions to deal with mixed fisheries interactions in rebuilding plans for stocks in mixed fisheries.

3.2 Comparison of different methods for evaluation of rebuilding plans

Table 3.1 compares advantages and disadvantages of the tools that were presented during the workshop and that could be used to evaluate rebuilding plans.

Table 3.1: Short summary of advantages and disadvantages of the tool presented at WKREBUILD.

Tool	Advantages	Disadvantages	See part(s)
MSEs package in FLR	Modular structure: each modules corresponds to one part of the MSE feedback loop (operating model, management scenario, observation error, implementation error). Uncertainty is accounted for within each module. The output of each module is the input of the following model to facilitate sequencing the steps. The model is set up to facilitate the implementation of a full-feedback MSE. Available HCRs already implemented (TACs, linear effort reduction, stepwise effort reduction) and possibility to easily develop and implement alternative HCRs. Wrappers can be developed to input stock assessment outputs from non-FLR based models.	Parallelization is needed to run the model in an efficient time frame. Technical measures, such as spatial and temporal closure or gear restrictions can only be simulated through effort reduction.	3.1.1
SimpSim	It is a simple tool, an R script that can be implemented in a short period of time, especially if input data are formatted in FLR. The tool is very flexible and can be easily adapted by the user. SimpSim enables to explore management strategies using a shortcut approach, i.e. enabling a short computing time. The script includes a number of functions to compile performance statistics and graphs to illustrate results. SimpSim has also been used to evaluate the performance of the Celtic Sea Herring monitoring TAC.	SimpSim is not an R package but rather an R script. It is not maintained and there is no repository with the source code. The input is supposed to be in FLR which does not give much flexibility to the user when another data structure is used. There is no feedback in the loop. The uncertainty and bias in relation to the stock assessment model are not taken into account in the forward projection. The operating model does not include an observation model.	3.1.2
Stochastic forecast with HCRs in SAM	Uncertainty in stock perception via simulating last year estimated population and fishing mortality (uncertainty in stock and assessment model) Uncertainty in future dynamics (recruitment, survival) Easy to run and implement above all for users with experience in doing forecasts in SAM Possibility to estimate rebuilding probability	No explicit implementation error but process errors that may account indirectly for some Necessitate a stock assessment fitted with the SAM model Depends on reference point estimates that can be uncertain but can easily change rebuilding targets to account for uncertainty	3.1.3 and 4.1.1

	Possibility to change the rebuilding targets		
Simple HCRs in FLR	Flexible code based on FLR. Import of SAM outputs directly into FLStock. Can also be applied to other assessment model outputs. Different recruitment relationships included. Simple HCR included and possibility to extend to different forms of HCR. Possibility to estimate rebuilding time and rebuilding possibility	No explicit implementation error included. Code not converted (yet) to function(s). Not fully generic.	3.1.4
MSE for the Iberian sardine stock using single stock FLBEIA	A wrapper was developed to implement a full feedback MSE using stock synthesis and FLBEIA, which may be a tool with wider applicability both within ICES and elsewhere. It can be used for a single-stock MSE and without economic data (i.e., very simple assumptions are made).	Requires a lot of time to prepare the code to implement an MSE; and high computation load for running the iterations	3.1.5
FLBEIA	Able to simulate technical interactions in mixed fisheries Full MSE loop possible ➔ Evaluation of probabilities to fall below B_{lim} etc. Code based on FLR Bio-economic model with a detailed economic sub-module ➔ Evaluation of economic and social indicators (e.g., employment, salary) Technical measures can be simulated (area based measures only indirectly via catchabilities)	Complex parameterisation of multi-species and multi-fleet scenarios (case specific) Complex code. Needs experience to run and adapt. Running time of simulations can be very long (depends on the parameterisation and availability of computing power incl. parallelisation)	3.1.9

3.3 Communication and visualisation of uncertainties

Visualisation is a factor in processing uncertainty regardless of whether it is presented graphically or only imagined by the person trying to understand uncertainty. Research shows conclusively that skilful representations of uncertainty can play a positive role in guiding decisions whenever risks are difficult to quantify or when large uncertainties remain unaccounted for once quantifications are done. This is precisely the situation of rebuilding scenarios, where the data and knowledge are often lacking but the need to understand and communicate uncertainty is more urgent since the evidence shows greater unpredictability of population dynamics once the stocks are depleted. The sensitivity to management decisions taken during the rebuilding phase is also higher.

The visual dimension is vital for the understanding of uncertainty, as well as representing it to other stakeholders. Before we can discuss design options, there are a number of recommended prerequisite steps, see the Figure 3.7 above from *Visualising Uncertainty: a short introduction* (AU4DM, Levontin et al., 2020).

The process should begin with the identification of uncertainty sources, and understanding the contribution of various factors to both a larger uncertainty context and the specific elements that require a graphical representation. In the context of rebuilding plans, both a data and knowledge basis for modelling need to be deconstructed and reviewed in terms of uncertainty. For example, it is critical to examine how much data (if any) are available that pertains directly to the population at low levels. What are the key biological, environmental, habitat-related, and implementation-related uncertainties that are important for understanding the population dynamics of a depleted stock that may differ from the better understood dynamics of a healthy stock of the same species? Crucially, there is a need to determine the sources of uncertainty that could hinder rebuilding; specifically, can there be depensation or other ecosystem-level effects that can slow the rebuilding process? These uncertainties can be represented as a tailor-made infographic in reference to a predefined list of uncertainties.

It is imperative to communicate that reliability of forecasts is lower for depleted stocks than for stocks that are fluctuating around the target level. This may be due to models going outside the range of values for which observations are available and consisting of structural assumptions that are inaccurate for depleted stocks: it is possible that the stock is experiencing different dynamics at low stock levels due to biological or ecosystem factors that become significant only when the biomass is reduced. It is therefore advisable to adopt a different graphical vocabulary than the one being used to communicate regular stock assessment results. Colour hue or colour transparency can be used to distinguish different levels of plausibility of modelling results for depleted and non-depleted stocks. This should be in addition to representing the wider uncertainty context using other graphical tools such as icon arrays, glyphs on a map, or a conceptual infographic representing the bio-economic system as a whole. A whole range of available graphical tools can be found in *Visualising Uncertainty: a short introduction* (AU4DM, Levontin et al., 2020). It is recommended that various alternatives are developed in collaboration with graphic designers and tested with intended audiences prior to being adopted as a standardised design for communicating uncertainty in rebuilding plans.

3.4 Methods for considering productivity changes in rebuilding plans

The success of a rebuilding plan is strongly influenced by how the productivity of the stock in question will develop over the rebuilding period. While several components of productivity can vary in a non-stationary manner over time (e.g., natural mortality, growth), a particular emphasis has historically been placed on recruitment. Unfortunately, the science of recruitment forecasting remains in its infancy, despite being a topic of active research in fisheries science for more than half a century now, and the idea is viewed with scepticism amongst many scientists. However, the inability to accurately and precisely foresee future recruitments does not excuse us from the necessity of choosing values to include in our simulation models, nor from ensuring that rebuilding plans are robust to all future scenarios. Here we consider how future productivity changes can be incorporated into the development of a rebuilding plan.

The simplest approach to ensure robustness of the rebuilding plan to productivity variation is via modification of the operating model. In this case, the goal is to ensure that the rebuilding plans are robust to potential changes in the productivity of the stock. Approaches can include

- **Incorporation of a basic stock recruitment model into the operating model**. E.g. Ricker, Beverton-Holt, segmented-regression or a combination thereof. This approach allows for productivity to be modified due to the effect of the biomass of the stock on recruitment, where this is thought to be appropriate. In its simplest form, the stock-recruitment model is fit over the full time series of available data, and the assumption made the future recruitment dynamics will reflect those of the past.

- **Recent Recruitment**. In many cases, however, there is good evidence, especially under a changing and variable climate, that recruitment is non-stationary and that recent years deviate from the long-term average. In this case, it may be more appropriate to reflect this in the operating model, for example, by using a stock-recruitment curve fit to a truncated time series, or by resampling from recent years.
- **Historically-inspired scenarios**. Alternatively, in some stocks there is clear evidence of regime shifts or periodic episodes of high or low recruitment. For example, North Atlantic blue whiting (*Micromesistius poutassou*) showed a 10 year period of high recruitment in the late 1990s-early 2000s that was approximately 5-10 times the previous decade, before returning to "normal" in the mid-2000s. As part of the MSE of this stock's HCR, scenarios of future recruitment with similar statistical properties were evaluated to ensure that the rule could withstand such variability.
- **Climate predictions / projections**. Modern climate models have the ability to skilfully predict the state of the ocean in some regions up to 10 years or more into the future. Such predictions can be used to generate realistic scenarios of the future evolution of the environment, and therefore potentially productivity in cases where there is good knowledge of the influence of environment on recruitment. While these tools are relatively new and have yet to employed in this manner in the development of rebuilding plans and harvest control rules, there is little doubt that they can play a potentially important role in informing productivity trends in the operating models of the future.

A more developed approach involves the incorporation of understanding about the links between the environment and recruitment directly into the harvest control rule itself. Approaches include

- **Environmentally informed harvest control rules (eHCRs).** Such control rules adapt the adaptation to the state of the environment (and therefore of the productivity) as well as the state of the stock. The most well-known example is that of California Sardine, where exploitation rates are curtailed at low sea-surface temperatures. Such an approach has the ability to take advantage of changing and variable productivity in the fish stock, increase exploitation when the stock is capable of handling it. While such rules have primarily been explored in the context of harvest control rules, it seems reasonable that they could also be applied to rebuilding plans as well.
- **Incorporation of predicted future productivity into an HCR.** The use of forecast environmental information has also been studied in the California Sardine system (Tommasi et al., 2017). In this case, forecast future environmental conditions were used together with the current and recent conditions to modify the exploitation rate. Such a system was shown to outperform both the standard harvest control rule (including recent environmental conditions) and a rule without any environmental information, improving the yield and sustainability of the management system. Again, this study also appears to be highly relevant to the development and implementation of rebuilding plans.

While the use of environmentally-influenced exploitation rates has yet to see much uptake in the context of fisheries management, it clearly remains a promising opportunity for future development. A recent review of the use of such rules (Haltuch et al., 2019) highlighted that while they can give benefits in some situations, it is also highly dependent on the nature of the stock and the fishery under consideration. Nevertheless, when developing a rebuilding plan or harvest control rule, the inclusion of environmental variability is a relatively minor step once the rest of the machinery (e.g. operating model and assumptions about future productivity etc.) is setup, and such an approach can be readily evaluated alongside other proposed plans for relatively little additional cost. Given the widely recognized role of the environment in shaping productivity, it would therefore seem reasonable to explore such approaches in the development of future rebuilding plans.

