DTU Aqua
National Institute of Aquatic Resources

# Improving the management basis for Danish data-limited fish stocks (ManDaLiS)

By J. Rasmus Nielsen, Tobias K. Mildenberger, Casper W. Berg, Alexandros Kokkalis and Martin W. Pedersen

DTU Aqua Report no. 354-2019

DTU Aqua
National Institute of Aquatic Resources

# Improving the management basis for Danish data-limited fish stocks (ManDaLiS)

J. Rasmus Nielsen, Tobias K. Mildenberger, Casper W. Berg,
Alexandros Kokkalis and Martin W. Pedersen

DTU Aqua Report no. 354-2019

## Colophon


| | |
|---|---|
| Title: | Improving the management basis for Danish data-limited fish stocks (ManDaLiS) |
| Authors: | J. Rasmus Nielsen[1], Tobias K. Mildenberger[1], Casper W. Berg[1], Alexandros Kokkalis[1] and Martin W. Pedersen[2] |
| | [1] National Institute of Aquatic Resources, Technical University of Denmark<br>[2] ENFOR A/S, Lyngsø Allé 3, 2970 Hørsholm, Denmark |
| DTU Aqua report no.: | 354-2019 |
| Year: | The scientific work was completed in November 2019. The report was published in December 2019 |
| Reference: | Nielsen, J.R., Mildenberger, T.K., Berg, C.W., Kokkalis, A. & Pedersen, M.W. (2019) Improving the management basis for Danish data-limited fish stocks (ManDaLiS). DTU Aqua Report no. 354-2019. National Institute of Aquatic Resources, Technical University of Denmark. 35 pp. |
| Cover photo: | Trawl. Photo: Line Reeh |
| Published by: | National Institute of Aquatic Resources, Kemitorvet, 2800 Kgs. Lyngby, Denmark |
| Download: | www.aqua.dtu.dk/publications |
| ISSN: | 1395-8216 |
| ISBN: | 978-87-7481-277-7 |

# Preface

The present report is based on the ManDaLiS project funded with 2,47 million DKK by the European Maritime and Fisheries Fund and the Danish Fisheries Agency.

DTU Aqua, Lyngby Denmark, November 2019

# Contents

# Summary

A substantial proportion of EU's fish stocks lack a quantitative assessment and are therefore regarded as data-limited. The goal of the present project and report, i.e. to provide and improve quantitative assessments of data-limited stocks, is therefore a prerequisite to the implementation of the Common Fisheries Policy (CFP) and to promote sustainable fisheries. Specifically, the project and report addresses Article 2 of the CFP stating that the objective is to achieve exploitation levels that restore and maintain populations above levels which can produce the maximum sustainable yield (MSY). This cannot be achieved without quantitative assessments. Furthermore, as a result of the landing obligation (CFP article 15) data-limited stocks acting as "choke-species" in mixed fisheries have a significant risk of limiting the fishery of high-value stocks. Obtaining quantitative assessments and fleet-specific fishing mortalities as further developed in this project is a necessary step toward mitigating the impact of choke-species and improving management of such fisheries. By improving knowledge about data-limited fish stocks, the project minimises the risk of yield reductions that result from an increased precautionary buffer applied when quantitative stock assessments are lacking. Similarly, the risk of overexploitation is minimised with the aim to prevent a subsequent potential long-term stock rebuilding period with reduction in quotas.

The specific objectives of the project is to develop and implement further newly developed statistical methods by DTU Aqua for assessment and management strategy evaluation of data limited stocks in relation to MSY (Maximum Sustainable Yield) - with focus on broad accessibility and implementation – benefitting Danish, European and global fisheries. Furthermore, the aim is to improve the management basis for 4-6 data limited fish stocks with special importance for Danish fishery and which are managed conservatively because of limited available information. The specific stocks are selected in consultancy with stakeholders. The project has involved close collaboration with and feed-back from stakeholders within fisheries and management to ensure that the stocks selected as case studies are the most relevant to management and the fisheries industry.

The project provides quantitative knowledge and new assessments regarding more than the 4-6 Danish data-limited fish stocks that the project was originally aiming for by project start. This knowledge is not only new, but has also been necessary to enable implementation of sustainable management for the stocks. Furthermore, the project has created the foundation for analytical assessments of these stocks and not least further development of the statistical assessment and forecast models.

The sustainable management of fisheries demands the quantitative assessment of fisheries resources and exploitation patterns. However, underlying ecological and mathematical models are often a simplified representation of natural systems and are particularly challenged if available data is limited in quantity or quality. Therefore, it is important to not only understand underlying model assumptions, but also to quantify and account for associated assessment uncertainty. ManDaLiS has assessed several data-limited stocks with high relevance for the Danish fishery and evaluated existing and developed new data-limited assessment methods and management strategies. The focus has been on length-based assessment methods and biomass dynamic models, which are two important suits of methods for the assessment of data-limited stocks.

The performance comparison of different length-based assessment methods under various recruitment and exploitation scenarios revealed strengths and shortcomings of the various methods and provides important guidance on model selection for stock assessors and managers. A novel approach to length-based stock assessment allows the quantification of assessment uncertainty and adds a new method to the stock assessment toolbox. The modification of the stochastic production model in continuous time (SPiCT) allows modelling time-variant productivity changes or regime shifts by a time-variant parameter for the intrinsic population growth rate. ManDaLiS has improved existing management strategies by incorporating stochastic harvest control rules which allow adjusting management advice (e.g. the total allowable catch (TAC)) as a function of assessment uncertainty. This approach is in line with the precautionary principle and reduces the TAC if the stock status is uncertain. The methodological developments achieved within the scope of ManDaLiS shed light on the trade-offs of different data-limited assessment methods and provide new assessment methods and management strategies. Most importantly, these developments allow the quantification and consideration of assessment uncertainty and thus, contribute to a sustainable management of fisheries.

The landing obligation has drastically increased the importance of data-limited stocks as a result of the "choke-species" phenomenon. The DTU Aqua model used (SPiCT) has been upgraded to an ICES (International Council for Exploration of the Sea) standard assessment model for data poor stocks not least due to input from the current project. Furthermore, the novelty of the model improvements provided by the project has had a high impact to both the current and future advisory and scientific assessment development work within ICES. The case studies and model implementations have very much covered a large number of fish stocks that are important to Danish fishery. As such the models, their improvements and their implementation provide advice directly to and relevant for the Danish fisheries industry and all stakeholders within the fisheries sector. The results and methodological developments of the project are disseminated through four scientific manuscripts, whereof one is published, one accepted, and two are pending submission for publication, and through scientific conference presentations as well as summarised in several ICES working group reports (e.g. ICES WKLIFE VI-VIII, ICES WGNSSK, ICES WGBFAS, ICES WKMSYCat34, ICES WKPROXY, ICES WGECON). Project participants attended these working groups to make specific recommendations regarding future data calls, methodological directions, and assessment, advice and management strategies in general and for several stocks including stocks where a robust assessment cannot be provided.

Furthermore, the implementation of the models have been affiliated further through ManDaLiS contributions to other EU projects covering the EU-Tender DRUMFISH, EU-Tender PROBYFISH, EU Tender EFICA, and EU-H2020-MEESO, and not least conducting a full PhD Study cofinanced between ManDaLiS (2 years) and a DTU Aqua internal PhD project (1 year) with input to stock assessments, methodological reviews and improved assessment methods. As such, the ManDaLiS project has also been further implemented and disseminated through the cooperation in international expert networks working under these international research projects, as well as implementation of the model developments under ManDaLiS in the assessments conducted under those research projects.

There has been conducted three project workshops held in cooperation between the EMFF ManDaLiS and MSPTOOLS projects. One of the workshops was international and was held in association with and just after an International Conference Special Session: IIFET Conference,

Seattle, USA, July 2018, (IIFET 2018 International Institute of Fisheries Economics and Trade, *https://www.xcdsystem.com/iifet/website/)*. This Special Open Session was directly arranged by the ManDaLiS and MSPTOOLS projects with invitation of stakeholders and including stakeholder perspectives. Besides initiative taking, planning, arranging, organizing, coordinating, announcing, leading and carrying through this special session directly under the MSPTOOLS and ManDaLiS Projects the projects produced the session abstract and a full scientific publication reporting of the outcomes of the session (Nielsen *et al*., 2018). In accordance with several of the stakeholder perspectives from the above workshops and the IIFET session future perspectives and needs raised by the stakeholders during the ManDaLiS and MSPTOOLS workshops included suggestions for continuation of the implementation of the data poor stock assessments and model developments on additional candidate stocks with importance for Danish fishery.

# 1. Background and Structure of the Project

A substantial proportion of EU's fish stocks lack a quantitative assessment and are therefore regarded as data-limited. The goal of the present project and report, i.e. to provide and improve quantitative assessments of data-limited stocks, is therefore a prerequisite to the implementation of the Common Fisheries Policy (CFP) and to promote sustainable fisheries. Specifically, the project and report addresses Article 2 of the CFP stating that the objective is to achieve exploitation levels that restore and maintain populations above levels which can produce the maximum sustainable yield (MSY). This cannot be achieved without quantitative assessments. Furthermore, as a result of the landing obligation (CFP article 15) data-limited stocks acting as "choke-species" in mixed fisheries have a significant risk of limiting the fishery of high-value stocks. Obtaining quantitative assessments and fleet-specific fishing mortalities as further developed in this project is a necessary step toward mitigating the impact of choke-species and improving management of such fisheries.

By improving knowledge about data-limited fish stocks, the project minimises the risk of yield reductions that result from an increased precautionary buffer applied when quantitative stock assessments are lacking. Similarly, the risk of overexploitation is minimised with the aim to prevent a subsequent potential long-term stock rebuilding period with reduction in quotas. The project has involved close collaboration with and feed-back from stakeholders within fisheries and management to ensure that the stocks selected as case studies are the most relevant to management and the fisheries industry.

The project provides quantitative knowledge and new assessments regarding more than the 4-6 Danish data-limited fish stocks that the project was originally aiming for by project start. This knowledge is not only new, but has also been necessary to enable implementation of sustainable management for the stocks. Furthermore, the project has created the foundation for analytical assessments of these stocks and not least further development of the statistical assessment and forecast models. The landing obligation has drastically increased the importance of data-limited stocks as a result of the "choke-species" phenomenon. The DTU Aqua model used (SPiCT) has been upgraded to an ICES (International Council for Exploration of the Sea) standard assessment model for data poor stocks not least due to input from the current project. Furthermore, the novelty of the model improvements provided by the project has had a high impact to both the current and future advisory and scientific assessment development work within ICES. The case studies and model implementations have very much covered a large number of fish stocks that are important to Danish fishery. As such the models, their improvements and their implementation provide advice directly to and relevant for the Danish fisheries industry and all stakeholders within the fisheries sector.

The results and methodological developments of the project were disseminated through peer reviewed scientific publications, scientific conference presentations and through ICES working groups (e.g. ICES WKLIFE VI-VIII, ICES WGNSSK, ICES WGBFAS, ICES WKMSYCat34, ICES WKPROXY, ICES WGECON). Project participants attended these working groups to make specific recommendations regarding future data calls, methodological directions, and assessment, advice and management strategies in general and for several stocks including stocks where a robust assessment cannot be provided.

