ELEVENTH WORKSHOP ON THE DEVELOPMENT OF QUANTITATIVE ASSESSMENT METHODOLOGIES BASED ON LIFE-HISTORY TRAITS, EXPLOITATION CHARACTERISTICS, AND OTHER RELEVANT PARAMETERS FOR DATA-LIMITED STOCKS (WKLIFE XI)

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i Executive summary

The **Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks** (WKLIFE XI), chaired by Carl O'Brien (UK), Tobias Mildenberger* (Denmark) and Simon Fischer* (UK) met in Copenhagen, Denmark 16-20 January 2023 (with hybrid meeting access), to further develop methods for stock assessment, stock status, and catch advice for stocks in ICES Categories 2–6, including the clarification of key issues previously raised by the ICES' Community when implementing methods developed by WKLIFE for use in the ICES' advice.

Intersessional work had taken place ahead of the WKLIFE XI meeting and was presented during the workshop. The presentations defined the work programme for the workshop and the identification of virtual subgroups; eight of which were identified within three Themes – Theme 1 (assessment methods), Theme 2 (challenges independent of assessment method) and Theme 3 (advice for stocks in ICES' Categories 4-6, model diagnostics, control rules and management strategy evaluation).

This workshop report contains detailed responses to collated comments from the ICES' community on the empirical harvest control rules for Category 3 data-limited stocks and surplus production models for Category 2 stocks; together with further guidance. However, WKLIFE XI decided not to update the *ICES technical guidance for harvest control rules and stock assessments for stocks in categories 2 and 3* (published 20 May 2022) at this stage.

A draft roadmap was developed during the workshop for future data-limited research, assessment and management advice within ICES. The intended focus will be to make use of the best available science to further improve the provision of data-limited advice within ICES and to review new developments from both inside and outside of ICES; including FAO, RFMOs and scientists outside ICES' membership. Topics include: data and their preparation, Categories 4-6 stocks including revisiting PSA (Productivity and Susceptibility Analysis), empirical indicators and harvest control rules (HCRs), length-based assessments, surplus production model assessments, data-limited reference points, simulation frameworks, short-lived and fast-growing species, and long-lived and slow-growing species, elasmobranchs, and sensitive and rare species. Timelines for delivery of the activities within the roadmap are to be identified at the next meeting of WKLIFE; together with prioritising tasks.

ii Expert group information

Expert group name	Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE XI)
Expert group cycle	Annual
Year cycle started	2012
Reporting year in cycle	1/1
Chair(s)	Carl O’Brien, United Kingdom
	Tobias Mildenberger*, Denmark
	Simon Fischer*, United Kingdom
Meeting venue(s) and dates	16-20 January 2023, Copenhagen, Denmark with hybrid meeting access (57 Participants)

1 Introduction

1.1 Terms of reference

The **Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks** (WKLIFE XI), chaired by Carl O'Brien (UK), Tobias Mildenberger* (Denmark) and Simon Fischer* (UK) met in Copenhagen, Denmark 16-20 January 2023 (with hybrid meeting access), to further develop methods for stock assessment, stock status, and catch advice for stocks in ICES categories 2–6, including the clarification of key issues raised by the ICES Community when implementing methods developed by WKLIFE for use in the ICES advice. The workshop addressed the following Terms of Reference (ToRs):

1. Summarize recent work by the scientific community, including published papers and exploratory work on Empirical rules and production models; review and address these publications with respect to ICES advice;
2. Review recommendations (e.g. from WKMSYSPiCT1, WKMSYSPiCT2) and requests for clarification made by ICES groups (e.g. Elasmobranch, Celtic Seas and Deep Seas advisory processes) on the application of the methods presented in WKLIFE X Annex 3 and provide clear and concise feedback on issues raised and incorporate into suggested updates to the ICES Guidance, as appropriate. These issues include:
    a. Application of methods to species with specific elasmobranch and deep-water life-history strategies;
    b. Advisable time series length for surveys and indices as well as how best to incorporate variability in the index for use in Surplus production model methods;
    c. Definition and use of $I_{trigger}$ and $I_{loss;}$
    d. Guidance on changing the frequency of application of the rules (i.e. using a method designed for biennial advice on an annual basis);
    e. Describe how sources of uncertainty are incorporated in each of the Empirical methods and examine the robustness of the parameter values;
    f. Provide detailed guidance on how to tune and test the methods, including the choice of multiplier m, for stock-specific application;
    g. Under what conditions could a catch advice increase from zero using current methods?
    h. Address other relevant issues as identified by WKLIFE and ACOM. A detailed list of issues for WKLIFE's consideration will be provided in advance of the workshop.
3. Discuss work relevant to WKLIFE to advance ICES data-limited advice for categories 2-6 and scope future directions. Draft a roadmap of aims, goals and perceived requirements for the coming 5 years. Potential elements that may be considered are:
    a. Assessment methods (e.g. length-based methods and indicators and Production models);
    b. Future directions and priorities for method development for advice on catch and stock status for ICES stocks for which there is no index of abundance (categories 4, 5 and 6);

c. Approaches for specific life-history types (e.g. short-lived species, *Nephrops*, elasmobranches, and deep-water species);
d. Quantifying and accounting for uncertainty (e.g. precautionary buffers and ensemble models);
e. Considerations of moving away from single-stock single-species methods towards including mixed fisheries, multi-species, ecosystem, or integrated approaches; and,
f. Input data diagnostics, requirements, and standardisation.

WKLIFE XI will report to ACOM no later than 17 February 2023.

1.2 Background

ICES provides advice on more than 260 stocks on an annual basis and more than sixty percent of these stocks are in Categories 2–6. Further developments of the approaches used in providing advice on fishing opportunities for these stocks are needed. WKLIFE is the premier venue for method development and discussion of stock assessments and advice approaches for stocks in Categories 2–6.

ICES is working to provide catch advice for all stocks that is in line with the Precautionary approach. The methods developed and tested by WKSLDLS and WKLIFE are key to ICES' advancements in this area.

WKLIFE XI was requested to explicitly address the following issues regarding the application of the methods as described in WKLIFE X.

Deep-water and elasmobranch stocks

The suitability of the methods for the suite of different life-histories (e.g. geographic separation of life stages, sex changes) represented in the ICES' stock list. Are the methods suitable for deep-sea stocks?

Comment on the value of additional testing across a wider-range of life-history strategies to resolve the issues in using these methods by stocks assessed by WGEF and WGDEEP.

M value selection

Enhanced guidelines for stock-specific simulations to set natural mortality (M) at a value other than the default would be very useful.

Incorporating uncertainty in the methods

Describe how uncertainty is incorporated in the Empirical methods and SPiCT.

I_{loss} and $I_{trigger}$

Provide clarifying guidance on the selection and use of I_{loss} and $I_{trigger}$

Advice frequency

Each method was tested and developed to provide advice on an annual or biennial frequency. What are the consequences of changing the periodicity of the advice (e.g. can the biennial advice methods be applied every year if necessary? and would parameter values need to be changed?)

1.3 Conduct of the meeting

The list of participants and agenda for the workshop are presented in Annex 1 and Annex 2, respectively.

Much intersessional work had taken place ahead of the WKLIFE XI meeting by its participants, and this was presented during the workshop. The presentations were used to define the work programme for the remainder of the workshop and the identification of virtual subgroups; eight of which were identified within three Themes – Theme 1 (assessment methods), Theme 2 (challenges independent of assessment method) and Theme 3 (model diagnostics, control rules and MSE):

- Theme 1, Subgroup 1 – surplus production models/delay-difference models
- Theme 1, Subgroup 2 – length-structured models
- Theme 1, Subgroup 3 – indicators and empirical rules
- Theme 2, Subgroup 1 – fast-growing and short-lived
- Theme 2, Subgroup 2 – slow-growing and long-lived
- Theme 3, Subgroup 1 – reference points, uncertainty and harvest control rules
- Theme 3, Subgroup 2 – MSE and simulation frameworks
- Theme 3, Subgroup 3 – advice on catch and stock status for ICES' stocks without an index of abundance (Categories 4, 5 and 6)

Given ICES' role as a knowledge provider, it is essential that experts contributing to ICES' science and advice maintain scientific independence, integrity and impartiality. It is also essential that their behaviours and actions minimise any risk of actual, potential or perceived Conflicts of Interest (CoI).

To ensure credibility, salience, legitimacy, transparency and accountability in ICES' work, to avoid CoI and to safeguard the reputation of ICES as an impartial knowledge provider, all contributors to ICES' work are required to abide by the ICES' Code of Conduct. The ICES' Code of Conduct document dated October 2018 was brought to the attention of participants at the workshop and no CoI was reported.

1.4 Plenary presentations

12 presentations were given during the plenary sessions of WKLIFE XI; presenter, title and synopsis summarised below.

1.4.1 Anne Cooper – Data-limited stocks and management in ICES

Synopsis - More than 60% of all ICES stocks are data-limited. When thinking about the work that ICES does with data-limited methods and advice, it is valuable to place this work within a larger context. ICES is an international, intergovernmental organization. A large part of what ICES does is provide the best available scientific advice to decision-makers on the sustainable exploitation of fish and shellfish in the northeast Atlantic. We follow global agreements, such as the UN Fish Stocks Agreement (UN, 1995) and other international policy instruments that provide guidelines and standards for applying a precautionary approach within an MSY framework.

The aim is, in accordance with the aggregate of international guidelines, to inform policies for high, long-term yields while maintaining productive fish stocks in marine ecosystems that meet expected environmental standards (ICES, 2022a). To do this, ICES relies on scientific experts from our member countries and our network, which includes over 6000 experts, 700 institutes and organizations, and 150 expert groups to develop fit-for-purpose science and advice; advice that is consistent with the precautionary approach.

ICES provides advice on more than 260 stocks on an annual basis and more than 60% of these stocks are in categories 2-6. Until very recently, all data-limited methods at ICES were defined as those without fully accepted models, reference points, and short-term forecasts. Today, this definition has changed to some degree, but we still use these basic category definitions, and all methods are subject to peer review and the ICES advisory principles. WKLIFE is the premier venue for method development and discussion of stock assessments and advice approach for stocks in categories 2-6. ICES is working to provide catch advice for all stocks that is in line with the precautionary approach. The methods developed and tested by WKLIFE are key to ICES advancements in this area.

At ICES, data-limited method development and testing began in earnest in 2010, when ICES began exploring approaches for advice on data-limited stocks, and in 2012 ICES provided the first quantitative advice on these stocks. Since the beginning, the demand for data-limited tools has increased steadily, and WKLIFE has worked continuously to meet the needs of decision-makers and the ICES community with tools to provide MSY reference points, short-term forecasts, risk equivalency, and the tools to support MSY-based advice for these stocks.

In 2012, ICES implemented the six stock data categories (category 1 as "data rich" and category 6 as the most data limited "bycatch" stock) to bin method and advice types based on the types of data used to provide advice. These categories and advice for data-limited stocks are evolving as the suite of methods are continuously developed and tested by WKLIFE. The methods and the stock-specific application of methods for categories 3-6 underwent peer review.

When first released, all data-limited methods (categories 3-6) followed the ICES precautionary approach, and category 1 and 2 stocks with reference points and forecast followed the ICES MSY approach. At that time, 35% of all stocks fell under the ICES MSY approach. The Stock Information Database, sid.ices.dk, contains information on the category, method, and advice type for each ICES stock. The data are updated annually. Reviewing these data over time shows that the proportion of stocks in each category has changed somewhat over time. Most notably, the proportion of stocks in category 1 has increased and the proportion in categories 5 and 6 has decreased since 2012.

Core principles that guide this work include:

- No requests for collections of new data to support this work (i.e. no new survey requests);
- All methods should adhere to ICES MSY and precautionary approaches;
- Risk equivalency across the categories;
- Simple, not bespoke methods;
- Build capacity within our network to develop, test, apply, and understand the methods;
- Peer review; and,
- Continuous improvement to meet the needs of best available science for ICES advice requesters.

In 2020, new methods were accepted for use in the ICES advice by ACOM, and about 40 stocks are now using these new methods and up to 74% of ICES stocks are now eligible for MSY advice, including categories 1, 2, and 3. These new methods are detailed in several WKLIFE reports, including Annex 3 of WKLIFE X, and their application in the ICES advice is detailed in ICES (2022b). As the catch advice is updated, the new methods should be applied to stocks. ICES will continue to use the ICES (2012) methods for stocks in categories 4, 5, and 6 until new methods for stocks in these categories are peer reviewed and approved by ACOM for use in the ICES advice.

1.4.2 Simon Fischer – Updates on empirical harvest control rules: generic method testing, case studies and risk equivalence, R package (ToR 1)

Synopsis - Since the last WKLIFE X meeting in October 2020, three more peer-reviewed scientific articles about the generic method of the empirical category 3 data-limited harvest control rules have been published, two about the rfb rule (Fischer *et al.*, 2021a, 2021b) and one about the chr rule (Fischer *et al.*, 2022a). The abstracts of these publications are presented in the following section.

This means there has been extensive simulation testing and review of the methods in support of the further rollout in ICES. According to the ICES technical guidelines (ICES, 2022b), the choice of method and their parameterisation depends on the individual growth rate (expressed through the von Bertalanffy growth parameter k). The rfb rule is recommended for species with $k < 0.32\ \text{year}^{-1}$ and the chr rule for species with $0.32\ \text{year}^{-1} \leq k < 0.45\ \text{year}^{-1}$. Fischer *et al.* (2022a) concluded that the chr rule could also be applied to stocks with slower individual growth (i.e. $k < 0.32 year^{-1}$) and its management performance can exceed the rfb rule, if tuned appropriately. However, the challenge of setting a target harvest rate remains.

In conclusion, the empirical harvest control rules (the rfb, rb and chr rule) are suitable to provide catch in ICES and there is currently no need to revise the ICES technical guidelines.

R package

During the rollout of the new empirical harvest control rules in 2022, there was no standardised software package to apply the rules and there was sometimes confusion about how to apply the rules exactly. To address this situation, an R package is currently being developed. This R package will allow the application of the rfb, rb, and chr rules and ensure that ICES technical guidelines are followed. The idea is to include this R package into the ICES Transparent Assessment Framework (TAF) so that the application of the rules is transparent and reproducible. The output of the R package will be values required for the ICES advice sheets.

At the time of WKLIFE XI in January 2023, the package was not ready yet but was still under active development (https://github.com/shfischer/cat3advice) and the aim is to have the first version ready for the 2023 ICES assessment season.

Paper abstracts

Fischer, S. H., De Oliveira, J. A. A., Mumford, J. D., & Kell, L. T. 2021a. Using a genetic algorithm to optimize a data-limited catch rule. ICES Journal of Marine Science, 78(4), 1311–1323. https://doi.org/10.1093/icesjms/fsab018

Many data-limited fish stocks worldwide require management advice. Simple empirical management procedures have been used to manage data-limited fisheries but do not necessarily ensure compliance with maximum sustainable yield objectives and precautionary principles. Genetic algorithms are efficient optimization procedures for which the objectives are formalized as a fitness function. This optimization can be included when testing management procedures in a management strategy evaluation. This study explored the application of a genetic algorithm to an empirical catch rule and found that this approach could substantially improve the performance of the catch rule. The optimized parameterization and the magnitude of the improvement were dependent on the specific stock, stock status, and definition of the fitness function. The genetic algorithm proved to be an efficient and automated method for tuning the catch rule and removed the need for manual intervention during the optimization process. Therefore, we conclude that the approach could also be applied to other management procedures, case-specific tuning, and even data-rich stocks. Finally, we recommend the phasing out of the current generic

ICES "2 over 3" advice rule in favour of case-specific catch rules of the form tested here, although we caution that neither works well for fast-growing stocks.

Fischer, S. H., De Oliveira, J. A. A., Mumford, J. D., & Kell, L. T. 2021b. Application of explicit precautionary principles in data-limited fisheries management. ICES Journal of Marine Science, 78(8), 2931–2942. https://doi.org/10.1093/icesjms/fsab169

Many management bodies require applying the precautionary approach when managing marine fisheries resources to achieve sustainability and avoid exceeding limits. For data-limited stocks, however, defining and achieving management objectives can be difficult. Management procedures can be optimized towards specific management objectives with genetic algorithms. We explored the feasibility of including an objective that limited the risk of a stock falling below various limit reference points in the optimization routine for an empirical data-limited control rule that uses a biomass index, mean catch length, and includes constraints (the "rfb-rule"). This was tested through management strategy evaluation on several fish stocks representing various life-history traits. We show that risk objectives could be met, but more restrictive risk limits can lead to a potential loss of yield. Outcomes were sensitive to simulation conditions such as observation uncertainty, which can be highly uncertain in data-limited situations. The rfb-rule outperforms the method currently applied by ICES, particularly when risk limitation objectives are considered. We conclude that the application of explicit precautionary levels is useful to avoid overfishing. However, we caution against the indiscriminate use of arbitrary risk limits without scientific evaluation to analyse their impact on stock yields and sustainability.

Fischer, S. H., De Oliveira, J. A. A., Mumford, J. D., & Kell, L. T. 2022a. Exploring a relative harvest rate strategy for moderately data-limited fisheries management. ICES Journal of Marine Science, 79(6), 1730–1741. https://doi.org/10.1093/icesjms/fsac103

Moderately data-limited fisheries can be managed with simple empirical management procedures without analytical stock assessments. Often, control rules adjust advised catches by the trend of an abundance index. We explored an alternative approach where a relative harvest rate, defined by the catch relative to a biomass index, is used and the target level derived from analysing historical catch length data. This harvest rate rule was tested generically with management strategy evaluation. A genetic algorithm was deployed as an optimisation procedure to tune the parameters of the control rule to meet maximum sustainable yield and precautionary management objectives. Results indicated that this method could outperform trend-based strategies, particularly when optimised, achieving higher long-term yields while remaining precautionary. However, optimum harvest rate levels can be narrow and challenging to find because they depend on historical exploitation and life history characteristics. Misspecification of target levels can have a detrimental impact on management. Nevertheless, harvest rates appear to be a suitable management option for moderately data-limited resources, and their application has modest data requirements. Harvest rate strategies are especially suitable for stocks for which case-specific analyses can be conducted.

Risk equivalence in the revised ICES data-limited advisory framework

A recent publication by Fischer *et al.* (2022b) on risk equivalence in the revised ICES data-limited advisory framework was presented at WKLIFE XI. The abstract is given below. This publication explored the new empirical category 3 data-limited harvest control rules for three ICES case studies and found that these rules follow both the ICES precautionary approach and MSY. Furthermore, if the rules are tuned to a specific stock, they can outperform the more complex ICES category 1 MSY rule. This publication was highly relevant to WKLIFE because it provided further evidence that the new empirical category 3 data-limited harvest control rules are ready to be implemented by ICES.

Paper abstract

Fischer, S. H., De Oliveira, J. A. A., Mumford, J. D., and Kell, L. T. 2022b. Risk equivalence in data-limited and data-rich fisheries management: An example based on the ICES advice framework. Fish and Fisheries: 17 pp. https://doi.org/10.1111/faf.12722.

Fisheries management needs to ensure that resources are exploited sustainably, and the risk of depletion is at an acceptable level. However, often uncertainty about resource dynamics exists, and data availability may differ substantially between fish stocks. This situation can be addressed through tiered systems, where tiers represent different data limitations, and tier-specific stock assessment methods are defined, aiming for risk equivalence across tiers. As case studies, we selected stocks of European plaice, Atlantic cod and Atlantic herring, where advice is provided by the International Council for the Exploration of the Sea (ICES). We conducted a closed-loop simulation to compare risk equivalence between the data-rich ICES MSY rule, based on a quantitative stock assessment, and the revised data-limited empirical management procedures of the ICES advice framework. The simulations indicated that the data-limited approaches were precautionary and did not lead to a higher risk of depletion than the data-rich approach. Although the catch based on generic data-limited approaches was lower, stock-specific optimisation improved management performance with catch levels comparable with the data-rich approach. Furthermore, the simulation indicated the ICES MSY rule can fail to meet management objectives due to increased depletion risk when management reference points are set suboptimally. We conclude that the recent revisions of the ICES system explicitly account for risk equivalence for data-limited fisheries management and are a major step forward. Finally, we advocate further consideration of simple empirical management procedures irrespective of data limitations due to their ability to meet fisheries management objectives with greater simplicity.

1.4.3 Tobias Mildenberger – Data-limited management advice with SPiCT (ToR 1)

Synopsis - Uncertainty in fisheries management can arise from various sources, such as natural variability, the data collection process, simplifying models, the estimation procedure, or implementation, and can lead to uncertain state estimates (fishing mortality and biomass) as well as uncertain reference points. Thus, a precautionary approach to fisheries management should be used (Mildenberger *et al.*, 2022). This can be implemented by for example biomass threshold rules and/or uncertainty buffers. While the biomass thresholds and limits reduce fishing mortality if biomass decreases, the uncertainty buffer reduces recommended catch advice as a function of quantified uncertainty in the predicted catch distribution or relative states (e.g. F/F_{MSY} or B/MSY $B_{trigger}$). The optimal harvest control rule (for SPiCT) should (i) be based on stock-specific management strategy evaluation (MSE), (ii) include biomass reference points and an uncertainty buffer, (iii) include a biomass threshold between 0.5-2 B_{MSY} and a rather larger threshold for short-lived species, (iv) includes a biomass limit that is proportional to the biomass threshold, (v) includes risk fractiles on the predicted catch distribution f_C = 0.15-0.45 or all quantities $f_{C,B,F}$ = 0.25-0.45, and (vi) is always more risk-adverse than non-probabilistic rules (risk fractile < 0.5).

