WORKSHOP FOR SALMON LIFE CYCLE MODELLING (WKSALMODEL)

VOLUME 3 | ISSUE 24

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

ISSN number: 2618-1371

ICES Scientific Reports

Volume 3 | Issue 24

WORKSHOP FOR SALMON LIFE CYCLE MODELLING (WKSALMODEL)

Recommended format for purpose of citation:

ICES. 2021. Workshop for Salmon Life Cycle Modelling (WKSalModel).
ICES Scientific Reports. 3:24. 20 pp. https://doi.org/10.17895/ices.pub.7921

Editors

Etienne Rivot • Gérald Chaput • Dennis Ensing

Authors

Etienne Rivot • Gérald Chaput • Dennis Ensing • Julien April • Hlynur Bardarson • Geir Bolstad • Cindy Breau • George Brown • Colin Bull • Mathieu Buoro • Guillaume Dauphin • Graeme Diack • Colm Fitzgerald • Jonathan Gillson • Stephen Gregory • Nora Hanson • Pierre-Yves Hernvann • Jan Arge Jacobsen • Douglas Jones • Nick Kelly • Hugo Maxwell • Michael Millane • Marie Nevoux • Rasmus Nygaard • Maxime Olmos • James Ounsley • Rémi Patin • Dustin Raab • Jeff Reader • Martha Robertson • Tim Sheehan • Alan Walker • Rebecca Whitlock

ICES
International Council for the Exploration of the Sea
CIEM
Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

A workshop of jurisdictional experts and modellers working on Atlantic salmon in the North Atlantic was held to develop competencies in using a newly developed Life Cycle Model (LCM) and to formalize the workflow of the new modelling framework for assessing and providing fisheries catch advice for Atlantic salmon stocks in the North Atlantic. The workshop evaluated the LCM which incorporates all Atlantic salmon stocks at the North Atlantic scale in a single model, reviewed comparisons of current ICES pre-fishery abundance (PFA) models and the LCM approach, and discussed the data inputs and process for running the LCM. The LCM framework is embedded within a suite of R programs and a shiny web application, which are available online, that simplify and strengthen the robustness of the stock assessment workflow from the input data to the production of catch advice. Timelines for providing data from jurisdictions for input to the LCM were discussed and it was indicated that data from jurisdictions are generally not ready until March of the assessment year, which underscores the need to have automated processes for the ICES PFA model and the new LCM processes. The decision was made at the workshop to provide the required assessment and provision of catch advice in March 2021 based on the previous PFA models used by ICES. The LCM would be run in parallel and the results of the PFA model and LCM outputs compared. A follow-up workshop is proposed for late 2021/early 2022 to prepare the elements of LCM and PFA model descriptions, data inputs, and workflow processes in preparation for a proposed ICES Benchmark process in 2022.

ii Expert group information

Expert group name	**Workshop for Salmon Life Cycle Modelling (WKSalModel 2021)**
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chairs	Etienne Rivot, France
	Gérald Chaput, Canada
	Dennis Ensing, UK
Meeting venue and dates	Online meeting 5–8 January 2021, 34 participants

1 Introduction, ToRs, objectives and agenda

1.1 Introduction

This report is the output of the International Council for the Exploration of the Sea (ICES) **Workshop for Salmon Life cycle Modelling (WKSalModel)**, co-chaired by Etienne Rivot (France), Gérald Chaput (Canada) and Dennis Ensing (UK) that met by web conference 5–8 January 2021.

The ICES Working Group on North Atlantic Salmon (WGNAS) has developed run reconstruction (PFA, Pre Fishery Abundance) and forecast models of Atlantic salmon (S*almo salar*) abundance at the stock complex (North America Complex, NAC; Southern Northeast Atlantic Complexes, SNEAC; Northern Northeast Atlantic Complexes, NNEAC) and regional scales (six regions in NAC; eight jurisdictions in SNEAC; seven jurisdictions in NNEAC) for the provision of catch advice for NASCO and to better understand population dynamics.