ICES (International Council for Exploration of the Sea) operates with different categories of stocks – determined by the availability and quality of data. ICES (2018) defines the following 6 categories:

> **Category 1** – stocks with quantitative assessments. Includes the stocks with full analytical assessments and forecasts as well as stocks with quantitative assessments based on production models.
> **Category 2** – stocks with analytical assessments and forecasts that are only treated qualitatively. Includes stocks with quantitative assessments and forecasts which for a variety of reasons are considered indicative of trends in fishing mortality, recruitment, and biomass.
> **Category 3** – stocks for which survey-based assessments indicate trends. Includes stocks for which survey or other indices are available that provide reliable indications of trends in stock metrics, such as total mortality, recruitment, and biomass.
> **Category 4** – stocks for which only reliable catch data are available. Includes stocks for which a time-series of catch can be used to approximate MSY.
> **Category 5** – landings only stocks. Includes stocks for which only landings data are available.
> **Category 6** – negligible landings stocks and stocks caught in minor amounts as bycatch. Includes stocks where landings are negligible in comparison to discards and stocks that are primarily caught as bycatch species in other targeted fisheries.

In order to improve assessments, especially of category 3-5 stocks, the specific objectives of the project were the following:

**Specific Objectives**

- Develop and implement further newly developed statistical methods by DTU Aqua for assessment and management strategy evaluation of data limited stocks in relation to MSY (Maximum Sustainable Yield) - with focus on broad accessibility and implementation – benefitting Danish, European and global fisheries.
- Improve the management basis for 4-6 data limited fish stocks with special importance for Danish fishery and which are managed conservatively because of limited available information. The specific stocks are selected in consultancy with stakeholders.

**Structure of the report**

According to this, the present report is structured as follows: First, the report presents the methodological developments and improvement of the data limited stock assessment and forecast models with references to the scientific reports and journal papers produced under the project. This is followed by overviews of the implementation of the model and the project contributions to specific stock assessments and relevant ICES working groups. Finally, the report includes a description of further dissemination of model developments and assessments made through national and international stakeholder workshops and international scientific conference sessions directly arranged and made under the project.

# 2. Results of the project for Data Poor Stock Assessment and Forecast

## 2.1 Model Development and Method Improvement

*By Tobias K. Mildenberger[1], Casper W. Berg[1], Alexandros Kokkalis[1], Martin W. Pedersen[2], and J. Rasmus Nielsen[1] ([1]DTU Aqua), ([2]ENFOR)*

The methodological developments carried out within the scope of ManDaLiS encompass the development and testing of assessment methods and harvest control rules. We focused on length-based assessment methods and biomass dynamic models, which are two important suits of methods for the assessment and management of data-limited stocks. In the following, we describe the different methodological developments with respect to length-based methods, biomass dynamic models, and harvest control rules. The methodological work is summarised in several ICES working group reports and four scientific manuscripts, whereof one is published, one accepted, and two are pending submission for publication (see descriptions and summaries below in Chapter 3, dissemination). The developments of methods and models in ManDaLiS have to high extent been produced and achieved under a PhD project partly financed by and conducted under ManDaLiS (approximately 2 years) and partly financed by DTU Aqua (approximately 1 year). The results and methodological developments achieved under ManDaLiS have been communicated and implemented among other through project participation in ICES working groups (e.g. ICES WKLIFE VI-IX, ICES WGNSSK, ICES WGBFAS, ICES WKMSYCat34, ICES WKPROXY, ICES WGECON) and through the ICES scientific and management advice communities. Furthermore, specific recommendations have been put forward regarding future data calls, methodological directions, and assessment, advice and management strategies in general and for several stocks including stocks where a robust assessment cannot be provided.

### 2.1.1 Length-Based Methods

Length-based methods represent an important class of models for the assessment of data-limited fisheries. Length measurements are relatively easy and cost-effective to collect and can be sufficient to estimate life-history traits of the species and indicate biological reference levels, such as spawning potential ratio (SPR), $F_{MSY}$, or $F_{0.1}$. Length-based methods, such as the length-based spawning potential ratio methods (LBSPR; Hordyk et al. 2014), the s6 model (Kokkalis et al. 2015), the yield-per-recruit model (YPR; Thompson and Bell 1934), are commonly applied to stocks within ICES categories 3 to 5 (e.g., ICES 2018d). We compared the performance and trade-offs of different length-based methods under various scenarios and developed a novel approach which allows to quantify assessment uncertainty.

#### 2.1.1.1 Performance comparison of data-limited length-based assessment methods

With the development of new methods and modification of existing ones, the toolbox of data-limited assessment methods is growing constantly. For managers, it is important to understand the assumptions and trade-offs of the different approaches. Simulation-estimation testing can provide guidance about model applicability and limitations. We compared the performance of four prominent length-based stock assessment methods: the length-based Thompson and Bell yield-per-recruit model (YPR; Thompson and Bell 1934), the length-based spawning potential

ratio method (LBSPR ; Hordyk et al. 2014), the length-based integrated mixed effects model (LIME; Rudd and Thorson 2018), and the length-based risk analysis (LBRA; Ault, Bohnsack, and Meester 1998; Ault et al. 2008; Ault et al. 2019), under varying life histories, exploitation status and recruitment error scenarios. While the performance of these methods has been evaluated before (e.g., Hordyk et al. 2014; Rudd and Thorson 2018), this study uses an individual-based modelling framework to track individuals in populations rather than using an approximation of lengths distributed in a population by age. Thus, this study offers an alternative testing of these length-based approaches, where the assumptions of operating model and assessment model differ substantially. An individual based model was used to simulate population dynamics and generate length structured catch data. The model was parameterised based on three species with different life history traits consisting of a short-lived species (max. age ≈ 4), a medium-lived species (max. age ≈ 18 years), and a long-lived species (max. age ≈ 26). The exploitation pattern consisted of a 10 year period with no fishing (burn-in period) and 25 years of fishing at the target rate leading to a spawning potential ratio (SPR) (≈40%). Recruitment was assumed constant with no variability. All assessment models used one year of length frequency data and unbiased growth parameters and natural mortality rate. Estimated quantities relevant for management, such as $F/F_{MSY}$ and SPR were compared to the true values of the operating model (Fig. 1). The results are based on 300 replicates. Additional scenarios with different exploitation and recruitment patterns were explored and are explained in Chong et al. (2019).

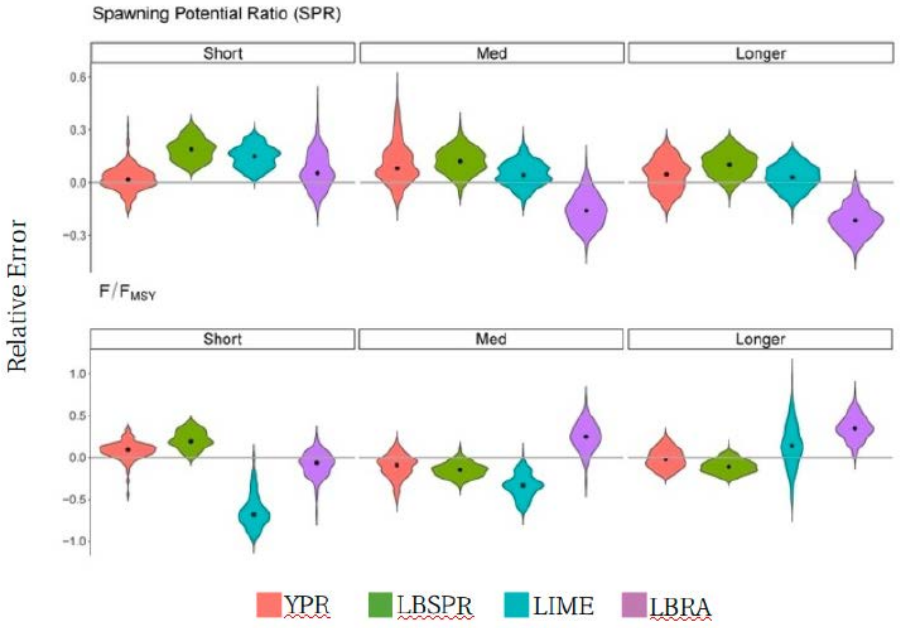


*Figure 1: Redrawn from Chong et al. (2019). Violin plots of relative errors for SPR (first row) and $F/F_{MSY}$ (second row) based on 300 iterations with 200 individuals per month for one year across three life histories. Different colours refer to the different methods (see text). The grey horizontal line is the zero relative error line, and the black dot is the median relative error indicating bias. Each plot has a different y-axis range with a smoother tail.*

Across all scenarios and quantities, YPR and LBSPR were the most consistent and accurate assessment methods with one year of data and asymptotic selectivity (Fig. 1). While LIME shows a good performance for the base scenarios with medium and longer-lived species, the

uncertainty and bias is large in other scenarios. These results indicate that LIME might be more suitable with time-series data and under non-equilibrium conditions confirming the findings of Rudd and Thorson (2018). However, under equilibrium conditions and when only one year of data is available, YPR and LBSPR might be more suitable. Although LBRA showed highly biased and imprecise results, the biases were precautionary (underestimated SPR, overestimated $F/F_{MSY}$). The methods are less accurate in estimating the degree of recruitment over-fishing (SPR; Fig. 1) when the stocks are severely over-exploited and inconsistent in determining growth over-fishing ($F/F_{MSY}$; Fig. 1) when the stocks are under-exploited. In the majority of the scenarios, fishing morality was underestimated, which highlights the challenge of accurately estimating mortality rates. Increased recruitment error reduces precision but can decrease bias in estimations (Fig. 1).

This study highlights the importance of quantifying the accuracy of stock assessment methods and testing methods in different scenarios to determine their strengths and weaknesses, which will provide guidance on which methods to employ given various situations. It provides guidance on model applicability and limitations of four prominent length-based assessment methods and encourages to use a combination of length-based methods for data-limited stock assessments to either compare their performances or define a range of possible stock estimates. More details can be found in Chong et al. (2019).

#### 2.1.1.2 Bootstrapped length-based assessment method

Many length-based assessment methods do not estimate assessment uncertainty when deriving growth and mortality parameters, or biological reference levels. However, the uncertainty can inform management advice and identify shortcomings in data or methods. In this section, we introduce the BOotstrapped Length-based ASsessment method (BOLAS) - a stochastic approach to a traditional length-based stock assessment method. BOLAS allows to estimate life-history parameters, such as asymptotic length or natural mortality rate, and biological reference levels, such as spawning potential ratio (SPR) or $F_{MSY}$, with confidence intervals based on length-frequency distributions (LFDs) of one year.