4 Criteria for acceptability of rebuilding plans

ToR d) Propose criteria for the acceptability of rebuilding plans including rebuilding target, time and probability that would be consistent with international best practices.

During the workshop, it was proposed that when evaluating a rebuilding plan, two criteria could be defined first: the rebuilding targets and probability. From these two, the time frame for the evaluation can be calculated. This section also discusses other criteria that are important to consider during the evaluation, such as uncertainty and stock or fisheries considerations.

4.1 Summaries of presentations

4.1.1 Reconciling scientific advice and management decisions

Vanessa Trijoulet, DTU Aqua

In the North Atlantic and the Baltic Sea, advice for many fish stocks follows the ICES MSY approach, where a zero catch will be recommended if the stock is below B_{lim} and cannot rebuild in the short-term (2 years). However, zero catch advice is rarely implemented by managers. Indeed, the stock can be fished in a mixing area, as bycatch, or in a mixed fishery. A zero catch would therefore mean closing an area to fishing or an impossibility to fish on other stocks. In addition, zero catch may be difficult to implement for socio-economic reasons as it can threaten fishers' livelihood. It is therefore necessary to investigate the consequences of fishing below B_{lim}.

An exercise was conducted on two contrasting fish stocks currently estimated below B_{lim}, western Baltic spring-spawning (WBSS) herring and North Sea cod. The recommendation for WBSS herring has been zero catch for 2019 and 2020, while recent catch advice for North Sea cod was positive since cod could rebuild above B_{lim} in short-term forecasts. Short/medium-term stochastic forecasts with harvest control rules (HCRs) were used to investigate the consequences of allowing reduced fishing below B_{lim} (see part 3.1.3 for detailed methods). Three recruitment assumptions were considered: (i) a neutral assumption, where recruitment is sampled from the most recent recruitment estimates from the assessment, similar to assuming recruitment stays at current (low) levels; (ii) an optimistic assumption where recruitment follows a segmented regression relationship with SSB so that it increases with increases in SSB; (iii) a pessimistic assumption where recruitment keeps decreasing in the future via a random walk with negative drift.

Recruitment is almost always the largest source of uncertainty in stock response to management. The difference in outputs for different stock recruitment assumptions can exceed differences between the HCR shapes. Several recruitment assumptions should be compared to get the full range of plausible recruitment scenarios.

B_{lim} can be difficult to reach if recruitment assumptions are not in line with current reference points. For instance, if F_{MSY} was estimated using a stock recruitment relationship where recruitment increases with increasing SSB, and if recruitment levels are currently low compared to historical levels (often the case for depleted stocks), only an increase in recruitment in the future can allow the stock to rebuild with high probability in the medium-term. Reference points should therefore be in accordance with current recruitment regime if want to be used for short-term advice.

The maximum threshold of 5% risk to the stock, implied by the MSY approach, could be impossible to reach in the short-term for stocks with current zero catch advice. For these, a medium-term approach should rather be considered and an acceptable risk on the stock that may be larger than 5% should be discussed.

For both species, it is possible to keep fishing at reduced levels for similar cumulative catch, SSB and risk on the stock in the medium-term compared to no catch below B_{lim}. It may therefore be essential to look at trade-offs between risk on the stock and fishing catches in the medium-term to reconcile fisheries management decisions with scientific advice.

4.1.2 Advice systems, stakeholders and management issues

Henrik Mosegaard, DTU Aqua

In general modern fisheries management builds of the concept that international agreements on fishing rights and allowed catches, guided by scientific analysis and advice on the fishing opportunities, through regulations and control of fishing activities will promote sustainable exploitation of common resources.

The history of establishing fishing rights goes far back to community rules with examples of ownership to local fishing waters and regulations of access and fishing effort. Internationally, the expansion of the open access fishery from the 1950s to the 1980s, led to concern of overfishing of the local/national fishing opportunities.

The development of fishing rights in Iceland has had great influence on emerging international policies and the United Nations Convention on the Law Of the Sea (UNCLOS, UN, 1982). The Icelandic history is filled with examples of the forces behind the exploitation of fisheries resources (Kurien 2000). In the 14th century, Hanseatic, merchants from Bergen followed up on the old Viking tradition of importing dried cod from Iceland; this probably inspired English merchant to take up the same import but also to finance fishing expeditions to Iceland. This was not acceptable to the Danish crown ruling Iceland, but lack of naval power prevented an exclusion of the English activities. The English fishery in coastal Icelandic waters went on for the next more than hundred years until the English focus shifted to more favorable fishing grounds off the Newfoundland coast. With diminished English interests, the Danish crown monopolized the fish trading for almost 250 years until 1855. In 1901, a maritime fishing limit of 3 nautical miles was declared in Iceland. In 1904, Iceland got a home rule and local Icelandic merchants developed and industrialized the fishery in the following years, and in 1918, Iceland became a state under the Danish crown. A Fisheries Association was formed in 1911 that together with the later establishment of the Icelandic Fisheries Laboratories and Marine Research Institute lead to openness and a good foundation for governance of the fishery. In 1920 Iceland got the first coast guard vessel to better protect the existing 3 miles exclusive fishing zone from English vessels. In 1944, Iceland became an independent republic with full charge of their fishing policies.

Following the Truman declaration (1945) several Latin American countries proclaimed national sovereignty over continental shelf fisheries. In 1952, the Icelandic fishing zone was extended to 4 miles, and in 1958, Iceland enacted a law for scientific conservation continental shelf fisheries. Following the failure of the 1958 UNCLOS, Iceland unilaterally extended the fishing zone to 12 miles. After the failure of the UNCLOS II, Iceland in 1972 extended the jurisdiction to 50 miles and again in 1975 to 200 miles, with the Icelandic coast guard to some degree successfully preventing foreign trawlers from fishing within the closed zones. The UK, which had pursued their fishing activities in these waters under protection of the UK warships, further challenged each of the Icelandic expansions with landing bans on Icelandic ships, and W. Germany followed in 1972. The European Economic Community (EEC) also applied import duty sanctions after the third extension, and the conflict led to several escalating confrontations between the UK warships and Icelandic patrol vessels during so called "Cod wars". The sanctions ended in 1976 when Iceland and EEC agreed on the 200-mile limit. A 200-mile Exclusive Economic Zone (EEZ) gained general international acceptance and was codified in the UNCLOS III 1982 and entered into force in 1994 (Knútsson et al., 2011).

Beneath the Icelandic sovereignty over fishery resources, the coastal fishery had, in reality, become an open access realm where everybody could invest and practice free fishing. This led to heavy over capitalization and with time overfishing. To overcome the tragedy of the commons, very gradually, a concept matured to allow privatization of individual fishing property rights. In 1983 a vessel Individual Transferable Quota (ITQ) system was amended to the fisheries act of 1976, allocating a permanent quota share based on historical catches from 1981-1983.

Other European countries followed the Icelandic example. In the UK, parts of quotas for mackerel and herring reserved for the pelagic freezer trawler sector in 1980. In the EU Common Fishery Policy (CFP), a TAC/quota component was implemented in 1983. From 1984-1985, the UK Producer Organisations (POs) organized own annual quotas (haddock) based on historic catches, a situation that gradually gave the POs increased control between 1985 and 1995. In this period, POs were managing on behalf of members – employing quota swaps with other POs, whereas the UK government managed other non PO vessels or quotas on stocks where PO member vessels had not requested a quota by national monthly limits. In 1993-1997, fleet capacity reductions (Multi-Annual Guidance Programs, MAGPs) were introduced with series of annual decommissioning schemes tendering as sealed bids, however with a partial suspension of this rule for new pelagic freezer trawlers until 30 June 2001 (VCU). In 1999, industry driven fixed quota allocations was established.

In the EEC, the CFP was developed with four principle components, initially in 1971 a common structural policy and a common marked organization. Later, the external policy, which was concerned with fisheries agreements with third countries in 1977, adopted the 200 miles EEZ. Finally, the resource conservation and management system adopted the agreement on national shares in 1983 (relative stability), which increasingly is challenged by climate change.

Since then the development of the CFP, EU has introduced a number of measures to improve management. The CFP in 2002 introduced long-term management plans and stakeholders' involvement. The 2013 reform continued to change the goals by adding the MSY objective, Multi-Annual management Plans introducing F_{MSY} ranges and regionalization establishing high level groups for regional governance e.g. Baltfish for the Baltic Sea and Scheveningen for the North Sea but not fully implemented within the EU (MedFish4Ever). Finally, and as a step towards ecosystem-based fisheries management, the landing obligation (LO) made the fishing industry accountable for its impact on, not only the share of the catch that may be landed and sold, but on all species and sizes caught. The LO is increasingly being challenged by zero-TAC regulations e.g. the Celtic Sea mixed fisheries.

Although the LO may address important questions of fisheries ecosystem interactions, it does not solve basic problems of non-sustainable target species fisheries, where inappropriate incentives for fishers and the ineffective governance prohibit sustainable outcomes. Incentive-based approaches that identify individual/group fishing- or territorial rights, as well as appreciate ecosystem services, promote both economic and ecological sustainability (Grafton et al. 2006). As Sidney Holt notes in 2001 (Holt, 2001), allocation issues become contentious and difficult when the activities of those with the smallest allocations are threatened by a reduction in their allocation below the minimum needed to maintain their participation in a fishery.

The provision of fisheries advice by ICES relies on the best available science at the specific point in time. This science is typically updated at benchmarks or during management plan evaluations. Long-term management plans (LMP) that are evaluated to be sustainable may add robustness to the advisory process with less chance of drastic annual changes. If no LMP is developed or if clients of ICES advice do not agree on a LMP, then the fallback solution is applying the precautionary principle implemented in the ICES MSY approach.

In the unfortunate situation that ICES assesses the stock status to be below B_{lim} and not able to recover in the short-term even at zero catch, the precautionary principle is interpreted as giving zero catch advice. This situation may arise from several circumstances, where one likely situation could be a change in perception of the status of an otherwise well managed stock, which gives rise to new reference points and therefore a change in management advice. This flip to a zero TAC advice is often not a real life option and it starts a chain reaction. Fishers foresee a loss of basis for existence or limitations on fisheries with bycatches of the stock in question, and therefore apply pressure on politicians that in turn try to influence the Commission, which starts to look for legal loopholes to avoid closing the fishery. This, in turn, makes the Marine Stewardship Council (MSC) reconsider certifications and Green organizations react to make politicians follow the ICES scientific advice. Additional advice from ICES may include the need for development of a rebuilding plan for the particular stock, however ICES lacks a framework for an immediate action on a client response to such an advice.