Paper abstract

Mildenberger, T.K., Berg, C.W., Kokkalis, A., Hordyk, A.R., Wetzel, C., Jacobsen, N.S., Punt, A.E. and Nielsen, J.R., 2022. Implementing the precautionary approach into fisheries management: Biomass reference points and uncertainty buffers. Fish and Fisheries, 23(1), 73-92. https://doi.org/10.1111/faf.12599.

The precautionary approach to fisheries management advocates for risk-averse management strategies that include biological reference points and account for scientific uncertainty (i.e.

process, model and observation uncertainty). In this regard, two approaches have been recommended: (a) biomass reference points to safeguard against low stock biomass, and (b) uncertainty buffers that reduce the catch limit as a function of the scientific uncertainty. This study compares the effectiveness of these two precautionary approaches in recovering over-exploited fish stocks. We evaluate the performance of more than 80 harvest control rules (HCRs) within a stochastic management strategy evaluation (MSE) framework for three stocks with contrasting life-history parameters and under various levels of scientific uncertainty. The results show that both approaches reduce the risk of overfishing at the expense of expected yield. This risk-yield trade-off strongly depends on the HCRs, life-history parameters of the species, as well as the level of the scientific uncertainty. Nevertheless, some combinations of biomass threshold and limit reference points as well as uncertainty buffers lead to a more favourable risk-yield trade-off than other rules. This study elucidates the multiple factors affecting the effectiveness of management strategies and highlights key features of HCRs for precautionary fisheries management.

1.4.4 Laurie Kell – Evaluation of the skill of length-based indicators to identify stock status and trends

Paper abstract

Kell, L. T., Minto, C., and Gerritsen, H. D. 2022. Evaluation of the skill of length-based indicators to identify stock status and trends. ICES Journal of Marine Science: 15 pp. https://doi.org/10.1093/icesjms/fsac043.

In data-poor situations, length-based indicators (LBIs) and reference points based on life history parameters have been proposed to classify stocks according to conservation status and yield optimization. Given the variety of potential LBIs, life history traits, and fisheries, it is necessary to evaluate the robustness of length-based advice to ensure that despite uncertainty that management objectives will still be met. Therefore, a simulation procedure was employed where an Operating Model conditioned on life history parameters was used to generate pseudo data. Receiver operator characteristics and the true skill score were then used to screen LBIs based on their ability to identify overfishing and recovery. It was found that LBIs performed better for long-lived species with low individual growth rates, those aimed at ensuring the conservation of mature fish performed better than those aimed at the conservation of immature fish, are better at indicating trends than at quantifying exploitation level, and in general were robust to uncertainty about dynamic processes.

1.4.5 Lisa Chong – Performance evaluation of data-limited, length-based life history and stock assessment methods

Synopsis - Length-based methods are still valuable in data-limited fisheries as length data are easy to collect and still allow exploration of important stock assessment information and most importantly stock status. There are several biases that are common across length-based methods, including life history type and information quality, non-representative sampling (e.g. sample size and biased sampling), exploitation level, and recruitment variability. Length-based stock assessment methods are also sensitive to input parameters (i.e. life history parameters of growth, mortality, maturity). To address these biases and understand how current length-based methods can handle these issues, there is a need to test and evaluate their robustness and performance. Performance evaluations will help address model misspecifications and test methods across various scenarios. Current work is being developed to evaluate how uncertainties in growth parameters of the von Bertalanffy function affect model outputs across various

scenarios. There is a data-driven life history tool called ELEFAN that can estimate growth parameters by tracing growth curves across monthly data. There is a meta-analysis tool called FishLife that predicts life history parameters based on taxonomy and information from databases (e.g. FishBase). The goal is to understand when ELEFAN or a data-driven tool would perform better than using life history information obtained from literature or databases (or FishLife) across different settings. Chong *et al.* (2020) evaluated the performance of various length-based stock assessment methods (i.e. Thompson and Bell, LBSPR, LIME, and Length-Based Risk Analysis) across scenarios of life history types, exploitation level, and recruitment variability. They found that all length-based methods across scenarios were less accurate estimating recruitment overfishing when stocks were severely overexploited and inconsistent in estimating growth overfishing when stocks were underexploited. Methods tend to perform poorly on short-lived or long-lived species as the annual time-step does not provide enough information about their dynamics. This project brings the question of how errors on life history inputs or measurement error on length data propagate through the assessment process and affect estimates of stock status. There is a need to develop formal guidelines on how to deal with uncertainty and model misspecifications in the stock assessment process for data-limited fisheries.

Paper abstract

Chong, L., Mildenberger, T. K., Rudd, M. B., Taylor, M. H., Cope, J. M., Branch, T. A., Wolff, M., et al. 2020. Performance evaluation of data-limited, length-based stock assessment meth-ods. ICES Journal of Marine Science, 77: 97–108. https://doi.org/10.1093/icesjms/fsz212.

Performance evaluation of data-limited, length-based methods is instrumental in determining and quantifying their accuracy under various scenarios and in providing guidance about model applicability and limitations. We conducted a simulation–estimation analysis to compare the performance of four length-based stock assessment methods: length-based Thompson and Bell (TB), length-based spawning potential ratio (LBSPR), length-based integrated mixed effects (LIME), and length-based risk analysis (LBRA), under varying life history, exploitation status, and recruitment error scenarios. Across all scenarios, TB and LBSPR were the most consistent and accurate assessment methods. LBRA is highly biased, but precautionary, and LIME is more suitable for assessments with time-series longer than a year. All methods have difficulties when assessing short-lived species. The methods are less accurate in estimating the degree of recruitment overfishing when the stocks are severely overexploited, and inconsistent in determining growth overfishing when the stocks are underexploited. Increased recruitment error reduces precision but can decrease bias in estimations. This study highlights the importance of quantifying the accuracy of stock assessment methods and testing methods under different scenarios to determine their strengths and weaknesses and provides guidance on which methods to employ in various situations.

1.4.6 Jason Cope - Keynote – Data-limited assessment methods

Synopsis - *Data-limited* fisheries provide unique challenges for analysts to provide science-based information to managers. Assessment models (analyses used to produce a useful measure of population condition or status) are necessary abstractions of reality because we never have all of the information needed to measure reality exactly. But the type of analysis can also be constrained by issues of resource and capacity limitations, not just data limitations. And the details for the reasons behind these constraints can vary from situation to situation. It is first beneficial to understand the sources of constraints in order to: i) find the right fit analysis and ii) understand how to improve those conditions (if desired). When it comes to approaching the analytical options, it is important to recognize that there is a continuum of methods based in life-history theory and standard data types (e.g. catch, indices of abundance and/or biological compositions). The lack of any information becomes a trade-off between data and making assumptions. Characterising uncertainty therefore becomes a fundamental task for all assessments in order to manage the assumptions coming from the abstract model structures and the information content (or lack thereof) of the available data. Model exploration (whether among model types or within model treatment of data and parameters) become alternative hypotheses that should be weighed against each other and ultimately reported in order to capture sources of uncertainty and the effects they have on desired model outputs. When considering the combinations of data and parameters, there are essentially eight different categories of stock assessments. And each of these assessments can be understood in how they inform the three dimensions of stock assessments: scale (i.e. absolute size of the population), status (i.e. the relative size of the population) and productivity (i.e. the resiliency of the population based on life-history). Mastering an understanding of how any change in any given assessment type changes the three dimensions of stock assessment can help communicate both what assumptions are being made in the assessment and how results are expected to change. Management procedures can then be specified, which combine assessment output, reference points and control rules. Management procedures can sometimes be directly specified (i.e. indicator methods) without the need to run additional analyses (e.g. model-fitting approaches) and be powerful data-limited assessment options if the reference points can be reliably defined. Simulation testing such as management procedure (or strategy) evaluation is another powerful tool that can define the performance of any given management procedure but takes high-level analytical capacity and ability to digest the results. Performance of any management procedure will be case-specific, so beware of any generic solutions to data-limited situations. Integrated modelling frameworks (e.g. Stock Synthesis (SS) as implemented in the SS-DL tool) hold promise to accumulate the many different data-limited approaches into a unified framework, and provide clear ways to characterize uncertainty and apply control rules while also inviting further data inputs as they are acquired. Furthermore, decision-support tools (e.g. FishPath) can help organise local knowledge and match them with the right fit analytical and management approaches. The above principles and tools can be used to build capacity in areas that need support. This support ideally is not left behind once the experts leave, but instead builds into the future through ongoing engagements. Ideally, a network of expert analytical practitioners would be available to spread this ongoing capacity building globally and maintain support into the future in order to strongly establish analytical capacity, reducing the issue of *data-limitations* by one dimension.

1.4.7 Tanja Miethe – Length-based indicators and reference points

Paper abstracts

Miethe, T., Reecht, Y., and Dobby, H. 2019. Reference points for length-based indicator $L_{max5\%}$ to support assessment of data-limited stocks and fisheries. ICES Journal of Marine Science, 76:7, 2125-2139. https://doi.org/10.1093/icesjms/fsz158.

In the absence of abundance indices from scientific surveys or commercial sources, reliable length frequency data from sampled commercial catches can be used to provide an indirect assessment of fishing mortality. Length-based indicators are simple metrics which describe length frequency distributions. The length-based indicator $L_{max5\%}$, the mean length of the largest 5% of individuals in the catch, combined with appropriately selected reference points, can be used to evaluate the presence of very large individuals in the catch and hence determine exploitation level. Using analytical per-recruit models, reference points consistent with a spawning potential ratio of 40% can be derived. The reference points depend on the life history parameters for natural mortality, maturity, and growth (M, k, L_{mat}, L_∞, CV L_∞). Using simulation tools, we investigate the sensitivity of the reference points to errors in these parameters and explore the usefulness of particular reference points for management purposes for stocks with different life histories. The proposed reference points are robust to uncertainty in length at first capture, Lc, and take into account the maturation schedule of a species. For those stocks with high M/k ratios (>1), $L_{max5\%}$, combined with the appropriate reference point, can be used to provide a data-limited stock assessment.

Miethe, T., and Dobby, H. 2021. Testing length-based reference points in a management strategy evaluation for cuckoo ray (*Leucoraja naevus*) and thornback ray (*Raja clavata*). ICES Journal of Marine Science, 79:1, 129-146. https://doi.org/10.1093/icesjms/fsab248.

Elasmobranchs grow relatively slowly and mature at a relatively high age, leading to longer generation time. Due to low fecundity of these stocks, sufficient numbers of mature individuals are important to ensure a viable recruitment level and sustainable management. Length-based indicators (LBIs), such as the mean length and the mean length of the largest 5% in the catch, can be used to characterize the length distribution of exploited stocks and aid a data-limited assessment. Reference points for these indicators are calculated using basic life history parameters. Using cuckoo ray, *Leucoraja naevus*, and thornback ray, *Raja clavata*, as example species, we apply management strategy evaluations to test the performance of LBI-based harvest control rules (HCRs, rxf) in their ability to recover overexploited stocks. We illustrate the importance of the stock–recruitment relationship for the management outcome. If immature individuals are targeted by the fishery, HCRs perform better in terms of stock recovery when coupled with reference points, which account for the maturation schedule of the stock. The sensitivity of reference points to parameter misspecification means that elasmobranchs stocks in which immature individuals are exploited by the fishery may require more precautionary reference points, with consideration of the trade-off between biomass recovery and yield.

WD to this report

Miethe, T. & Dobby, H. Further testing length-based harvest control rules in a management strategy evaluation for cuckoo ray (*Leucoraja naevus*) and thornback ray (*Raja clavata*)

Synopsis - Harvest control rules (HCRs) using a combination of LBI relative to their reference point (f), CPUE index trend (r) and a biomass safeguard (b) used together with TAC constraints have been proposed by ICES WKLIFE X and Fischer *et al.*, 2020. Using the elasmobranch species cuckoo ray, *Leucoraja naevus*, and thornback ray, *Raja clavata*, as examples, we apply management strategy evaluations to test the performance of these HCRs using different length-based reference points in their ability to recover overexploited stocks. HCRs of the form r×f and r×f×b using different TAC constraints and CPUE index trends are compared. As immature individuals are targeted by the fishery, harvest control rules perform better in terms of stock recovery when coupled with reference points which account for the maturation schedule of the stock. Highly asymmetric TAC constraints, limiting the annual increase in catch, increase the recovery speed and are important for recovery if recruitment depends on the number of mature females in the stock. A strong dependence of recruitment on the number of mature females increases the risk of some of the HCRs, particularly using r×f rules. For depleted stock (one-way-trip) the biomass threshold b is therefore an important component in the HCRs to reduce risk for the stock of falling to very low stock sizes.

1.4.8 Jan Horbowy – Analysis of F_{MSY} in light of life-history traits: Effects on its proxies and length-based indicators

Synopsis - Results presented in this section are based on papers by Horbowy and Hommik (2020, 2022); the text is largely based on the abstract for Horbowy and Hommik (2022), with some additions for improved context.

Equilibrium yields and biomasses in relation to fishing mortality were generated for a wide range of life history traits (LHTs), which included growth parameters, natural mortality, maturity, selectivity, and steepness (h) of the Beverton and Holt stock-recruitment relationship. Steepness ranged from 0.35 to 0.9, natural mortality from 0.15 to 0.4, growth rate from 0.05 to 3.3. For each combination of LHTs, equilibrium yield (Y_{eq}) and equilibrium biomass (B_{eq}) as functions of fishing mortality (F) were derived using the following formulas (Horbowy and Hommik, 2020):

$$Y_{eq}(F) = YPR(F)\frac{SPR(F)-a}{b*SPR(F)} \quad \text{and} \quad B_{eq}(F) = \frac{SPR(F)-a}{b}$$

where

- YPR and SPR denote yield-per-recruitment and stock-per-recruitment, respectively,
- a, b are parameters of Beverton and |Holt stock-recruitment model parameterised as R=B/(a+b*B),

Parameters a and b were used as functions of steepness as in Francis (1992).

Next, the fishing mortality expected to produce maximum sustainable yield (F_{msy}), its selected proxies ($F_{0.1}$, $F_{40\%}$, $F_{40\%SSB}$, and F_{max}), and mean length at F_{msy} (L_{msy}) were estimated. Linear models combining the estimated F_{msy} and L_{msy} with the traits were fitted (R^2 >0.95). Almost all of the LHTs were statistically significant, and the largest effect on F_{msy} was from steepness, while natural mortality and growth rate had smaller effects. In the case of L_{msy}, however, the largest effect in the fitted model was from the growth rate, while steepness influenced L_{msy} only slightly. The F_{msy} proxies were evaluated, and $F_{40\%SSB}$ appeared to be a generally conservative F_{msy} proxy, while F_{max} always overestimated F_{msy}, generally to a large extent. $F_{0.1}$ and $F_{40\%}$ may be used as F_{msy} proxies or conservative proxies mainly for steepness values of 0.6 and higher; for lower h, they may markedly overestimate F_{msy}. Natural mortality, sometimes used as F_{msy} proxy, was higher than F_{msy} for steepness =<0.6.

The ratio of biomass at F_{msy} to virgin biomass was on average 0.34, and for a steepness of 0.9, some values were lower than 0.2.

The analysis indicates that the use of the mean length of a catch in relation to L_{msy} for evaluating stock status should be done with caution, especially for species with a high growth rate.

1.4.9 Tony Thompson – FAO deep-sea fisheries under the ecosystem approach project

Synopsis - The *Deep-Sea Fisheries under the ecosystem approach* (DSF) project (2022-2027) operates in the ABNJ on deep-sea fish stocks. It is implemented by FAO, executed by GFCM, and supports its partners to improve sustainable fisheries and reduce environmental impacts. The project works globally and all deep-sea RFMOs are project partners. The DSF project would like to invite ICES to support data collection and assessments of two seamount species - alfonsino and armourhead – in the north and south Pacific, and the northwest, northeast and southeast Atlantic. Activities could include to review and support fit-for-purpose data collection for data-limited fish stocks (global) and provide training and monitoring of observers, and develop and apply assessment methodologies for data-limited stocks and host a workshop. The DSF Project and ICES' Secretariat will develop the activities over the coming year and run the project in 2024-2025.

1.4.10 Andres Uriarte/Alex Kokkalis – Updates on advances from the Workshop on data-limited stocks of short-lived species (WKDLSSLS3 Sept 2021 and afterwards)

Synopsis - WKDLSSLS had as main objective to further develop assessment, catch advice and management methods for short-lived stocks in ICES categories 3–4, focusing on the provision of advice rules that are within the ICES MSY framework. Short-lived species are characterized by fast growth, and high natural mortality, along with a high recruitment variability. This leads to fast turnover and great biomass variability. The implication is that the population consists mostly of 1 year old fishes (or 2 at most). Therefore, the management period should not start much after the last index observation, i.e., the shorter the time lag between the survey biomass indicator and implementation of the TAC advice the better. In addition, no steady state length composition of the catch is expected (as it will vary a lot according to relative recruitment strengths), thus the ***f*** term of the standard ICES ***rfb*** cannot be applied.

During the third Workshop (WKDLSSLS3) (TOR 1), on assessment methods, reviewed the implementation of precautionary harvest control rules based on SPiCT assessments, based on the paper of Mildenberger et al. (2021) (see summary in Section 1.4). In addition, exploratory approaches to the assessment of two category-5 sprat stocks were presented and discussed within the group, both sharing uncertainties in stock identity and the lack of complete coverage by acoustic surveys of their potential spatial distribution: sprat in the Celtic Seas Ecoregion and the Scottish Mallaig Sprat fishery. In previous WKDLSSLS other case studies were investigated aiming at improving their assessments with surplus production methods, such as the Anchovy in 9aSouth and 9a West, Octopus vulgaris in the North of Spain, and the cuttlefish (*Sepia officinalis*) in the English Channel (7.de).

In relation to TOR 2, on the evaluation of the appropriateness of the management procedures based on direct use of abundance indices (for category 3 stocks), first a summary of the work and conclusions of WKLIFE VII-X (ICES, 2017, 2018, 2019, 2020) on empirical (i.e. model-free) management procedures was presented, highlighting their limitations for fast-growing species and suggesting the use of alternative management procedures (e.g. harvest rate-based rules or escapement strategies) (Fischer et al. 2020; 2021a and 2021b). In previous WKDLSSLS meetings (ICES 2019; 2020) and in Sánchez-Maroño et al. (2021), an ample analysis of the performance of the trend rules "*n-over- m*" rules on DLSSLS was carried out, showing that HCR 1-over-2 outperforms 2-over-3 (ICES default rule) mainly in terms of risk in all time frames (short, medium and long), obtaining best results for in-year advice (i.e., starting the management just after the survey index is available or as soon as possible). In addition, regarding Uncertainty Cap constrains (UC) of the interannual variability, no-UC and a wide range of symmetrical and asymmetrical UCs were explored. It was found that the 1-over-2 without UC or with large UC (UC(0.8,2.75) or UC(0.8,4)) resulted in the highest catches at sustainable risks (for all OMs) in the long-term. However, the 1-over-2 rule with UC (0.8,0.8) was preferred as a good compromise between risk and catches, particularly in medium term. Nevertheless, the application of the symmetric 80% UC can lead to major reduction of catches in the long term. The rule is recommended to be applied with a biomass safeguard, as it improves its performance mainly in terms of risk. However, given the reduction properties of these rules and that they are blind rules not necessarily leading to harvest around MSY, they should be applied provisionally until better management is achieved.

This has led to search for harvest rate rules, and in particular for a sustainable constant harvest rate rule.

During WKDLSSLS2 and WLDLSSLS3 insights in the Operating model (OM) and MSE for defining a Constant Harvest Rate (CHR) for the sprat in the English Channel (ICES Divisions 7.de) were presented. The search aims at defining the maximum CHR sustainable in the long term and accounting for major uncertainties in the fishery and the stock dynamics and in the monitoring system of the resource, which should be applicable to the available indicator of biomass within the year and for the selected management procedure. The interbenchmark in ICES (ICES 2021) to revise the advice framework for the Sprat stock in 7.de made this search and showed that a CHR of 8.57% applied to an acoustic estimate in autumn (year Y) was sustainable, for a management system running between July (Y+1) and June (Y+2), as for the North Sea Sprat. The new intra-annual MSE of Mildenberger et al. (2021) was parameterised for the Channel sprat with a monthly time step in WKDLSSLS3, accounting for seasonal growth and exploitation pattern. This showed that the intra-annual events (such as survey observation, implementation of advice and recruitment) may impact the performance of harvest control rules (HCRs), in addition to the lag between these events.

In addition, MSE of the performance of some alternative dynamic harvest rate rules (DHR) under the in-year calendar were presented in WKDLSSLS3. The set of HR rules were adapted from Carruthers et al. (2016) transforming them from TAC modifiers to HR modifiers. Another HR rule, called Perturbation rule (Pert) was also included in the MSE. That work and further modelling after WKDLSSLS meeting by Sánchez-Maroño et al. (oral presentation to the Lisbon Symposium on small pelagic fishes Nov 2022) have shown that some of these rules (Dyn-F, Fadapt_hr and G-control, and the Pert-rule) are able to reduce risks in the long term to values at or around 5% or below, depending mostly on the initial exploitation status. Compared with the default 1-over-2 rule with 80% UC, the DHR rules showed similar or better performance in terms of balance between catches and risks. These rules are seen as a set of promising HCRs of intermediate performance between the CHRs and the 1over2+biomass-safeguard which deserve consideration through ad hoc MSE for case studies seeking managing DLSSLSs.