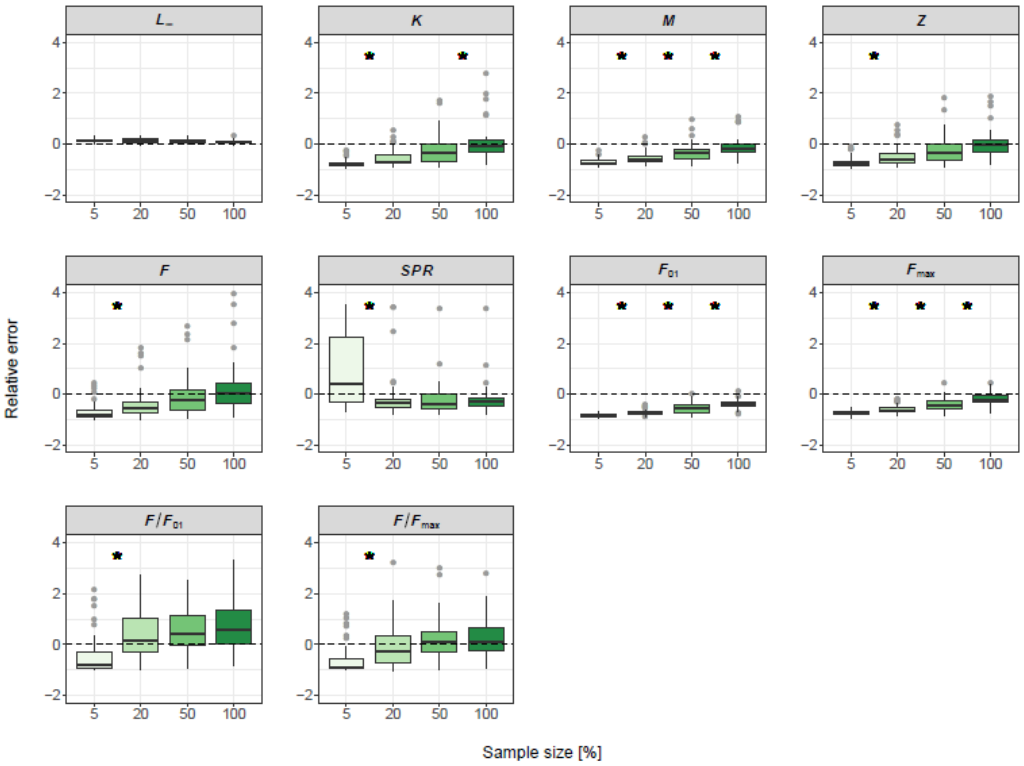


*Figure 2: Relative errors for all parameters and 4 different sample sizes. Results are based on 100 resamples. Stars between the boxplots indicate significant differences between respective scenarios based on the two-sided signed Wilcoxon rank test.*

The method uses a bootstrapping framework that resamples collected LFDs preserving their temporal resolution. For each set of resampled LFDs, growth parameters are estimated by means of a modified version of the Electronical LEngth Frequency Analysis (ELEFAN; Pauly 1982; Mildenberger, Taylor, and Wolff 2017; Taylor and Mildenberger 2017), mortality parameters by Then's empirical formula (Then et al. 2015) and the length-converted catch curve analysis (Pauly 1984), and biological reference levels are estimated by means of the length-based Thompson and Bell model (Thompson and Bell 1934). This results in non-parametric distributions for all parameters, which can be used for deriving 95% confidence intervals based on (multivariate) kernel density estimation. We use simulation testing with an individual-based operating model to demonstrate the performance of the method in comparison to the traditional approach. Seven different scenarios and 50 different stocks allow to quantify the effect of different sample sizes and fishing intensities on the performance of the two methods.

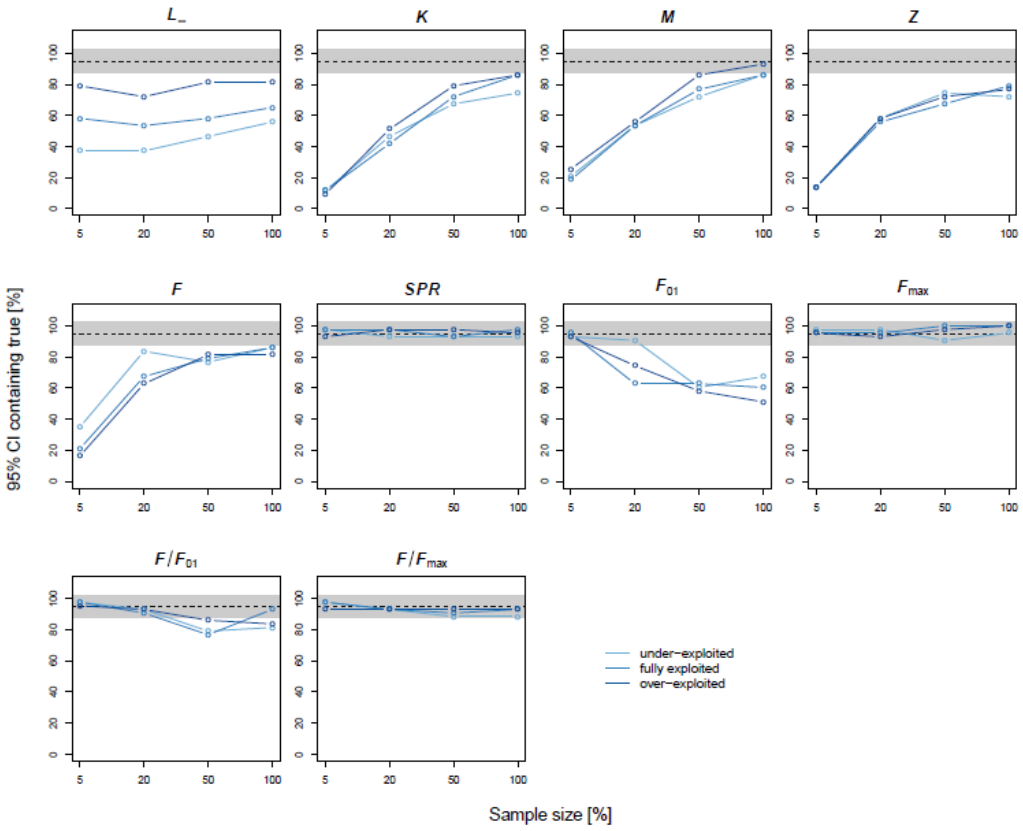


*Figure 3: Proportion of stocks where 95% confidence intervals contain the target value. Different lines represent the different exploitation scenarios.*

BOLAS shows consistent results across the scenarios and an overall high precision. Results show that the sample size has a high impact on the model performance (Fig 2). A lower number of monthly length measurements hinders tracking of cohorts in the LFDs, which compromises the estimation of growth parameters and thus all subsequent assessment steps. However, with sufficient data, BOLAS estimates all parameters without bias and its performance does not depend on the life history traits. Higher fishing mortality increases the accuracy and precision of estimated parameters. The results indicate the importance of the minimum length in the catches (influenced by the selectivity parameter $L_{50}$). Estimated 95% confidence intervals are within expected range (Fig. 3).

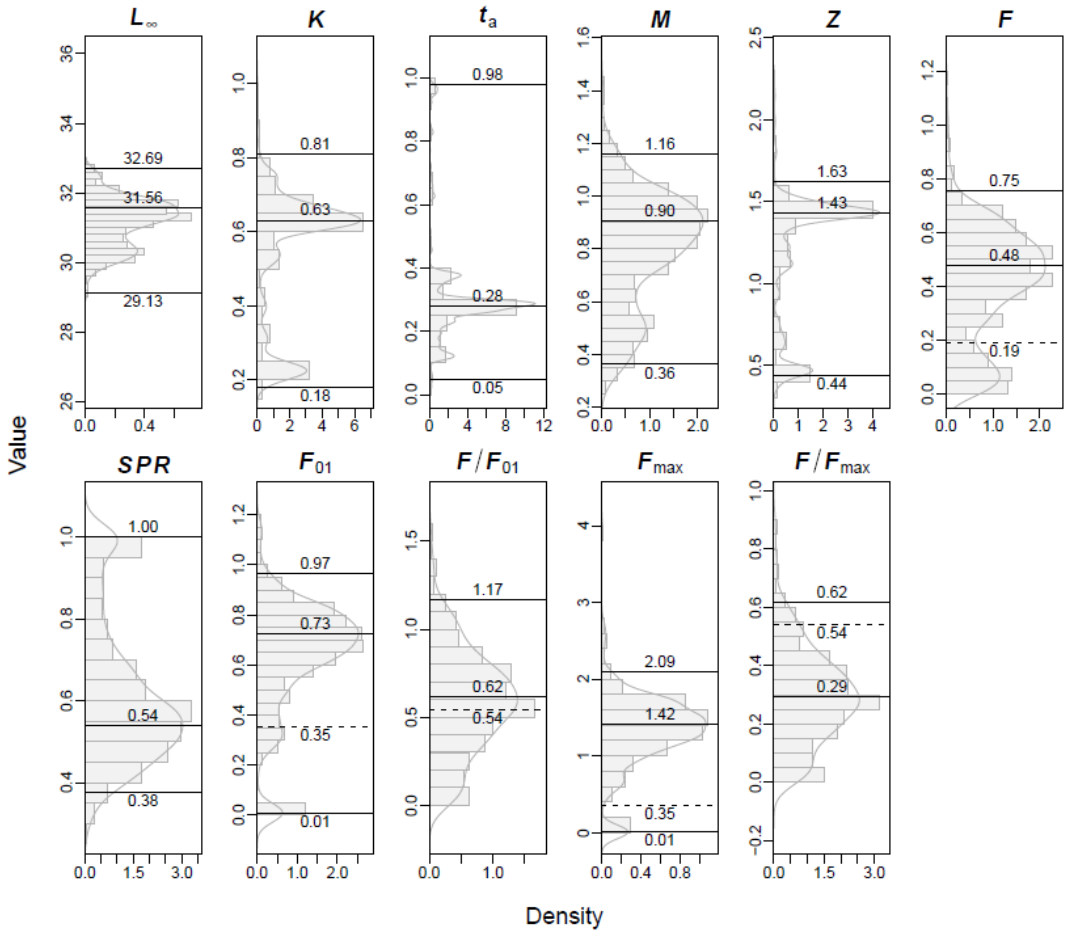


*Figure 4: Univariate density of instantaneous mortality rates (natural mortality M, total mortality Z, fishing mortality F) and absolute and relative reference levels $F_{0.1}$ and $F/F_{0.1}$, respectively. Lines and values represent 95% confidence intervals and maximum density estimates, dashed line represent literature reference level.*

The application of BOLAS to real data of the North Sea dab demonstrates that this method does not require any input parameters or prior knowledge about parameter ranges to estimate stock status in terms of biomass (or spawning potential ratio) and fishing mortality. Estimated von Bertalanffy growth parameters for the North Sea dab stock as well as corresponding growth performance index fall within the range of literature values and estimated stock status is qualitatively in line with the official stock assessment based on the Stochastic Production model in Continuous Time (SPiCT; Pedersen and Berg 2017, ICES 2018a), even though absolute values vary between the two assessments (Fig. 4). All SPiCT estimates are within the 95% CIs of the BOLAS assessment. However, some parameters show bi-modal sampling distribution and have wide confidence intervals (e.g. growth coefficient K), indicating that the information content of the LFDs is limited and estimates should be interpreted with caution.