To avoid the advice flip or to be better prepared for its eventual consequences some suggestions are provided:

- **Map which fisheries are dependent on the exploitation of a specific stock**
- **Improve knowledge about rebuilding capacity of individual stocks**
- **Create robust rules for handling biological reference points**
- **Develop management tools with short response time**

4.2 Rebuilding targets and basis for reference points

Currently, in ICES, stock status is determined by the biomass limit and trigger reference points. The limit reference point (LRP) is B_{lim} and the trigger reference point (TRP) is MSY $B_{trigger}$. The target fishing mortality (F_{target}) reference points is F_{MSY}. Other jurisdictions have their own LRP, TRP and F_{target} that may differ from the ICES ones. Since F_{target}, LRP and TRP are derived from reference point estimates in ICES, methods used in ICES and other jurisdictions are discussed below.

4.2.1 The limit and trigger reference points

The specification and determination of a LRP for stock biomass is central to the initiation and implementation of a rebuilding plan. Because this limit reference point serves as the **alarm bell** for action in the ICES context, it is important that it rings when it should, and not when it should not. This requires understanding the sensitivity to biological, fishing and environmental factors.

The definition of reference points and methods used to specify them differ in different countries. The basis for these, and the consequences they have for establishing consistent guidelines for the development of rebuilding plans are worth comparing. Drawing on the experience of the participants, the approach used by ICES was compared with that being developed in Canada, the US and NAFO. The key points are described below (Table 4.1) and illustrated in Figure 4.1.

Details on the reference points used in the Canadian framework

Fisheries and Oceans Canada's (DFO) Fishery Decision-Making Framework Incorporating the Precautionary Approach (PA Policy; DFO, 2009b) is a policy that describes a framework where reference points and harvest decision rules are used to make management decisions to support sustainable fisheries. The PA Policy applies to key harvested stocks managed by DFO. The limit reference point (LRP) represents the stock status below which serious harm is likely occurring to the stock. The Upper Stock Reference (USR) can perform two functions. The USR is the stock level below which removals must be progressively reduced to avoid reaching the LRP. It should be set, at a minimum, sufficiently far above the LRP to provide time for a declining stock to be recognized and for management actions to have effect. The USR can also be a target reference point that takes into account broader biological, social, and economic objectives. The LRP is based on biological criteria and established by Science through a peer review process. The USR is informed by science advice and consultations with the fishery and other interests and is adopted by fishery managers.

The PA Policy provides guidance on determining reference points. In general, reference points should be based on the best information available on the stock biology and fishery while taking into account the limitations of the available data. Approaches to define reference points vary greatly given the range of fisheries managed by DFO. In situations where there is insufficient information on which to base the selection of reference points, a general framework is provided for guidance where the LRP is 40% of B_{MSY} and the USR is 80% of B_{MSY}. Where an estimate of B_{MSY} is not available, provisional estimates (proxies) can be used. Examples of provisional estimates are provided and include: the biomass corresponding to the biomass per recruit at F0.1 multiplied by the average number of recruits, the average biomass (or index of biomass) over a productive period, or the biomass corresponding to 50% of the maximum historical biomass. The PA Policy provides some guidance, however, reference points may also use metrics other than biomass or may be set lower or higher than the guidance provided in the general framework. Regardless of the approach used, reference points are intended to use the best information available and be consistent with the intent of the PA Policy.

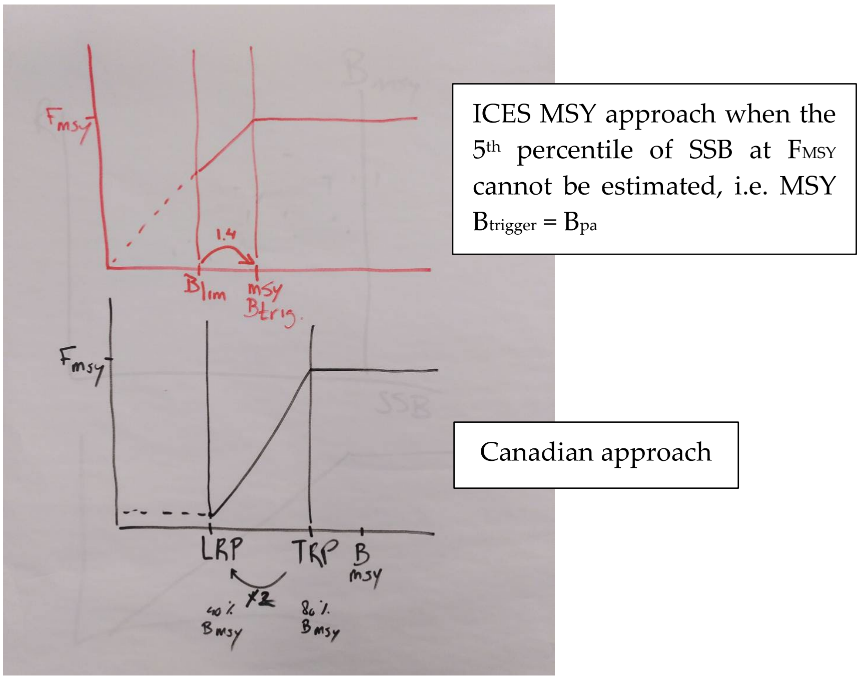

Figure 4.1: Illustration of ICES and Canadian approaches to reference points

Table 4.1: Comparison of the ICES, Canadian, US, and NAFO approaches to define limit and trigger reference points

	ICES approach	Canadian Approach	US approach	NAFO approach
General approach to limit reference point (LRP) and trigger reference point (TRP)	First the LRP (= B_{lim}) is derived and then the trigger reference point (MSY $B_{trigger}$) at higher stock sizes is set, based on the LRP (B_{pa}) if the 5th percentile of SSB at MSY cannot be estimated.	The LRP represents the point below which serious harm is likely occurring to the stock. The equivalent of the TRP, the upper stock reference (USR) is the point below which removals must be progressively reduced to avoid reaching the LRP and can also be a target reference point. The scientific information available can vary substantially from one stock to another. Therefore, different approaches must be used for calculating reference points.	LRP and TRP are based on MSY reference points.	NAFO precautionary approach is based on a set of limit, buffer and trigger reference points.
Specification of LRP and TRP	For stocks with analytical assessments (Category 1 and 2 stocks), B_{lim} is defined as the biomass limit below which a stock is considered to have impaired recruitment and is estimated based on either (i) the inflexion point of the segmented regression fitted to the stock-recruitment pairs, (ii) is fixed based on a classification of stock-recruitment type following a visual analysis of the stock-recruitment pairs (ICES, 2017).	Several approaches to calculating the reference points are in use. For many stocks, setting reference points in biomass terms is suitable, but other units may be used to indicate stock status where appropriate. General guidance suggests that setting the LRP at 40% of B_{MSY} and the USR and 80% of B_{MSY} may be considered. Where an estimate of B_{MSY} is not available, provisional estimates can be used.	B_{MSY} is used as target biomass reference point for rebuilding plans and as TRP in harvest control rules. The minimum size threshold (MSST, aka B_{lim} or LRP) is set as $0.5*B_{MSY}$ for many stocks.	The LRP (= B_{lim}) is defined as the biomass below which recruitment is likely to be seriously impaired. A variety of approaches for estimating B_{lim} have been explored, including Bayesian Surplus Production, Catch-resilience, and ASPIC models. Empirical reference points based on proxies for B_{msy} have also been used. B_{buf} is a biomass level above B_{lim}, required in the absence of analyses of the probability that current or projected biomass is below B_{lim}. The TRP ($B_{trigger}$) is the biomass level triggering the decrease in F in HCRs.
Consequences of approaches to specification of reference points	When B_{lim} and MSY $B_{trigger}$ (= B_{pa} or the 5th percentile of SSB fished at F_{MSY}) are close to one another, small reductions in biomass below MSY $B_{trigger}$ can lead to large changes in F and	The USR should be set, at minimum, at an appropriate distance above the LRP to provide sufficient opportunity for the management system to recognize a declining stock	Estimating the LRP as a fraction of B_{MSY} allows for distance between the LRP and the TRP. This recognizes that natural fluctuations around the	The NAFO PA framework requires setting of limit reference points for stock status and exploitation, defined as those implying “serious harm” to the resource. Lim-

	ICES approach	Canadian Approach	US approach	NAFO approach
	frequent triggering of rebuilding plans, with little time to adapt/respond. Despite being done in a rigorous and transparent way during benchmark process involving experts, stakeholders and independent reviewers, the process of setting B_{lim} based on a characterization of stock-recruitment relationship types could lead to a 'negotiation/trade-off' process when the observed patterns do not fit into a type class. It could be inconsistent, making it unsuitable for establishing reliable automated means to evaluate the performance of rebuilding plans and management strategies.	and sufficient time for management actions to have effect.	TRP are expected when fishing near F_{MSY}. Many stocks have planned reduction in F when B < TRP. to reduce chance of breaching LRP.	its for biomass comply with this definition but varies between stocks.
References	ICES (2017)	DFO (2009b)	NRC (2014)	NAFO (2004), Gonzalez-Troncoso et al. (2013) and Simpson et al. (2015)

4.2.2 The fishing target in rebuilding plan evaluation

In ICES, the fishing mortality target (F_{target}) used in harvest control rules is F_{MSY}. F_{MSY} is estimated using the EqSim method in the "msy" package. SSB and recruitment pairs estimated from the assessment model are provided to fit the stock recruitment relationship used for the projections. Sometimes, period of high productivity are removed from the pairs to avoid too optimistic stock projections for stocks that show regime shifts in recruitment. However, removing pairs may make the fit to a stock recruitment relationship, notably at high abundance, difficult. These types of choices are discussed during benchmarks. For stocks with current low recruitment, keeping pairs with high productivity may result in a F_{MSY} value that is too high and could lead to non-precautionary management. This was notably presented for WBSS herring during the workshop where fishing at F_{MSY} with the current low recruitment does not allow the stock to rebuild above B_{lim} (see 3.1.4 and 4.1.1).

In the US, F_{target} is always lower than F_{MSY} to avoid falling below B_{MSY} (NRC, 2014). Indeed, it is difficult to obtain in practice a realized F exactly at F_{MSY}. Similarly, in NAFO precautionary approach framework, the limit for fishing mortality is stated to be the MSY rate (F_{MSY}), although in other contexts this level is seen as sustainable, desirable and achievable without serious harm (Hvingel & Kingsley, 2014). At the same time, the MSY rate (F_{MSY} or its proxies e.g. $F_{0.1}$ and F_{max}) is in practice — i.e. for setting of management actions — often taken as a target value instead.

4.2.3 Conclusions on rebuilding targets

The review of the international experiences on reference points have highlighted a number of potential limitations in the ICES approach to estimate reference points. Current reference points may suffer from both limitations mentioned above: (i) estimation of biomass reference points in ICES, (ii) F_{MSY} possibly too high depending on the choice of the stock-recruitment pairs (see also the recommendation for a workshop on reference point estimation in section 6.1).