A new Bayesian life cycle model (LCM) has been proposed to improve the biological realism of the stock assessment model and to advance exploration of factors that are driving salmon abundance. The LCM development has been led by Etienne Rivot (Institut Agro, France) and several collaborators (Maxime Olmos, Rémi Patin, Pierre-Yves Hernvann, Gérald Chaput, Etienne Prévost, Marie Nevoux, Félix Massiot-Granier) using North Atlantic salmon data compiled by WGNAS.

Following discussions at the WGNAS 2020, in preparation for a future Benchmark, and the adoption of the LCM by the WGNAS for stock assessment and provision of multi-year catch advice, a workshop of jurisdictional experts and modelers was held to develop competencies in using the LCM and to formalize the workflow of the new modelling framework.

1.2 Terms of Reference

The following Terms of Reference were provided to the Workshop.

The **Workshop for Salmon Life cycle Modelling** (WKSalModel), co-chaired by Etienne Rivot (Institut Agro, France), Gérald Chaput (DFO, Canada) and Dennis Ensing (AFBI, UK; Chair ICES WGNAS) will meet by web conference 5–8 January 2021 to:

- Advance the Bayesian LCM for the assessment of North Atlantic salmon (*Salmo salar*);
- Train ICES experts in the use of this LCM, which is currently coded in R (https://r-project.org) and NIMBLE (https://r-nimble.org/);
- Improve and formalize the workflow from data specification, preparation, and maintenance to the production of the assessment and for provision of multi-year forecasts and catch advice.

WKSalModel will report to ICES WGNAS in March 2021 and by 24 April 2021 for the attention of ACOM.

Supporting information

Priority	This workshop will advance the ability of ICES to assess North Atlantic salmon. The WKSalModel will advance our ability to examine the ecosystem effects of fisheries, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Scientific justification	The WGNAS has developed run reconstruction (PFA) and forecast models of abundance of Atlantic salmon at the stock complex (North America Complex, NAC; Southern Northeast Atlantic Complex, SNEAC; Northern Northeast Atlantic Complexes, NNEAC) and regional scales (six regions in NAC; eight jurisdictions in SNEAC; seven jurisdictions in NNEAC) for the provision of ICES catch advice for NASCO and to better understand population dynamics. A new Bayesian LCM has been proposed to improve the biological realism and to advance exploration of factors that are driving salmon abundance. The LCM development is led by Etienne Rivot (Institut Agro, France) and several collaborators (Maxime Olmos, Rémi Patin, Pierre-Yves Hernvann) using WGNAS data. Following discussions at the WGNAS 2020, in preparation for a future Benchmark, and the application of the LCM by the Working Group for stock assessment and provision of multi-year catch advice, a workshop of jurisdictional experts and modelers to develop competencies in using the LCM and to formalize the workflow of the new modelling framework was recommended to take place in late 2020 or the latest January 2021.
Preparation for the Workshop	Codes for running the model and the workflow (from data to outputs) will be deposited online before the meeting. To maximize meeting efficiency, attendees will have to familiarize with these codes before the meeting, or with examples of the use of r-nimble (https://r-nimble.org/) and shiny (https://shiny.rstudio.com/).
Expected outputs from the workshop	It will contribute to a shared vision among the WGNAS expert group to build a new methodological framework for providing catch advice based on the LCM. A Working paper describing the Bayesian LCM and its application to the development of multi-year catch advice (workflow from data input to model fitting and forecasting) to be presented at the upcoming WGNAS meeting in late March 2021.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The programmes received funding from the Agence Française de la Biodiversité (OFB) under grant agreement INRAe-AFB SalmoGlob 2016–2018, and from the European Regional Development Fund through the Interreg Channel VA Programme, Project SAMARCH Salmonid Management Round the Channel. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	Jurisdiction experts and modelers of the ICES WGNAS. LCM experts: Maxime Olmos (UW, Seattle) Rémi Patin (Institut Agro), and Pierre-Yves Hernvann (Institut Agro) invited for presentations.
Sharepoint	ICES Sharepoint site is used for workshop documents and materials. http://community.ices.dk/ExpertGroups/wksalmodel
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	WGNAS
Linkages to other committees or groups	There is a very close working relationship with all the groups of the Fisheries Technology Committee. It is also very relevant to the Working Group on Ecosystem Effects of Fisheries (WGECO) and the Working Group on Science to Support Conservation, Restoration and Management of Diadromous Species (WGDIAD).
Linkages to other organizations	The work of this group is closely aligned with similar work in the Food and Agriculture Organisation (FAO) and in the Census of Marine Life Programme and responds direclty to advice requested by the North Atlantic Salmon Conservation Organisation.