Though significant progresses have been made within WKDLSSLS, its work is still considered unfinished, with further research on the definition of optimal HCRs for data-limited short-lived stocks still ongoing. The group decided to join WKLIFE because there are obvious overlapping synergies and in search of a broader forum for discussion. By the time being, the tuned constant harvest rate or the (provisionally applicable) trend rule (1-over-2 with symmetrical 80% UC and biomass safeguard) are the rules included in the ICES guidelines for short lived species.

1.4.11 Casper Berg – Updates from WKMSYSPiCT I + II

Synopsis – Some new functionality has been added to SPiCT, which includes extended management functionality (harvest control rules, fractile rules, intermediate year assumptions) as well as extended diagnostics (hindcast crossvalidation and process residuals). Also, a new plotting function "plotspict.compare" has been added for comparing multiple SPiCT runs.

In addition the following recomendations were made:

- Historical catches should be considered, and ideally include the start of the fishery; In particular, the peak fishing period can hold information about carrying capacity.
- For data that lack historical catches and show limited contrast in the abundance index, it is recommended to fix or use an informative prior for the ‘n’ parameter and to use informative priors for ‘r’ (e.g., Thorson, 2020).

- When a prior on the initial depletion level (b/k ratio) is needed to achieve convergence, it is recommended to evaluate the fits, retrospective pattern and ideally the prediction skill (see below) of additional sensitivity runs (e.g., b/k = 0.3, 0.5, 0.8).
- Consider replacing the default 'alpha' and 'beta' priors with informative priors on observation variances ('logsdi' and 'logsdc'). The information for these priors should be case specific and could for logsdi for example be based on the estimated CV (or sd on log scale) of the abundance index / CPUE calculation. The process error in surplus production 'logsdb' is another candidate for a more informative prior (almost perfect production curves or production curves with highly negative values are unlikely).
- Recommendations regarding abundance indices ('obsI'):
    - Compare the length distribution and spatial distribution of the survey(s) with commercial fleet and catches (what and where is the exploited part of the population?).
    - Avoid doing indices for small sub-areas (e.g., one nation), as these may not be representative of the stock. Indices for sub-areas should instead be combined into a single index.
    - However, do not combine several independent representative indices.
- Recommendations regarding CPUE indices (survey and commercial):
    - Standardise CPUE: The standardization of (commercial) CPUE should include a spatial-time interaction factor, zeroes and different assumptions of technological creep (the latter specifically in the case of commercial CPUE). Different assumptions regarding the targeting, error distribution, and model formula in general should be explored.
    - Don't smooth over time as the CPUE index observations are then no longer independent.

Future versions of SPiCT should also include for instance MCMC to check the Laplace approximation.

1.4.12 Jon Pitchford – Pyramids of life

Synopsis - The Pyramids of Life project is an interdisciplinary research collaboration funded by UKRI https://pyramidsoflife.york.ac.uk/home. The subtitle "working with nature for a sustainable future" reflects the need to move towards more creative and holistic management, especially where datasets are limited. Our focus is on size-resolved multispecies management, and the work very naturally falls within areas of WKLIFE expertise.

The Pyramids of Life research programme combines overlapping expertise in socio-economics and human behaviour (University of East Anglia), ecology and detailed spatio-temporal datasets (Cefas), and mathematics and marine ecology (University of York). Our partners Seafish and Waitrose bring detailed expertise in market dynamics, consumer behaviour and fishing effort, as well as matching our commitment to long-term sustainability. Together, this body of work will provide a multidimensional perspective of the value of marine ecosystems so that future management interventions are based squarely on what is sustainable.

In addition to introducing the Pyramids of Life project, there were two main themes to the presentation:

(1) Where datasets are limited, general ecological frameworks based on carbon flow through ecosystems may help to fill the gaps. In our context, the R software Mizer https://sizespectrum.org/mizer/ (Scott *et al.*, 2014) allows multi-species size-resolved communities to be assembled and fishing scenarios to be investigated. A relatively small number of parameters are needed for such models, and their outputs allow for sanity checking at individual (e.g. emergent von Bertalanffy-esque growth curves) as well as population- and community-levels.

(2) Much could be learned from assembling idealised marine ecosystems and assessing their general behaviour, while acknowledging they cannot hope to accurately capture every feature of a given system. For example, recent work by Law and Plank (2023) points to a careful interpretation of "balanced harvest" as a way to manage simultaneously for sustainable harvest and biodiversity conservation.

These are valuable academic tools for investigating "what if...?" scenarios and for developing ecosystem-scale indicators. Translating such outputs into advice relevant in the real world needs more detailed knowledge of fishing fleets, market pressures and consumer behaviour.

1.5 Structure of the report

The structure of the report is as follows:

- Section 2 focuses on responses to comments from the ICES' community on the empirical harvest control rules for Category 3 data-limited stocks – ToR 2);
- Section 3 focuses on responses to comments from the ICES' community on surplus production models – ToR 2);
- Section 4 focuses on the work under Theme 1 (assessment methods) and its three subgroups (surplus production models/delay-difference models, length-structured models, indicators and empirical rules), – ToR 3);
- Section 5 focuses on focuses on the work under Theme 2 (challenges independent of assessment method) and its two subgroups (fast-growing and short-lived, slow-growing and long-lived)– ToR 3);
- Section 6 focuses on the work under Theme 3 (model diagnostics, control rules and MSE) and its three subgroups (advice on catch and stock status for ICES' stocks without an index of abundance (Categories 4, 5 and 6); reference points, uncertainty and harvest control rules; MSE and simulation frameworks) – ToR 3); and
- Section 7 focuses on future data-limited research, assessment and management advice within ICES; together with ToRs for the next WKLIFE XII meeting proposed for October 2023.

The conclusions of this report are presented as a roadmap consisting of 60 issues or relevant topics for data-limited research within ICES (Section 7.1).

1.6 Follow-up process within ICES

The participants at WKLIFE XI agreed to provide text for the draft workshop report by Tuesday 31st January 2023 and to then comment on the compiled draft report no later than 10th February 2023; when the report can be finalised by the Chairs and formatted by the ICES Secretariat.

The recommendations from WKLIFE XI are listed in Section 8 of this report.

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2 Empirical harvest control rules for Category 3 data-limited stocks – response to comments from the ICES' community

2.1 Introduction

This Section focusses on collated responses to comments from the ICES' community on the empirical harvest control rules for Category 3 data-limited stocks – ToR 2).

ToR 2 for WKLIFE XI in January 2023 stated:

> Review recommendations (e.g. from WKMSYSPiCT1, WKMSYSPiCT2) and requests for clarification made by ICES groups (e.g. Elasmobranch, Celtic Seas and Deep Seas advisory processes) on the application of the methods presented in WKLIFE X Annex 3 and provide clear and concise feedback on issues raised and incorporate into suggested updates to the ICES Guidance, as appropriate.

The sub-points of ToR 2 are addressed in the following sections.

2.2 Responses

2.2.1 Application of methods to species with specific elasmobranch and deep-water life history strategies

The empirical harvest control rules (Method 2 of ICES, 2022; i.e. the rfb/rb/chr rules) were developed and simulation tested for a range of life histories (ICES, 2017, 2018, 2019a, 2020a; Fischer *et al.*, 2020, 2021a, 2021b, 2022a). The operating models used in the closed-loop simulations accounted for 29 different life histories and included (1) elasmobranchs species typically assessed by the ICES working group on elasmobranchs (e.g. Thornback ray *Raja clavata* [two different stocks], Lesserspotted dogfish *Scyliorhinus canicula* [two different stocks], Starry smooth-hound *Mustelus asterias*) as well as species typically considered by the ICES working group on deep sea stocks (e.g. ling *Molva molva*, wolffish *Anarhichas lupus*). The operating models for these species were characterised by slow individual growth and usually late maturity.

The empirical harvest control rules suggested in the ICES technical guidelines (ICES, 2022) were parameterised to account for these life histories to ensure the catch advice from these methods follows the ICES precautionary approach and aims towards long-term sustainable fisheries management. This means that the empirical harvest control rules can be used generically for elasmobranch and deep-sea species.

The previously used default method for category 3 stocks (the 2 over 3 rule) was shown to fail ICES management objectives in simulations (Fischer *et al.*, 2021b, 2022a) with high long-term risks of stock depletion, whereas the new rules are designed to meet ICES management objectives.

While the empirical methods can be implemented generically, the ICES technical guidelines explicitly allow and encourage conducting case-specific simulation studies to modify methods for the provision of the ICES catch advice.

2.2.2 Advisable time series length for surveys and indices as well as how best to incorporate variability in the index for use in Surplus production model methods

Not applicable to the empirical harvest control rules.

2.2.3 Definition and use of Itrigger and Iloss

The empirical harvest control rules include a biomass safeguard b, which reduces the catch advice when the biomass index I falls below a threshold value I_{trigger} (ICES, 2022):

$$b = min\left\{\frac{I_{y-1}}{I_{\text{trigger}}}\right\}$$

The ICES technical guidelines state that in the absence of better information, I_{trigger} can be based on the lowest observed index value I_{loss}, similar to the approach used for defining category 1 data-rich ICES management reference points:

$$I_{\text{trigger}} = 1.4 I_{\text{loss}}$$

This principle is visualised in Figure 2.2.3.1. The empirical methods have been simulation tested for many life histories and fishing histories and the catch advice derived from this parameterisation was found to be appropriate and followed ICES management objectives. This principle should be used unless there is compelling scientific evidence for an alternative approach, ideally supported with case-specific simulation testing.

There were comments from the ICES community on the use of indices, which years to include and if, for example, the first year of an index can be used. The biomass index should be representative of the whole stock and provide a consistent time series of the stock over time. If there are concerns about the index values from specific years, these values should not be used in the index and, consequently, not for the reference levels. If there are concerns about changes in the index over time, e.g. because of a shift in the stock distribution, changes in the gear selectivity or catchability, the index should not be used for providing advice in the first place.

Clarification: The reference points I_{trigger} and I_{loss} should be defined once the first time the empirical harvest control rule is applied. The definition and rationale of reference points should clearly be described in the stock annex. This value should then be kept constant in the following years. Modification to the reference points should only occur if there are substantial changes in the survey and this should be reviewed before implementation, following the same principles as for when changes to the reference points for data-rich category 1 stocks occur (e.g. in inter-benchmarks/benchmarks).

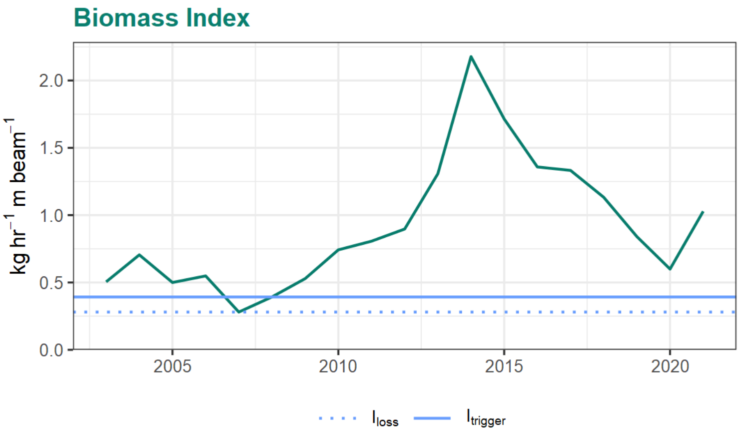

Figure 2.2.3.1: Illustration of how to derive I_{trigger} from I_{loss}. The data are based on the 2022 ICES assessment of plaice in the western English Channel.

2.2.4 Guidance on changing the frequency of application of the rules (i.e. using a method designed for biennial advice on an annual basis)

The ICES technical guidelines (ICES, 2022) recommend that the rfb and rb rules are applied biennially and the chr rule annually. This section describes a short exploration of the impact of changing the frequency of the application.

2.2.4.1 The rfb rule

The generic simulations were based on a biennial catch advice for the rfb rule (ICES, 2020a).

Fischer *et al.* (2021a) explored the impact of using an annual or triennial catch advice for one example stock (pollack) and found that this led to a deterioration of the management performance (i.e. ability to meet MSY and precautionary objectives) of 20% for the annual catch advice and 12% for the triennial catch advice. Although this exploration is only based on one example stock, it indicated that changing the default biennial catch advice can be detrimental to management performance and should be avoided.

The ICES technical guidelines (ICES, 2022) for the rfb rule recommend the application of a multiplier depending on the individual growth rate (von Bertalanffy k), with a multiplier of 0.95 for species with $k < 0.20\ \mathrm{year}^{-1}$ and a multiplier of 0.90 for species with $0.20 \leq k < 0.32\ \mathrm{year}^{-1}$. These multipliers were defined by using the average multiplier required for species in these groups where the risk of falling below the biomass limit reference point B_{lim} meets 5%, corresponding to the ICES precautionary criterion.

An identical simulation setup was used to explore the impact of changing the frequency of the catch advice. See section 3 of the WKLIFE X report (ICES, 2020a) for details on the simulation. Figure 2.2.4.1.1 shows the results of WKLIFE X, which were used to define the multiplier and a comparison with results from setting the catch advice annually. The difference in the multipliers leading to a B_{lim} risk of 5% when the advice is set annually and not biennially was stock specific. In general, when the results from the stocks were averaged (median curves in Figure 2.2.4.1.1), using an annual catch advice interval does not lead to a higher B_{lim} risk. This might potentially indicate that a higher generic multiplier could be used. For example, for the medium-k stock group (Figure 2.2.4.1.1), a multiplier of 1.00 could be used with an annual catch advice instead of the 0.95 multiplier for the biennial catch advice and lead to the same average risk. However, this parameterisation would lead to a lower long-term catch.

Consequently, using the rfb rule with an annual catch advice interval instead of the recommended biennial interval with the same multipliers as defined for the biennial interval is possible and does not jeopardize the principle of the ICES precautionary approach. However, such an approach might reduce catch advice and will increase (double) the workload of stock assessors and ICES to produce advice.

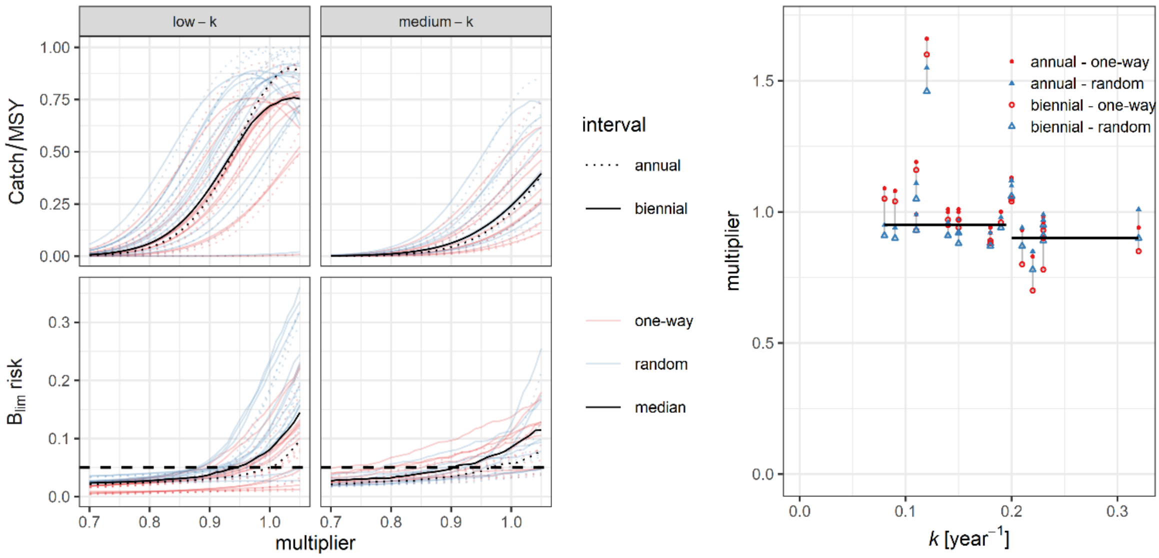

Figure 2.2.4.1.1. Comparison of the impact of annual and biennial catch advice on the performance of the rfb rule in the generic closed-loop simulations conducted by WKLIFE X (ICES, 2020a). On the left, each curve corresponds to the results from one of the generic stocks in the simulation. On the right, the multiplier values correspond to those that lead to a risk of 5% and values for the same generic stock are connected by vertical grey lines. "one-way" and "random" correspond to fishing histories before the implementation of the harvest control rule, where one-way is an exponential increase in the fishing mortality and random consists of random fishing mortality trajectories.

2.2.4.2 The rb rule

The generic simulations were based on a biennial catch advice for the rb rule (ICES, 2020a).

The same exercise described above for the rfb rule was conducted for the rb rule. The results are presented in Figure 2.2.4.2.1. Similarly, to the rfb rule, considering only the B_{lim} risk would allow the use of a larger multiplier; however, this leads to a considerate reduction in the long-term catch. This is because the rb rule does not have a target and only follows trends. The generic multiplier of 0.5 essentially halves the catch advice from the biomass trend at every application. If the rb rule is applied annually, this reduction happens more frequently. Consequently, applying the rb rule on an annual basis is not recommended.

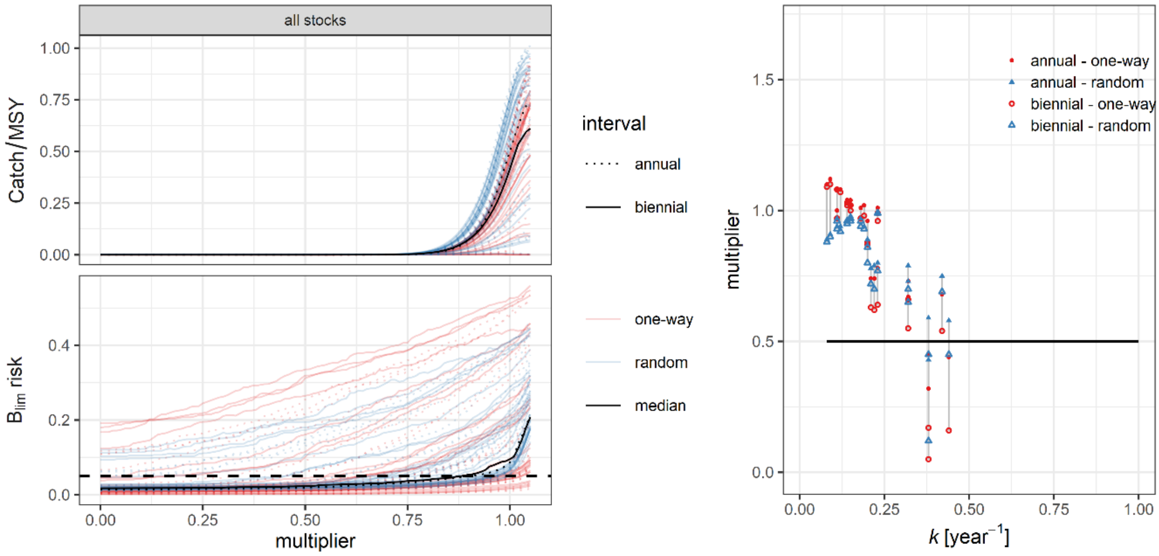

Figure 2.2.4.2.1. Comparison of the impact of annual and biennial catch advice on the performance of the rb rule in the generic closed-loop simulations conducted by WKLIFE X (ICES, 2020a). On the left, each curve corresponds to the results from one of the generic stocks in the simulation. On the right, the multiplier values correspond to those that lead to a risk of 5% and values for the same generic stock are connected by vertical grey lines. "one-way" and "random" correspond to fishing histories before the implementation of the harvest control rule, where one-way is an exponential increase in the fishing mortality and random consists of random fishing mortality trajectories.

2.2.4.3 The chr rule

The generic simulations were based on an annual catch advice for the chr rule (ICES, 2020a). The ICES technical guidelines recommend the use of the chr rule for stocks with von Bertalanffy growth rates of $0.32 \leq k < 0.45$ year^{-1}. The generic simulations from ICES (2020a) were based on stocks within this range of k values and included only five stocks. However, the analysis was subsequently extended to the full 29 stocks and published by Fischer *et al.* (2022a). For WKLIFE XI, the impact of changing the catch advice from an annual interval to a biennial interval was explored based on the simulations of Fischer *et al.* (2022a). The results are shown in Figure 2.2.4.3.1.

For stocks within the range of k values for which the chr rule is recommended, the multiplier for the biennial interval needed to be more conservative (lower) compared to the default annual interval. For the remaining stocks, the situation depended on the stock, with some lower and higher multiplier values. However, the changes were largely small and the chr rule could be applied biennially (with the multiplier of 0.5), reducing the work required for ICES and stock assessors.