Defining rebuilding biomass and fishing targets is critical to the evaluation of rebuilding plans and should be clearly defined at the beginning of the evaluation. While ICES is currently using B_{lim} as the LRP, MSY $B_{trigger}$ as the TRP, and F_{MSY} as the F_{target}; other targets could also be considered in a rebuilding plan if relevant.

4.3 Mixed-fishery and mixed stock considerations

The majority of fisheries worldwide are mixed-stock and multi-species fisheries. Nearly all mixed fisheries capture a mix of stocks and species that differ in status, productivity and vulnerability to the fisheries (Murawski, 2010; Hilborn et al., 2015). Harvesting productive stocks to maximize sustainable yield will likely result in overfishing of less productive stocks unless their vulnerability to the fishery is low. Conversely, harvest policies aimed at rebuilding or optimally harvesting less productive stocks may result in substantial forgone yield for more productive stocks (Hilborn et al., 2004, 2012; Fulton et al., 2007). This is commonly referred to as the "weak stock problem", which arguably poses one of the greatest challenges for developing and implementing rebuilding plans. All else being equal, rebuilding a weak stock that has been depleted by fishing within normal prescribed timelines will often require large reductions in the catch of other 'healthy' stocks in the fishery. These reductions may be of such magnitude as to be economically or socially unacceptable. **Given these concerns, fishery regulators may**

choose to accept lower rebuilding targets, longer rebuilding time frames, or higher risk tolerance for unfavourable stock outcomes.

In the Northeast Atlantic, mixed fisheries considerations in rebuilding plans may be necessary due to the landing obligation. Rebuilding of stocks in mixed fisheries is often more complicated than rebuilding stocks in fisheries with low bycatch. For example, the SSB of North Sea cod is currently estimated to be below B_{lim}. This led to a strong drop in advice (-61% compared to TAC in 2019) to bring the stock back to B_{lim} in one year (according to the ICES MSY framework). Finally, a 50% reduction has been agreed by EU and Norway. However, mixed fisheries forecasts show that status quo fishing effort would lead to a substantial overshoot of cod quotas because cod is either a target or at least a valuable bycatch in most demersal fisheries in the North Sea. Under current selectivities and catchabilities in North Sea demersal fisheries, cod will be the main choke species in 2020. This means a substantial loss of yield and profit when fisheries have to stop fishing for other species because their cod quota is exhausted. Therefore, typical single species HCRs are meaningless in this situation without further considerations (see also 3.1.9).

Rebuilding of a stock that is exploited in a mixed stock fishery, where different stocks of the same fish species are caught, creates a special problem since the fishery in overlapping distribution areas is often directed simultaneously at all the stocks belonging to the same species. If the stocks are distributed in several management areas this may further complicate the situation; e.g. WBSS and North Sea autumn-spawning (NSAS) herring in the eastern part of North Sea (4), in the Kattegat-Skagerrak area (3a) and the western Baltic Sea (SD22-24).

Due to policy issues and international agreements, e.g. the arrangement of the relative stability, it is not always an option to close the fishery in one area to allow bycatches of the same stock in other areas. ICES may advise that in an area that includes two stocks of a species, the species TAC should be set such that the risk of overexploitation of the weakest stock is minimized. There has not been any requests for considering mixed stock issues in the advice for NSAS. ICES has not based its catch advice for NSAS herring on the occurrence of a weaker herring stock in parts of the NSAS distribution area. With the present need for a recovery of the WBSS herring stock, a solution may point at different spatial and temporal restrictions on the herring fishery in areas where migration of the WBSS would overlap with adjacent stocks. A detailed real time monitoring of the composition of the mixed stock fishery in the eastern North Sea, the Skagerrak, Kattegat and the western Baltic may direct dedicated real time management measures.

In other cases, the European Commission has requested a presentation of catch options that cover mixed stock fishery opportunities of western Baltic cod (WB cod) when mixing with eastern Baltic cod (EB cod) in the western Baltic Sea (SD24). Here the recent depletion of the EB cod stock has led to zero catch advice and therefore special management considerations when providing

Considerations in other jurisdictions

In the United States, the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) requires that fishing mortality be kept below that which would produce maximum sustainable yield (F_{MSY}) for all stocks and that time-constrained rebuilding plans be implemented for all overfished stocks (Restrepo and Powers 1999). The MSFCMA, as operationalized through National Standard 1 Guidelines, provides a "mixed-stock exception", which accepts increased probability of overfishing a stock to reduce the potential of foregone yield from healthy stocks captured in the same fishery. However, the exception only applies when a stock is not currently overfished and the fishing mortality level will not cause it to fall below its minimum stock size threshold more than 50% of the time. Furthermore, other management options aimed at mitigating fishing mortality (e.g., increased selectivity, avoidance) must have been considered and the incremental yield from the healthy stocks "must generate long-term positive net benefits to the nation" (National Research Council of the National Academies, 2014).

Australian policy and guidelines (DAWR, 2018) allow for target reference points for individual stocks in mixed-stock fisheries to be set such as to achieve fishery-level maximum economic yield, not necessarily individual maximum sustainable yield. However, fisheries must be managed to respect individual limit reference points for all stocks, which are to be set in a consistent manner. Depleted stocks must be rebuilt to a level representing a 90% probability of exceeding their limit reference points within a specified time period, although the prescribed duration of that period may take into consideration the challenges of constraining fishing mortality across all stocks in the fishery.

4.4 Rebuilding probability

ICES usually advises on minimum of 95% probability for the stock to stay above B_{lim} as a precautionary threshold for management scenario evaluation. Several review and case studies presented at the workshop raised the concern that for depleted stocks with current zero catch advice, this probability may restrict the number of management scenarios that will result in rebuilding of the stock for any time frame (see sections 2.1.8, 4.1.1 and 4.5.3). For these stocks, it may be necessary to agree on an acceptable risk on the stock that is below 95%. In other jurisdictions, probability used in rebuilding plan evaluation and management varies between 50-95%. For instance, the US refers to stocks being rebuilt when they have at least a 50% probability of having reached B_{MSY} targets (US government, 2007). In Australia, the precautionary rebuilding probability is 90% (DAWR, 2018) but most recent assessments defined being above the LRP with a reasonable level of certainty as a 75% probability that the stock is at, or above, the LRP. In New Zealand, stocks are considered rebuilt when they have an acceptable (at least 70% probability) that the target has been achieved (New Zealand Ministry of Fisheries, 2011) (see also section 2). We suggest the evaluation of rebuilding plan scenarios that will clearly represent the trade-offs between risk on the stock, fishing scenarios and time to rebuild.

The rebuilding probability or range of probability should be consistent throughout the rebuilding plan exercise.

4.5 Rebuilding time frames

According to the Common Fishery Policy, *multi-annual plans should be adopted as a priority, […] and should contain measures to restore and maintain fish stocks above levels capable of producing maximum sustainable yield*. This indicates that rebuilding plans should be an integral part of long-term management plans (LTMP). Reality is that only a limited number of stocks are currently managed according to a LTMP, and rebuilding plans are available for an even smaller number of cases.

Rebuilding plans require the definition of at least **three different time frames**: (1) *leading to*, (2) *leading out*, and (3) *for the evaluation of rebuilding plan*. The discussion on time frames below use the current ICES definition for the LRP (B_{lim}) and the TRP (MSY $B_{trigger}$). Biomass targets may differ depending on the agreed rebuilding plan.

4.5.1 Time frame leading to a rebuilding plan

It is good practice that rebuilding plans are developed prior to a stock falling below B_{lim} to be eventually ready for prompt advice and implementation. Based on the ICES precautionary approach, when a stock is reduced below MSY $B_{trigger}$ (but it is still above B_{lim}), fishing mortality should be reduced accordingly to halt the decrease and especially reduce the risk of a stock to fall below B_{lim}. However, there are cases where this is not enough and the development of rebuilding plan options should be considered, when not already in the management plan, as soon as:

the median SSB of a stock is estimated below MSY $B_{trigger}$ at the beginning of the advice year and the forecast based on the ICES rule (F from the slope) does not reverse the decline in SSB at the end of the forecast year.

Given that the ICES advice rule is not expected to lead to further decrease in SSB, this should be regarded as an early warning to be communicated by the working group (WG, for instance, mentioned in the section issues relevant for the advice). Moreover, the WG should explore possible reasons for the decline, and proactively start considering first components of a rebuilding plan such as adding a ToR to develop medium-term forecasts for the following year assessment.

While the advice and management systems should guarantee prompt response for the recovery of stocks which fall to a poor state ($<B_{lim}$), it is important to avoid mechanisms that would trigger rebuilding plans unnecessarily given the dynamic nature of stocks and ecosystems. Under the ICES advice rule, a stock should have no more than 5% probability to fall below B_{lim}, so the probability that it is estimated below B_{lim} in two consecutive years is very low. Consequently, implementation of a rebuilding plan, when not already in the management plan, should be advised if:

the median SSB of a stock is estimated below B_{lim} at the beginning of the advice year and the forecast based on the ICES rule (F from the slope) does not allow the stock to get above B_{lim} at the end of the forecast year.

In those cases where these conditions are met but a rebuilding plan is not available, ICES advises zero catch and the need to develop a rebuilding plan. In addition, the working groups should conduct **medium-term forecasts** of different low levels of fishing mortality (incl. F=0, F limited to bycatch fisheries and if it exists the F that would stop/reverse the decrease in SSB) to provide managers with more catch options and their consequences beyond the advice year. These medium-term forecasts should be based on the same assumptions as the short-term forecast and be **included in the advice sheet** by expanding the catch scenarios table or in a separate dedicated section.

It is recognised that changes in the model, large retrospective patterns and/or changes in the reference points could result in sudden changes in perception of the status of a stock. Also in these cases, if conditions for the implementation of a rebuilding plan are met, the advice should follow accordingly as described above.

4.5.2 Time frame leading out from a rebuilding plan

In principle, a rebuilding plan used for advice both complies with the ICES precautionary approach and is agreed by the relevant parties in all its components, including an exit strategy. The exit strategy should be embedded in the rebuilding plan and evaluated via simulations before it could be adopted for advice. This should guarantee a timely transition outside the rebuilding phase when certain conditions are met. In practice, the objective of those simulations should be to avoid that the advice is constrained by a rebuilding plan unnecessarily for too long (i.e., loss of fishing opportunities) or that it leaves a rebuilding plan too early (i.e., high risk).

The exit from a rebuilding plan should be robust to uncertainty in the estimation of the stock status to reduce the risk to fall back to a rebuilding phase soon after the exit. Robustness to uncertainty could include setting a certain probability of SSB being above rebuilding targets, being above rebuilding reference points, for a number of consecutive years, a consistent positive trend in SSB, evidences of a strong year class confirmed by independent observations (i.e., survey and commercial fishery) and through time.