The method makes an important contribution to the available data-limited stock assessment methods by allowing for quantification of assessment uncertainty.

### 2.1.2 Biomass Dynamic Models

Biomass dynamic models such as SPiCT comprise another valuable class of methods for the assessment of data-limited fisheries. These models only require a time series of the commercial catches and of a stock size indicator. This is usually a survey biomass index (e.g. calculated using international bottom trawl surveys like IBTS or BITS in the Northeast Atlantic). Alternatively, a catch per unit effort from the commercial fleet could be used as an index . SPiCT is a prominent biomass dynamic model which has been applied to various data-limited stocks (ICES category 3 and 4; e.g., ICES 2018d). Biomass dynamic models have been challenged for their assumption of constant carrying capacity and productivity over the whole period of available time series, while empirical evidence and simulations point at the importance of time-variant parameters (Vert-pre et al. 2013; Britten et al. 2017). Furthermore, these models oversimplify population dynamics by regarding the population as an unstructured biomass pool. We advanced SPiCT to allow the estimation of time-variant productivity and developed a stage-based implementation of SPiCT, which allows to model the dynamics of the juveniles and adults separately, thus reflecting the population structure more realistically.

#### 2.1.2.1 Time-Variant Productivity in Biomass Dynamic Models

The productivity of fish populations varies naturally over time, dependent on integrated effects of abundance, ecological factors, and environmental conditions. These changes can be expressed as gradual or abrupt shifts in productivity as well as fluctuations on any time scale from seasonal oscillations to long-term changes (Vert-pre et al. 2013; Britten et al. 2017). We developed three extensions to the biomass dynamic model SPiCT that accommodate time-variant productivity in fish populations as long-term step-wise shifts between productivity regimes, long-term gradual changes, or seasonal oscillating productivity. This is achieved by modelling the productivity (parameter *m* in the biomass process (Eq. 2 in Pedersen and Berg 2017)) as the combination of a mean productivity parameter, a seasonal component, and an additional component determining the long-term changes in productivity.

Simulation testing revealed that estimated reference levels and stock status is biased when seasonal productivity is not accounted for and that the relative biases and uncertainties depend on the characteristics of the seasonal patterns (fishing mortality and productivity), such as the relative amplitudes and positioning of the peaks, as well as the number of survey indices per year (Fig. 5). Furthermore, the results highlight the importance of biannual biomass indices and their timing relative to the peaks of the seasonal biological processes (i.e. recruitment, growth, mortality) for the estimation of seasonally time-variant productivity. The application of the model extensions to real-world data of the Eastern Baltic cod (*Gadus morhua*) stock confirms the results of the simulation study and shows that the model is able to disentangle differences in seasonal fishing mortality as well as seasonal and long-term changes in productivity. The combined model with long-term and seasonally varying productivity performs significantly better than models that assume constant productivity. Estimated variability in the productivity correlates well with environmental conditions and ecological processes.

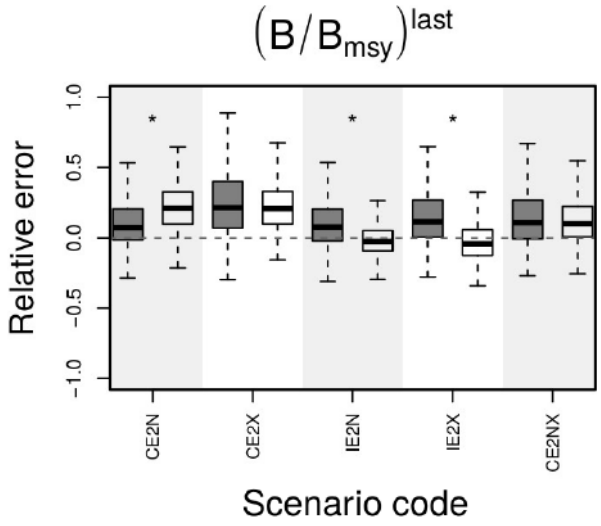


*Figure 5: Redrawn from (Mildenberger et al. 2019). Results of the simulation study for the quantities* $(B/B_{MSY})^{last}$ *for all scenarios. Dark filled bars and circles represent seasonal model (S-C), while white bars and circles represent the non-seasonal model (C-C). The boxplots do not include outliers. The stars above the boxplots in the first row indicates for which scenario the differences between the two models (C-C and S-C) are significant based on the Signed-Rank Wilcoxon test.*

This novel approach allows to incorporate environmental change into stock assessments without the need of complex and data-demanding (ecosystem) models and defines time-variant reference levels for fisheries management and advice. Although the extensions of biomass dynamic models increase requirements for data quality and quantity (seasonal catches and biannual survey indices required), accounting for time-variant productivity is important as stocks in low-productivity regimes cannot support the same yield as stocks in high-production regimes and neglecting seasonality might severely bias estimated reference levels and relative states and, therefore, management advice. More details can be found in Mildenberger et al. (2019).

#### 2.1.2.2 Stochastic Stage-Based Biomass Dynamic Model

One of the main assumptions of SPiCT is that the biomass corresponds to the total exploitable stock biomass (Pedersen and Berg 2017). However, the selectivity of scientific surveys and commercial fisheries differs for most stocks, with commercial fleets being usually more selective towards larger individuals. Thus, the biomass indices of the survey have to be corrected to include only the part of the stock which is vulnerable to the commercial fleet (Pedersen and Berg 2017). In practice, that means that information about smaller (younger, potentially juvenile) part of the population is excluded, which does not follow the guidelines of CFP to use all available data to the best capabilities in a data-limited context (CFP 2013). A stage-based version of SPiCT would potentially be able to utilise this information (Ibaibarriaga et al. 2008; De Roos et al. 2008; Soudijn and Roos 2017).

We developed a stage-based simulation model based on physiological theory of De Roos et al. (2008) (Fig. 6). The stage-based compliment to the SPiCT estimation model based on Soudijn

and Roos (2017) was over-parameterised. Therefore, we added constraints between model parameters and re-defined population stages, which improved the model convergence ratio. However, there are still unresolved issues with this method. Future work will focus on a re-parametrisation of the estimation model to allow parameter estimation as well as considering different definitions of the stages.

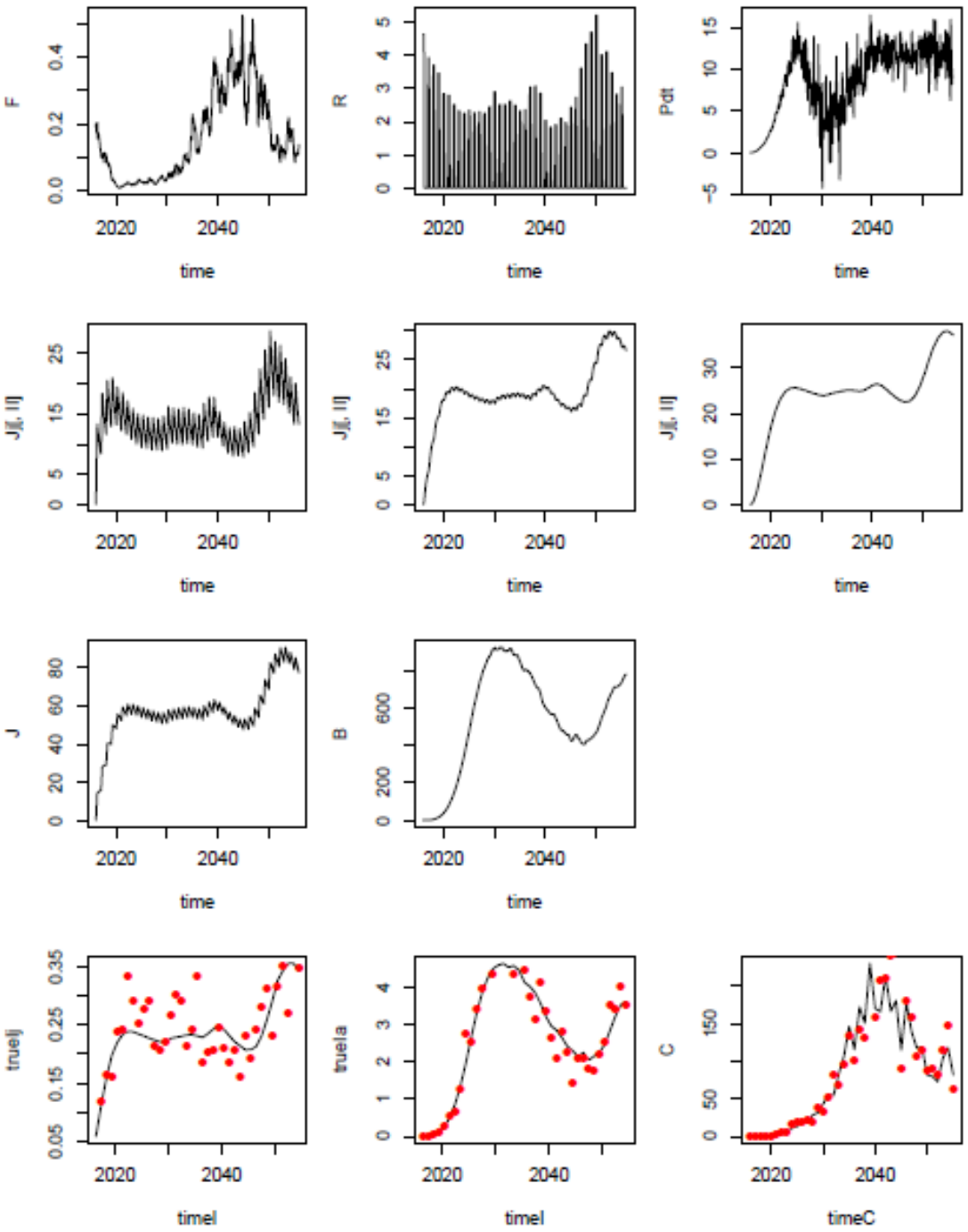


*Figure 6: Stock dynamics of the stage-based implementation of SPiCT.*

### 2.1.3 Harvest Control Rules

Harvest control rules define a set of management measures based on which the input or output of the fisheries is controlled with. HCRs allow translating the results of the stock assessments into quantities useful for fisheries management, such as the Total Allowable Catch (TAC). While the recommended harvest control rule for accepted SPiCT assessments considers the stock status in terms of fishing mortality and biomass reference levels, it does not account for the uncertainty in those levels or the predicted catch. We developed two MSY-based HCRs that take assessment uncertainty into account.