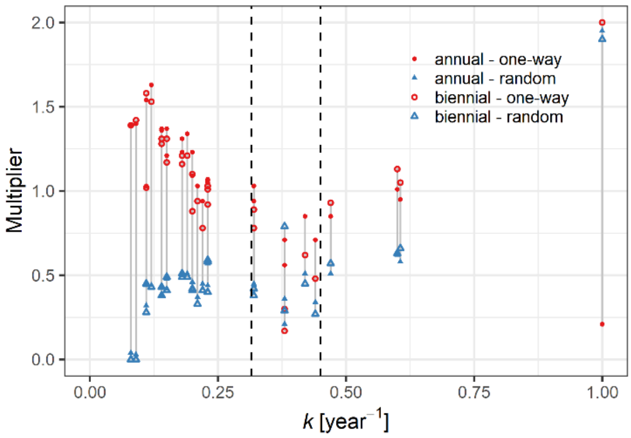

Figure 2.2.4.3.1. Comparison of the impact of an annual and biennial catch advice interval on the chr rule, based on the generic simulations of Fischer *et al.* (2022a). The multiplier values correspond to those that lead to a risk of 5% and values for the same generic stock are connected by vertical grey lines. "one-way" and "random" correspond to fishing histories before the implementation of the harvest control rule, where one-way is an exponential increase in the fishing mortality and random consists of random fishing mortality trajectories.

2.2.5 Describe how sources of uncertainty are incorporated in each of the Empirical methods and examine the robustness of the parameter values

The empirical harvest control rules (the rfb/rb/chr rules) were developed with generic closed-loop simulations. This work has been developed during WKLIFE VII to WKLIFE X (ICES, 2017, 2018, 2019a, 2020a) and has also been published in several peer-reviewed publications (Fischer *et al.*, 2020, 2021a, 2021b, 2022a). These generic simulations follow a typical closed-loop (management strategy evaluation, MSE) design and include several sources of uncertainty. Uncertainty was included with a Monte Carlo approach with 500 simulation replicates, each with random errors. Uncertainty was considered for:

- Life history

  The parameterisation for operating models for specific life-history groups (characterised through the von Bertalanffy growth parameter k, i.e. the individual growth rate) was always based on several simulated stocks with different life-history characteristics (e.g. individual growth, longevity, maturity, natural mortality, selectivity, etc.) and the results from these stocks were combined to derive an appropriate harvest control rule parameterisation. This means that variability was explicitly accounted for life-history parameters.

- Stock status

  The stock status (depletion, fishing pressure) is usually unknown for data-limited fish stocks. Consequently, in order to account for this uncertainty, the generic simulations used several fishing histories leading to different depletion levels when the harvest control rules were applied the first time. Three fishing histories were used: (1) a "one-way" fishing history in which the fishing mortality was increased exponentially, which led to a highly depleted stock, (2) a "roller-coaster" fishing history in which the fishing mortality was also increased exponentially, then kept constant, and subsequently reduced again, which lead to a depleted stock that had just started to recover, and (3) a "random" fishing history in which random fishing mortality trajectories occurred, including constant fishing mortality at various levels as well as increasing and decreasing trajectories. The fishing histories are illustrated in Figure 2.2.4.4.1.

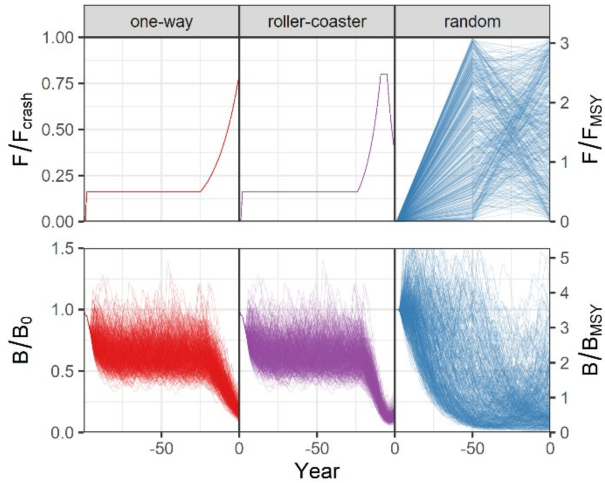

Figure 2.2.5.1. Illustration of the three fishing histories used in the generic simulations for the rfb/rb/chr rules. F_{crash} is the lowest fishing mortality that led to the stock crashing in the long term, B is the spawning stock biomass, and B_0 the unfished SSB. The individual lines correspond to the 500 simulation replicates of one example stock (pollack). Figure taken from Supplementary Figure S1 of Fischer et al. (2022a).

- Observation error

  Observation error was included for the data used in the harvest control rules, i.e. the biomass index and the index of mean catch length. This observation error was considered both during the application of the harvest control rules as well as for the definition of management reference points, e.g. the biomass index trigger value I_{trigger}. The observation error followed a log-normal distribution (default: $\sigma_{\text{obs}} = 0.2$).

- Process error

  A process error was considered for recruitment deviations in the simulation. The stock-recruitment model for the generic stocks was based on a Beverton-Holt model. The actual recruitment values in the simulation included log-normal random deviates (default: $\sigma_{\text{R}} = 0.6$).

The generic simulations used specific model parameterisations and some of these model parameters could be considered potentially arbitrary. Therefore, the impact of simulation parameters and the level of uncertainty on the results was explored. For the simulation parameters, the depletion level at the start of the simulation, the risk definition, and the number of years in the simulation was explored. The level of uncertainty was explored for recruitment variability, recruitment auto-correlation, recruitment steepness, and observation uncertainty. The results of these sensitivity analyses are present in Fischer *et al.* (2021b; Figure 3) for the rfb rule and in Fischer *et al.* (2022a; Figure 5) for the chr rule. The sensitivity analyses found that the uncertainty used in the generic simulations was appropriate and did not affect the conclusions.

In addition to the generic simulations, Fischer *et al.* (2022b) simulation tested the rfb and chr rule for three case studies (plaice, cod, and herring). The operating models for these three case studies were conditioned on real ICES stocks and were based on the perception of the state-space stock assessment model SAM (Nielsen and Berg, 2014) and might therefore be considered more realistic and included more realistic estimates of uncertainty and uncertainty structure. Additionally, alternative operating models representing alternative scenarios for recruitment, natural mortality, and discarding were considered. These case-specific simulations concluded that the generically developed empirical harvest control rules meet the targeted management objectives (MSY, limited by the ICES precautionary approach). This could be considered another layer of verification that the harvest control rules are ready to be implemented by ICES.

2.2.6 Provide detailed guidance on how to tune and test the methods, including the choice of multiplier m, for stock-specific application

Tuning and testing methods for use by ICES to provide advice on fishing opportunities should follow the ICES guidelines on management strategy evaluation and practices for MSE. For details on the ICES MSE guidelines, see the ICES WKGMSE workshop reports (ICES, 2013, 2019b, 2020b). MSE best practices are available in Punt *et al.* (2016).

An example of how case-specific simulations can be conducted to parameterise the empirical category 3 data-limited harvest control rules was published in Fischer *et al.* (2022b). Fischer *et al.* (2022b) conducted a closed-loop simulation for three ICES stock, including plaice in the western English Channel. Although this plaice stock is considered a category 3 data-limited stock by ICES, it was possible to fit a stochastic state-space stock assessment model (SAM; Nielsen and Berg, 2014) and the operating model could be conditioned on this model fit. This approach facilitated the characterisation of uncertainty for the simulation. Furthermore, alternative operating models representing alternative scenarios for recruitment, natural mortality, and discarding were considered. This is likely a rare case because it will not be possible for most ICES category 3 stocks to fit stochastic age-structured stock assessment models.

Operating models should be age-structured and stochastic. If it is not possible to condition operating models on stock assessments, they can be created based on life-history parameters. However, such operating models need to go beyond the considerations of the generic simulations (ICES, 2017, 2018, 2019a, 2020a; Fischer *et al.*, 2020, 2021a, 2021b, 2022a) and include a wider range of uncertainty to ensure harvest control rules are robust to uncertainty.

As a minimum, such simulations should include uncertainty considerations for the following elements:

- Life-history characteristics

  If operating models are generated based on life-history parameters and not conditioned on age-structured stock assessments, uncertainty in these parameters and how they are linked should be included. This includes, e.g. individual growth parameters and parameters derived from these, such as natural mortality or maturity as well as their functional relationship.

- Stock status

  The stock status (depletion and fishing pressure) of data-limited stock is usually unknown. Consequently, alternative fishing histories need to be used to create different starting points. In the absence of stock status information, the development of harvest control rules needs to ensure that these are able to manage stocks sustainably as well as being able to recover a depleted stock.

- Alternative operating models

  Simulations should not only be based on a single operating model but consider alternative scenarios. This should include plausible alternative scenarios for factors such as recruitment. The tuning of harvest control rules can be based on the most plausible baseline operating model but the tuned parameters need to be checked for robustness with the alternative operating models.

- Process error

  Process error should be included for processes that are not known precisely, e.g. for recruitment through recruitment residuals.

- Observation error

  All data used by the harvest control (e.g. catch, biomass index, length data) should include uncertainty because they are unlikely to be known exactly.

- Implementation error

  An implementation error should be included if illegal, unreported, and unregulated fishing, miss/underreporting, or other non-compliance with catch advice is known or suspected.

The tuning of the harvest control rules should aim to meet ICES management objectives, i.e. follow the ICES MSY approach while meeting the ICES precautionary approach criteria. This usually means to maximise the long-term catch while ensuring that the risk of the stock falling below the biomass limit reference B_{lim} (a value below which stock productivity, e.g. expressed through recruitment, is thought to be impaired) does not exceed 5%. This requires the definition of a suitable value for B_{lim}, which can be challenging in a data-limited situation. If the stock-recruitment model is based on a segmented regression (hockey-stick model), the breakpoint can be a suitable value for B_{lim}.

2.2.7 Under what conditions could a catch advice increase from zero using current methods?

The rfb and rb rule can potentially lead to a continued zero catch advice. This is because both rules work by adjusting (multiplying) the previous catch advice and if the previous catch advice is zero, the new catch will also be zero. However, this is only likely to happen after continued application of the rules for many years and or when a drastic reduction in the stock size occurs, e.g. caused by recruitment failure over several years (Fischer *et al.*, 2022b). In reality, the catch advice is unlikely to reach zero because the change in the catch advice is usually limited by a catch constraint (uncertainty cap).

For the rfb rule, if the catch advice reaches zero or values close to zero, this usually indicates a major issue with the stock, such as a continued decline in the stock size or very low recruitment. This means that the zero-catch advice is likely to be justified.

On the other hand, the rb rule will reduce catch advice over time by design because it lacks a target and needs to reduce catches to ensure long-term compliance with the ICES precautionary approach.

Before the WKLIFE XI meeting in 2023, there was insufficient time to test potential approaches to increase catch advice from zero with simulations. However, possible approaches are:

- Use the average catch over previous years
- Define a new reference catch, e.g. in the same way a reference catch is defined for the chr rule

2.2.8 Address other relevant issues as identified by WKLIFE and ACOM. A detailed list of issues for WKLIFE's consideration will be provided in advance of the workshop.

Overly precautionary advice

Some members of the ICES community expressed concern that the new empirical harvest control rules might be too precautionary and lead to a lower catch advice than the previous 2 over 3 rule.

The reason for the potentially lower catch advice is that the new empirical harvest control rules were tuned so that they explicitly follow the ICES precautionary approach. Furthermore, the harvest control rules were designed so that they could be applied generically. Essentially, the lack of data, models or knowledge is penalised with a lower catch advice. The ICES technical guidelines (ICES, 2022) encourage conducting case-specific simulations to tune the empirical harvest control rules, which could result in higher catches.

Continuous reduction in catch advice

There is sometimes the incorrect perception that the multiplier of the rfb and chr rules continuously decreases the catch advice over time. The multiplier of the empirical harvest control rules is a tuning parameter that ensures that the advice follows the ICES precautionary approach. The components of the harvest control rules are multiplicative, this means that the multiplier can be thought of as adjusting the target of the harvest control rules, i.e. the reference length in component f of the rfb rule and the target harvest rate of the chr rule. This principle is illustrated in the following equation for the rfb rule:

$$A_{y+1} = A_y \, r \, f \, b \, x = A_y \, r \frac{L_{y-1}}{L_{F=M}} b \, x = A_y \, r \frac{L_{y-1}}{L'_{F=M}/x} b = A_y \, r \frac{L_{y-1}}{L'_{F=M}} b$$

where A_{y+1} is the new catch advice, A_y the previous catch advice, r, f, and b the components of the rfb rule, x the multiplier, L_{y-1} the mean catch length, and $L_{F=M}$ the MSY proxy reference length.

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3 Surplus production models – response to comments from the ICES' community

3.1 Introduction

This Section focusses on collated responses to comments from the ICES' community on surplus production models (ToR 2), specifically to following remarks:

- **2a**) Application of methods to species with specific elasmobranch and deep-water life history strategies
- **2b**) Advisable time series length for surveys and indices as well as how best to incorporate variability in the index for use in Surplus production model methods
- **2d**) Guidance on changing the frequency of application of the rules (i.e., using a method designed for biennial advice on an annual basis)
- **2h**) Address other relevant issues as identified by WKLIFE and ACOM. A detailed list of issues for WKLIFE's consideration will be provided in advance of the workshop

3.2 Application of methods to species with specific elasmobranch and deep-water life history strategies

Elasmobranch and deep-water life history strategies are generally categorised by slower growth, low productivity (low fecundity, late maturity, etc.), and low variability. Two tusk stocks (usk.27.1–2, usk.27.3a456a7–912) and the Thornback ray stock in Division 8c (rjc.27.8c) were part of SPiCT (Pedersen and Berg, 2017) benchmark workshops in the last years. While the Thornback ray assessment is accepted for providing management advice, the tusk stocks were rejected. However, the reasons for rejections were short CPUE time series and problems with the CPUE standardisation and thus unrelated to the life history strategies. Short index and/or catch time series challenge production models and the estimation of all parameters and specific model configurations might be required (see Section 3.3). In the future, it could be considered to perform a meta study to derive specific prior distributions for deep-water species and elasmobranchs life history strategies for production models. Furthermore, the effect of geographic separation of life stages and sex differences should be explored in spatially explicit and sex-specific management strategy evaluation frameworks. Elasmobranchs and deep-water species often provide biennial advice within ICES (see Section 3.4). In conclusion, so far there is no indication that SPiCT is not applicable to species with specific elasmobranch or deep-water life history strategies. A lower and more risk-averse fractile of the predicted catch distribution could be considered for the catch advice to account for the lower productivity of these sensitive species, as was done for the advice for porbeagle (15th percentile).

3.3 Advisable time series length for surveys and indices as well as how best to incorporate variability in the index for use in Surplus production model methods

Generally, the longer the time series and the more data the better; historical catches can carry important information about absolute scale and might include the peak of the catches, which can provide required contrast to a surplus production model. In addition, even if historic catches are more uncertain, this information about uncertainty can and should be utilised in SPiCT (see below). A period of >10-15 years is likely to be the minimum requirement for production models considering the number of parameters in SPiCT (8 by default) relative to the number of observations. While longer time series are generally better, at the same time, the model then assumes constant parameters over longer time periods and models with time-varying process might be considered (see e.g., Mildenberger et al. 2020). Overall, contrast is generally more important than time series length for production models. Lack of information due to lack of data quantity (e.g., time series length) or data quality (e.g., lack of contrast) demands more informative priors, e.g., on the shape of the production function, the initial depletion level, or the intrinsic population growth rate. Data-limited trend-based SPiCT HCR and recommendations for model configurations and selection should be considered for SPiCT assessments based on very short time series in the future.

The uncertainty of input data can and should (if available) be included in a SPiCT assessment. Relative information can be included as a scaling of the standard deviation ("stdevfacI" and "stdevfacC" in SPiCT). This vector should be standardised to have an average of one, otherwise the interpretation of the variance parameters changes (as well as the variance ratio (default priors)). If quantitative information is not available, qualitative scaling is possible, e.g., abundance index before 2003 is more uncertain than after. However, the assessment should then include a sensitivity exploration to the level of uncertainty assumed (e.g., 2,3,5 times more uncertain?). Absolute information about the uncertainty of input data should be included as a prior for variance parameters ("logsdc" and "logsdi" in SPiCT). In that case, one should remember the default variance ratio priors ("logalpha" and "logbeta" in SPiCT) which should be turned off when adding priors for variance parameters. The following is example code to do these manipulations for SPiCT, please do not copy the exact values! The code assumes a spict input list “inp” with one catch time series and 2 index time series, a vector with the uncertainty of catches “cv_catches”, a vector for uncertainty of the first “cv_surv1” and the second index “cv_surv2”.

```
## Relative information regarding uncertainty as variance scaling

inp$stdevfacC = cv_catches / mean(cv_catches)

inp$stdevfacI = list(cv_surv1 / mean(cv_surv1), cv_surv2 / mean(cv_surv2))


## Absolute information regarding uncertainty as priors for variance parameters

inp$priors$logsdc = c(log(0.1), 0.5, 1)

inp$priors$logsdi = list(c(log(0.2), 1, 1), c(log(0.3), 0.5, 1))


## Turn off variance parameters ratio priors when adding variance priors

inp$priors$logalpha = c(0,0,0)
```

```
inp$priors$logbeta = c(0,0,0)

## Qualitative scaling
inp$stdevfacC = rep(1, length(inp$timeC))
inp$stdevfacC[inp$timeC < 2003] = 2
inp$stdevfacC = inp$stdevfacC / mean(inp$stdevfacC)

inp$stdevfacI = list(rep(1, length(inp$timeI[[1]])),
                     rep(1, length(inp$timeI[[2]])))
inp$stdevfacI[[2]][inp$timeI[[2]] < 2003] = 2
inp$stdevfacI[[2]] = inp$stdevfacI[[2]] / mean(inp$stdevfacI[[2]])
```

3.4 Guidance on changing the frequency of application of the rules (i.e. using a method designed for biennial advice on an annual basis)

All simulations and testing of current rules assumed annual advice (Mildenberger et al. 2022). There are different catch prediction options to derive a TAC for biennial advice:

1. Forecast 2 years and provide annual TAC for each year
2. Forecast 2 years and provide aggregated TAC for 2 years (times 0.5)
3. Forecast 1 year and provide TAC for one year (times 2)

Preliminary results for haddock and the ICES advice rule with a limit reference point at 0.3 B_{MSY} and a threshold reference point at 0.5 B_{MSY} and the 35th percentile of the catch distribution show that on average these three approaches result in similar trajectories for a highly exploited stock (Fig. 3.1). However, the implementation with two forecast years and individual TACs for both years indicate a lower TAC for the second year and thus lead to oscillating dynamics (Fig. 3.1). This can likely be attributed to the increasing uncertainty and thus larger effect of the 35th percentile with increasing years in the forecast period. The other two approaches give similar results as annual advice (Fig. 3.2).

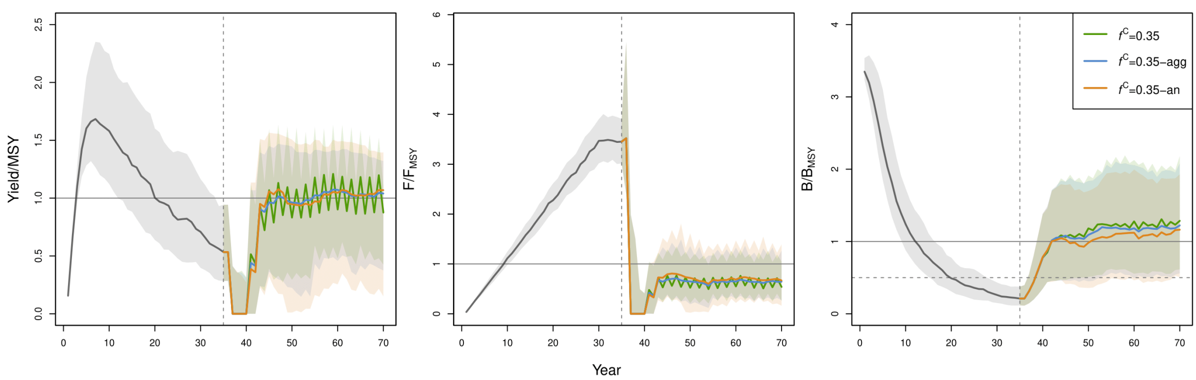

Figure 3.1: Median relative trajectories (yield/MSY, F/FMSY, B/BMSY) over all replicates for the three catch prediction options (colours) to provide biennial advice.

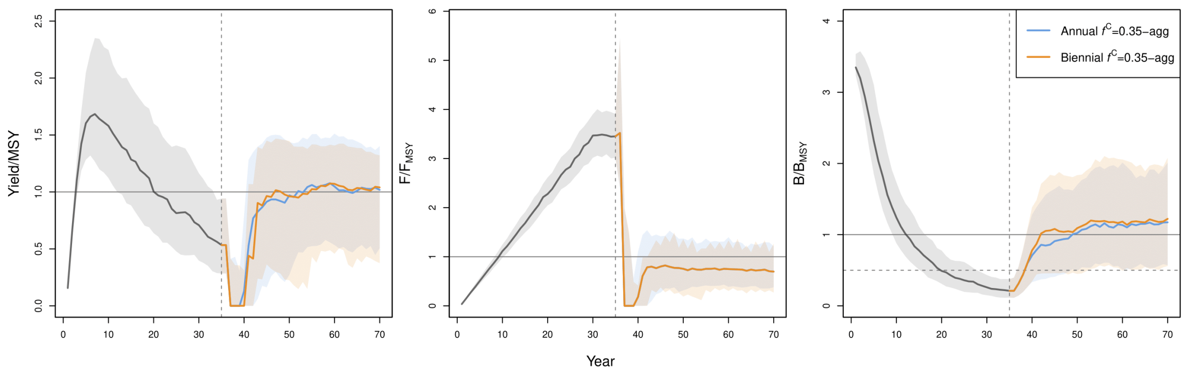

Figure 3.2: Median relative trajectories (yield/MSY, F/FMSY, B/BMSY) over all replicates for the catch prediction option (2) assuming annual (blue) and biennial advice (orange).