1.3 Objectives of WKSalModel

To address the Terms of References, the objectives of the workshop include:

- To advance the Bayesian LCM for the assessment of North Atlantic salmon;
- To familiarize ICES experts in the use of the LCM, that is currently coded in R using the package NIMBLE;
- To discuss and formalize the workflow from data specification, preparation, and maintenance to the production of the assessment and for the provision of multi-year forecasts and catch advice.

Given the limited time established for the workshop and the virtual setting of the meeting, the workshop focused on:

- Overview of the LCM at the North Atlantic scale;
- Overview of comparison of current PFA models used by WGNAS and the LCM approach;
- Data inputs and the workflow for running the LCM;
- Discussing and prioritizing next steps with priority on timelines for data inputs, running the LCM for assessment and catch advice during WGNAS in March 2021.

Preparation for the workshop

Codes for running the model and the workflow (from data to outputs) were deposited online before the meeting. To maximize meeting efficiency, attendees were asked to familiarize with these codes before the meeting, or with examples of the use of r-nimble (https://r-nimble.org/) and shiny (https://shiny.rstudio.com/).

Expected outputs from the workshop

- It will contribute to a shared vision among the WGNAS expert group to build a new methodological framework for providing catch advice based on the LCM.
- A Working paper describing the Bayesian LCM and its application to the development of multiyear catch advice (workflow from data input to model fitting and forecasting) to be presented at the upcoming ICES WGNAS meeting in late March 2021.
- To finalize a collective manuscript comparing model structure and outputs of PFA and LCM.

1.4 Agenda

The Workshop held by web conference 5–8 January 2021 (four sessions of three hours each, 14h00 to 17h00 (GMT + 1)).

Tuesday 5 January, 2021

- Welcome / Introduction / Review of logistics (Dennis Ensing, AFBI, UK);
- Description and review of the current LCM emphasizing (Etienne Rivot, Institut Agro, France):
    - Model structure;
    - Data flow - how the data from jurisdictions are used in the model;

    - Workflow from hindcasting (fit on historical time-series of data) to forecasting (risk analysis and provision for catch advices) using the same model.

Wednesday 6 January, 2021

- Review of comparison between results obtained from the PFA models and the LCM, emphasizing the consequences of the differences in model structures (Maxime Olmos, Institut Agro, France, and University of Washington/NOAA, USA);
- Data flow: inputs from jurisdictions into run reconstruction model used to generate input data for LCM:
    - Presentation for NEAC (Geir H. Bolstad, NINA, Norway)
    - Presentation for NAC (Gérald Chaput, DFO, Canada)

Thursday 7 January, 2021

- Review of the R-Nimble codes and workflow (Rémi Patin, Institut Agro, France);
- Demo/ discussion through a beta-version of a database and shiny app used to store / visualise / export / update all data inputs needed to run the Bayesian LCM (Pierre-Yves Hernvann, Institut Agro, France).

Friday 8 January, 2021

- Discussion / Feedback;
- Next steps for WGNAS 2021 (Process and deadlines for data inputs from jurisdictions for run-reconstruction and the LCM);
- ICES Benchmark process possible for 2022.

2 Overview of the Bayesian Life Cycle model

The new modelling framework developed for the stock assessment of Atlantic salmon in the North Atlantic basin was presented in detail during the first two days of the workshop, together with a review of the comparison between results obtained from the PFA models and the LCM, emphasizing the consequences of the differences in model structures.