According to NRC (2014), "*Rebuilding plans that focus more on meeting selected fishing mortality targets than on exact schedules for attaining biomass targets may be more robust to assessment uncertainties, natural variability, and ecosystem considerations, and may have lower social and economic impact*". Therefore maintaining F below F_{MSY} for a sufficient time (at least one generation) then smoothly transitioning to F_{MSY} could also be a possible strategy to exit a rebuilding plan.

The exit strategy should preferably contain elements on how to ensure a "smooth" transition between the rebuilding phase and the post-rebuilding phase (i.e., ICES advice rule or a LTMP) to reduce the risk of inversion of positive trends.

Good recruitment is expected to speed-up the recovery but cannot trigger *per se* the exit until the biomass based criteria for the rebuilding is fulfilled.

4.5.3 Time frame for evaluation of a rebuilding plan

A rebuilding plan to be used for advice by ICES requires an evaluation. Definition of a time frame is required for the evaluation. The evaluation period represents the time window between T_{MIN} and T_{MAX}:

- **T_{MIN}** is defined as the time taken for the stock to rebuild with zero fishing to above B_{lim} or the agreed rebuilding target with 95% probability, or other level of probability depending on the state of depletion of the stock
- **T_{MAX}** is defined as the maximum amount of time for rebuilding the stock, usually specified by managers/requesters but could be expressed as x* T_{MIN} with x > 1

The level of rebuilding achieved by alternative rebuilding strategies within this time frame can be examined. Rebuilding plan candidates should result in SSB > B_{lim} with the above probability by the latest at T_{MAX}. The trade-off between catch level and recovery time can be examined along the range between T_{MIN} and T_{MAX}. Recruitment and other assumptions should be consistent among T_{MIN}, T_{MAX} and the evaluation (see section 4.6 on uncertainties for setting of recruitment and other processes).

The time to rebuild will be affected by the level of depletion and the productivity of the stock. One of the benefits in the use of T_{MIN}, as defined above, is that the expected time of recovery increases the greater the level of depletion relative to B_{lim}. This is not accounted for when based timelines on generation time. Moreover, T_{MIN} is a stock-specific metric which links the stock productivity and other stock-specific properties. Because T_{MAX} is defined in relation to T_{MIN} it shares some of its properties (i.e., gets larger as the stock is in poorer conditions). However, definition of a multiplier may suffer of subjectivity. Patrick and Cope (2014) proposed T_{MAX} = 2 * T_{MIN} based on an analysis of 62 U.S. stocks, but other approaches can be found in literature, including T_{MAX} fixed to a predefined time horizon or expressed as twice the generation time.

The specification of T_{MAX} is important because theoretical considerations and empirical evidence indicate that the potential for recovery following reductions in fishing mortality is negatively related to the extent and the duration of depletion (Hutchings, 2015). The longer it takes for fishing mortality to be meaningfully reduced once a population is considered depleted, the longer the recovery period and the greater the uncertainty of recovery (Neubauer et al., 2013).

At the workshop, it was also proposed that simulation of the probability of SSB as a function of F and recovery time could provide an alternative approach worth further investigation (see section 4.5.3.1, Figure 4.2 and Figure 4.3).

WKREBUILD was not able to conclude on a value to use for x in the estimation of T_{MAX}, and a dedicated comparative analysis on a number of ICES stocks would be necessary before a methodology could be recommended.

4.5.3.1 Simulations performed during the workshop to investigate time for recovery (potentially T_{MAX})

Some quick simulations were run during the workshop to investigate how long it would take for two stocks currently below B_{lim} (North Sea cod and WBSS herring) to recover above B_{lim}. For these simulations, both stocks were projected forward for different average F values, kept constant in the forecast after the intermediate year. The forecast assumptions were the same as of the 2019 advice forecast, except that for WBSS herring, the forecast was made stochastic to be able to estimate a probability of rebuilding above B_{lim}. The simulations were done with 1000 iterations and the probability was calculated by the number of iterations were SSB ≥ B_{lim}.

Figure 4.2 illustrates the number of years it takes to have a 95% probability for the stocks to get above B_{lim} in the forecast for different F values (y-axis). T_{MIN} for cod is 3 years after the intermediate year (2019), while it is 4 years after 2019 for herring. Cod rebuilds above B_{lim} for F below 0.34, which is consistent with a F_{MSY} of 0.31 for this stock. The recovery for cod may take a maximal of 10 years for high values of F. However, WBSS herring recovers with a 95% probability only with F values below 0.08 (F_{MSY} for WBSS herring is 0.31). A 95% probability of rebuilding above B_{lim} for WBSS herring is therefore difficult to achieve and necessitate a large decrease in F (F_{2019} = 0.24). For this stock, it may also be useful to investigate the change in rebuilding probability as a function of F and rebuilding time. This latter is illustrated in Figure 4.3. Investigating the risk on the stock as a function of time for recovery and fishing mortality could also be useful for management of severely depleted stocks to illustrate trade-offs between stock conservation and fisheries considerations.

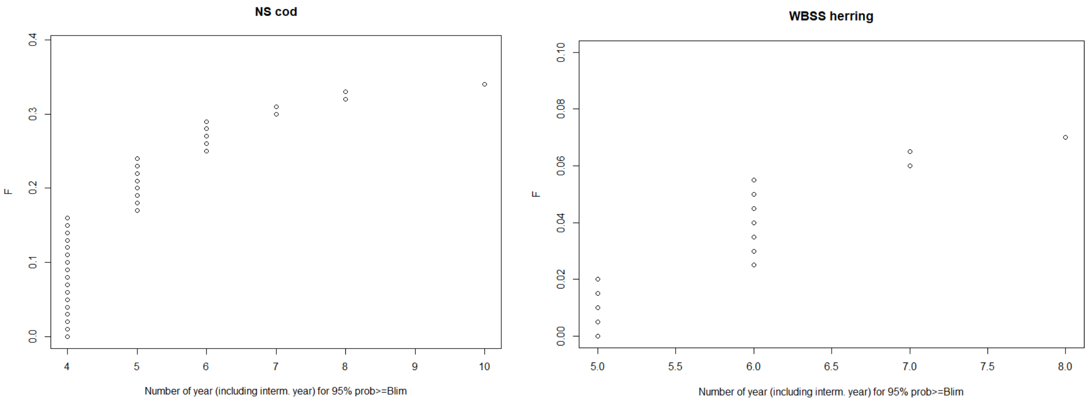

Figure 4.2: Number of projected years necessary to get a 95% probability of SSB to be above B_{lim} as a function of average F for North Sea cod (left panel) and WBSS herring (right panel).

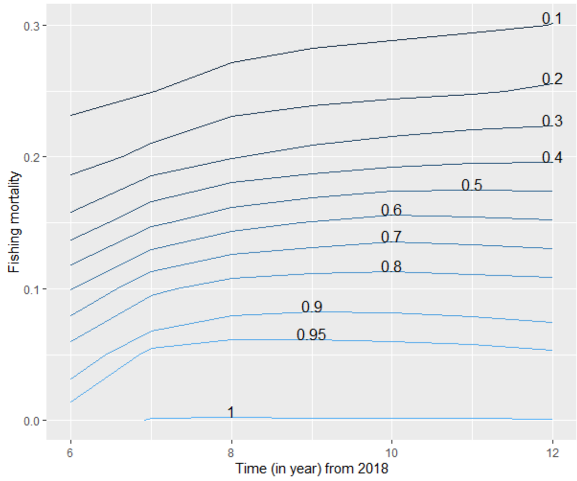

Figure 4.3: Probability of rebuilding above B_{lim} for WBSS herring, as a function of rebuilding time and fishing mortality. Probabilities are given in decimal form.

4.5.3.2 Mixed-fishery considerations on time frames from other jurisdictions

In practice, rebuilding strategies in US fisheries recognize that longer rebuilding times may be required for weak stocks captured in mixed fisheries (Punt and Ralston, 2007; Benson et al., 2016). Australian (DAWR, 2018) and New Zealand (New Zealand Ministry of Fisheries, 2011) policy similarly recognizes the difficulties associated with unavoidable bycatch, which results in the need to accept longer rebuilding times. There are no guidelines available to inform these trade-offs in any jurisdiction and decisions must therefore be case-specific.

The recently revised Canadian Fisheries Act, mandates the necessity to develop a rebuilding plan when a major stock (as prescribed by regulation) 'has declined to or below its limit reference point'. The legislation addresses complexities associated with rebuilding, including mixed-fishery considerations, by stating that "*if a plan could result in adverse socio-economic or cultural impacts, the Minister may amend the plan or the implementation period in order to mitigate those impacts while minimizing further decline of the fish stock*". Policy and guidelines are presently being developed to specify acceptable amendments.

4.5.3.3 Checking the progress of the rebuilding plan

In the European Union the European Commission has to provide an impact assessment (IA) for every new regulation. Implementing a regulation with a rebuilding plan is, therefore, not different from any other fisheries regulation. The STECF has developed a protocol for the analysis of the impacts of long-term management plans (STECF 2010a, see also Simmonds et al. 2011), which at that time had all a rebuilding phase. For many of the newly proposed long-term management plans, STECF provided the background information for the IA of the plan (e.g. STECF 2010b). For some of the plans, ICES provided also information on the possible biological effects of different harvest control rules, mainly status quo and the preferred option by the European Commission. For ICES, however, this was always 'an evaluation' of the contents of the plans and not an IA. Therefore, throughout this report we also use the term 'evaluation' for the assessment at the beginning of the plan and the analysis of effects of the plan after the implementation.

All of the long-term management plans had a provision for an evaluation after three years to assess the outcome of the plan against the objectives. **WKREBUILD proposes to evaluate each rebuilding plan at least in cases where the stock trajectory is outside the range of the ex-**

pected performance (e.g. it takes longer than expected) or other exceptional circumstances arise (e.g. unexpected data or a new understanding of the stock).

4.6 Uncertainty

Within the process of evaluation of a rebuilding plan, different sources of uncertainty need to be accounted for in order to advise not only on the management process but also on its robustness to internal and external variability. The development of a rebuilding plan will be based on the results of an assessment process (see section 4.5.1), therefore during its evaluation process the first step would be to implement robustness tests of the assessment model. Developing alternative operating models is common practice when running robustness tests. In section 4.5.1 it is stated that SSB is the key estimate to observe when defining the need of a rebuilding plan: "*the development of rebuilding plan options should be considered, when not already in the management plan, as soon as: the median SSB of a stock is estimated below MSY $B_{trigger}$ at the beginning of the advice year and the forecast based on the ICES rule (F from the slope) does not reverse the decline in SSB at the end of the forecast year.*" Therefore, robustness tests should first focus on the parameters which directly affect the variability in estimating SSB, such as parameters of **stock-recruitment relationship models** (e.g. steepness in Beverton and Holt model) and the **recruitment regime** considered at the time of the assessment. Specifically, the steepness of the stock-recruitment relationship will allow to test the sensitivity of the assessment model to alternative SR models assumptions within the stock assessment model. Accounting for alternative recruitment regimes allows to consider the effects of underestimating or overestimating the recruitment regime characterizing a stock in need of a rebuilding plan. Stock recruitment relationships' steepness and recruitment regime also affect reference point estimates.