Figure 3.3 to 3.5 shows the yield-risk, yield - variability in yield trade-off graphs as well as the Kobe plot for the terminal year using different projection periods for the estimation of the metrics (1-8 years, 3-8 years, and 3-35 years, respectively).

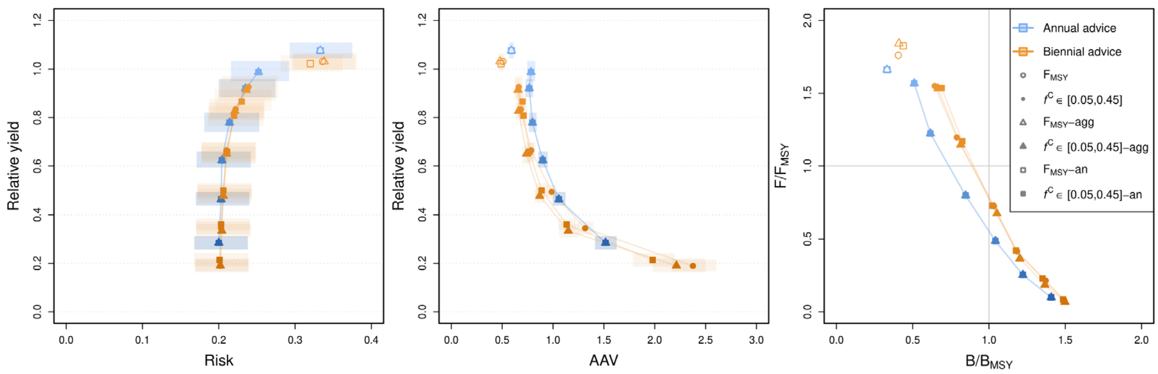

Figure 3.3: Yield-risk, yield - variability in yield trade-off graphs as well as the Kobe plot for the terminal year for the projection years: 3 - 8 (max. age).

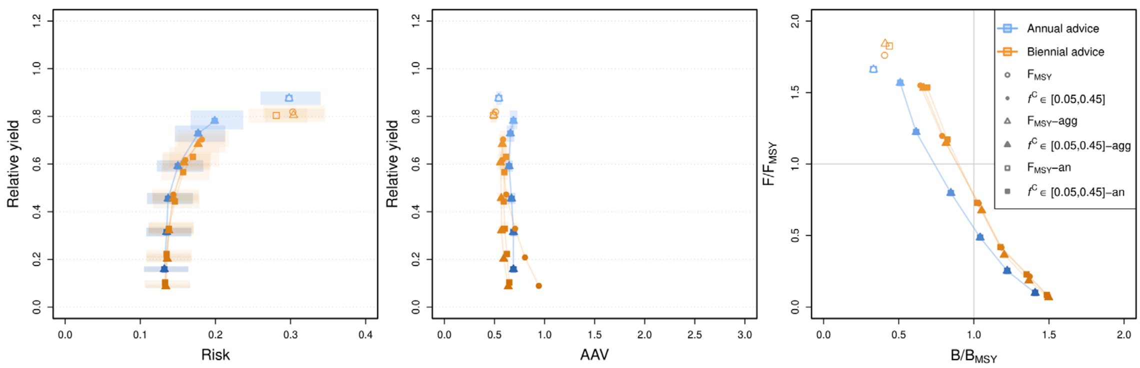

Figure 3.4: Yield-risk, yield - variability in yield trade-off graphs as well as the Kobe plot for the terminal year for the projection years: 1 - 8 (max. age).

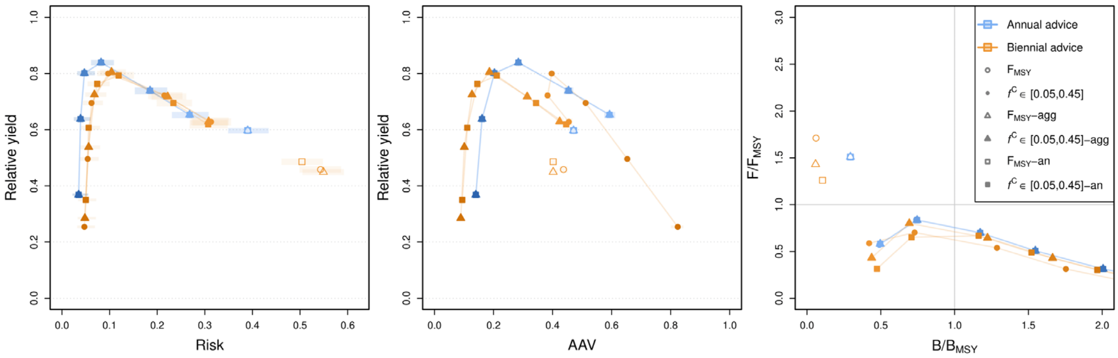

Figure 3.5: Yield-risk, yield - variability in yield trade-off graphs as well as the Kobe plot for the terminal year for the projection years: 3 - 35.

These results suggest that recommended probabilistic HCR works with annual and biennial advice, but should be confirmed for other life history traits. The relative risk-yield trade-offs are similar, but absolute values are different. The absolute values depend of course on a multitude of factors, such as the initial depletion, projection period (cp. Figures 3.3 - 3.5), assessment bias, or assumed uncertainty. We recommend applying annual advice and if not possible applying biennial advice with aggregated catch prediction (Option 2). This can be achieved in SPiCT by following example code. This code assumes a biennial management interval from 2023 to 2025 and the input list “inp”.

```
inp$maninterval = c(2023,2025)

inp$maneval = 2025

fit = fit.spict(inp)

fit = manage(fit, scenarios = “ices”)

mansum = sumspict.manage(fit)
```

It should then be remembered that the predicted catch corresponds to 2 years and has to be divided by 2 to extract the annual catch advice:

```
mansum$est[,”C”] / 2
```

3.5 Address other relevant issues as identified by WKLIFE and ACOM. A detailed list of issues for WKLIFE’s consideration will be provided in advance of the workshop

3.5.1 Methods need to be evaluated further with more uncertainty and more flexibility

There is always more that can be explored, structural uncertainty is a good place to start. We expect these precautionary HCRs to be even more important the more uncertainty is included in the simulations. Until, future research indicates differently, we think that current assessment and management guidelines can be used and reflect current best knowledge.

3.5.2 Is it possible to define the risk fractile in an SPiCT-based MSE?

Accounting for density-dependence on natural mortality and growth (as indirectly done by surplus production models) is likely to be an important alternative operating model configuration (also regarding structural uncertainty). The infrastructure for SPiCT-based MSEs will be developed until WKLIFE XII. However, whether simulations based on a framework where assessment equals operating model will be sufficient to define the optimal risk fractile or HCR remains to be shown.

3.5.3 Biomass threshold and limit reference points in the SPiCT HCR

While target reference points are clearly defined in SPiCT, the currently used definition of threshold and limit reference points in SPiCT-based HCRs goes back to an ICES report for Greenland halibut from 2013, which defines the biomass limit reference point as the biomass that corresponds to half of the productivity of MSY and the threshold reference point as 1.4 times that (ICES, 2013). This corresponds to biomass levels of 0.3 and 0.5 B_{MSY} for a Schaefer model. Furthermore, the biomass can be evaluated relative to reference points at start or end of management interval.

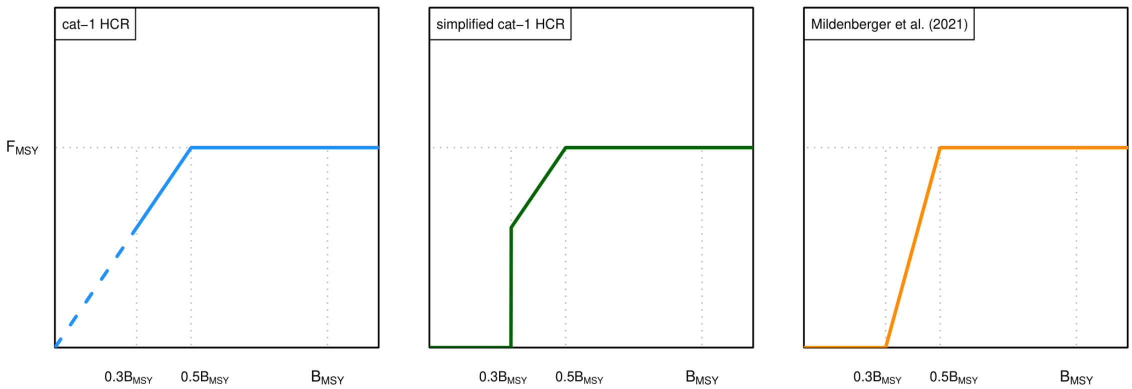

Figure 3.6: Three alternative harvest control rules: (1) Reduce F linearly to 0 at B=0 and find the F that leads to a higher predicted biomass than Blim at the end of the management interval if the predicted biomass would be below Blim with the suggested F of the hockey-stick rule (blue line); (2) Reduce F linearly to 0 at B=0 and set F=0 if biomass at the beginning or end of the management interval is below Blim (green line); (3) Reduce F linearly to 0 at Blim (biomass can be evaluated at the beginning or end of the management interval; orange line).

In the future, the cat-1 and simplified cat-1 HCR should be implemented and tested in MSE (Fig. 3.6). Until then and simulations suggest anything different, we recommend using the Mildenberger et al. (2022) HCR with a limit reference point at 0.3 B_{MSY} and a threshold at 0.5 B_{MSY} and evaluate the biomass at beginning of management interval.

3.5.4 Is process and observation noise in SPiCT linked?

The default setting of spict has two vague priors on the hyper parameters "alpha" and "beta" around 1 (with a standard deviation of 2 on log scale). These hyper parameters are not model parameters but depend on those (thus referred to as "hyper" parameters) and link the process and observation errors for the biomass process and indices, and fishing mortality process and catches, respectively. The individual noise parameters ("logsdb", "logsdi", "logsdf", and "logsdc") are actual model parameters and are still estimated. Other than the default noise ratio hyper parameters (alpha and beta), SPiCT does not assume any link between the individual noise parameters. Nevertheless, the estimated noise parameters are still likely to be correlated. The default prior for the hyper parameters were merely introduced as a support for model convergence in data-limited cases. Pedersen and Berg (2017) wrote: "In cases where it is not possible to separate process and observation error, a common simplification is to assume process error of Bt and observation error of It to be equal (Ono et al. 2012; Thorson et al. 2013), that is to fix alpha=1. A similar relationship between the process error of Ft and the observation error of Ct could be envisioned, that is that beta=1, which we use when sigmaC and sigmaF cannot be estimated separately." Thus, the general recommendation is to deactivate the default priors for these hyper parameters if they are not needed for model convergence or better information is available about the individual noise parameters, e.g., from the abundance index calculation or meta studies. For example, the survey indices might be associated with higher observation error (e.g., low encounter rates) and the process error might be disproportionately smaller due to longer generation times and the reproductive biology for slow growing, low fecundity and bycatch species such as elasmobranchs. In this case, default priors should be deactivated, and this prior knowledge should be translated into prior distributions for the individual noise parameters. Meta studies should be performed to derive prior distributions for species with these life history strategies. In any case, prior-posterior distributions can and should be checked (see e.g., the function "plotspict.priors()" in SPiCT) and the sensitivity of the assessment to all priors should be evaluated.

3.5.5 Can SPiCT with the default options be used for management advice?

Yes, if there is not enough information from the data default priors can be okay. But if there is prior information about magnitude of observation error etc, then replacing the default priors is sensible.

3.5.6 SPiCT gives higher catch advice than empirical rules

Switching from a trend-based advice to an assessment method, could of course lead to big jumps (up or down). This is stated in the advice sheet under the catch scenario table with a sentence like "The increase in the advice (XX%) is due to change of assessment method used." These jumps are to be expected as we now have reference points and a way to estimate stock status as the basis of the advice. Another reason for much higher landings advice from an assessment model than observed landings, could be the fact that previous advice (and thus available landings data) was based on highly precautionary empirical rules. If we accept the assessment, the advice should follow from it. That said, if the variability in the advice is of concern, it's a good idea to introduce an increase cap or transition rules when moving from one mode (e.g., rfb rules) to another (e.g., SPiCT) when there is a large increase in advised landings. However, one should be more cautious with the decrease cap, as we now have an assessment that estimates a lower stock status.

3.5.7 Is SPiCT biased?

Bouch et al. (2021) stated that "due to the tendency for default SPiCT assessments to underestimate relative fishing and overestimate relative biomass [...] there is a real danger that assessments might be overly optimistic and result in mismanagement and stock collapse." At the same time, a plethora of simulation testing has been performed and does not indicate any (directed) bias in SPiCT (see e.g., Pedersen and Berg 2017; Mildenberger et al. 2020; Mildenberger et al. 2022). Bouch et al. (2021) defined the true B_{MSY} as 2 MSY $B_{trigger}$, which is likely much higher than the actual B_{MSY} given the left skewed production curve for most species (e.g., Thorson et al. 2012) and, thus, leads to overly pessimistic assessment results. Furthermore, the authors did not use any uncertainty scaling for the catches or indices, the uncertainty of input data should be considered (see Section 3.3). The uncertainty of the assessments is not presented, but if they were very uncertain, the estimated status is essentially arbitrary.

3.6 References

Bouch, P., Minto, C. and Reid, D. G., 2021. Comparative performance of data-poor CMSY and data-moderate SPiCT stock assessment methods when applied to data-rich, real-world stocks. ICES Journal of Marine Science, 78(1), 264-276. https://doi.org/10.1093/icesjms/fsaa220.

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4 Assessment methods

This Section of the report focusses on the ToR 3) and the work under Theme 1 (assessment methods) and its three subgroups (surplus production models/delay-difference models, length-structured models, indicators and empirical rules).

4.1 Surplus production models/delay-difference models

4.1.1 Summary

Participants: Alexandros Kokkalis, Bárbara Pereira, Casper W. Berg, Cristina R. Cabello, Ellie MacLeod, Fabian Zimmermann, Maria Soto Ruiz, Mitsuyo Miyagawa, Momoko Ichinokawa, Paul Bouch, Tine Nilsen, Tobias Mildenberger, Wendell Medeiros Leal

Rapporteur: Tobias Mildenberger

The subgroup discussed current approaches, challenges, and future work regarding the application of surplus production models as well as management based on surplus production models. While some data-limited empirical harvest control rules and CPUE-trend based rules are very precautionary leading to substantial loss in yield, assessment models suitable for the assessment of data-limited fish stocks, such as surplus production models, e.g. JABBA (Winker et al. 2018) and SPiCT (Pedersen and Berg, 2017), can lead to precautionary and high yields based on catch and abundance index (effort) time series alone (e.g. Mildenberger et al. 2022). Nevertheless, the quality of the data is still key, and priors might be needed if the information in the data is not sufficient. While the toolbox of diagnostic tests is constantly increasing and can help in model selection, there is still room for further development of surplus production models and testing within simulation frameworks. In particular, the definition of threshold and limit reference points in the context of surplus production models and the harvest control based on surplus production models should be further investigated and tested within management strategy evaluation (MSE) frameworks.

4.1.2 Data input

The assessment with a surplus production model will only be as reliable as the data that went into the model. A common problem for many stocks is very uncertain catch information back in time for example due to missing information of historical discard rates or a lack of species disaggregated information. This is not only a problem for data-limited stocks but affects data-rich stocks as well and general guidelines for catch reconstruction are needed. Although, it can be difficult to reconstruct historical catches (landings and discards), rough estimates with an associated uncertainty scaling can still be important for surplus production models to indicate if historic catches were of a completely different magnitude and thus providing important contrast. The uncertainty of input data is generally an important factor that should be considered in the assessment of surplus production models. For example, in SPiCT, the uncertainty of the abundance index or catch time series can be included as a factor scaling the estimated variance parameters. For stock assessments, where a fisheries-independent abundance index is not available, LPUE/CPUE can be used as an abundance index. However, the CPUE standardisation plays an important role and specific guidelines should be developed. Similarly, the guidelines to derive the abundance index from scientific surveys should be revisited and extended by including spatio-temporal modelling in addition to stratified mean approaches. Another potentially informative data type that is currently not used sufficiently is effort information. This might partly be due to the difficulties associated with sharing sensitive effort information between countries as well as difficulties standardising effort data for different gear types, vessels, etc. Further effort should be allocated to compiling an effort data base, effort standardisation, and incorporating effort data into stock assessments.

4.1.3 Priors

Some production models, in particular, Pella and Tomlinson models that allow for a flexible shape of the production curve can give uncertain or inaccurate results "out of the box" (e.g., Bouch et al. 2021). However, there are an increasing number of recommendations outlining important model configurations and model selection steps, such as the use of priors and uncertainty scaling, that can help deriving the most plausible and robust surplus production model or lead to rejecting potentially biased and uncertain production models. While for a fully Bayesian model (e.g., JABBA), prior distributions have to be specified for all fixed parameters, other surplus production models (e.g., SPiCT) can be run without any priors or priors on some or all parameters. Ideally, these priors are based on the data and information available for the stock that is being analysed or based on meta studies of the same or related species. Generic guidelines need to be available how to define these case-specific priors and default priors in SPiCT need to be revisited. The downside of providing generic rules is the possibility that people blindly apply rules to their stock and copy example code for their case study. The group acknowledged that absolute biomass levels are more uncertain and less accurate than relative levels (relative to reference points or a reference period). Although, informative priors for the carrying capacity can result in more reliable absolute biomass levels, it is not recommended to use a prior for the carrying capacity as it is usually less known. If needed and additional information is available a prior for the intrinsic growth rate, the catchability coefficient, or the initial depletion level could be considered.

4.1.4 Assessments

In some cases, multiple model configurations or scenarios can lead to equally plausible alternative estimates and stock status. The subgroup discussed the question what to do if these alternative model results show conflicting signals or states. First and foremost, the models need to be validated against model assumptions and diagnostics. If multiple opposing assessments pass all diagnostic tests and sensitivity analyses, the more precautionary assessment could be used for management advice. Alternatively, an ensemble approach could be used, but model averaging, and their pros and cons demands more investigation. Either approach might be better than falling back to too precautionary harvest control rules.

4.1.5 Model development

The development of production models should be advanced further, focusing on the utilisation of information that was neglected so far, such as discards, effort information, the unexploited part of the abundance index, or fisheries-dependent or independent length distributions. A multi-fleet production model could account not only for distinct fleets and their effort, but also include a fleet representing all discards. This would then allow to include a longer landings time series and a potentially shorter time series with discard information. A stage-based production model could utilise the part of the abundance index that does not correspond to the commercial selectivity. Currently, the abundance index has to be corrected for the selectivity of the commercial fleets, which often leads to neglecting data, in particular, data that is indicative of the juvenile part of the population and might contribute to better forecasts with surplus production models. Furthermore, in many cases, additional (sporadic) length measurements are available in addition to catch and effort data. The production model should be able to utilise information from length distributions.

4.1.6 Reference points

The group highlighted that while target reference points are clearly defined in production models, threshold and limit reference points lack a clear definition. The currently used definition goes back to an ICES report for Greenland halibut from 2013, which defines the biomass limit reference point as the biomass that corresponds to half of the productivity of MSY and the threshold reference point as 1.4 times that (ICES, 2013). This corresponds to biomass levels of 0.3 and 0.5 B_{MSY} for a Schaefer model. In Japan, current threshold and limit reference points for surplus production models are based on data-rich reference points. Future work should investigate alternative definitions of biomass threshold and limit reference points and the performance of harvest control rules with various reference points. Reference periods or data-rich assessments could help defining more generic reference points.

4.1.7 Harvest control rule (HCR)

There are not only alternative definitions of reference points, but the stock status relative to these reference points can be evaluated at different times, for example at the start or end of the management interval. Furthermore, the steepness of the hockey-stick harvest control rule is an important factor affecting the variability in the catch advice from year to year (Mildenberger et al. 2022) and alternative less steep HCRs should be considered. General guidelines should also be revisited, and alternative recommendations based on life-history traits considered, e.g., short-lived species might want to use a higher threshold biomass reference point and sensitive species (e.g., elasmobranchs) might want to use a lower fractile in the fractile approach. It should also be considered to use fractiles on other quantities than the catch distribution. Furthermore, a trend-based HCR rule should be developed that puts less weight in the reference points but tries to stabilise the relative biomass.