The core of the framework is a Bayesian hierarchical LCM that tracks the abundance of fish through time and life stages from eggs to adults that return to spawn in their homewater after one or two sea winters spent at sea, and for all stock units (SU) in northern Europe, southern Europe and North America (total 25 SU). The new framework brings a major contribution to improve the scientific basis of Atlantic salmon stock assessment, and constitutes a benchmark for the assessment and forecast models used by ICES for Atlantic salmon stock assessment in the North Atlantic.

The main advances of the new modelling framework are outlined below. The new model is detailed in a Working paper to be presented during WGNAS 2021 (Rivot *et al.*, 2021).

- In the new model, the dynamics of all SU in northern Europe, southern Europe and North America (25 SU; Figure 1) are considered within a single unified model where all SU follow a similar life-history process (Figure 2). This represents a major improvement and a paradigm shift from the pre-fishery abundance (PFA) stock assessment and forecasting approach currently used by ICES. The current PFA modelling approach considers the North American and European (southern and northern) continental stock groups separately, and these models have different demographic structures (Chaput, 2012). Three different and independent PFA models are currently used for northern Europe, southern Europe and North America. Some core demographic hypotheses are not harmonized among these models. Specifically, the two European PFA models explicitly consider 1SW and 2SW fish in the population dynamics, while the PFA model for North America only considers the dynamics of 2SW fish (Chaput *et al.*, 2012). The North America model implicitly assumes that 2SW spawners only produce 2SW fish in future cohorts, and excludes contributions of 1SW spawners. Temporal variations in productivity in the North America PFA consider only the 2SW component and are therefore not comparable to those estimated for European PFA that considers both 1SW and 2SW components. Because of these differences, it is not possible to evaluate the commonality in temporal trends among all SU in the North Atlantic. In contrast, the new LCM provides a single harmonized framework to assess two sea classes of Atlantic salmon for all SU in North America and Europe simultaneously, emphasizing the commonality in the population dynamics of all 25 SU of the North Atlantic basin.
- The new model hence constitutes an important tool for future improvement of our understanding of the mechanisms driving the response of Atlantic salmon populations to variations in biological and environmental factors at a hierarchy of spatial scales (Olmos *et al.*, 2019; Olmos *et al.*, 2020). Formulating the dynamics of all 25 SU in a single hierarchical model provides a tool for modelling covariations among different populations that may share part of their migration routes at sea and may be exploited by the same marine fisheries. It is a framework for quantifying the spatial coherence in the temporal variations of post-smolt survival and of the sea-age composition of returns for SU distributed across a broad gradient of longitude and latitude in the North Atlantic basin.
- The same model is used for both hindcasting (i.e. fitting the model on time-series of historical data) and forecasting (i.e. forecast of the dynamics in future years after the last year of fitting). All model properties are readily integrated into the forecast process. First,

the model is used to forecast the population dynamics of all SU simultaneously, which is of interest when assessing catch options for fisheries operating on a mixture of stocks from both North America and Europe. Second, all sources of stochasticity in the model (temporal variations) and parameter uncertainty (joint posterior distribution) are integrated in the hindcasting and forecasting phases. Last, covariations among SUs in the temporal variations in post-smolt survival and in the proportion of fish maturing as 1SW are incorporated. The use of the LCM to evaluate the probability that returns in all SU achieve management objectives (expressed as total egg deposition relative to conservation limits) for different catch options in both the Western Greenland and Faroes mixed stock fisheries has been demonstrated. However, the model could also be used to provide catch options for other fisheries, or to assess conservation measures for the different sea-age classes, or the SU separately.

- The integrated life cycle framework is expandable and provides an opportunity to assimilate new sources of information. For instance, it incorporates a new likelihood function to assimilate genetic data to allocate catches at West Greenland among the SU, which is more realistic than the hypothesis of a homogeneous harvest rate among SU used in the current ICES model.