The Workshop on the Development of the ICES approach to providing MSY advice for category 3 and 4 stocks (WKMSYCat34; ICES 2017) suggested management procedure to provide advice based directly on SPiCT assessments, illustrated in the following equations about the total allowable catch and a short term forecast of the catch

$$TAC_{y+1} = \text{median}(C_{y+1}) \quad \text{(Eq. 1)}$$

$$C_{y+1} = F_y \frac{\min(1, \text{median}(\frac{B_{y+1}}{MSYB_{\text{Trigger}}}))}{\text{median}(\frac{F_y}{F_{MSY}})}, \quad \text{(Eq. 2)}$$

where $MSYB_{Trigger}$ is defined as $0.5B_{MSY}$. However, it was pointed out by ICES WKLIFE VII (ICES 2018b) that this advice rule does not consider assessment uncertainty, which can be substantial depending on the quantity and quality of available data. WKLIFE VII and WKLIFE VIII concluded that the assessment uncertainty has to be accounted for and proposed two modifications (Eqs. 3 and 5).

$$TAC_{y+1} = \Phi^{-1}{}_{(C_{pred \mid F = F_y \ldots F_{y+1}})}(f) \quad \text{(Eq. 3)}$$

where

$$F_{y+1} = F_y \frac{\min(1, \Phi^{-1}{}_{(\frac{B_{y+1}}{MSYB_{\text{Trigger}}})}(f))}{\Phi^{-1}{}_{(\frac{F_y}{F_{MSY}})}(1-f)}. \quad \text{(Eq. 4)}$$

where $MSY\ B_{Trigger}$ is defined as 0.5 $B_{MSY}$ (ICES, 2018a), $\Phi^{-1}$ is the inverse distribution function, e.g. $\Phi^{-1}{}_{(C_{pred})}(f)$ means the $f$-th fractile of the $C_{pred}$ distribution, and $f$ is a chosen fractile less than or equal to 0.5. By considering any fractile of the distributions $\frac{B}{MSY\ B_{Trigger}}$ and $C_{pred}$ smaller than the median (i.e. 0.5-th fractile) and any fractile larger than the median for $\frac{F}{F_{MSY}}$, the uncertainty of the estimated stock status in terms of relative fishing mortality and biomass is accounted for and thus leads to more conservative advice than the median advice rule (ICES 2018c). Additionally, WKLIFE VII and WKLIFE VIII introduced another modification of the equation 4, which adjusts the TAC dependent on predicted biomass distribution relative to reference levels (Eq. 5).

Equation 4

$$TAC_{y+1} = \begin{cases} \Phi^{-1}{}_{(C_{pred \mid F = F_{MSY}})}(f) & if\ P(B_{pred} \mid F = F_{MSY} < B_{lim}) \leq 0.05 \\ \Phi^{-1}{}_{(C_{pred \mid F = F_{opt}})}(f) & if\ P(B_{pred} \mid F = F_{MSY} < B_{lim}) \leq 0.05 \end{cases} \quad \text{(Eq. 5)}$$

where $F_{y+1}$ is estimated with the MSY rule (Eq. 4), $B_{lim}$ is defined as $0.3B_{MSY}$, and $F_{opt}$ is the maximum fishing mortality fulfilling $P(B_{pred} | F = F_{opt} < B_{lim}) <= P_{PA}$, with $P_{PA}$ representing the accepted risk level (probability of the predicted biomass being below $B_{lim}$). This harvest control rule is comparable with the MSY rule with corresponding fractiles, but allows in addition to control the accepted risk of the biomass falling below the limit reference point $B_{lim}$ taking the assessment uncertainty into account.

The results indicate that absolute levels of risk and yield vary for different life history traits, scenarios (data quality and quantity as well as process noise) and depend on the specific fractile and/or probability for risk aversion ($P_{PA}$; Fig. 7). A higher risk aversion is accompanied by lower potential yields. Nevertheless, the modified harvest control rules all outperform the currently in place 2/3 rules by producing much higher yields with similar or even lower risk levels.

More details to the harvest control rules and their testing can be found in the reports of the ICES workshop for data-limited assessment methods in 2017 and 2018 (WKLIFE VII & VIII). Future work will test the rules under additional scenarios and with alternative operating models.

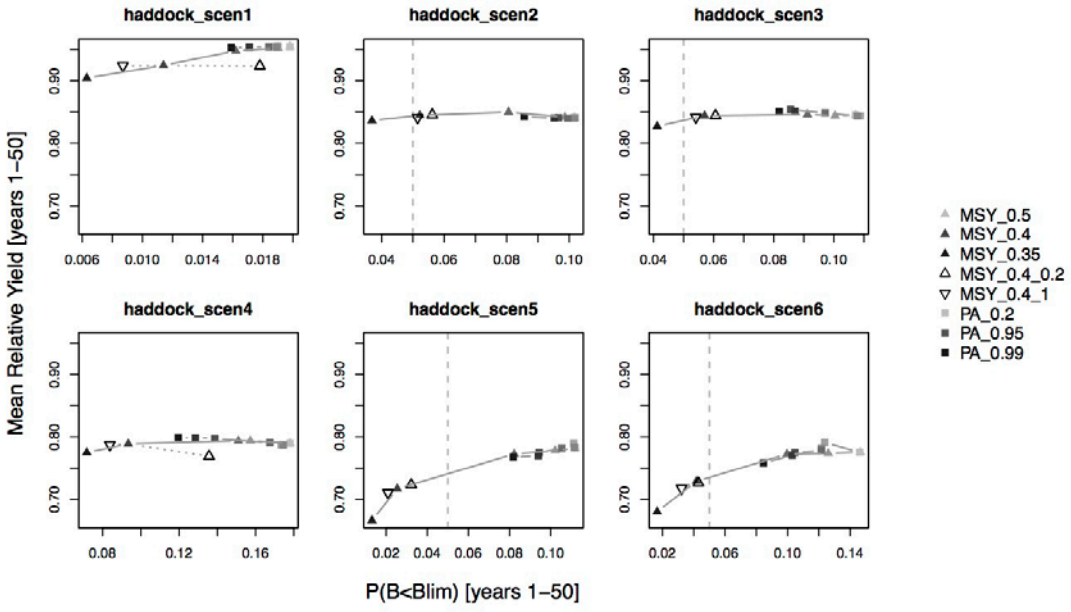


*Figure 7: Trade-off graph of mean relative yield and risk 1 for the haddock stock over all projection years (1–50) and all scenarios. Vertical dashed line represents the reference risk level of 5%. Solid lines between advice rules display the connection of common advice rules which only differ in the fractile or probability level.*

## 2.2 Implementing Quantitative Stock Assessments and Short Term Projections into Management Advice

*By J. Rasmus Nielsen[1], Tobias K. Mildenberger[1], Casper W. Berg[1], Alexandros Kokkalis[1], Martin W. Pedersen[2], Morten Vinther[1], Lars O. Mortensen[1], Clara Ulrich[1], Kirsten B. Haakonsson[1], and Josefine Egekvist[1] ([1]DTU Aqua), ([2]ENFOR)*

### 2.2.1 Implementation of Models into the ICES Advice and Scientific Network

The ManDaLiS work has very much focused on model implementation with focus on the SPiCT model and implementation of the methodological developments under the project through the ICES management advisory system and community, as well as the ICES scientific community and network. The project has as such contributed significantly to a row of ICES methodological development working groups such ICES WKLIFE V-IX, ICES WKMSYCat34 ICES WKPROXY, and ICES WGECON as well as direct contributions with new fish stock assessments in major ICES assessment and benchmark assessment working groups such ICES WGNSSK, ICES WKNSEA, ICES WGBFAS, and ICES WKBALTCod. Here, there have practised extensive implementation of the SPiCT model and the method development under the ManDaLiS project through direct project (financed) participation in those working groups. This has also included specific recommendations regarding future data calls, methodological directions, assessment and advice, as well as management strategies in general under ICES for several stocks including stocks where a robust assessment cannot be provided.

The contributions with implementation of the SPiCT (and s6) models and the model developments for SPiCT for specific stock assessments and ICES working groups are summarised in the overview tables below (Table 1 & 2). These tables present the working group, the years of the contributions to respective working groups and working group reports associated hereto, the type of working group, and the type of the ManDaLis contribution, as well as the role and level of the ManDaLiS contribution hereto including ManDaLiS participants involved in the work and responsible assessors. Furthermore, in Table 2 the performance of the assessment model for the individual stocks are given including model convergence, robustness, acceptance or reasons for non-acceptance as well as the level of implementation of the assessment into management advice. Besides of the overview of the contributions provided in those tables, the details of the input, assessments, and MSE/HCR evaluations conducted in relation to the ManDaLiS project are reported in the respective ICES working group reports for each working group and year. Here the ManDaLis and SPiCT assessment contributions as well as the participation of the ManDaLiS project scientists appear in general in accordance with the overview tables, and all those working group reports and assessments included herein for the specific working groups and years are available from the ICES web site and home page: *http://www.ices.dk/community/groups/Pages/default.aspx.* The reports are available from this web site link for each of the respective working groups, years and stocks listed in the Tables 1 and 2.

*Table 1: Overview of the ManDaLiS implementation of models and model developments in ICES working groups and the ICES management advisory framework.*

| ICES Working Group | Years | Type of working group | Type of work (and stocks if relevant) | ManDaLis Role; Participants |
|---|---|---|---|---|
| ICES WKLIFE (V-IX) | 2015, 2016, 2017, 2018, (input to 2019) | Methodological Development & Test Applications | Model development, evaluation, and application of the SPiCT & S6 models; Management Strategy Evaluation (MSE) and evaluation of Harvest Control Rules (HCR) with the models; Development of methods for MSE & Advisory Rules; | Major, essential; T. Mildenberger, C. Berg, A. Kokkalis, M.W. Pedersen, J.R. Nielsen (DTU Aqua) |
| ICES WKPROXY | 2015 | Test Applications | Model evaluation and application of SPiCT & S6 models; Management Strategy Evaluation (MSE) with the models; | Major, essential; A. Kokkalis, M.W. Pedersen, C. Berg (DTU Aqua) |
| ICES WKMSYCAT34 | 2017 | Test Applications; Assessments | Model evaluation of SPiCT; Application and Implementation of SPiCT Assessments and evaluation of harvest control rules; | Major, essential; J.R. Nielsen, C. Berg, A. Kokkalis, M. Vinther (DTU Aqua) |
| ICES WGNSSK | 2016, 2017, 2018 | Applications; Assessments | Application and Implementation of SPiCT Assessments for important North Sea and Skagerrak data limited stocks (with high importance for Danish fishery); | Major, essential; J.R. Nielsen, C. Berg, A. Kokkalis, C. Ulrich, L.O. Mortensen, K.B. Haakonsson, J. Egekvist (DTU Aqua) |
| ICES WKNSEA | 2017; 2018 | Benchmark assessments | Benchmarking stocks with SPiCT for important North Sea and Skagerrak data limited stocks (with high importance for Danish fishery); | Major, essential; C. Berg, J.R. Nielsen, A. Nielsen, A. Kokkalis (DTU Aqua) |
| ICES WGBFAS | 2016, 2017, 2018 | Applications; Assessments | Application and Implementation of SPiCT Assessments for important Baltic Sea and Kattegat data limited stocks (with high importance for Danish fishery); | Major, essential; T. Mildenberger, C. Berg, K.B. Haakonsson, J. Egekvist (DTU Aqua) |
| ICES WKBALTCod | 2017, 2018 | Benchmark assessment | Benchmarking Baltic sea cod stocks with the SPiCT assessment model; | Major, essential; C. Berg, A. Nielsen (DTU Aqua) |
| ICES WKSprat | 2018 | Benchmark assessment initial input | Benchmarking sprat in IIIa with the SPiCT assessment model to contribute with information relevant in advance of the working group on decisions on stock assessment boundaries; | Medium, important; T. Mildenberger (DTU Aqua) |
| ICES WGECON | 2018, 2019 | Further perspectives in development and implementation of models | Presentation and evaluation of progress with model development, implementation and application among other associated to ICES WKTRADE2 and ICES WGFBIT. | Medium, important; J.R. Nielsen (DTU Aqua) |