4.1.8 MSE and simulation testing

MSE and simulation testing remains an important tool to evaluate harvest control rules and production models in general. The group highlighted that the importance of contrast and time series length for production models and management advice based on them should be explored in a simulation testing. Another important question that should be investigated in a simulation framework is a change in the definition or interpretation of the exploitable biomass, such as a change in fleet selectivity. In Japan, a framework with a surplus production model as the operating model is currently used to evaluate the performance of competing surplus production model-based harvest control rules. This framework would not only allow a straight-forward

MSE for any accepted stock assessment without further need of detailed life history parameters and assumptions, but also include density-dependent effects in all processes (recruitment, natural mortality, somatic growth, and maturation) rather than in recruitment only as it is the case for most age-based operating models.

4.1.9 References

Bouch, P., Minto, C. and Reid, D.G., 2021. Comparative performance of data-poor CMSY and data-moderate SPiCT stock assessment methods when applied to data-rich, real-world stocks. ICES Journal of Marine Science, 78(1), 264-276. https://doi.org/10.1093/icesjms/fsaa220.

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4.2 Length-structured models

4.2.1 Summary

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Rapporteur: Lisa Chong

Length-structured models are often used in data-limited stock assessments as this method does not require time series such as historical total catches or an index of abundance which are often lacking. Length frequency data is a common source of fishery information because they are easy and inexpensive to obtain from a portion of the catch (Germon et al., 2015; Mildenberger et al., 2017; Rudd et al., 2021). Obtaining age information and fishery-independent/dependent surveys that are representative of the population are expensive and difficult to collect of many fisheries in the world. Length data is still a viable resource for data-limited assessments that allows (based on estimated or borrowed additional parameters) the estimation of life history parameters (e.g. growth, maturity, natural mortality), exploitation rates, stock size, biological reference points and stock status.

A list of length-structured models that are used in ICES, additional models that could be used in ICES assessments in the future, and life history estimators for life history parameters are listed in Table 4.2.1.1. Most of these models derive the Spawning Potential Ratio (SPR) reference points, which is defined as the proportion of Spawning Biomass Per Recruit (SBPR) in an exploited stock with regards to SBPR in an unfished (virgin) stock (Goodyear, 1993). Current length-based methods that are used in ICES are the Length-Based Indicators, Length-Based Spawning Potential Ratio, and the Mean Length mortality estimator. There are more length-structured models that could be considered for the ICES length-based stock assessment toolbox. These include Length-

Based Bayesian Biomass, Length-based Integrated Mixed Effects, Length-based Pseudo-cohort Analysis, Length-based Risk Analysis, and Thompson and Bell.

Challenges when applying length-structured models

Several challenges remain in the application of length-structured methods in data limited fisheries. The output of these models are highly dependent on the i) assumptions of the models, ii) uncertainty of the required inputs (i.e. life history parameters), and iii) limitations on the length data. The truthfulness of the length based model's results is equally dependent on the total uncertainty of the required life history parameter estimates, the inputs in the methods, and the assumptions made.

Length-based models often rely on equilibrium conditions. Equilibrium conditions means that fish population dynamics and processes arise from deterministic relationships and/or are not time-varying (e.g. constant recruitment and fishing pressure). However, these equilibrium assumptions are often violated (Gedamke and Hoenig, 2006). Recruitment is often stochastic due to natural causes such as regime shifts or climate change. Natural mortality could vary by age/size, sex, maturity, or temporally (Cronin-Fine and Punt, 2022). All these methods also model only a single sex, and deviations from the 1:1 (male:female) ratio can influence population dynamics and result in disproportionate representation of one sex. Lastly, these models assume that the input parameters and life history information are known, which is often not the case in many data-limited fisheries.

Obtaining well-informed life history parameters has been identified as a high priority as they have a strong influence in the model metrics (i.e., relative stock status) and outputs. Even in data-rich assessments, gathering life history information is one of the most commonly unresolved issues in the stock assessment process (Maunder and Piner, 2015). As auxiliary data (e.g. age composition, otoliths) are difficult to obtain in many data-limited fisheries, data-limited stock assessments resort to borrowing life history information either by using a database (e.g. FishBase) or using a life history estimation tool. These tools provide estimates of important life history parameters that cannot be easily obtained with auxiliary data, especially in data-limited fisheries. Current data-limited models and applications that estimate life history parameters of growth, maturity, size, recruitment, and/or natural mortality include ELEFAN, FishLife, and the Natural Mortality Tool. Electronic Length Frequency ANalysis (ELEFAN) uses the length-frequency data directly to obtain growth parameters (Mildenberger et al. 2017, Taylor and Mildenberger, 2017). FishLife is a meta-analysis approach that predicts life history parameters (growth, maturity, size, mortality, and recruitment) conditioned on taxonomy and life history data for fishes worldwide (Thorson et al., 2017). The Natural Mortality Tool accumulates empirical estimates of natural mortality into one application, which can either provide individual estimates or be combined into a weighted density function that can be used to develop a natural mortality prior (uncertainty around the estimate; Cope and Hamel, 2022). However, one major issue with using database information or methods like FishLife is that the information extracted is not representative of data-limited species as the data within the databases are sparse, unreliable, or only representative of a specific area (e.g. tropical vs temperate).

These length-structured models assume that the differences between observed and expected length distributions are not due to variability of recruitment or mortality (i.e. equilibrium conditions). The models also assume that the length data are representative of population and have a unimodal distribution. Many of these length-structured models require representative length composition data, meaning that the data represents the entire spatial and temporal extent of the species of interest. Most of these methods provide just a snapshot of the status of fishery, meaning that status determination is based on one year of data at time and estimates of status over multiple years are based on that year's length composition alone. With only a single year of data, it would be difficult to ascertain if a large proportion of small fish in catch is caused by a strong cohort in recent years or removal of larger fish from the system (Rudd and Thorson, 2018). However, obtaining either longer time-series of length distributions or true representative data are challenging in many data-limited fisheries. Thus, there is a need to improve the data collection for data-limited species and evaluate the implications of continuous sampling vs snapshot length frequency distributions across methods.

Future directions

When data or information is limited, it is important to make the most of what is available. In the data-limited context, fisheries scientists need to look at more sporadic and subjective data and understand potential biases in the data and how they may affect the estimation process (Bentley, 2015). There is also a need for increasing capacity to collect life history information and guidelines on how to estimate or borrow information when there is a lack of auxiliary data. When the collection of more complex life history parameters is not viable, at least incentivize the construction of a length data time series. Several suggestions on borrowing life history information includes using length-based indicators (e.g. top 5% length distribution and Lmax) and conducting Bayesian approaches or ensemble modeling. When borrowing life history parameters, use as criteria ecological/geographic similarity instead of taxonomic proximity. More simulation analyses are needed to compare the performance of various methods (e.g. Chong et al., 2020; Pons et al., 2020), explore the effects of various settings and scenarios on model performance, and create guidelines for the application of these methods. Understanding how these models perform under various scenarios will help highlight the strengths and weaknesses of these models, which will help in the development of new length-based models (e.g., length-informed production model). More sensitivity analyses, uncertainty analyses, model diagnostics, and model validations need to be conducted to determine robustness and effectiveness of the methods. These additional analyses also need to be formalized in the stock assessment and management process.

Table 4.2.1.1. Summary of the subgroup discussion.

Method	Description	Code source	Reference
Current methods used in ICES			
Length-Based Indicators (LBI)	The Length-Based Indicators (LBI) method ranks stocks according to conservation, sustainability, yield optimization and maximum sustainable yield (MSY) objectives by calculating a set of indicators based on the length composition of the catches/landings.	https://github.com/ices-tools-dev/ICES_MSY	ICES. 2015. Report of the Fifth Workshop on the Develop-ment of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V), 5–9 October 2015, Lisbon, Portugal. ICES CM 2015/ACOM:56. 157 pp. https://doi.org/10.17895/ices.pub.19283927.

Method	Description	Code source	Reference
Length-Based Spawning Potential Ratio (LBSPR)	The Length-Based Spawning Potential Ratio (LBSPR) method assesses stock status by comparing the spawning potential as measured through the length composition data to that expected in an unfished stock.	https://github.com/Adrian-Hordyk/LBSPR	Hordyk, A., Ono, K., Sainsbury, K., Loneragan, N., Prince, J., 2015a. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES J. Mar. Sci. 72 (1), 204–216. https://doi.org/10.1093/icesjms/fst235. Hordyk, A., Ono, K., Valencia, S., Loneragan, N., Prince, J., 2015b. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES J. Mar. Sci. 72 (1), 217–231. https://doi.org/10.1093/icesjms/fsu004. Hordyk, A.R., Ono, K., Prince, J.D., Walters, C.J., 2016. A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks. Can. J. Fish. Aquat. Sci. 73 (12), 1787–1799. https://doi.org/10.1139/cjfas-2015-0422.
Mean length mortality estimator	The Mean Length Mortality (MLZ) method estimates the year-specific total mortality rates from the annual mean lengths of fish whose lengths are larger than Lc (i.e. the length at which fish are fully vulnerable to the fishery) and a time series of fishing effort. Gedamke and Hoenig (2006) provides a simple MLZ version that does not require fishing effort data but instead of year-specific total mortalities estimates it provides time-blocks total mortality rates.	https://github.com/ices-tools-dev/ICES_MSY	Mean length mortality estimator
Additional length-based methods			
Length-based Bayesian Biomass (LBB)	The Length-Based Bayesian Biomass (LBB) method that estimates relative biomass for the exploited size range from length-frequency data.	https://github.com/SISTA16/LBB	Froese, R., Winker, H., Coro, G., Demirel, N., Tsikliras, A.C., Dimarchopoulou, D., Scarcella, G., Probst, W.N., Dureuil, M. and Pauly, D., 2018. A new approach for estimating stock status from length frequency data. ICES Journal of Marine Science, 75(6), 2004-2015.

Method	Description	Code source	Reference
Length-based Integrated Mixed Effects (LIME)	Length-based Integrated Mixed Effects accounts for time-varying recruitment and fishing mortality, one of the few models that relaxes the equilibrium assumption.	https://github.com/merrill-rudd/LIME	Rudd, MB and Thorson, JT. 2017. Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries. Canadian Journal of Fisheries and Aquatic Sciences https://doi.org/10.1139/cjfas-2017-0143.
Length-based Pseudo-cohort analysis	Length-based Pseudo-cohort Analysis is a per-recruit pseudo-cohort analysis model that can fit multiple years of length frequency data simultaneously	https://github.com/criscan/LBPA	Canales, C.M., Punt, A.E. and Mardones, M., 2021. Can a length-based pseudo-cohort analysis (LBPA) using multiple catch length-frequencies provide insight into population status in data-poor situations?. Fisheries Research, 234, 105810.
Length-based Reference Points	The Length-Based Reference Points method uses three metrics based on catch length compositions: i) mature individuals, ii) fish of optimal size (size at which the highest yield occurs), and iii) large, mature individuals	https://github.com/shcaba/LBRP	Cope, J.M. and Punt, A.E., 2009. Length-based reference points for data-limited situations: applications and restrictions. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 1(1), 169-186.
Length-based Risk Analysis	Length-based Risk Analysis (LBRA) uses the mean length of catch to calculate reference points, incorporates probabilistic mortality and growth dynamics and defines sustainability risk in terms of probability distributions.	** not publicly available **	Ault, J.S., Smith, S.G., Luo, J., Monaco, M.E. and Appeldoorn, R.S., 2008. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. Environmental conservation, 35(3), 221-231. Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Stevens, M.H., DiNardo, G.T., Johnson, M.W. and Bryan, D.R., 2019. Length-based risk analysis for assessing sustainability of data-limited tropical reef fisheries. ICES Journal of Marine Science, 76(1), 165-180.
Thompson and Bell (in TropFishR)	The Thompson and Bell is a yield-per-recruit model that evaluates stock status in relation to reference levels and the impact of fishing effort or gear selectivity.	https://github.com/tokami/TropFishR	Mildenberger, T.K., Taylor, M.H. and Wolff, M., 2017. TropFishR: an R package for fisheries analysis with length-frequency data. Methods in Ecology and Evolution, 8(11), 1520-1527.
Life-history estimators			

Method	Description	Code source	Reference
Electronic Length Frequency Analysis (ELEFAN) (TropFishR)	ELEFAN is a method that derives growth parameters of the von Bertalanffy growth curve from length frequency data.	https://github.com/tokami/TropFishR	Mildenberger, T.K., Taylor, M.H. and Wolff, M., 2017. TropFishR: an R package for fisheries analysis with length-frequency data. Methods in Ecology and Evolution, 8(11), 1520-1527. Taylor, M.H. and Mildenberger, T.K., 2017. Extending electronic length frequency analysis in R. Fisheries Management and Ecology, 24(4), p
FishLife	FishLife allows future life history predictions of mortality, maturity, size, and growth parameters for all described fishes based on taxonomy and life history data obtained from databases.	https://github.com/James-Thorson-NOAA/FishLife	Thorson, J.T., Munch, S.B., Cope, J.M. and Gao, J., 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications, 27(8), pp.2262-2276. Thorson, J.T., 2020. Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model. Fish and Fisheries, 21(2), 237-251.
Natural Mortality Tool	The Natural Mortality Tool estimates natural mortality using a wide variety of empirical M estimators, and can combine estimates into a weighted density function that can be used to develop an M prior.	https://github.com/shcaba/Natural-Mortality-Tool	Cope, J.M. and Hamel, O.S., 2022. Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality. Fisheries Research, 256, 106493.

4.2.2 References

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Taylor, M. H. and Mildenberger, T. K. 2017. Extending electronic length frequency analysis in R. Fisheries Management and Ecology, 24(4), 330-338. https://doi.org/10.1111/fme.12232.

Thorson, J. T., Munch, S. B., Cope, J. M. and Gao, J. 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications, 27(8), 2262-2276. https://doi.org/10.1002/eap.1606.

4.3 Indicators and empirical rules

4.3.1 Summary

Participants: Tanja Miethe, Peter Kidd, Nicola Walker, Joe Ribeiro, Simon Fischer, Alex Holdgate, José De Oliveira, Ivone Figueiredo, Erick Chatalov, Andrés Uriarte, Piera Carpi, Jon Pitchford, Ella Brock, Elena Balestri, Laurie Kell

Rapporteurs: Andrés Uriarte, Piera Carpi, Erick Chatalov, Simon Fischer

This subgroup discussed various topics on empirical indicators and their challenges.

There was a general consensus that empirical indicators should be tested with simulations so that they can be used in harvest control rules to provide advice for data-limited stocks. Simulations could either be generic based on life history or based on case studies. Elasmobranchs and deep-sea species were mentioned as possible case studies. Using a screening method to filter indicators, e.g. with receiver operating characteristics (ROC) curves, can be a useful approach before indicators are included in an MSE simulation.

4.3.2 Presentations

Presentation on spatial indicator work by Peter Kidd

Fish populations are known to exhibit non-random spatial patterns of distribution, movement, and connectivity but these patterns are ignored within traditional stock assessment methods. Simulation studies have shown that when spatial components have been included in assessment, parameter estimation can be improved; but complex spatially explicit models require large amounts of data and are therefore not appropriate for many ICES stocks with data limitations. Instead, an empirical indicator approach can inform management based upon the performance of indicators computed directly from monitoring data, rather than estimates from stock assessment models. However, ICES empirical assessments for data-limited stocks do not utilise available spatial information.

For a spatial indicator to be useful within assessment they need to show some relationship with the health status of the exploited stock. Many studies have used presence-absence

> spatial indicators to show support for a density-dependent habitat selection hypothesis, whereby increases in overall abundance leads to range extension, and decreases in abundance leads to range contraction. As well as presence-absence indices, other spatial indicators have been used to show a similar positive relationship with abundance or biomass. These indicators include centre of gravity, inertia, and isotropy which together describe the mean location of the population and the range around it. Findings from these studies have indicated shifts in location, fragmentation, and contraction as abundance decreases. There are therefore numerous spatial indicators that have been related to abundance, and future work should explore whether spatial indicators could be a useful proxy of stock status that can be incorporated into harvest control rules for data-limited stocks.

Spatial indicators can be useful for data-limited stocks if they can be linked to stock abundance. This could allow the development of an index for stocks for which there are no traditional indices are available and they could then potentially be used in harvest control rules.

Presentation on SWAF R package by Joe Ribeiro

> Swaf (SWept Area Fishing mortality) is a library we are currently writing in R. It is a data-limited approach for assessing fishing pressure and exploitation status based on the methods described in Walker *et al.* (2019). The method calculates fishing mortality from the spatial overlap of surveyed species distributions with the footprint of the fishery (combined with catchability information if this is available). This fishing mortality is then fed into spawner-per-recruit models, parameterised from life history information, to estimate %SPR. The method uses available survey, fishing effort and life-history data and could provide an approach to estimate the exploitation status of species without an index of abundance or where existing data-limited methods are hindered by poor or unrepresentative commercial data.

The subgroup discussed that the SWAF package is essentially a quantitative version of a productivity susceptibility analysis (PSA) and could be considered by ICES for more data-limited stocks e.g. in category 4.

Presentation on a case study of the rfb rule for thornback ray by Erick Chatalov

> The application of Fischer *et al.*'s methodology for optimizing the rfb-rule for the Raja Clavata often yields unsatisfactory results when using a generic process. Simply adjusting biological parameters is insufficient for optimizing the proposed rule; a revision of both the fitness function and operating model is necessary to meet the management objectives for specific species cases. The intensive computational and memory demands of the optimization process can pose a challenge for testing changes in the operating model and fitness function. Nonetheless, starting with fewer population and iterations in the Genetic Algorithm can still result in acceptable outcomes and reduce running time.

It was noted that the work is still very preliminary and requires further work. It was also noted that the simulation was based on the framework developed for the generic method testing of the rfb rule. This means although the operating model is meant to represent a specific stock (thornback ray), it is based on generic life-history considerations and therefore needs to include a wider range of uncertainties (e.g. growth, depletion, etc) to ensure any outcome is robust.

4.3.3 References

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4.4 Catch-only methods

4.4.1 Summary

There was no dedicated subgroup on catch-only methods at WKLIFE XI but a short discussion was held in plenary and is summarised below.

Rapporteur: Laurie Kell

Sharma *et al.* (2021) found that catch-only models can show notable bias when run with their inbuilt default heuristics, and that as the quality of prior information increased, classification improved. Kell et al. (2022) configured a biomass stock assessment method as a catch-only model to compare the benefits of improving prior information. A main finding was that in the catch-only models, the data have no effect. Although catch-only methods have been used to provide a "snapshot", i.e. a review of stock status in a region, this requires that factors that affect depletion are known, which precludes adaptive management. A major problem with catch-only methods cannot be validated using observations nor used in Management Strategy Evaluation as a feedback controller. These findings are supported by Ovando et al. (2022), who, in a review of catch-only models, concluded that the improvement of catch-only models depends on developing robust biomass, fishing effort or mortality priors.

4.4.2 References

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5 Subgroup theme 2 - Challenges independent of assessment method

This Section focusses on the ToR 3) and the work under Theme 2 (challenges independent of assessment method) and its two subgroups (fast-growing and short-lived, slow-growing and long-lived).

5.1 Fast-growing and short-lived

5.1.1 Summary

Participants: Momoko Ichinokawa, Ellie MacLeod, Piera Carpi, Peter Kidd, Nicola Walker, Alex Holdgate, Andrés Uriarte, Laurie Kell, Pedro Lino, Lisa Chong

Rapporteur: Andrés Uriarte

The problems of managing data-limited short-lived species (DLSLS) and of building up MSE frameworks suitable for testing alternative HCRs for these stocks in category 3 (i.e., with a biomass index) were first discussed. It was recalled that there is a need to shorten as much as possible the time lag between the abundance index, advice and management to optimise the performance of HCRs for such species. The need to set up the OM and consequently the MSE with seasonal time steps to sufficiently incorporate the rapid turnover of these populations (with strong seasonal growth, pulses of recruitments) and to cope with the timing of the survey monitoring system and the management calendar. It was reminded that several modelling frameworks allow such seasonal approach for MSE, such as FLR (Kell *et al.*, 2007, Bastardie et al., 2022), FLBEIA (García *et al.*, 2017), SPiCT (Mildenberger *et al.*, 2021), or for stock assessment e.g. DL modelling with Stock Synthesis (https://github.com/shcaba/SS-DL-tool).

From the WKDLSSLS3 report and recent modelling (Sánchez-Maroño *et al.* in preparation, Kell *et al.*, submitted) it seems that Dynamic Harvest Rate Rules (DHRR), which change harvest rates (applicable to a biomass index) according to index trends, and other rules have equal or better performance than the 1-over-2 rule in the medium and long term. Therefore, these DHRR may form an intermediate step between having a constant harvest rate and the 1-over-2 rule. The performance of these HCRs should be evaluated through MSE on a case-specific basis, e.g. as required for defining a constant harvest rate CHR and other rules.

Different species with different life-history characteristics show differences in the form of interannual variability in biomass, since trends and fluctuations in populations are determined by complex interactions between extrinsic forcing and intrinsic dynamics (Bjørnstad et, al. 2004), which depend on the natural mortality, growth, and the stock-recruitment relationship and variability of recruitments. For example, there are large differences between anchovy, sprat and sardine-like stocks. It was considered that some further specific guidelines on stock type characterization would be convenient, with the inclusion of its implication in terms of most suitable HCRs and their configuration for the form of their dynamics, for instance, in terms of Uncertainty Caps etc.