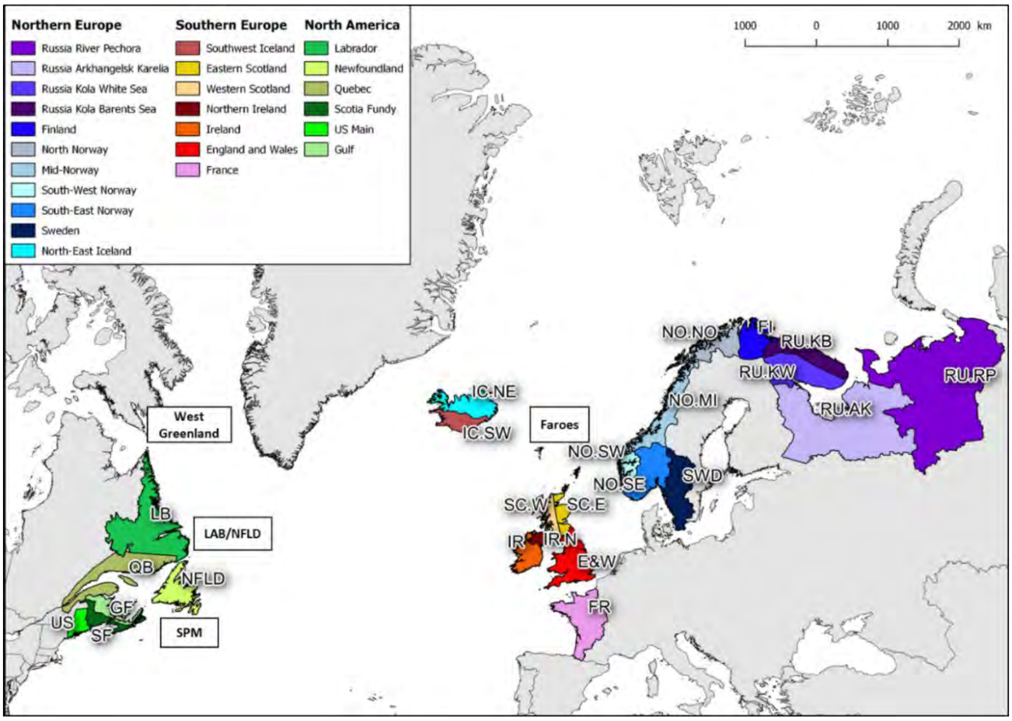


Figure 1. The 25 stock units considered in North Atlantic. Stock units of North America: NFDL=Newfoundland, GF=Gulf, SF=Scotia-Fundy, US=USA, QB=Quebec and LB=Labrador ; Stock units in Southern Europe: IR=Ireland, E&W=England & Wales, FR=France, E.SC=Eastern Scotland, W.SC=Western Scotland, N.IR=Northern Ireland FO and FB (note that the split between FO and FB is not represented on the map), IC.SW=South-West Iceland ; Stocks units in Northern Europe: FI=Finland, IC.NE=Northeast Iceland, NO.MI=Middle Norway, NO.NO=North Norway, NO.SE=Southeast Norway, NO.SW=Southwest Norway, RU.AK=Russia Arkhangelsk Karelia, RU.KB=Russia Kola Barents Sea, RU.KW=Russia Kola White Sea, RU.RP=River Pechora, SWD=Sweden. Germany and Spain are not included in the model. Boxes indicate the main fisheries at sea operating on mixed stocks: Faroes, West Greenland, Labrador and Newfoundland (LAB/NFLD), and Saint Pierre and Miquelon (SPM). (Source: Rivot *et al.*, 2021).