*Table 2: Overview of the implementation of the SPiCT model and model developments for different ICES stocks under the ICES working groups.*

| Stocks with SPiCT Applied: Stock ID | Converged and Robust SPiCT | Accepted / Implemented SPiCT | Main reason for potential non-acceptance | Working Group | Responsible Assessor and DTU Aqua input | ManDaLis Role (major, medium, minor) |
|---|---|---|---|---|---|---|
| Cod ICES SD25-32 | Yes, seasonal SPiCT used | Yes, Benchmarked | Seasonal SPiCT accepted and implemented 2018 | ICES WGBFAS; ICES WKBaltCod; | C. Berg, T. Mildenberger & M. Eero, DTU Aqua | Major, essential |
| Lemon sole ICES IV, IIIa, VIId | Yes, if long survey time series are used | No, Benchmarked; | No robust assessment with short survey time series | ICES WGNSSK; ICES WKNSEA; | J.R. Nielsen & C. Berg, DTU Aqua | Major, essential |
| Witch flounder ICES IV, IIIa, VIId | Yes | Yes, partly. Benchmarked; | Accepted, but taken over by robust SAM assessment; | ICES WGNSSK; ICES WKNSEA; | A. Kokkalis & J.R. Nielsen, DTU Aqua; F. Vitale, SLU (S). | Major, essential |
| Sprat ICES IIIa | Yes, partly robust | No | Will be taken to benchmark w. contributions to this; | ICES HAWG; ICES WKSprat; | T. Mildenberger, DTU Aqua | Major, essential (ongoing work) |
| Brill ICES SD22-32 | Converged, uncertain, not robust | No | No robust assessment | ICES WGBFAS | T. Mildenberger, DTU Aqua | Major, essential |
| Whiting ICES IIIa | No (not converged), Initial exploratory | No | No robust assessment Will be taken to benchmark | ICES WGNSSK | M.W. Pedersen & A. Kokkalis & J.R. Nielsen, DTU Aqua; SLU; | Major, essential (ongoing work) |
| Turbot ICES IIIa / SD21-23 | Yes | No, Benchmarked; | Robust assessment; partly accepted | ICES WGNSSK | C. Ulrich, DTU Aqua | Major, essential (ongoing work) |
| Flounder ICES IV, IIIa | Yes | Yes, Benchmarked | Robust assessment | ICES WGNSSK; ICES Benchm; | H. Haslop, Vti (D) & C. Berg, DTU Aqua | Major, essential |
| Dab ICES IV, IIIa | Yes | Yes, Benchmarked | Robust assessment | ICES WGNSSK; ICES Benchm.; | H. Haslop, Vti (D) & C. Berg, DTU Aqua | Major, essential |
| Plaice ICES SD24-32 | Yes, uncertain, exploratory | No, Benchmarked | No robust assessment | ICES WGBFAS; ICES Benchm.; | vTI (D) with support from DTU Aqua scientists | Medium / Minor |
| Turbot SD22-32 | No (not converged), exploratory | No | No robust assessment | ICES WGBFAS; | vTI (D) with support from DTU Aqua scientists | Medium / Minor |
| Flounder ICES SD22-23 | Yes, uncertain, exploratory | No | No robust assessment | ICES WGBFAS | vTI (D) with support from DTU Aqua scientists | Medium / Minor |
| Dab ICES SD22-32 | Yes, uncertain | No | No robust assessment | ICES WGBFAS | vTI (D) with support from DTU Aqua scientists | Minor |

### 2.2.2 Implementation of Models in Cooperation with Sister Research Projects

Furthermore, the implementation of the models have been affiliated further through ManDaLiS contributions to other EU projects covering the EU-Tender DRUMFISH, EU-Tender PROBY-FISH, EU Tender EFICA, and EU-H2020-MEESO. These contributions are described in the dissemination overview Table 3 below under the Dissemination chapter. This has involved direct cooperation between those projects and several contributions from the ManDaLiS project to those projects with input to stock assessments, methodological reviews and improved assessment methods. As such, the ManDaLiS project has also been further implemented and disseminated through the international expert networks working under these international research projects, as well as implementation of the model developments under ManDaLiS in the assessments conducted under those research projects.

# 3. Dissemination of Results and Future Perspectives

*By J. Rasmus Nielsen[1], Tobias K. Mildenberger[1], Hanne M. Jacobsen[1], Casper W. Berg[1], Alexandros Kokkalis[1], Jørgen Dalskov[1], Anna Rindorf[1] and Karin Stubgaard[1] ([1]DTU Aqua)*

The ManDaLiS dissemination has very importantly included the above implementation of the assessment models, the model developments, and the actual assessments conducted with the models and improved methods under the ICES working groups and the ICES management advisory framework as described under chapter 2. The project dissemination through other research projects is also described under chapter 2 above as well as in the dissemination overview table given below (Table 3). This table lists the major dissemination activities conducted under the ManDaLiS project summarising the type of activity, work and contribution as well as the role and level of the ManDaLiS contribution.

Very specific and significant dissemination on methodological improvements and developments includes the production of the following four scientific manuscripts targeted at high ranking international scientific peer reviewed journals directly produced under ManDaLiS:

- Mildenberger, Tobias K, Casper W Berg, Martin W Pedersen, Alexandros Kokkalis, and J Rasmus Nielsen. 2019. Time-variant productivity in biomass dynamic models on seasonal and long-term scales. ICES Journal of Marine Science, September 2019. *http://doi.org/10.1093/icesjms/fsz154.*
- Chong, Lisa, Tobias K. Mildenberger, Merrill B. Rudd, Marc H. Taylor, Jason M. Cope, Trevor A. Branch, Matthias Wolff, and Moritz Stäbler. (In Press). Performance evaluation of data-limited length-based stock assessment methods. *In Press*, ICES Journal of Marine Science.
- Mildenberger, Tobias K., Ralf Schwamborn, Alexandros Kokkalis, J. Rasmus Nielsen, Marc H. Taylor. (In Prep). Quantification of uncertainty in length-frequency analysis: A novel approach to length-based stock assessments. (*In Advanced Prep / In Submission*).
- Mildenberger, Tobias K., Casper W. Berg, Alexandros Kokkalis, J. Rasmus Nielsen, Andre Punt. (In Prep). Simulating the ICES process for data-limited fisheries management. (In Advanced Prep).

Of those, the second manuscript has been selected as an Editor's Choice article within the ICES Journal of Marine Science, which includes the publication of the manuscript as open-access and a news article release. The published manuscripts are publicly available and the draft manuscripts are summarised under section 2.1, and can be provided by contact to the authors.

Furthermore, methodological results produced under ManDaLiS were also disseminated in form of a poster and an oral presentation with an extended abstract presented to the international scientific community at the ICES Annual Science Conference (ASC) 2019 in Gothenburg, Sweden:

- Mildenberger, Tobias K., Marc H. Taylor, Alexandros Kokkalis, Daniel Pauly. TropFishR: An R package for data-poor fisheries analysis. Poster at the ICES ASC 2019.

ICES ASC CM 2019/N:445a (Theme Session N: Advances in data-limited assessment methodologies for marine and diadromous stocks).

- Mildenberger, Tobias K., Ralf Schwammborn, Alexandros Kokkalis, J. Rasmus Nielsen, Marc H. Taylor. “BOLAS - A bootstrap approach to length-based stock assessment”. Oral presentation at the ICES ASC CM 2019/N:445b (Theme Session N: Advances in data-limited assessment methodologies for marine and diadromous stocks).

Concerning additional project contributions to the methodological developments, special emphasis should be put on the contributions to the ICES workshops WKLIFE VII-IX and to the WKDLSSLS workshop, where specifically the following chapters were produced under ManDaLiS:

- Chapter 3 titled “Simulation testing of advice rules based on SPiCT assessments, ToR a), and considerations on ToR d)” and Chapter 7 titled “SPiCT assessments with seasonal catches” in the report: ICES WKLIFE. 2017. Report from the Seventh Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3-6, 2-6 October 2017, Lisbon, Portugal. ICES CM 2017/ACOM:43. 221 pp.
- Chapter 2 titled “MSE testing of advice rules based on surplus production models” in the technical report: ICES WKLIFE. 2018. Report of the Eighth Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE VIII), 8-12 October 2018, Lisbon, Portugal. ICES CM 2018/ACOM:40. 172 pp.
- Chapter 5 titled “Stochastic surplus production models” in the technical report: ICES WKLIFE 2019a. Report of the Ninth Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE IX), 30 September-4 October 2019, Lisbon, Portugal.
- Chapter 2.1 titled "The stochastic production model in continuous time (SPiCT)": ICES.2019b. Workshop on Data-limited Stocks of Short-Lived Species (WKDLSSLS). ICES Scientific Reports 1:73, 166 pp. *http://doi.org/10.17895/ices.pub.5549*.

The dissemination overview Table 3 describes three project workshops held in cooperation between the EMFF ManDaLiS and EMFF MSPTOOLS projects. One of the workshops was international and was held in association with and just after an International Conference Special Session: IIFET Conference, Seattle, USA, July 2018, (IIFET 2018 International Institute of Fisheries Economics and Trade, *https://www.xcdsystem.com/iifet/website/*). This Special Open Session was directly arranged by the ManDaLis and MSPTOOLS Projects with invitation of stakeholders and including stakeholder perspectives. Besides initiative taking, planning, arranging, organizing, coordinating, announcing, leading and carrying through this special session directly under the ManDaLiS and MSPTOOLS Projects there projects produced the session abstract and a full scientific publication reporting of the outcomes of the session (Nielsen et al. 2018):

- Nielsen, J.R., Pallisgaard, B., Andersen, M., Dickey-Collas, M., Pascoe, S., Holland, D., Thébaud, O., Curtis, H., Thunberg, E., Mildenberger, T., Rufener, M.C., Nowlis, J., Yuniarta, S., and Bastardie, F. 2018. Challenges in implementing stock assessment, economic fishery analysis, and risk assessment for sustainable management strategies of data poor stocks. Paper presented at the Nineteenth Biennial Conference of the International Institute of Fisheries Economics & Trade (IIFET): Adapting to a Changing

World: Challenges and Opportunities. Seattle, WA, USA. Compiled by A.L. Shriver. International Institute of Fisheries Economics & Trade, Corvallis, Oregon, USA, 2019. *http://oregonstate.edu/dept/IIFET/publications.html*, *https://ir.library.oregonstate.edu/concern/-conference_-proceedings_or_journals/k643b6739? locale=en*.