Suggestions for exploring the validity of stock status indicators, such as spatial indicators, were suggested. The utility of receiver operator characteristic (ROC) curves for testing the performance, selection and weighting of empirical indicators was recalled (Kell *et al.*, 2022a). And comparisons of the performance of data-limited HCRs based on data-rich case studies were recommended to allow checking their relative performance on short-lived species (e.g. Kell *et al*., 2022b). Finally, challenges and lines of research for future TORs were discussed.

5.1.2 References

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Kell, L. T., Bentley, J., Egan, A., Feary D. A., Owen, H., and Nolan, C., Submitted, Developing management plans for sprat (Sprattus sprattus) in the Celtic Seas consistent with an Ecosystem Approach to Fisheries. Small Pelagic Fish Symposium, Lisbon Portugal, 2022.

Mildenberger, T. K., Berg, C. W., Kokkalis, A., Hordyk, A. R., Wetzel, C., Jacobsen, N. S., Punt, A. E., & Nielsen, J. R. (2022). Implementing the precautionary approach into fisheries management: Biomass reference points and uncertainty buffers. Fish and Fisheries, 23, 73-92. https://doi.org/10.1111/faf.12599

Sánchez-Maroño, S., Citores, L., and Uriarte, A., (in preparation): Managing data-limited stocks with harvest rate-based rules based on an abundance index. Oral presentation at the International symposium on Small pelagic fish (SPF) (November 2022, Portugal)

5.2 Slow-growing and long-lived

5.2.1 Summary

Participants: Tanja Miethe, Tobias Mildenberger, Cristina Rodriguez-Cabello, Simon Fischer, Bárbara Pereira, Paul Bouch, Jordan Moss, José De Oliveira, Hector Andrade, Ivone Figueiredo, Laurie, Elena Balestri, Ella Brock, Mitsuyo Miyagawa, Tine Nilsen

Rapporteurs: Tanja Miethe, Ella Brock, Mitsuyo Miyagawa

The subgroup discussed major issues, challenges and future work for data-limited methods of slow-growing species (elasmobranchs, deep-sea species). A number of life-history characteristics were identified, which make these species vulnerable to overexploitation and challenging to assess. In addition, issues were identified which contribute to non-representative catch length distributions and abundance indices. Suggestions were made with regard to improvement of data collection and method development for this species group. A recommendation was made to support assessment scientists with training on spatio-temporal models for survey data, to support estimation of abundance indices taking into account patchy distribution and frequent zero observations.

5.2.2 Life history

For many of the slow-growing species, spatial distribution is critical for management. Distributions can be very patchy and can change over a lifetime (ontogenetic changes). Life histories are characterized by late maturity and low fecundity. Reproductive output is constrained by physiology (max eggs/embryos) and does not necessarily increase with size. Recruitment is assumed to be relatively low, for the stock recruitment relationship it is useful to relate number of females to recruits directly. However, data is limited to allow for the estimation of specific stock-recruitment relationships. Due to the reproductive strategy, including internal fertilization and relatively larger offspring, natural mortality can be relatively low at young ages. Sexual dimorphism in growth is common, with females reaching larger asymptotic sizes. There are species which show a distinctive 2-phase growth, with relatively fast initial growth and growth slowing after maturation. This leads to L_{mat} being close to L_{max} and a heavy tail on the right side of the length distribution.

5.2.3 Length data

Length data are often deficient and not representative for the catches nor populations. This is due to low fishing effort and low sampling effort, typical for rare and bycaught species. There is often low observer coverage for this species group and catch which is not landed cannot be sampled. Furthermore, dome-shaped selectivity limits the occurrence of large individuals in the catch and prevents the observation of heavy tail of length distribution. The selection pattern is affected by the spatial distribution of life stages as well as regional management regulations (min and max landing size), which artificially truncate length distributions. While there is uncertainty on the length at first capture, a high discard survival can make the estimation of L_c easier if discards are unknown. Particularly vulnerable stocks can be subject to prohibition or closing of the fishery, which make data collection difficult. It remains a crucial question on how adults can be best protected given the data.

5.2.4 Abundance indices

For many of the slow-growing species, fisheries-independent information is sparse, with either no survey data or survey designs inappropriate for these species. Currently, there is a Scottish Deep Water survey collecting data. IBTS data is available but often difficult to use given the patchy abundance of these species, leading to locally high catch rates and frequent zero observations. Similarly, swept area estimators are difficult to apply for patchy species and might not be appropriate, for example, the SWAF method requires good quality distribution data.

5.2.5 Data collection

To improve the data quality, better sampling is recommended. This could be done in multiple ways, such as using images from onboard cameras, exploratory TACs and targeted sampling. For example, there is a Russian fleet exploiting seamount species. To allow for some data collection and stock recovery, this fishery is only active every 6 years. Another example was mentioned, relating to Rockall sampling. Only a limited number of demersal vessels fish there seasonally. While it is difficult to achieve random sampling, an increase in sampling and targeting particular regions can be helpful. It could be explored whether existing surveys can support better sampling of data-limited species, as exemplified on a spurdog cruise where rare and low-value shark species co-occur, extra samples could be collected. It is also possible to complement surveys with data collected in cooperation with the fishing industry (such as spin-off IBTS). It takes time to get longer data series and requires a standardized sampling protocol. Any cooperation would first require the identification of data collection gaps and essential sampling areas, and then seeking support from the fishing industry. Also qualitative data may be available as fishers have reported on local aggregations of rays and the spatial distribution of egg cases. Other non-invasive methods could be considered. The use of citizens science is encouraged, particularly in some coastal areas (Jackson et al. 2021). The correct use of citizen science data is crucial, it requires clear protocols and appropriate methods to analyse the data.

5.2.6 Method development

With a lack of representative length data, it is often difficult to apply the empirical rfb rule. Instead, the chr rule could be tried. This rule relies on an appropriate reference period (when the stock was doing well) which can be difficult to define and get good quality data for. Survey modelling for these stocks should be improved and spatial approaches applied. Assessment models have the potential for further more case-specific development. In SPiCT, a lower fractile for sensitive species could be used and explored to model slow-growing species with consideration of sex-specific set-up. With a focus on sexual dimorphism and larger females, getting sex-disaggregated input data is important but can be difficult, particularly on commercial catch data. In a recent ICCAT report, biomass dynamic models and stock synthesis models were compared for shortfin mako. The models show different outcomes due to process error and sporadic recruitment not captured well in biomass models making stock synthesis (SS) preferable. However, the difference in outcomes might not be a problem since long-lived stocks show low recruitment and low productivity. There is the option to include SS as an operating model in FLR. Comparisons, without doing an MSE, could also be done using shiny app presented by Jason Cope (SS-DL). Using the app, an SS assessment can be run on varying amounts of input data allowing for a comparison of approaches within a single framework. The estimation of natural mortality can be done using various estimators depending on life history or genetic methods (such as close-kin mark-recapture, which is expensive). Case-specific sensitivity and uncertainty analysis is suggested. An example of case-specific simulations using a genetic algorithm to optimize empirical harvest control rules was presented. Spurdog, as data-rich elasmobranch species, more abundant in surveys, could be used as a case study to compare the performance of methods.

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6 Subgroup theme 3 - Model diagnostics, control rules and MSE

This Section focusses on the ToR 3) and the work under Theme 3 (model diagnostics, control rules and MSE) and its three subgroups (advice on catch and stock status for ICES' stocks without an index of abundance (Categories 4, 5 and 6); reference points, uncertainty and harvest control rules; MSE and simulation frameworks).

6.1 Reference points, uncertainty and harvest control rules

6.1.1 Summary

Participants: Mitsuyo Miyagawa, Santiago Cerviño, Alex Holdgate, Andrés Uriarte, Tobias Mildenberger, Ellie MacLeod, Cristina Rodriguez-Cabello, Marc Taylor, Michael Spence, Rufus Danby, Alexandros Kokkalis, Wendell Leal

Rapporteur: Marc Taylor

Given that catch advice should be precautionary and consider uncertainty, the group addressed possible improvements to current data-limited stock advice procedures that may reduce risk. Discussion focused largely on the current procedures for stocks assessed with surplus production models (SPMs) and whether current biomass reference point definitions were precautionary and whether additional information on uncertainty could be used to inform advice. On the topic of biological reference points, such as $B_{trigger}$ and B_{lim}, which are used by the ICES harvest control rule (HCR) to trigger reductions in advised fishing mortality or zero-TAC advice, respectively, the group discussed whether the current approach of assigning simple B_{MSY} ratios (e.g. $B_{lim} = 0.3^* B_{MSY}$, $B_{trigger} = 0.5^* B_{MSY}$) could be improved upon. Further simulation work is ongoing to test alternative ratios and definitions for reference points, including whether the shape of the SPM should also be considered. Uncertainty of the assessment and projected catches corresponding to a given fishing mortality target could also be considered (e.g. a smaller fractile of projected catch distribution). Where the application of multiple assessment models is possible, ensemble approaches could also be used to provide a more robust estimate of a stock's status, with the possibility of reducing uncertainty when models align. Finally, the definition of SPM parameter priors was another topic discussed. Guidelines exist for SPiCT that help guide users to identify unrealistic results, e.g. shape parameter in the Pella-Tomlinson model, although it is clear that further guidance could be developed.

6.2 MSE and simulation frameworks

6.2.1 Summary

Participant: Piera Carpi, Lisa Chong, Ivone Figueiredo, Momoko Ichinokawa, Sonia Sánchez-Maroño, Fabian Zimmerman

Rapporteur: Lisa Chong

Simulation frameworks, such as management strategy evaluations (MSEs), are a powerful tool in testing harvest control rules and management procedures while considering many moving components of the fishery (i.e., fish population dynamics, fishery characteristics, management) and including uncertainties we have about the fishery. MSEs are a popular, closed-loop, simulation tool for developing and testing the performance of harvest control rules (HCRs; Punt et al., 2016). The MSE involves the creation of the operating model that simulates plausible hypothesis about the population, observation model that imitates the data collection processes, estimation model that assesses the data and stock (not always applied in data-limited fisheries), and management model that implements a management procedure (MP) or HCR.

Challenges when applying data-limited MSEs and simulation frameworks

Many data-limited MSEs have been developed for the explorations of data-limited MPs (e.g. Carruthers et al., 2014; Sagarese, 2018; Sun et al., 2018; Fischer et al., 2020; Sanchez-Maroño et al. 2021). However, there are challenges that remain for data-limited MSEs and simulations, including i) data availability, ii) type of operating model, iii) dimensionality, iv) and type of MP/HCR.

Application of data-limited approaches requires considerable input on data availability and quality, sensitivity analyses on all required data inputs, and defensible decisions rules (Sagarese et al., 2019). One major concern with data-limited fisheries assessments is the limited life history knowledge and data. Many assessment models (data-limited and -rich) rely on high quality life history information as input, especially if they are age- or length-structured models. Data-limited MSEs can be conducted to simulate alternative potential states despite limited knowledge of input parameters, underlying population dynamics, or catch levels. These MSEs can explore various input parameters and errors via sensitivity analyses or ensemble-modelling (e.g. Walsh et al., 2018) and various states of the population using alternative operating models. Common process errors to test in a MSE framework include recruitment events, variability in the stock-recruitment relationship and time-varying parameters (e.g., natural mortality, carrying capacity, selectivity). Common observation errors can include survey biases, aging error, and historical catch inaccuracy.

The most common type of operating model used is the age-structured, however these types of models can be challenging to develop for data-limited fisheries. Some factors to consider when selecting a structure for the operating model includes available data for conditioning and calibrating the model, species of interest (life history, ecological and biological characteristics), and fishery characteristics. For data-limited MSEs, a biomass-dynamics or a surplus production operating model could be considered, especially when it may not be possible to simulate an age-structured model. A biomass-dynamics model can simulate age-aggregated catch and the observation of an abundance index. While a biomass-dynamics operating model would not replace complex or age-based operating models, they can serve as a starting point for data-limited assessments and stocks that are in need for testing and development of HCRs and management strategies.

The number of operating models simulated in MSEs should be limited due to complexity and computational intensity and time. Ultimately, the dimensionality of the MSE and model types (e.g. biomass-dynamics operating model) will depend on research objectives and data availability. At minimum, MSE scenarios need to address a reference or base case and robustness to test uncertainties. Reference MSEs should reflect the most plausible hypotheses and should be the most representative of the stock of interest and objectives (Punt et al., 2014). Robustness sets should be used to determine if management procedures behave as intended in scenarios that are unlikely (Punt et al., 2014).

As new MPs and HCRs are being developed for data-limited fisheries, the type (model-based vs empirical-based or model-free) should be considered. Model-based HCRs use models to calculate catch limits that attempt to achieve maximum sustainable yield (MSY). Although model-based HCRs can calculate optimal reference points, auxiliary data such as age composition data are essential to obtain, Inaccurate stock status estimates and metrics can be produced when assumptions are violated, which is commonly the case in data-limited stock assessments (Hordyk et al., 2015). As an alternative, empirical-based approaches can be used to make relative adjustments to the catch limit or fishing mortality through output-control regulations (e.g. changes in fishing effort) in data-limited situations (Harford et al., 2016). Empirical-based approaches only require data (e.g., catch, CPUE, mean length) and do not depend on abundance estimates obtained from stock assessments. These empirical-based HCRs connect measured values of various indicators to regulatory tactics for controlling catches. This approach avoids issues associated with uncertainty in estimates from stock assessments, especially in situations where catch limits cannot be calculated or catch histories cannot be relied on (Apostolaki and Hillary, 2009).

MSE packages

There are several MSE R packages that are currently used in ICES and one under development. This includes FLR, FLBEIA, SPiCT, DLMtool, and SS-DL tool. The Fisheries Library in R (FLR) has a MSE framework (https://github.com/flr/mse) that uses an age-structured operating model. FLR is implemented using object-oriented programming, which allows components of the fisheries to be represented as core classes and new classes (e.g. implement additional model) can be added (Kell et al., 2007). FLBEIA (https://github.com/flr/FLBEIA) is an R package for conducting bio-economic evaluation of alternative management strategies (García et al., 2017). The model is flexible enough to deal with multiple stocks (age structured or with biomass dynamics), fleets and seasons and has been constructed in a modular way, allowing easily including additional functions to those already available for describing dynamics of the different processes. The Surplus Production model in Continuous Time (SPiCT) (https://github.com/DTUAqua/spict) is a stochastic surplus production/biomass-dynamics model that reports uncertainties in reference points, incorporates observation and process errors, and can incorporate arbitrarily sampled data. SPiCT has been developed as a stock assessment model and a MSE tool (Pedersen and Berg, 2017; Mildenberger et al., 2021). This is one of the few MSEs that has a biomass-dynamics models as an operating model. The Data-Limited Methods Toolkit (http://www.datalimitedtoolkit.org) is an open-source software package that allows for data-limited MSEs to identify acceptable HCRs based on user-specified settings of stock type, fishing fleet, management type, and performance metrics. One of most recent data-limited assessment R packages that has been developed is the Stock Synthesis Data-Limited Tool. The Stock Synthesis Data-Limited Tool (SS-DL tool; https://github.com/shcaba/SS-DL-tool) uses Stock Synthesis to implement several common data-limited assessment methods in one modelling framework, which includes length-structured models, age-only models, catch only methods, length and catch models, catch and index models, and fully integrated stock assessments. While the SS-DL tool is primarily a stock assessment model, it can be used as an operating model for the MSE framework.

Future directions

Overall, there is a lack of a proper framework or guidelines for conducting data-limited MSEs, which needs to be further developed. There is a need for guidelines on how to develop data-limited MSEs, especially for specific life-history strategies. These guidelines can be developed in collaboration with other ICES MSE groups, such as WKMSEDEV. Some additional research can also be conducted with the MSE framework. This includes the exploration of the use of the MSE framework to test a suite of data-limited stock assessment methods and indicators. New data-limited reference points and HCRs also could be tested in a MSE framework. As data collection can be sparse and sporadic in data-limited fisheries, the evaluation of the implications of data not being sampled regularly or continuously on stock status should be explored. Lastly, there is a need to develop MSEs that include ecosystem considerations (e.g. regime shifts, climate change), mixed fisheries, multi-species, and/or integrated models.

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6.3 Advice on catch and stock status for ICES' stocks without an index of abundance (Categories 4, 5 and 6)

6.3.1 Summary

Participants: Tanja Miethe, Hector Andrade, Peter Kidd, Simon Fischer, Nicola Walker, Paul Bouch, Patrícia Amorim, Jenni Grossmann, José De Oliveira, Tine Nilsen, Laurie Kell, William Lart, Ella Brock, Anne Cooper, Carl O'Brien, Elena Balestri, Pedro Lino, Joanne Morgan

Rapporteur: Simon Fischer

Over the past years, WKLIFE has worked on revising the methods for ICES categories 2 and 3. However, there has been little change in the methods used for more data-limited categories 4-6 since the original 2012 ICES data-limited method guidance was published (ICES, 2012). Therefore, one of the main priorities for WKLIFE in the future is to look at the methods for categories 4-6.

According to the ICES Stock Information Database (ICES, 2023), there were 272 active ICES stocks in 2022 and the number of stocks per category is illustrated in Figure 6.3.1.1.

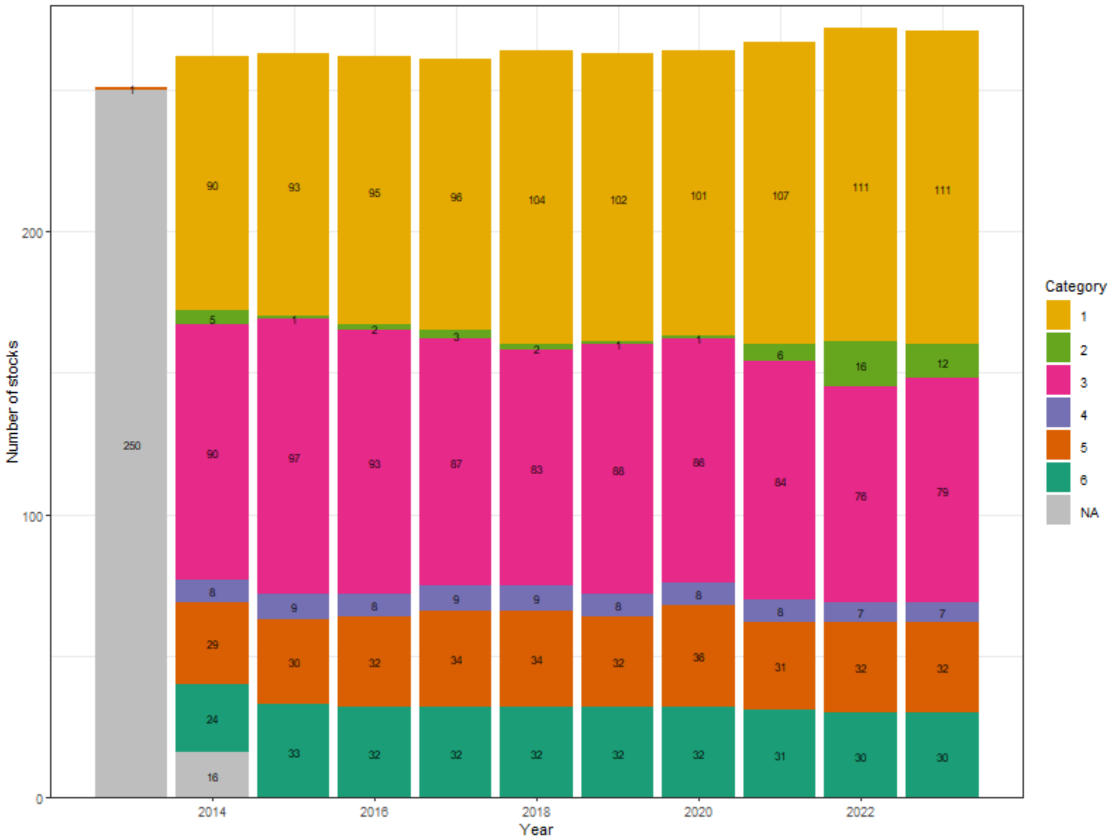

Figure 6.3.1.1. Number of active ICES stocks according by category to the ICES Stock Information Database (ICES, 2023).

ICES does not produce advice for all of these stocks yearly, e.g. because the advice is given for more than one year at a time. In 2022, ICES released advice sheets for 179 stocks (data from https://ices-library.figshare.com/). Of these advice sheets, 99 were in category 1, 11 in category 2, 43 in category 3, 4 in category 4, 14 in category 5, and 8 in category 6.

For the 2022 ICES advice sheets, only one finfish stock (pollack in the Celtic Seas and the English Channel) is in category 4. The remaining category 4 stocks are *Nephrops* functional units with their own approach (borrowing data from other functional units and not using standard ICES data-limited methods). Therefore, there is likely no need for WKLIFE to focus extensively on ICES category 4. The stocks in categories 5 and 6 are more diverse and are largely dominated by elasmobranchs and deep-sea species.

Before any new methods are considered or suggested for categories 4-6, the first step is to review the methods currently being applied by ICES. At the UK's Centre for Environment, Fisheries and Aquaculture Science (Cefas), there is currently work ongoing to review the ICES advice methods for categories 4-6. The first step will be to create an inventory of the stocks in categories 4-6 and their advice methods and then test these in the generic MSE framework developed for the rfb and chr rules (Fischer *et al.*, 2021b, 2021a, 2022a).