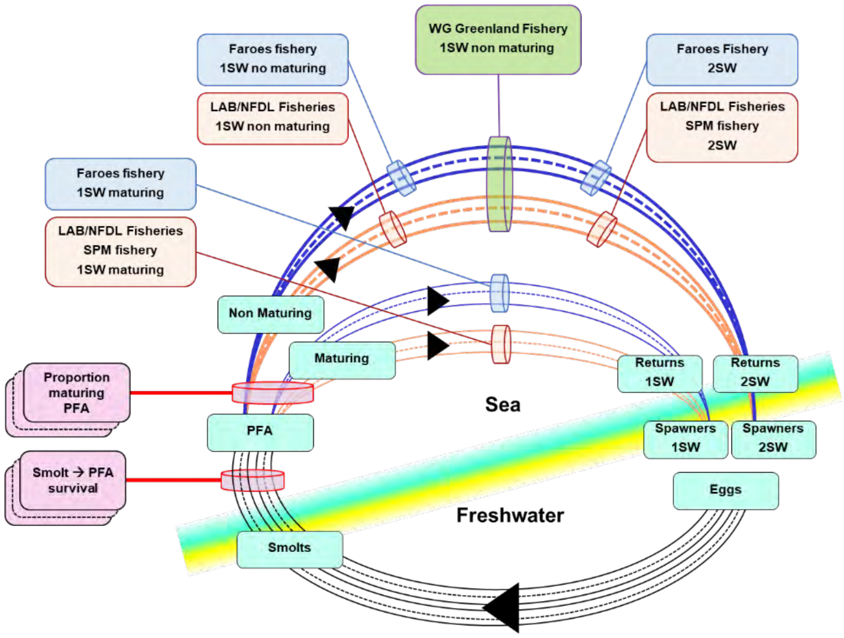


Figure 2. Structure of the age- and stage-based life cycle model for the 25 SU. Sources of covariation are two-fold: 1) covariations in the time-series of post-smolt survival and proportion maturing as 1SW; and 2) covariations through fisheries operating on mixtures of SU at sea. Blue boxes: different life stages. Blue arrows: North American stock units. Orange arrows: European stock units (Southern and Northern European). Cylinder: sources of covariations among the 25 SU. Red cylinders: key parameters (post-smolt survival and maturing probability). Orange cylinders: fisheries operating on mixture of European stock units. Blue cylinders: fisheries operating on mixture of North American stock units. Green cylinder: Fishery operating on mixture of both North American and European stock units. (Source: Rivot *et al.*, 2021).

3 The WGNAS-SalmoGlob ToolBox

The new framework is embedded within the WGNAS-SalmoGlob ToolBox that was presented and discussed during the third day of the workshop. The WGNAS-SalmoGlob ToolBox includes a suite of R programs, a database and a shiny web app (Hernvann *et al*., 2021; Figure 3) available online that considerably simplifies and strengthens the robustness of the stock assessment workflow from the input data to the production of catch advice.

3.1 A suite of R programs based on the Nimble package

A suite of R programs was presented that provide a consolidated streamline from hindcasting to forecasting, including formatting results in the form of key figures.

The new model was developed using NIMBLE (https://r-nimble.org/). NIMBLE is an efficient software package for fitting complex Bayesian models using MCMC simulation methods using the BUGS language. Codes are then easily passed from BUGS or JAGS to NIMBLE, thus making this package accessible for those who have a minimum of experience using BUGS and JAGS. When running NIMBLE from R, models and MCMC samplers are compiled in C++ thus improving the computational speed. NIMBLE also offers customisable MCMC samplers to improve computational efficiency and convergence speed. Recent development of the LCM allows for obtaining robust results in 12 hours, which makes it workable within the timeframe of a working group meeting.

In practice, forecasting uses the same LCM code written in NIMBLE and therefore the posterior MCMC samples from the hindcasting phase can be used to quickly run multiple scenarios. Using the same BUGS code for both the hindcasting and the forecasting phases ensures model consistency between the two phases and limits errors as no model recoding is required between the hindcasting and the forecasting phases.

3.2 A web application for supporting the workflow

The WGNAS-SalmoGlob ToolBox database and shiny app (Figure 3) is built in R using the Shiny package (a package designed to build interactive web applications). It is still under development, but a first operational version accessible online via any web browser was presented and discussed (available at http://sirs.agrocampus-ouest.fr/discardless_app/WGNAS-ToolBox/).