Under the IIFET 2018 Special Session "Tools for Stock Assessment, Economic Fishery Analysis, and Risk Assessment for Sustainable Management Strategies of Data Poor Stocks in Mixed, Small Scale and Indigenous Fisheries" conducted under the ManDaLiS and MSPTOOLS projects a number of stakeholder presentations addressed the current status, challenges, needs and future perspectives for implementation of management and ecological / economic assessment of data poor fish stocks and fisheries in management advice. This covered methods, simulation models and management strategy evaluation (MSE) tools to conduct assessment and evaluate economic efficiency and risks in exploiting data poor stocks caught in mixed, small scale, and indigenous fisheries. Particular focus was on accessibility of models and their development to ensure widespread and open access availability, user-friendly model operation, and efficient widespread adoption and implementation of those by scientists, stakeholders, and managers. Additional focus was on the data requirements for those models. Finally, the aim of the session was to discuss the best possible way to link economic assessments, risk assessment and MSE with biological (ecological) assessment of stock status according to sustainable harvest levels in those data limited situations and systems to provide robust assessment and advice – and maybe even integrated ecological-economic advice?

**State of the art**

In ICES there is an ongoing extensive advisory and scientific strategic initiative with respect to development and implementation of assessment methods for data limited and data poor stocks that involves integrating the stocks into TAC (Total Allowable Catch) advice according to the MSY (Maximum Sustainable Yield) and PA (Precautionary Approach) principles.

Such a focus is important because most fish and shellfish stocks in the world are in a data poor or a data limited condition/situation, and those stocks are to a much higher extent over-exploited and poorly managed than data rich stocks which most often are well managed. This is especially needed and urgent in a mixed, small scale and indigenous fisheries management context, in order to achieve the objectives of an ecosystem-based approach to fisheries management set out in UNCLOS (UNCLOS III 1982: United Nations Convention on the Law of the Sea) and its follow up in the Johannesburg 2002 Declaration. Among others ICES, PICES (North Pacific Marine Science Organization), NAFO (North West Atlantic Fisheries Organization), and FAO (Food and Agriculture Organization of the United Nations) have major focus on this situation and try to improve the advisory methods and provide necessary knowledge and expertise to meet this situation.

Under ICES, there have recently been reviewed and evaluated a large number of methods and models to enable assessment of data limited and data poor stocks and associated fisheries dynamics, management strategy evaluation (MSE), and fisheries advice. It has also involved development of advanced stochastic stock assessment models to provide MSY and PA advice. Here, the focus is especially on stocks acting as choke species in mixed fisheries as well as stocks in small scale and indigenous fisheries. Also methods and models using time series of fishery research survey and/or fishery information, either independently or on integrated basis,

have been developed to assess fish and fishery resource abundances and variability herein on an area specific and seasonal basis which can also be used for data limited stocks.

**Further needed progress and evaluation**

There is a growing need for economic methods, simulation models and MSE tools to be developed and implemented on top of the biological evaluation enabling economic assessment and establishment of indicators of economic sustainability of fisheries that exploit data poor and data limited stocks. This involves development and implementation of robust methods to evaluate efficiency, risks, sensitivity and robustness of different management strategies for mixed, small scale and indigenous fisheries where data poor and data limited stocks are caught, either as intended or un-intended by-catch or as target species. The medium to long-term economic profitability is part of incentive for improving fisheries management, economic efficiency and ecological sustainability in the exploitation and management of those stocks. To enable sustainable development of data poor stocks this should be the targeted goal. To achieve this, the management needs to consider economic efficiency in the fishery accounting for fishermen behaviour and overall incentives for exploitation.

Consequently, it is urgently necessary and important to review, investigate and discuss appropriate economic principles, methods, simulation models and MSE tools to evaluate economic viability and conduct risk assessment and robustness checks of different management strategies and harvest control rules for those stocks and fisheries. Also, it is relevant to identify, review and evaluate performance of those methods and their data needs according to their ability to provide efficient economic input to tactical and strategic management advice in data poor or limited stock situations. This is an important step toward achieving sustainable management and avoiding choke-species issues in high-value mixed fisheries as well as to ensure sustainability of small scale and indigenous fisheries.

In context of the above, the aim of the special open session and the paper produced on background of this (Nielsen et al. 2018) to which we refer for further descriptions and details) was to present state-of-the-art developments within a set of new methods, simulation models and MSE tools and on this basis to obtain stakeholder feed-back on the developments and future perspectives and needs. This was achieved by presentations and feed-back commenting from invited stakeholder representatives from fishing industry, fisheries management, fisheries advice (ICES), and fisheries biological and economic science who presented their perspectives and views on the above challenges.

The paper gives summaries of the set of new methods and tools initially presented at the session as well as summaries of the follow-up and feedback presentations and discussions provided by the stakeholders. On this basis, the paper draws some general conclusions on developments, challenges and future needs in relation to data poor stock assessment and management strategy evaluation in an ecological and economic perspective. The details of the stakeholder perspectives and feedback is given in Nielsen et al. (2018) produced under the ManDaLiS and MSPTOOLS projects, which we refer directly to here.

*Table 3. Overview of the ManDaLis Dissemination activities besides dissemination in ICES.*

| Type of Activity | Years | Type of Work and Contribution | ManDaLiS Role (Level of Involvement) & Participants |
|---|---|---|---|
| DTU PhD Project on further development of data limited stock assessment methods and management strategy evaluation | 2017-2019 (2020) | Co-financed PhD project between ManDaLiS (2 years) and DTU Aqua (1 year) on further development of data limited stock assessment methods (SPiCT model development).<br><br>Including an PhD External Research Stay for T. Mildenberger at University of Washington, Seattle, USA with presentation of project results and discussion on methodological developments including feed-back on those from an internationally highly recognized research group within the relevant scientific field and modelling topics. | Major, essential;<br>T. Mildenberger, DTU Aqua (PhD student), J.R. Nielsen, DTU Aqua (main supervisor), C. Berg & A. Kokkalis, DTU Aqua, & M.W. Pedersen, DTU Aqua / ENFOR (co-supervisors);<br><br>As one of the main developers of SPiCT, Martin W. Pedersen, left DTU Aqua early in the project, his necessary PhD co-supervision on making the SPiCT methodological developments under ManDaLiS has been ascertained under a sub-consultancy agreement. |
| International Conference Special Session: IIFET Conference, Seattle, USA, July 2018 (with invitation of stakeholders).<br><br>IIFET: International Institute of Fisheries Economics and Trade, *https://www.xcdsystem.com/iifet/website/*<br>IIFET Open Session & Stakeholder Perspectives. | 2018 | Special Session arranged by the ManDaLis and MSPTOOLS Projects: "Challenges in implementing stock assessment, economic fishery analysis, and risk assessment for sustainable management strategies of data poor stocks." IIFET, Seattle, USA, 18/7-2018 (09-12).<br><br>Initiative taking, planning, arranging, organizing, coordinating and carrying through this special session directly under the ManDaLiS and MSPTOOLS Projects<br>including Session announcement, Session Abstract, Session Lead, and producing a Session scientific publication (Nielsen et al. 2018). | Major, essential;<br>J.R. Nielsen, T. Mildenberger, M.C. Rufener, Francois Bastardie (DTU Aqua) |
| Stakeholder Workshops (ManDaLiS & MSPTOOLS) | 2017-2018 | Project Stakeholder Workshop I: DTU Aqua, Charlottenlund, DK, 17/03-2017 (9-15) with participation of Danish Stakeholders (totally 26 participants);<br>Project Stakeholder Workshop II: University of Washington (IIFET Conference Site), USA, | Major, essential; |

| | | | |
|---|---|---|---|
| | | 18/7-2018 (13-18) with participation of international stakeholders (8 participants);<br>Project Stakeholder Workshop III: DTU Aqua, Lyngby, DK, 13/8-2019 (12-17) with participation of national and international stakeholders (totally 16 participants). | National and International Stakeholders & DTU Aqua Scientists (involved in the ManDaLiS & MSPTOOLS projects) |
| Project Cooperation with Saudi Arabian Data Limited Stock Assessment Tender (Gulf of Arabia) | 2014-2017 | Model development, evaluation, and application of the SPiCT assessment model. | Major, essential;<br>J.R. Nielsen, M.W. Pedersen, S. Bossier, T. Mildenberger (DTU Aqua) |
| ICES Annual Science Conference (ICES ASC), Fort Lauderdale, USA, Sept. 2018 & Gothenburg, Sweden, Sept. 2019 & ICES WGECON 2018, Cph, DK June 2018 & ICES WGECON 2019, Paris, FR, June 2019. | | Presentation and discussion of the project developments and project implementation and model involvement in ICES management advice and science to the ICES SCICOM (ICES Science Committee) meeting during the ICES ASC 2018 and the broader ICES Scientific Community during the ICES ASC 2019 in form of a Poster and an oral presentation. | Major, essential;<br>J. Rasmus Nielsen; Tobias K. Mildenberger |
| Project Cooperation with EU Tender Lot2 – Data Limited Stocks in Mixed Fisheries (DRUMFISH) | 2015-2017 | Model evaluation and application of the SPiCT and S6 assessment models (and associated management strategy evaluation) for selected Baltic Sea and North Sea fish stocks of impotance to Danish fishery. | Medium;<br>C. Ulrich, J.R. Nielsen, C.P. Hansen, T. Mildenberger (DTU Aqua) |
| Project Cooperation with EU Tender PROBYFISH | 2018-2019 | Writing and providing an extensive review in relation to PROBYFISH Task 5.1 with input from ManDaLiS: "Review of existing indicators and trigger values for bycatch species in each case study."<br>This covers a) Work inside ICES on best practice guidelines for establishing reference points and advice rules for bycatch stocks;<br>b) Existing internationally agreed reference points and trigger levels for bycatch stocks;<br>c) Review of methods available to determine reference points and trigger levels inside and outside the ICES area. | Medium;<br>J.R. Nielsen, A. Kokkalis, C. Berg, T. Mildenberger (DTU Aqua).<br><br>Review authors: J. Rasmus Nielsen (DTU, DK), Holger Haslob (Thünen, D), Tobias Mildenberger (DTU, DK) and Alexander Kempf (Thünen, D). |
| Project Cooperation with EU H2020 MEESO Project on mesopelagic stocks (if financed) | 2019 | Guidelines on intended model application of S6 model to two selected NE Atlantic mesopelagic fish species / stocks. | Low;<br>J.R. Nielsen, A. Kokkalis, T. Mildenberger (DTU Aqua) |
| Project Cooperation with EU Tender EFICA, EU Framework Tender for Evaluation of Arctic Resources | 2019 | Guidelines on intended model application of S6 to selected Arctic stocks (e.g. Polar cod) in Arctic / North pole waters | Low;<br>J.R. Nielsen, A. Kokkalis, T. Mildenberger (DTU Aqua) |

Additional future perspectives and needs raised by the stakeholders during the ManDaLiS and MSPTOOLS workshops was suggestion for continuation of the implementation of the data poor stock assessments and model developments on additional candidate stocks with importance for Danish fishery. During the workshops discussions identified reasons for continuing on and proceeding with the following stocks: Greater Weaver in ICES subdivision IIIa, Deep sea species such as Ling, Roundnouse Grenadier and Argentine in ICES areas VI-IX, XII, XIV, IIIa, Iva, Deep Sea Shrimps in ICES IVa (European Zone), whiting in ICES subdivision IIIa, whiting in ICES SD22-24, Anglerfish in ICES Subdivision IIIa, Anchovy and Sardine in the North Sea,

Future projects should also cover further model developments according to make the SPiCT assessment model for data poor stocks more robust in cases where there exist longer catch data time series than research survey time series. Here the current experiences are that the SPiCT often does not converge in those cases. This should be done in future projects including how this is dealt with and resolved as well as to produce guidelines on the associated model transform. Also, future projects and research should develop a package that can conform the SAM assessment to a SPiCT assessment which requires that SPiCT model is made more robust first according to the above criteria because many SAM assessments include stocks with longer catch time series and research survey time series. Finally, for the SPiCT model, the prior distributions that are currently used by default, e.g. that prior distribution on the shape parameter of the production curve should be re-evaluated and improved to increase the robustness of the method.