Changes in **natural mortality** estimates used within the stock assessment process are reflected in a change of reference points estimates. Therefore, if there is evidence that reference points which will be evaluated during the rebuilding plan evaluation process were modified due to a change in natural mortality estimates, this should be accounted for in the robustness test procedure. Natural mortality estimates can be varying both, across the age specific vector or across the time series, and its influence on the reference point estimate will be directly correlated to the catch composition of the stock evaluated.

The stability and misspecification of stock assessment models is routinely checked through **retrospective analysis**, which estimates the level of deviation (retrospective pattern) from the final result when rerunning the model on a shorter set of the time series. Retrospective patterns can be quantified estimating the Mohn's rho factor (Mohn, 1999) where estimation methods have recently been reviewed during WKFORBIAS (ICES, 2020b). In addition to Mohn's rho estimates, Monte Carlo Markov Chain (MCMC) simulations can be used to estimate the accuracy of process error within models (Magnusson et al., 2013) and model stability testing for potential overparametrization.

During the evaluation of a rebuilding plan, **alternative management plans** aiming at rebuilding need to be tested, if such alternative scenarios suggested by managers are considered limited during the evaluation process, the advisory committee should introduce additional alternative scenarios based on experts' knowledge and reviews of scientific peer reviewed papers. All management scenarios need to be tested within the time frame defined in section 4.5.3.

When testing alternative management scenarios, the potential that their implementation will be biased by external factors (this is generally identified with overfishing but environmental and economic factors can also intervene), have to be taken into account by adding in the modelling framework used the **implementation error factor**. If information on historical bias is available, this should be used to inform the implementation error within the model, while if no information is available, implementation error should be represented by noise. In order to quantify the effect of implementation error on the model output scenarios, which do not account for implementation error should always be tested against scenarios that do account for it. Management scenarios, which are applied to mixed fisheries fleets, though, should not have scenarios that do not account for implementation error as the nature of such fleets will intrinsically have some level of implementation error embedded in it. Multiple TACs or choke species could alter the outcome of the catch reducing it, which will alter inevitably the implementation of the management in place.

4.7 Socio-economic aspects in rebuilding plans

For the fishing sector, a rebuilding plan means always a reduction of fishing opportunities for the coming year(s). In Figure 4.4, two possible scenarios for a rebuilding plan are included, where in Scenario 1 the reduction of catches compared to the current catch level is lower than for Scenario 2 but is limited to 2 years. From a management perspective, Scenario 2 may be preferable because the objective (MSY catch level) is achieved earlier.

For the involved fishing fleets these two scenarios can have very different impacts. Scenario 2 may create more economic problems for (parts of) the fleet than Scenario 1 or vice versa. There are, therefore, **trade-offs** between the two scenarios, **which managers need to take into account when implementing a rebuilding plan**.

The main problem is the uncertainty about the transition phase between Year 1 and the time the stock is rebuilt. Without a rule in the plan to give indications how quota may develop over time the fishing sector has no idea at the starting point how long the period of low catches may take. Therefore, they may not be in favour of a rebuilding plan and argue that the Status Quo may be beneficial because they know what they can expect. In economics, this is expressed in fishers having a high discount rate and not wanted to exchange future higher catch possibilities for constant catches now (e.g. Doering & Egelkraut 2008).

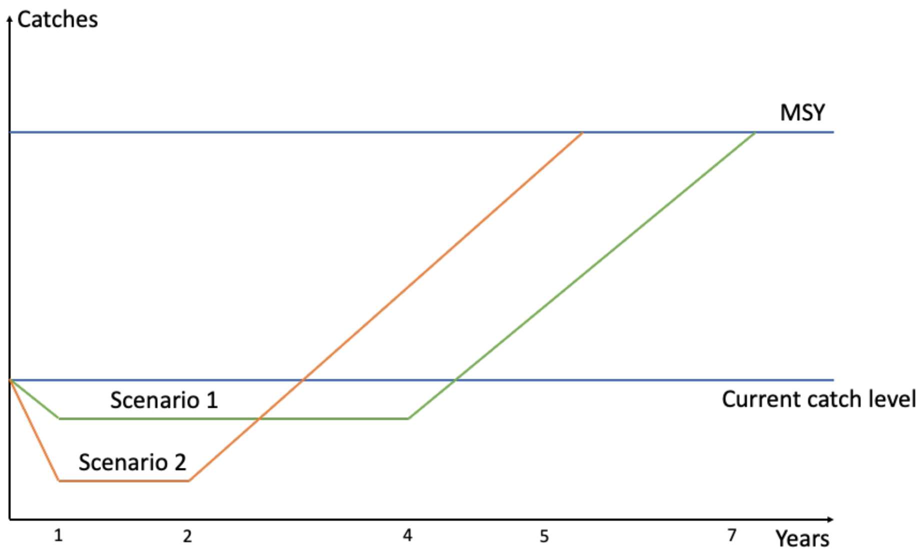

Figure 4.4: Two possible Scenarios for reaching MSY catch levels

So far, no implemented rebuilding or recovery plan included provisions regarding the distributional effects of a plan. Scenario 2 may force other parts of the fleet out of business compared to Scenario 1. Some vessel owners may be able to survive a few years with lower catches, others may not. Managers should, therefore, take distributional effects more into account as there may be socio-economic objectives, e.g. keeping fishing vessels in certain parts of remote areas, which are not achievable under certain management plans.

It may also make sense to have a closer look at the transition phase and negotiate with the fishing sector how a phase of lower catches may influence the fishing fleets and what measures can accompany a rebuilding plan to avoid negative outcomes. In some countries European Maritime and Fisheries Fund (EMFF) funding was issued, for example for temporal effort reductions to rebuild the stock while keeping the fishing vessels in business. This is basically a decision about who should benefit from a rebuilding program, either the existing fishers, or only a small group of fishers who will survive the rebuilding phase or even fishers from somewhere else in case the fishers originally fishing on that stock went out of business.

5 Recommendations for guidelines for evaluation of rebuilding plans

ToR c) Develop guidelines for the evaluation of rebuilding plans that take into account the precautionary approach, the species life history (incl. longevity), changes in productivity and rebuilding potential.

Table 5.1 summarises the guidelines that were developed with the participants of WKREBUILD. Given the lack of time to finalise the guidelines, these are recommendations more than firm guidelines and are only relevant to ICES Category 1 and 2 stocks. See section 6 for further recommendations, notably a second WKREBUILD workshop to develop and finalise the guidelines. Please refer to the other sections of the report for further details.

Table 5.1: Recommendations for guidelines for the evaluation of rebuilding plans from an ICES perspective. These recommendations are relevant for ICES Category 1 and 2 stocks.

Rebuilding targets	Defining rebuilding biomass and fishing targets is critical to the evaluation of rebuilding plans and should be clearly defined at the beginning of the evaluation. While ICES is currently using B_{lim} as the limit reference point, MSY $B_{trigger}$ as the trigger reference point, and F_{MSY} as the target fishing mortality; other targets could also be considered in a rebuilding plan if relevant.
Reference points	WKREBUILD raised some concerns regarding the estimation of reference points in ICES. If used in the evaluation of the rebuilding plan, reference points must be suitable, i.e. consistent with the current productivity of the stock at low SSB and current environmental conditions. Evaluation of rebuilding targets that may differ from current reference points, may be necessary for depleted stocks when those were estimated including periods of high productivity and optimistic stock-recruitment relationships.
Time frame leading to a rebuilding plan	Development of rebuilding plan options should be initiated, when not already in the management plan, as soon as the median SSB of a stock is estimated below MSY $B_{trigger}$ at the beginning of the advice year and the forecast based on the ICES rule (F from the slope) does not reverse the decline in SSB at the end of the forecast year. The effect of retrospective patterns on the possible future forecast of stock biomass should be taken into account when this is determined. Implementation of a rebuilding plan, when not already in the management plan, should be advised if the median SSB of a stock is estimated below B_{lim} at the beginning of the advice year and the forecast based on the ICES rule (F from the slope) does not allow the stock to get above B_{lim} at the end of the forecast year.

Time frame leading out from a rebuilding plan	The exit strategy should be embedded in the rebuilding plan. Leading out from the rebuilding plan too early or too late should be avoided. The exit strategy should preferably contain element on how to ensure a "smooth" transition between the rebuilding phase and the post-rebuilding phase (i.e., ICES advice rule or a LTMP) to reduce the risk of inversion of positive trends. The exit from a rebuilding plan should be robust to uncertainty in the estimation of the stock status to reduce the risk of falling back to a rebuilding phase soon after the exit. Robustness to uncertainty could include setting a certain probability of SSB being above rebuilding reference points, being above rebuilding targets for a number of consecutive years, a consistent positive trend in SSB, evidences of a strong year class confirmed by independent observations (i.e., survey and commercial fishery) and through time. Maintaining F below F_{MSY} for a sufficient time (at least one generation) then smoothly transitioning to F_{MSY} could also be a possible strategy to exit a rebuilding plan.
Time frame for the evaluation of a rebuilding plan	The evaluation period represents the time window between T_{MIN} and T_{MAX} which is used to assess the level of rebuilding achieved by alternative rebuilding strategies. T_{MIN} is defined as the time taken for the stock to rebuild with zero fishing to above B_{lim}, or the agreed rebuilding target with 95% probability, or other level of probability depending on the state of depletion of the stock. T_{MAX}, defined as the maximum amount of time for rebuilding the stock, is usually specified by managers/requesters but could be expressed as x* T_{MIN} with x > 1. WKREBUILD was not able to conclude on a value for x in the estimation of T_{MAX}. x=2 is often used in other jurisdictions.
Checking the progress of the rebuilding plan	Re-evaluation of the rebuilding plan may be necessary if the stock trajectory is outside the range of expected performance relative to timelines of the rebuilding plan or if other exceptional circumstances arise such as unexpected data or a new understanding of the stock. The new rebuilding plan evaluation will need to adapt to the new data or findings. A re-evaluation of the rebuilding targets or objectives may also be necessary.
Probability of achieving rebuilding	The default probability for rebuilding above the target is 95% but for certain stocks a lower probability may be more relevant in the short- to medium-term depending on the nature of the fishery and socio-economic considerations. This would be notably relevant for short-lived stocks with high recruitment variability that are estimated to be below B_{lim} with a probability larger than 5% even if unfished
Harvest rules in rebuilding phase	Several harvest rules should be evaluated during a rebuilding plan. These should be compared against the zero catch scenario and the ICES advice rule.