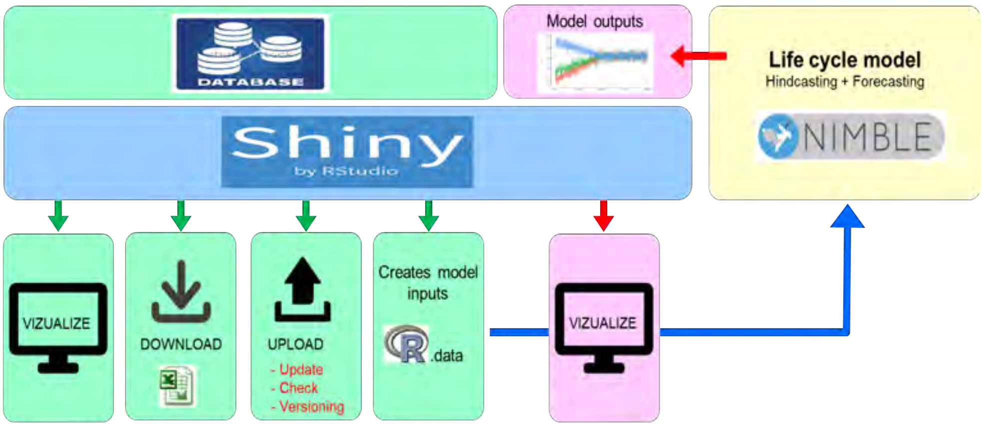


Figure 3. Scheme of the WGNAS-SalmoGlob ToolBox. Connections between the different modules and interactions between the Shiny application, the salmon database and the Bayesian life cycle model of North Atlantic salmon. (Source: Hernvann *et al*., 2021).

The toolbox is structured by a dashboard that displays the tools available for specific steps of the workflow (Figure 3).

- The SalmoGlobDatabase harmonizes the data and input for all 25 SU of both Europe and North America used for salmon stock assessment in a single, centralized and secured database. Online access facilitates the sharing of data.
- The web app includes interactive tools to explore and visualize the large amount of information contained in the SalmoGlobDatabase. It enhances transparency in the way the data are used, facilitates exchanges between WGNAS experts and provides standard graphs to streamline annual WGNAS reporting.
- The web app provides tools to export and update the data, which is critical and time-consuming part of the stock assessment process. By providing automated tests and visual checking when uploading updated data, it decreases the probability of errors during the updating procedure and substantially enhances data quality control. The automatic versioning brings additional security to the updating process. Last, updated data are automatically collated in the appropriate format to be passed to the LCM. This increases transparency in the way the data are used and contributes to strengthening data quality control.
- Finally, the web app also provides efficient graphical synthesis of the results for both the hindcasting and forecasting of North Atlantic salmon population dynamics. These synthesis graphs are made available for use in the WGNAS report and for any communication to a wider audience.

4 Feedback from the workshop and resolutions

4.1 The Life Cycle Model

Feedback on the new LCM is overwhelmingly positive and the group approved a transition to use the LCM for Atlantic salmon stock assessment and the provision of catch advices.

Because of the limited time during the workshop, the R code of the model was not reviewed in detail. However, all R-codes were made available to the group and feedback was received between January 2021 and the WGNAS in March 2021 that helped improving the coding.

Examples of outputs from the LCM (Figures 4 to 9) were presented during the workshop and some feedback was also received before the WGNAS 2021 to better fit the needs of the WGNAS. Further discussions are needed to better align the default outputs to those needed by WGNAS.

The LCM uses estimates of returns, homewater catches, and high seas catches as key inputs. These inputs are probability distributions that integrate uncertainty around the best estimates. For WGNAS 2021, existing PFA codes developed by WGNAS will be used to provide those inputs. The workshop stressed the need to encourage the development and improvement of those models to produce estimates of returns, homewater catches and catches at sea. In future, those models could eventually be developed by each jurisdiction and run outside the LCM to allow for the maximum of flexibility for each jurisdiction to make the best use of the data and expertise available locally.

Overviews of the run reconstruction model processes that are currently used to develop the estimates of returns and catches by jurisdiction for NAC and NEAC were presented at the workshop. Timelines for providing data from jurisdictions for the run reconstruction process were discussed and it was made clear that generally, the data from jurisdictions for this process are not ready until March of the assessment year, which strengthens the need to have nearly automated processes for undertaking this first key step leading to the current ICES PFA model and the new LCM.