# 4. References


Ault, Jerald S., James A. Bohnsack, and Geoffrey A. Meester. 1998. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fishery Bulletin 96 (3): 395–414.*

Ault, Jerald S., Steven G. Smith, James A. Bohnsack, Jiangang Luo, Molly H. Stevens, Gerard T. DiNardo, Matthew W. Johnson, and David R. Bryan. 2019. Length-based risk analysis for assessing sustainability of data-limited tropical reef fisheries. *ICES Journal of Marine Science* 76 *(1): 165–80. http://doi.org/10.1093/icesjms/fsy123.*

Ault, Jerald S., Steven G. Smith, Jiangang Luo, Mark E. Monaco, and Richard S. Appeldoorn. 2008. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. *Environmental Conservation 35 (3): 221–31. http://doi.org/10.1017/S0376892908005043.*

Britten, Gregory L., Michael Dowd, Lisa Kanary, and Boris Worm. 2017. Extended fisheries recovery timelines in a changing environment. *Nature Communications* 8 (May). *Nature Publishing Group: 15325. http://doi.org/10.1038/ncomms15325.*

CFP. 2013. Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC).

Chong, Lisa, Tobias K. Mildenberger, Merrill B. Rudd, Marc H. Taylor, Jason M. Cope, Trevor A. Branch, Matthias Wolff, and Moritz Stäbler. 2019. Performance evaluation of data-limited length-based stock assessment methods. *In Press ICES Journal of Marine Science*.

De Roos, André M., Tim Schellekens, Tobias Van Kooten, Karen Van De Wolfshaar, David Claessen, and Lennart Persson. 2008. Simplifying a physiologically structured population model to a stage-structured biomass model. *Theoretical Population Biology 73 (1): 47–62. http://doi.org/10.1016/j.tpb.2007.09.004.*

Hordyk, Adrian, Kotaro Ono, Sarah Valencia, Neil Loneragan, and Jeremy Prince. 2014. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES Journal of Marine Science 72: 217–31. 1. http://doi.org/10.1093/icesjms/fsu004.*

Ibaibarriaga, Leire, Carmen Fernández, Andrés Uriarte, and Beatriz A. Roel. 2008. A two-stage biomass dynamic model for Bay of Biscay anchovy: A Bayesian approach. *ICES Journal of Marine Science 65 (2): 191–205. http://doi.org/10.1093/icesjms/fsn002*.

ICES. 2017. Report of the Workshop on the Development of the ICES approach to providing MSY advice for category 3 and 4 stocks (WKMSYCat34), 6–10 March 2017, Copenhagen, Denmark. *ICES CM 2017/ ACOM:47. 53 pp.*

ICES 2018. Advice basis. In Report of the ICES Advisory Committee 2018. *ICES Advice 2018 Book 1 Section 1.2. https://doi.org/10.17895/ices.pub.4503.*

ICES 2018a. Report from the Baltic Fisheries Assessment Working Group (WGBFAS), 6-13 April 2018, ICES HQ, Copenhagen, Denmark. *ICES CM 2018/ACOM:11*, 748 pp.

ICES 2018b. Report from the Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3-6, 2-6 October 2017, Lisbon, Portugal. (ICES WKLIFE VII 2017 Report). *ICES CM 2017/ACOM:43, 221 pp*.

ICES 2018c. Report of the Eighth Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (ICES WKLIFE VIII 2018 Report), 8–12 October 2018, Lisbon, Portugal. *ICES CM 2018/ACOM:40, 172 pp*.

ICES 2018d. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 24 April - 3 May 2018, Oostende, Belgium. *ICES CM 2018/ACOM:22*.

ICES 2019a. Report of the Ninth Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (ICES WKLIFE IX 2019 Report), 30 September-4 October 2019, Lisbon, Portugal. *ICES CM 2019/ACOM:xx.*

ICES 2019b. Workshop on Data-limited Stocks of Short-Lived Species (WKDLSSLS). *ICES Scientific Reports 1:73, 166 pp. http://doi.org/10.17895/ices.pub.5549.*

Kokkalis, Alexandros, Uffe H. Thygesen, Anders Nielsen, and Ken H. Andersen. 2015. Limits to the reliability of size-based fishing status estimation for data-poor stocks. *Fisheries Research 171: 4–11. http://doi.org/10.1016/j.fishres.2014.10.007*.

Mildenberger, Tobias K, Casper W Berg, Martin W Pedersen, Alexandros Kokkalis, and J Rasmus Nielsen. 2019. Time-variant productivity in biomass dynamic models on seasonal and long-term scales. Edited by Shijie Zhou. *ICES Journal of Marine Science*, *September 2019. http://doi.org/10.1093/icesjms/fsz154.*

Mildenberger, Tobias Karl, Marc Hollis Taylor, and Matthias Wolff. 2017. TropFishR: an R package for fisheries analysis with length-frequency data. *http://doi.org/10.1111/2041-210X.12791.*

Mildenberger, Tobias K., Marc H. Taylor, Alexandros Kokkalis, Daniel Pauly. TropFishR: An R package for data-poor fisheries analysis. Poster at the ICES ASC 2019. *ICES ASC CM 2019/N:445a*.

Mildenberger, Tobias K., Ralf Schwammborn, Alexandros Kokkalis, J. Rasmus Nielsen, Marc H. Taylor. BOLAS - A bootstrap approach to length-based stock assessment. Extended Abstract and Oral presentation at the ICES ASC 2019. *ICES ASC CM 2019/N:445b.*

Mildenberger, Tobias K., Ralf Schwamborn, Alexandros Kokkalis, J. Rasmus Nielsen, Marc H. Taylor. (In Prep). Quantification of uncertainty in length-frequency analysis: A novel approach to length-based stock assessments. *(In Advanced Prep / In Submission)*.

Mildenberger, Tobias K., Casper W. Berg, Alexandros Kokkalis, J. Rasmus Nielsen, Andre Punt. (In Prep). Simulating the ICES process for data-limited fisheries management. *(In Advanced Prep)*.

Nielsen, J.R., Pallisgaard, B., Andersen, M., Dickey-Collas, M., Pascoe, S., Holland, D., Thébaud, O., Curtis, H., Thunberg, E., Mildenberger, T., Rufener, M.C., Nowlis, J., Yuniarta, S., and Bastardie, F. 2018. Challenges in implementing stock assessment, economic fishery analysis, and risk assessment for sustainable management strategies of data poor stocks. *Paper presented at the Nineteenth Biennial Conference of the International Institute of Fisheries Economics & Trade (IIFET): Adapting to a Changing World: Challenges and Opportunities. Seattle, WA, USA. Compiled by A.L. Shriver. International Institute of Fisheries Economics & Trade, Corvallis, Oregon, USA, 2019. http://oregonstate.edu/dept/IIFET/publications.html, https://ir.library.oregonstate.edu/concern/-conference_-proceedings_or_journals/¬k643b6739? locale=en*.

Pauly, Daniel. 1982. ELEFAN I, a basic program for the objective extraction of growth parameters from length-frequency data. *Ber. Dt. Wiss. Komm. Meeresf. 28 (4): 205–11.*

Pauly, Daniel 1984. Length - converted catch curves: a powerful tool for fisheries research in the tropics (part III). *Fishbyte*. *https://digitalarchive.worldfishcenter.org/handle/20.500.12348/3460.*

Pedersen, Martin W., and Casper W. Berg. 2017. A stochastic surplus production model in continuous time. *Fish and Fisheries 18 (2): 226–43. http://doi.org/10.1111/faf.12174.*

Rudd, Merrill B., and James T. Thorson. 2018. Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries." *Canadian Journal of Fisheries and Aquatic Sciences 75 (7): 1019–35. http://doi.org/10.1139/cjfas-2017-0143.*

Soudijn, Floor H., and André M. de Roos. 2017. Approximation of a physiologically structured population model with seasonal reproduction by a stage-structured biomass model. *Theoretical Ecology 10 (1): 73–90. http://doi.org/10.1007/s12080-016-0309-9.*

Taylor, M. H., and T. K. Mildenberger. 2017. Extending electronic length frequency analysis in R. *Fisheries Management and Ecology 24 (4): 330–38. http://doi.org/10.1111/fme.12232.*

Then, Amy Y., John M. Hoenig, Norman G. Hall, and David A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science 72 (1): 82–92. http://doi.org/10.1093/icesjms/fsu136*.

Thompson, William F, and F. Heward Bell. 1934. Biological statistics of the pacific halibut fishery. (2) Effect of change in intensity upon total yield and yield per unit of gear. *Report of the International Fisheries Commission* 8: *49. http://doi.org/10.1093/icesjms/10.3.249.*

Vert-pre, K. A., R. O. Amoroso, O. P. Jensen, and R. Hilborn. 2013. Frequency and intensity of productivity regime shifts in marine fish stocks." *Proceedings of the National Academy of Sciences 110 (5): 1779–84. http://doi.org/10.1073/pnas.1214879110.*

# Acknowledgements

The present report is based on the ManDaLiS project funded with 2,47 million DKK by the European Maritime and Fisheries Fund and the Danish Fisheries Agency.


ManDaLiS has facilitated international collaborations with scientists from the ICES Scientific and Management Advisory Community, the IIFET Scientific Community, the scientific research communities under the EU projects DRUMFISH and PROBYFISH. Furthermore, several stakeholders has contributed significantly with direct input to the project through the stakeholder workshops conducted under the EMFF ManDaLiS and MSPTOOLS projects. This involves managers from the fishery and environmental departments and directorates in the Danish Government, representatives from the fishing industry catch sector organizations, representatives from the fishing processing industry organizations, ICES Advisory Committee and Science Committee representatives, representatives from the Baltic Sea Advisory Council, representatives from several environmental NGOs and a long row of national and international fisheries scientists. All the above mentioned stakeholders and contributors, can directly benefit from the results of the project and implement the results further. Finally, the project has also facilitated special collaboration with scientists from the Leibniz Centre for Tropical Research and the Thünen Institute of Sea Fisheries in Germany, the Universidade Federal de Pernambuco (UFPE) in Brazil, the University of British Columbia in Canada, and the University of Washington, the University of Florida, and Northwest Fisheries Science Center of NOAA in the United States.

Technical
University of
Denmark

DTU Aqua
Kemitorvet
2800 Kgs. Lyngby

www.aqua.dtu.dk