Evaluation tools	Rebuilding plans necessitate a prompt management response. Evaluation tools should be available when the evaluation starts. Multiple tools already exist to evaluate rebuilding plans. Rebuilding plan evaluation should use tools that have been reviewed or validated.
Uncertainty considerations	Alternative operating models should be evaluated to account for stock specific uncertainties. Typical uncertainties to consider in the rebuilding plan context are uncertainties in stock productivity (e.g. recruitment), in the assessment model (e.g. stock perception, bias such as retrospective patterns) and in implementation error.
Special considerations	The context of the rebuilding plan may be framed based on mixed stocks, mixed fisheries and socio-economic objectives.
Use of ICES guidelines for rebuilding plan evaluations	The guidelines are intended to guide the decisions based on best practice throughout the evaluation. Following or deviating from the guidelines should be appropriately motivated.

6 Recommendations

6.1 Workshop on reference point estimation in ICES

The review of the international experiences on reference points and rebuilding plans have highlighted a number of potential features that could be taken up in the ICES approach to rebuilding plans.

Therefore, WKREBUILD recommends to organize a workshop on methods for setting reference points for the initiation and completion of rebuilding plans.

The workshop should notably look into the estimation of both the biomass and fishing reference points. B_{lim} and MSY $B_{trigger}$ may be sometimes estimated too close to each other so that small reductions in biomass below MSY $B_{trigger}$ can lead to large changes in F and frequent triggering of rebuilding plans, with little time to adapt/respond.

Also, using F_{MSY} as F_{target} suffer from the fact that variability and uncertainty in realized F may lead to F > F_{MSY}. WKREBUILD refers to section 4.2 for more details.

6.2 WKREBUILD2

The week workshop did not allow to come up with firm guidelines on rebuilding plans. WKREBUILD therefore suggests having a follow-up meeting for testing the guidelines with actual test cases, with the aim of defining more specific criteria and guidelines, i.e. learning by doing.

WKREBUILD2 will necessitate preliminary work on test cases before the workshop. If a workshop on reference point estimation is organized in ICES, WKREBUILD2 should be organized after this workshop as the outcomes of such workshop will directly affect the criteria of acceptability of rebuilding plans, reference points and possibly biomass and fishing targets used for the harvest control rules during rebuilding plan evaluation.

Proposed ToRs for WKREBUILD2 are:

a) Review the outcomes of WKREBUILD and the workshop on reference point estimation and identify how these affect rebuilding plan evaluation.

b) Test WKREBUILD guidelines (2020) on actual test cases.

c) Propose criteria for the acceptability of rebuilding plans including rebuilding targets, rebuilding probability, rebuilding time frames, uncertainty to consider, mixed fisheries and socio-economic considerations.

d) Develop guidelines for the evaluation of rebuilding plans.

6.3 Workshop on guidelines for rebuilding plan evaluation for data limited stocks (Category 3-6)

Most of the discussion at WKREBUILD was centred on stocks with analytical assessments (Category 1+2). Identifying when a data limited stock is in need of rebuilding (or has rebuilt) and how to evaluate rebuilding plan options for such stocks would likely require a separate process.

WKREBUILD recommends a Workshop on guidelines for rebuilding plan evaluation for data limited stocks (Category 3-6) co-chaired by Neil Campbell (Scotland) and TBD, with the following ToRs:

a) Review the history of scientific advice, evaluation and implementation of rebuilding plans in the world for data limited stocks.

b) Propose criteria for the acceptability of rebuilding plans including rebuilding target, time and probability that would be consistent with international best practices.

c) Evaluate technical tools that are available or could be developed for evaluating the performance of different types of rebuilding plans. Take into account the work of WKREBUILD 2020.

d) Develop guidelines for the evaluation of rebuilding plans that take into account the precautionary approach, the species life history (incl. longevity), changes in productivity and rebuilding potential.

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Annex 1: Resolutions

The Workshop on guidelines and methods for the evaluation of rebuilding plans (WKREBUILD) chaired by Vanessa Trijoulet (Denmark) and Martin Pastoors (Netherlands) met from 24 - 28 February 2020 at ICES headquarters with the following ToRs:

a) Review the history of scientific advice, evaluation and implementation of rebuilding plans for fisheries management in the Northeast Atlantic and in other fora around the world.

b) Evaluate technical tools that are available or could be developed for evaluating the performance of different types of rebuilding plans. Take into account the work of WKGMSE2 (2019) on characterizing relevant uncertainties and bias.

c) Develop guidelines for the evaluation of rebuilding plans that take into account the precautionary approach, the species life history (incl. longevity), changes in productivity and rebuilding potential.

d) Propose criteria for the acceptability of rebuilding plans including rebuilding target, time and probability that would be consistent with international best practices.

Annex 2: Recommendations for development of rebuilding guidelines in Canada

In January 2020, Fisheries and Oceans Canada (DFO) held a Canadian Science Advisory Secretariat peer-review meeting on Science guidelines to support development of rebuilding plans for Canadian fish stocks. A summary of some of the draft recommendations for development of rebuilding guidelines is provided here. The meeting documents are in preparation and will be published on the Canadian Science Advisory Secretariat website: http://www.isdm-gdsi.gc.ca/csas-sccs/applications/events-evenements/result-eng.asp?year=2020.

The text below is an excerpt from the following draft research document: Kronlund, A.R., Marentette, J.R., Olmstead, M., Shaw, J., and Beauchamp, B. In prep. Considerations for the design of rebuilding strategies for Canadian fish stocks. DFO Can. Sci. Advis. Sec. Res. Doc.

The following elements and advice should be included in scientific guidelines for rebuilding strategies:

1. Define rebuilding strategies as integral to management strategies and seek to specify measures intended to rebuild stock to target levels prior to a limit reference point breach and seamless transitions to target levels when rebuilding from low abundance.
2. Specify how stock abundance (biomass) and fishing mortality are characterized and the stock trend:
    - 2.1. Report the abundance or proxy status relative to the limit reference point (LRP), i.e., the probability (or qualitative likelihood, IPCC 2007) that $B / B_{lim} < 1$.
    - 2.2. Report the fishing mortality status relative to the limit fishing mortality rate, e.g., the probability (or qualitative likelihood, IPCC 2007) that $F / F_{lim} > 1$.
    - 2.3. Define criteria to determine when a limit has been breached, inclusive of situations where a probabilistic determination can be made, only a deterministic determination is possible, and for cases when a weight of evidence approach must be used.
    - 2.4. Define criteria for handling:
        - 2.4.1. False positive determinations of a limit breach,
        - 2.4.2. Stocks fluctuating around a limit,
        - 2.4.3. Changes in status determination due to new data and assumptions in updated analyses,
        - 2.4.4. An error in status determination (e.g., a data or assessment error).
    - 2.5. Guidance is needed on whether determination of a limit reference point breach should be based on projected stock states (where possible), or current stock states, or accumulating persistent low stock states over time.
    - 2.6. Distinguish between stocks that are losing yield, and those stocks depleted to the extent that there is unacceptable risk of "serious harm" (e.g., recruitment overfishing, ecological losses, or loss of benefits to resource users).
        - 2.6.1. Introduce terminology for categories of "overfished" (e.g., recruitment overfished, depleted, recovering, etc.), to address both the abundance (biomass) axis of status.

2.6.2. Introduce "overfishing" which could be defined in a Canadian context as a state where the fishing mortality rate is determined to exceed a limit, F_{lim}, e.g., F_{MSY} or proxy.

2.7. Further characterize status by reporting stock trends or trajectories (e.g., criteria for "approaching a limit reference point" based on projection, or "decreasing, stable, increasing" trend characterization).

3. Identify or propose reasons for the stocks decline historically and factors that affect future stock prognosis:

3.1. Describe potential drivers of trends (e.g., "reasons for the stock's decline," including anthropogenic, biological, habitat and environmental conditions).

3.2. Distinguish time-dependent changes in the relative importance of anthropogenic and environmental factors (e.g., what caused the decline, what is currently keeping the stock at a low level?).

3.3. Characterize the management conditions at the time of status determination (e.g., "a rebuilding plan is in place, with prescribed timelines").

4. Defined (rebuilding) management objectives for the stock and fishery related to reference points, or benchmarks:

4.1. Define interim objectives that allow evaluation of rebuilding progress and create process steps to allow adaptation of the rebuilding strategy using new information and updated analyses and allow revision to objectives if appropriate.

4.2. Revised objectives for avoiding a limit reference point breach may be required for application when the stock grows above the LRP in the course of the rebuilding plan given a breach has occurred.

4.3. Define what default stock states could be used to characterize a rebuilt state and the criteria to determine the rebuild state has been achieved (given the desired risk tolerance); additional alternative rebuilt states may be specified by decision-makers.

4.4. Specify any decision to introduce time-varying reference points into rebuilding strategies should be supported by evidence derived from feedback simulations to provide some assurance that desired outcomes can reasonably be expected (e.g., reference points are not adjusted downwards to levels where policy intent is unlikely to be preserved, or there is possibility that an assumption of compensatory stock-recruit response dynamics may not hold based on evidence or analogy to similar stocks).

4.5. Include a decline tolerance objective and performance statistic, where possible, given specified risk tolerance and time period for evaluation.

4.6. Scientific advice can be provided as to whether a proposed "lowest possible level" catch sequence is likely to fail, given measurable objectives established or proposed under a rebuilding strategy.

5. Describe methods for the calculation of rebuilding time frames that may vary depending on available data and model support:

5.1. An estimate of the minimum time to a rebuilt state in consideration of the current stock depletion, generation time, and productivity to the extent possible,

5.2. Defined methods of calculating generation time (i.e., specific equations) depending on available data support (e.g., when T_{MIN} cannot be calculated, multiples of generation time could be used), and

   5.3. Communicate the trade-offs incurred by selecting a target rebuilding time, i.e., by demonstrating how choosing a time longer than T_{MIN} affects biological outcomes vs. economic and socio-cultural trade-offs.

6. A statement of acceptable levels of risk in the context of the time period for meeting objectives, noting that context-specific specification of risk tolerance is guided by policy and fishery management choice:

   6.1. Objectives that include reference points should clearly specify how time should be interpreted, e.g., does a 90% probability of avoiding a limit breach mean a 1-in-10 year chance of a breach, or 90% in each and every year?

   6.2. The choice of probability in objectives may vary depending on whether current status is being evaluated, or a management strategy is being designed to meet time-prescribed rebuilding objectives. Guidelines should include a description of how these cases are different and the implications of risk tolerance choice as a stock transitions from rebuilding to target outcomes.