So far, ICES category 4-6 approaches only use catch data (tonnage), although additional data might be available (e.g. length distributions or indices). A possible approach could be to consider length data to inform the application of the precautionary buffer or use length data directly to adjust the catch advice.

The principle of risk equivalence in fisheries management (Fischer *et al.*, 2022b) should be considered. In practice, this means that categories 4-6 methods should not allow higher catches and a higher risk of stock depletion than those for categories 1-3. The current ICES methods for categories 4-6 likely do not follow the principles of the precautionary approach because the stock status is not assessed.

The use of pure catch-only methods was mentioned during the WKLIFE XI subgroup discussion, but there was a general consensus that ICES should not pursue such methods. The reason is that there is plenty of evidence from the peer-reviewed literature that these methods do not work well without additional information. However, the principles of catch-only methods combined with data sources (e.g. length data) could be considered.

Another potential approach mentioned was a productivity susceptibility analysis (PSA). Although PSA was suggested in the 2012 ICES guidelines (ICES, 2012) and has been explored in the past (Cotter *et al.*, 2015), this approach has never been implemented and could be revisited, e.g. to decide on precautionary multipliers. Furthermore, instead of purely qualitative PSAs, alternative, more quantitative PSAs (e.g. CSIRO's SAFE or Cefas' SWAF) might be more useful for application in harvest control rules.

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6.4 Considerations of moving away from single-stock single-species methods towards including mixed fisheries, multi-species, ecosystem, or integrated approaches

6.4.1 Summary

There was no dedicated subgroup on this topic at WKLIFE XI but a short discussion was held in plenary and is summarised below.

Rapporteurs: Laurie Kell and Jon Pitchford

Management Strategy Evaluation (MSE) has become a key method for evaluating the ability of alternative management strategies to meet multiple objectives, and for communication between stakeholders and decision makers. For example, in order to move towards an Ecosystem Approach to Fisheries (EAF, Fao, 2003) multiple objectives must be balanced, considering the available knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions. Therefore, the use of MSE is continuing to grow, and although originally a single-species approach is equally relevant to multi-species and ecosystem-based management (Kaplan *et al*., 2021).

A key part of MSE is to define objectives and to evaluate reference points that can ensure they are met despite uncertainty. For example, there are several ways in which ecological reference points can be explicitly considered in MSE, to move towards EAF. How to do this depends on the level of knowledge, data and models available. The options include

1. Using an ecosystem model as an Operating Model,
2. One-way coupling of a single-species Operating Model with a Predator Model, and/or with models of prey dynamics,
3. Within a single-species Operating Model, splitting natural mortality into the background (M1) and predation mortality (M2),
4. Treating predators as a fishing fleet,
5. Using performance metrics based on ecosystem thresholds,
6. Informing control parameters of the Harvest Control Rule, or
7. Adjusting performance metrics related to the ecosystem.

Currently, advice for most ICES Category 1 stocks is based on single-species assessments and MSEs. It is unlikely that tactical ecosystem reference points will be developed, initially, using ecosystem models. Therefore, an alternative is to stress test the ICES PA and MSY advice framework using a single species model, i.e. are ecosystem objectives still achieved under the current advice rules? For example, using option 3) a single-species Operating Model can be used where natural mortality is split into background (M1) and predation (M2) mortalities. Each of these mortalities could be informed by strategic information from a Model of Intermediate Complexity for Ecosystem assessments (MICE, so-called because they are small and fast). The performance of alternative advice rules for performance metrics based on PA, MSY and ecosystem objectives, including community size structure and trophic balance, can then be evaluated. Additional work would then be to move to option 5, and identify the advantages and pitfalls of options 6 and 7. For example, using the work of F_{eco} to scale fishing mortality down when the ecosystem conditions for the stock are poor and up when conditions are good (Bentley, 2022).

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7 Roadmap and ToRs for WKLIFE XII

This Section focuses on future data-limited research, assessment and management advice within ICES; together with ToRs for the next WKLIFE XII meeting.

7.1 Roadmap for data-limited research, assessment and management within ICES for the next 5 years

This section is a draft of the roadmap to map out the work intended by WKLIFE over the coming years. The list is split into several sections, roughly corresponding to the outcomes of the WKLFE XI subgroup discussions. The list will be further refined and tasks prioritised at the next WKLIFE meeting.

7.1.1 General considerations

1. Any new data-limited methods developed by ICES and WKLIFE should follow the principle of risk equivalence and ensure that ICES advisory objectives are met by testing methods with simulations before their application is considered
2. Collaborate with FAO and other RFMOs to create synergies, e.g. on case studies outside the ICES region.
3. Make the broader community more aware of and collaborate on methods and guidelines for data-limited data-preparation and assessment.
4. Make use of best available science to improve the provision of data-limited advice in ICES and review new developments from inside and outside ICES community.
5. Map ICES groups and their interactions with WKLIFE.
6. Aim to explain changes in the advice/method better, particularly if there are large changes in the advice value or method. Improve the communication of advice uncertainty. If considering phasing in advice based on a new method, consider asymmetric caps.
7. Consider revising the ICES stock categories.

7.1.2 Data and data preparation

WKLIFE is mainly a methods working but because the methods rely on data, WKLIFE should have a voice in the provision of data and collaborate with other ICES groups (including WGISDAA, DIG, ICES training group). For the effective working of WKLIFE, the following topics are considered important:

8. Consider the value of information of different data-limited data types (e.g., length-data, biological data for the estimation of life-history parameters) which can help inform recommendations to design additional surveys and sampling.
9. Historical catch data is usually highly uncertain or only reflecting landings, i.e. no information about discard rates. Additional effort should be put into the reconstruction of historical catches and discard rates to allow defining the most probable catch time series and quantify the uncertainty associated with that time series.

10. Effort data can be incorporated into many assessment methods and can provide crucial information for the estimation of fishing mortality rates.
11. Life-history parameters and biological information, such as natural mortality values or stock-recruitment relationship for elasmobranchs are highly uncertain and not studied well enough. Additional surveys or sampling, e.g., tagging studies or surveys focusing on data-limited/sensitive species can help inform length-based indicators and assessment methods as well as the definition of operating models for simulation testing of management procedures.
12. Specific guidelines (e.g. on how the required input data of the recommended empirical harvest control rules and assessment methods should be prepared) could help standardise data preparation and improve data quality (e.g., on length data).
13. Training in data preparation, such as CPUE standardisation and abundance index estimation using spatio-temporal models for species with patchy distributions and zero-inflated data (e.g., elasmobranchs) could help stock assessors with the applications of the updated/developed data preparation guidelines.
14. Explore and develop guidelines on how to derive case specific priors from available (limited) data.
15. Length data for specific life-history types (e.g. elasmobranchs or other slow-growing species) might not be representative of a full stock because of spatially restricted sampling or dome shaped selectivity that catches a restricted window of lengths. Consider approaches for addressing this issue.
16. Consider approaches for combining multiple abundance indices or surveys for use in empirical harvest control rules.

7.1.3 Stocks in ICES stock category 4, 5, 6

17. Review the ICES advice framework for categories 4, 5, and 6.
    a) Summarise the ICES stocks in these categories and their advice methods.
    b) Involve other groups (including stakeholders) and experts or set up initiatives to explore the data currently being used, available data not being used, or data that could be collected to improve method application.
    c) Evaluate the current approaches with respect to risk equivalence and their ability to follow the ICES precautionary approach.
    d) Explore alternative approaches (e.g., length-based methods or catch-only methods supplemented by additional data such as length data).
    e) Explore, test, and tune alternative approaches.
18. Revisit the suitability of PSA (productivity and susceptibility analysis) and PSA-like approaches for use in ICES, including approaches such as CSIRO's SAFE or Cefas' SWAF.
19. Quantify uncertainty of estimates of length-based indicators, e.g., LBIs, by means of bootstrapping and/or Monte Carlo.

7.1.4 Empirical indicators and empirical harvest control rules

20. Explore the suitability of alternative indicators, e.g., spatial indicators to inform on stock abundance and how they could be used in harvest control rules.

21. Explore the suitability of length indicators for specific species or life-history strategies, e.g., mean catch length might be replaced with Lmax5%, and alternative reference point definitions.
22. Consider adapting current indicator-based empirical harvest control rules for specific life-history strategies (e.g., elasmobranchs).
23. Consider how observation and parameter uncertainty could be included into empirical harvest control rules, e.g., uncertainty in the abundance index time series or uncertainty in growth parameter K.
24. Consider using receiver operating characteristics (ROC) curves to select and weight indicators when including them into harvest control rules and MSEs.
25. Explore linking qualitative (stock status) indicators to quantitative harvest control rules.
26. Further exploration and testing of the rb rule.

7.1.5 Length-based methods (indicators & models)

27. Evaluate the implications of continuous sampling vs. snapshot length frequency distributions (length data not representative of a whole year). Develop guidelines and methods that can accommodate or account for snapshot data.
28. Consider the use of length-based models in ICES and how they could be used to provide advice, e.g., in addition to category 2-3 approaches or to inform the advice for category 4-6 stocks.
29. Consider borrowing information for life-history parameters.
30. Better model diagnostics for length-based models, performance testing of length-based models, sensitivity analyses (e.g. regarding life-history parameter input), uncertainty analyses, model validation.
31. Consider quantifying the uncertainty associated with the estimated exploitation (stock) status of length-based models.
32. Develop new length-based assessment models that relax the equilibrium assumption, e.g., implement a length-informed production model.
33. Simulation testing of length-based models, e.g., explore and quantify the lag effect in the length frequency distributions.

7.1.6 Surplus production models

34. The default priors of SPiCT might in some cases not be sufficient or adequate. Specific guidelines on model fitting and validation and priors are required. This includes generic priors reflecting likely doubling times or process noise levels for taxonomic groups as well as guidance on how to derive priors from case-specific data or analyses.
35. Develop SPiCT further by, for example,
    a) Implementing the option for multiple fleets.
    b) Implementing a stage-based version that models the unexploitable stock biomass.
36. Diagnostics, in particular reflecting prediction skill, are essential for model validation. Additional prediction skill metrics, such as ROC (receiver operating characteristic) curves or leave-one-out method, should be included in the diagnostics toolbox of SPiCT.

37. Evaluate the performance of surplus production models under the assumption of strong recruitment pulses or non-stationary processes (e.g. gradual environmental changes and shocks).
38. Evaluate the methods for accepting, rejecting, weighting of individual models in an ensemble, e.g. SPiCT models with different prior assumptions.
39. Develop a data-poor harvest control rule management advice on production models that is not based on reference points, but rather on stabilising the biomass or a biomass level from a reference period.
40. Consider including catch constraints to reduce inter-annual variability.

7.1.7 Data-limited reference points and harvest control rules

41. The current definition of the biomass limit and threshold reference points for production models goes back to a suggestion made in the ICES assessment of the Greenland halibut stock in 2013, where B_{lim} was defined as the biomass where the productivity corresponds to half of B_{MSY} and $MSYB_{trigger}$ was defined around 1.4 times that biomass (0.5 B_{MSY}). This definition is only valid for a symmetrical Schaefer-like production curve and should be revisited. A more general definition of these reference points should be derived by e.g.
    a) Defining the reference points based on the relationship between target and threshold/limit reference points for data-rich stocks,
    b) Defining these reference points as a function of the estimated uncertainty around B_{MSY},
    c) Defining these reference points based on the estimated lowest ever observed biomass,
    d) Accounting for the spawning potential ratio of the stock,
    e) Defining B_{MSY} as the biomass threshold reference point.
42. Productivity of fish stocks is likely not stationary, but changes over time. Assuming constant productivity and/or reference points is likely overestimating sustainable harvest rates assuming that the productivity for many stocks has likely decreased over the last decades due to e.g., environmental changes. Explore dynamic reference points that account for changes in productivity (e.g. the ecosystem-based fishing mortality value F_{ECO} developed during ICES WKIRISH).

7.1.8 Simulation framework / MSE /operating models

43. Develop alternative operating models suitable for data-limited stocks, e.g., production models as operating models (not as a replacement for more complex or age-based operating models, but still better than no MSE).
44. Explore the use of model frameworks such as Stock Synthesis to test a suite of data-limited methods and indicators, e.g. using diagnostic test of prediction residuals, and, thus, calculate the value of information either with generated data or a data-rich case study.
45. Further develop MSE (closed-loop) simulation frameworks for evaluating data-limited harvest control rules, e.g. adapting for specific life-history strategies or developing case studies conditioned on data-rich stocks.

46. Collaborate with other ICES MSE groups, such as WKMSEDEV.
47. Explore options to move away from single-stock single-species models towards including mixed fisheries, multi-species, ecosystem, or integrated models and ecosystem considerations (e.g. climate change).
48. Evaluate the implications of sporadic data (i.e. data not sampled regularly or continuously) on estimated stock status.

7.1.9 Short-lived/fast-growing species

49. Further develop and refine the ICES advice framework for short-lived species. Further develop simulation frameworks for short-lived/fast-growing species to ensure these are appropriate for simulation testing, e.g., by including seasonal time steps in the operating model.
50. Explore alternative harvest control rules such as dynamic harvest rate rules or escapement strategies and aim to find generic parameterisations that could be an alternative to the x over y rules. Evaluate alternative recommendations on harvest control rules best suited for specific short-lived species types (e.g. anchovy-like vs. sardine-like stocks).
51. Further develop and evaluate the impact of time lags between observations, assessment and management cycle on harvest control rules and the impact of lags on indicators.
52. Take into account ecosystem considerations for the management advice of short-lived species, and the definition of appropriate reference points (e.g. considering forage fish).

7.1.10 Long-lived/slow-growing species, elasmobranchs, and sensitive & rare species

53. Improve the provision of advice for slow-growing species so that their specific life-history characteristics are better considered.
54. Consider alternative approaches before running full MSE, e.g., screen indicators with receiver-operating characteristic (ROC) curves to ensure only promising indicators are used.
55. Develop simulations that are more specific to slow-growing species (growth model, natural mortality, recruitment, sex-disaggregated models, etc), either by adapting generic simulations or basing case studies on stocks with more data (e.g., spurdog).
56. Aim to improve the quality of available data (better or more representative data to allow analyses, collaboration with industry, making better use of surveys, identify gaps, citizen science, catch reconstruction), e.g. through collaboration with other ICES data expert groups.
57. Improve spatio-temporal modelling of distribution and estimation of abundance indices considering patchy distribution and ontogenetic migrations as well as zero-inflated data.
58. Improve natural mortality estimates (e.g. through collaboration with other ICES data expert groups), e.g., with mark-recapture studies.
59. Explore the applicability and suitability of alternative harvest control rules, e.g., harvest-rate based rules.
60. Explore more precautionary management measures, e.g., lower fractiles in the probabilistic harvest control rule for highly sensitive species.

7.2 Future ToRs

WKLIFE XI recommends that there be a twelfth meeting of WKLIFE in Lisbon 16th – 20th October 2023 (at the original timing of WKLIFE) whose draft ToRs are proposed in this report for the consideration of ACOM. It is recommended that ToRs be developed in consultation with the ACOM Leadership but as a starting point for discussion should include:

1. Support the rollout of the WKLIFE X category 2 and 3 methods in 2023 and beyond.
    a. Respond to questions from the ICES community.
    b. Conduct additional analyses if required.
    c. Revisit the multiplier of the rb rule (Method 2.1) and consider alternative multipliers for specific life-history groups.
    d. Check if the technical guidelines require updating based on recent developments.
    e. Develop an R tool to facilitate and standardise the application of the rfb/rb/chr rule and link the tool to TAF.
2. WKLIFE XI drafted a 5-year roadmap of work required to improve the provision of ICES data-limited advice. Based on this roadmap, map topics to stocks in ICES categories 2-6, prioritise topics depending on ICES requirements and create a work plan for the next years.
3. Initiate a review of the ICES advice framework for categories 4, 5, and 6.
    a. Summarise the ICES stocks in these categories and their advice methods.
    b. Evaluate the current approaches in these categories with respect to risk equivalence and their ability to follow the ICES precautionary approach.
    c. Start exploring alternative approaches for these stocks.
4. Further explore the use of empirical Indicators
    a. Explore spatial indicators to inform on stock abundance (e.g. bycatch species) to facilitate their use in harvest control rules.
    b. Consider alternative empirical indicators that could be useful as part of harvest control rules.
5. Evaluate and improve the application of and management advice based on surplus production models, such as SPiCT.
    a. Further develop guidelines for model fitting and validation and the use of priors.
    b. Evaluate alternative definitions of biomass limit and threshold reference points for harvest control rules based on surplus production models.
    c. Explore the implications of dynamic reference points.
    d. Evaluate the incorporation of additional information (e.g. length data) into surplus production models.
6. Explore data-limited stock assessments, harvest control rules (e.g. dynamic harvest rate rules), and simulations approaches for specific life-history strategies
    a. Short-lived species, e.g. Celtic Sea sprat.

   b. Elasmobranchs and other slow-growing species (e.g. thornback ray in Iberian waters, application of SPiCT, simulation of empirical harvest control rules).
   c. Other life-history strategies, e.g. *Nephrops*, or crabs.
7. Further explore and develop assessment and advice methods with focus on data- and/or resource-limited fisheries, together with exploring approaches of moving towards an ecosystem perspective, from both within and outside the ICES' community.

8 Recommendations

Recommendation	For follow up by:
It is recommended by WKLIFE XI that there be a twelfth meeting of WKLIFE in Lisbon, Portugal from 2-6 October 2023, whose draft ToRs are proposed in this report for the consideration of ACOM.	ACOM
It is recommended by WKLIFE XI that ICES continues the rollout of the new ICES data-limited methods developed by WKLIFE X for categories 2 and 3 as specified in the *ICES technical guidance for harvest control rules and stock assessments for stocks in categories 2 and 3.*	ACOM
It is recommended that ICES considers the principle of risk equivalence when changing existing or developing new data-limited advice methods so that more data-limited methods do not allow a higher risk tolerance.	ACOM

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Annex 2: Workshop agenda

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16 Jan (Monday)

09:00 – 09:30 Introductions & Meeting ToRs

09:30 – 12:00 Presentations and plenary discussions (ToR 1)

- **Anne Cooper** – Data-limited stocks and management in ICES
- **Simon Fischer** – Updates on empirical harvest control rules – generic method testing, case studies and risk equivalence, R package (ToR 1)

12:00 – 13:00 Lunch break

13:00 – 17:00 Presentations and plenary discussions (ToR 1)

- **Tobias Mildenberger** – Data-limited management advice with SPiCT (ToR 1)
- **Laurie Kell** – Evaluation of the skill of length-based indicators to identify stock status and trends
- **Lisa Chong** – Performance evaluation of data-limited, length-based life history and stock assessment methods
- **Jason Cope** – **Keynote:** Data-limited assessment methods
- **Jason Cope:** Data-limited assessment with Stock Synthesis

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17 Jan (Tuesday)

09:00 – 12:00 Presentations and plenary discussions (ToR 1)

- **Tanja Miethe** – Length-based indicators and reference points
- **Jan Horbowy** – Analysis of Fmsy in light of life-history traits—Effects on its proxies and length-based indicators
- **Anthony Thompson –** FAO deep-sea fisheries project (2022-2027) work with ICES

12:00 – 13:00 Lunch break

13:00 – 17:00 Presentations and plenary discussions (ToR 1 + ToR 2)

- **Andres Uriarte/Alex Kokkalis** – Updates from WKDLSSLS II
- **Casper Berg** – Updates from WKMSYSPiCT I + II
- **Simon Fischer** – Respond to questions from ICES – category 3 empirical control rules (ToR 2)

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18 Jan (Wednesday)

09:00 – 10:00 Presentations and plenary discussions (ToR 2)

- **Tobias Mildenberger** – Respond to questions from ICES – category 2 SPiCT (ToR 2)

10:00 – 12:00 Subgroups theme session 1 (ToR 3)

12:00 – 13:00 Lunch break

13:00 – 14:30 Subgroups theme session 1 (ToR 3)

14:30 – 15:30 Presentations of subgroups and plenary discussions (ToR 3)

- Rapporteurs summarise subgroup work in plenary
- Plenary discussion

15:30 – 17:00 Subgroups theme session 2 (ToR 3)

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19 Jan (Thursday)

09:00 – 10:45 Subgroups theme session 2 (ToR 3)

10:45 – 11:30 Presentations of subgroups and plenary discussions (ToR 3)

- Rapporteurs summarise subgroup work in plenary
- Plenary discussion

11:30 – 12:00 Subgroups theme session 3 (ToR 3)

12:00 – 13:00 Lunch break

13:00 – 15:00 Subgroups theme session 3 (ToR 3)

15:00 – 16:00 Presentation of subgroups and plenary discussions (ToR 3)

- Rapporteurs summarise subgroup work in plenary
- Plenary discussion

16:00 – 17:00 Plenary discussions on ecosystem and multi-species considerations

- **Jon Pitchford** – Pyramids of Life
- Plenary discussion

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20 Jan (Friday)

09:00 – 13:30 Plenary discussions

- Draft roadmap for future of ICES data-limited work
- Adoption of executive summary
- Development of ToRs for WKLIFE XII
- Agree on venue and time of WKLIFE XII

13:30 Official workshop end

14:30 – 17:00 Open plenary session

- Option to present work to the group