   6.3. Adopt and provide guidance on defensible practices for describing and communicating risk to decision-makers.

7. Describe various methods by which key uncertainties affecting science advice can be identified and quantified given the state of data and model poverty:

   7.1. Uncertainties include those associated with stock status, biology, environmental conditions facing the stock, habitat, potential drivers (or reasons) for the stock's decline, and implementation error (uncertainties in fishing mortality or total removals).

   7.2. Uncertainties can be irreducible, which means that rebuilding measures should be selected based on their robustness to unknown stock and fishery dynamics.

   7.3. Uncertainties can be reducible, in which case the rebuilding strategy should include provisions for collecting the data needed, or conducting the analyses required, to resolve those uncertainties.

8. Measures of stock and fishery performance related to the objectives, including:

   8.1. The spawning biomass <u>state</u> achievable for a specified time period and specified probability (e.g., what spawning biomass level can be achieved in 2 generations with 50% certainty?),

   8.2. The expected <u>duration</u> to achieve $B_{rebuild}$ for a specified probability (e.g., how many years will it take to achieve the $B_{rebuild}$ state with 70% certainty?), or

   8.3. The <u>probability</u> of reaching $B_{rebuild}$ for a specified time period (e.g., how certain is a spawning biomass of at least $B_{rebuild}$ in 2 generations?),

   8.4. Use of natural numbers when possible in performance measures (years to rebuilt target, catch, number of years of fishery closure, etc.).

9. Management procedures intended to meet stock and fishery objectives under the rebuilding strategy and transition to target outcomes:

   9.1. Stock and fishery monitoring needed to collect the data to evaluate performance,

   9.2. Assessments, inclusive of model-based and empirical approaches, to determine if targets are being met according to the pre-determined performance measures,

   9.3. Feedback management systems including harvest control rules and any meta-rules that adjust fishing pressure in response to the assessments. In particular the feedback should reduce fishing mortality when the stock is perceived to decline and increase it when the stock is perceived to increase, subject to meeting any imperative objectives and providing acceptable trade-offs of outcomes related to other objectives.

9.3.1. The purpose of a reference point is to separate objectives from the tactics employed to achieve the objectives. As such the configuration of a harvest control rule should not be constrained to align with, or even include, the reference points used to define objectives. The purpose of the management procedure (tactics) is to acceptably avoid limits and achieve targets.

9.3.2. For states of data poverty where reference points and biomass cannot be estimated reliably and therefore catch limits based on a "biomass times harvest rate" calculation established, empirical rules that reduce fishing mortality via input controls may be more effective than strategies based on catch limits and B_{MSY} targets.

10. A means of conducting evaluation of stock and fishery performance of existing or proposed management strategies relative to objectives appropriate to the state of data or model poverty:

10.1. Proposed rebuilding strategies may need to account for alternative hypotheses that govern the stock trajectory and identify management actions that do not depend on a single "best" interpretation of stock conditions and rebuilding potential. Attribution of stock depletion to environmental factors should not be taken as an indication that fishing mortality has little, or no effect, without evidence that is the case.

10.2. Describe how to show trade-offs in management outcomes that result from choice of alternative management procedures, including data collection:

10.2.1. Trade-offs include possible costs (e.g., persistent or worsening stock and fishery states) and benefits (e.g., stock growth in support of attaining desired stock states, shorter rebuilding times, and restoration of benefits to resource users), and how they vary in response to enhanced data collection (value of information).

10.3. Where possible, a zero fishing mortality management procedure is needed for each hypothesis under consideration to serve as a benchmark for comparison with alternative procedures and estimate T_{MIN}, where possible.

10.4. Related to (10.3), an evaluation of the probability of biomass increase to the LRP and target reference point (TRP) (default to B_{MSY} or proxy), respectively, at $T_{rebuild}$ (or specified milestones) under a zero fishing mortality procedure.

10.5. Where possible, a "perfect information" scenario that assumes both stock size estimation and management implementation is without error over the rebuilding time frame to serve as a benchmark.

10.6. Data-poor frameworks are needed where precautionary steps include data acquisition as part of the rebuilding strategy, and a rebuilding plan where management adaptation can occur as new information accumulates.

11. The value of enforcement systems to provide reliable catch monitoring and implementation of rebuilding strategies as intended by showing the loss of performance due to imprecise data or implementation errors:

11.1. Explicit accounting for catch estimate quality (e.g., plausible direction and magnitude of catch estimation bias).

12. Possible management actions to be taken during the interim period required to identify an acceptable rebuilding strategy and implement a rebuilding plan following an LRP breach that are consistent with the Precautionary Approach Policy intent (DFO 2009b), noting re-

views of rebuilding performance identify early reduction of fishing mortality as a key feature of successful plans.

13. Adaptation of rebuilding strategies:

    13.1. Advice on determining how frequently the rebuilding strategy should be evaluated for progress which may vary according to:

        13.1.1. Time-prescribed interim objectives agreed to in the development of the rebuilding plan,

        13.1.2. Life history (short-lived fish may require more frequent progress evaluation than long-lived species),

        13.1.3. Schedule of anticipated data collection or availability of new data or analytical resources for updating assessments or simulations, and

        13.1.4. Exceptional circumstances such as unexpected data, or new understanding of the stock and fishery.

    13.2. Specify that not meeting interim or overall rebuilding objectives is not failure; failure is failing to adapt to new data, altered system understanding, updated analyses, or revised objectives. It is to be expected that a rebuilding prognosis will in general evolve from initial expectations through the lifespan of the plan.

14. Roles and responsibilities of various contributors to the development of rebuilding strategies and plans, including provisional terms of reference for science advisory requests.

    14.1. Science has a role in helping to set realistic expectations for stock rebuilding by identifying those management actions unlikely to produce desired rebuilding outcomes over a range of possible stock conditions and adapting the selected rebuilding strategy based on the stock response observed over time.

15. Identify items for alignment and efficiencies with related processes, such as terms of reference (and roles and responsibilities) for science advice needed for stocks meriting both rebuilding strategies under the Fish Stocks provisions of the *Fisheries Act* and recovery potential assessments under the *Species At Risk Act*.

16. Describe a consistent communication format for science advice on rebuilding strategies.

Annex 3: NAFO's Conservation and Enforcement Measures regarding rebuilding plans

NAFO 3LNO American Plaice Rebuilding Strategy

1. Objective(s):

(a) Long-term Objective: The long-term objective of this Conservation Plan and Rebuilding Strategy is to achieve and to maintain the 3LNO American plaice Spawning Stock Biomass (SSB) in the 'safe zone', as defined by the NAFO Precautionary Approach framework, and at or near B_{MSY}.

(b) Interim Milestone: As an interim milestone, increase the 3LNO American plaice Spawning Stock Biomass (SSB) to a level above the Limit Reference Point (B_{lim}). It may reasonably be expected that B_{lim} will not be reached until after 2014.

2. Reference Points:

(a) Limit reference point for spawning stock biomass (B_{lim}) – 50 000 tonnes

(b) An intermediate stock reference point or security margin B_{isr} – [100 000 tonnes]

(c) Limit reference point for fishing mortality ($F_{lim} = F_{MSY}$) – 0.31

(d) B_{MSY} – [242 000 tonnes]

3. Re-opening to Directed Fishing:

(a) A re-opening of a directed fishery should only occur when the estimated SSB, in the year projected for opening the fishery, has a very low probability of actually being below B_{lim}.

(b) An annual TAC should be established at a level which is projected to result in: continued growth in SSB, low probability of SSB declining below B_{lim} throughout the subsequent 3-year period.

4. Harvest Control Rules:

Noting the desire for relative TAC stability, the projections referred to, in items (a) through (d) below, should consider the effect of maintaining the proposed annual TAC over 3 years. Further, in its application of the Harvest Control Rules, Commission may, based on Scientific Council analysis, consider scenarios which either mitigate decline in SSB or limit increases in TACs as a means to balance stability and growth objectives.

(a) When SSB is below B_{lim}:

i. no directed fishing, and
ii. bycatch should be restricted to unavoidable bycatch in fisheries directing for other species

(b) When SSB is between B_{lim} and B_{isr}:

i. TACs should be set at a level(s) to allow for continued growth in SSB consistent with established rebuilding objective(s)
ii. TACs should result in a low probability of SSB declining below B_{lim} throughout the subsequent 3-year period, and Biomass projections should apply a low risk tolerance

(c) When SSB is above B_{isr}:

i. TACs should be set at a level(s) to allow for growth in SSB consistent with the long-term objective, and
ii. Biomass projections should apply a risk neutral approach (i.e. mean probabilities)

(d) When SSB is above B_{MSY}:

i. TACs should be set at a level of F that has a low probability of exceeding F_{MSY}, and
ii. Biomass projections should provide a risk neutral approach (i.e. mean probabilities).

<u>Flemish Cap Cod (Div. 3M)</u>

The work related to 3M Cod has been the subject of much debate in the Scientific Council, the WG-RBMS and the Commission. The development of a risk-based management strategy was first raised as a priority for NAFO in 2012. In 2016, a detailed work plan was developed and approved. In 2017, the work plan for 3M Cod was delayed one year because of the additional work required to complete the work on the Greenland halibut Management Strategy Evaluation. This delay was a cause for concern for some Contracting Parties.

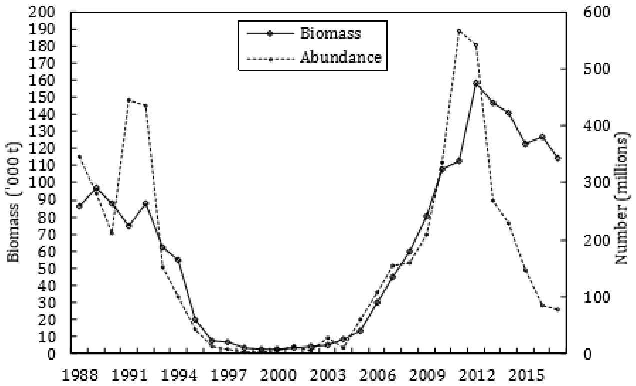

Figure 0.1: Trends in biomass and abundance of cod on the Flemish Cap (Div.3M), 1988 - 2016.

The 2017 advice indicates this stock is subject to fishing mortality rates higher than the currently identified fishing mortality reference point (F_{lim}). The Commission did not agree on a TAC for this stock for 2018 consistent with scientific advice. The Commission approved a timeline for the work to be carried out regarding 3M Cod, which includes two key tasks: benchmarking the assessment and an evaluation of the management strategy for this stock.

The benchmark assessment and the provision of new scientific advice for this stock took place during the April to June period in 2018 resulting in new scientific advice being available for the 40th Annual Meeting in 2018. The Management Strategy Evaluation will take a little longer and could be available for the 41st Annual Meeting in 2019. NAFO was commended in its 2018 independent performance assessment for making an effort to ensure key stocks are rebuilt and maintained at levels at which they can be sustainably harvested.