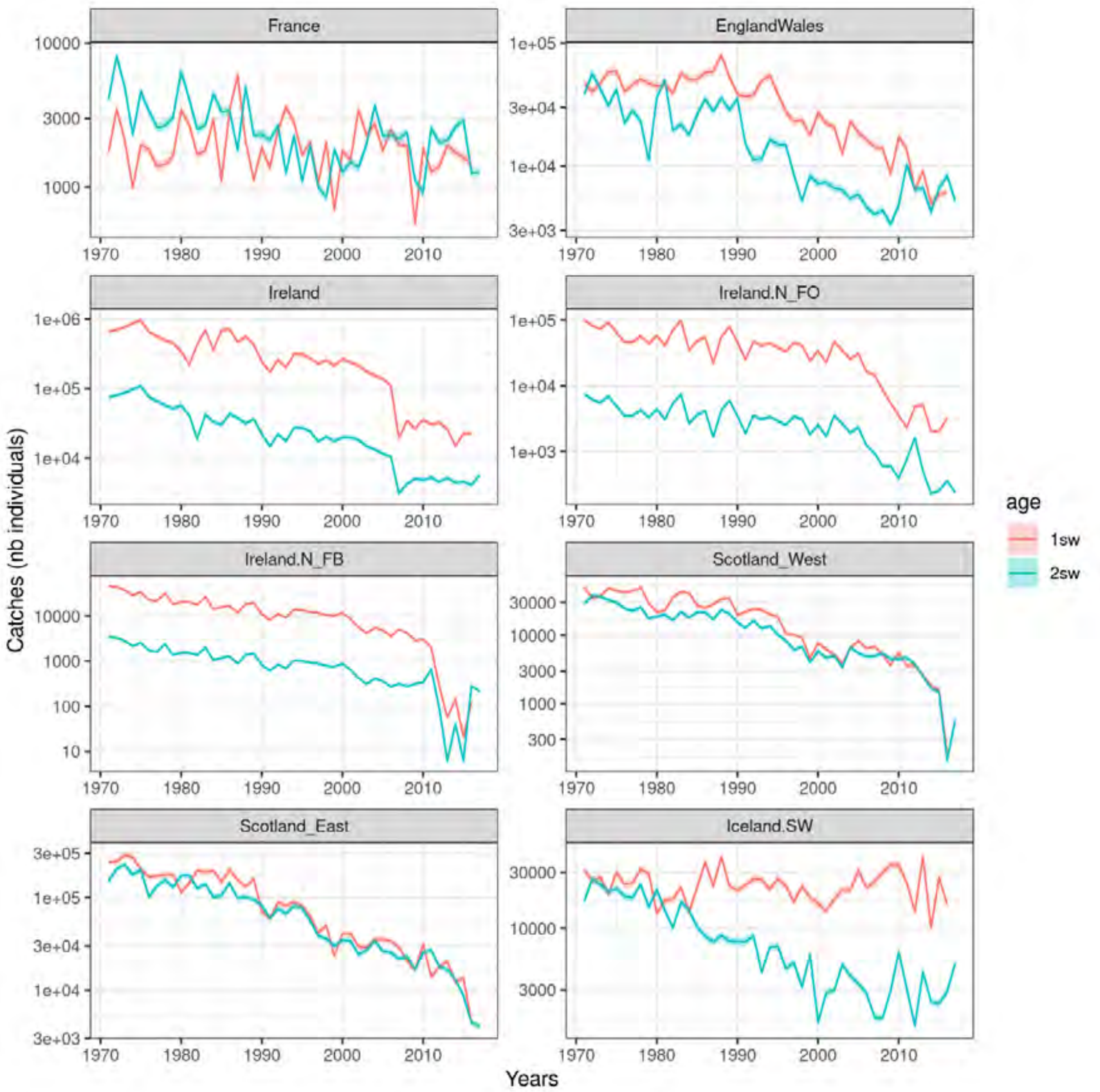


Figure 4. Homewater catches (retained) Southern Europe. Time-series of point estimates (median) and 90% credibility intervals (logNormal probability distributions with CV arbitrarily fixed to 5%) of homewater catches for the eight SU of Southern Europe (Source: ICES, 2018). Notice: different scales are used for y-axis.

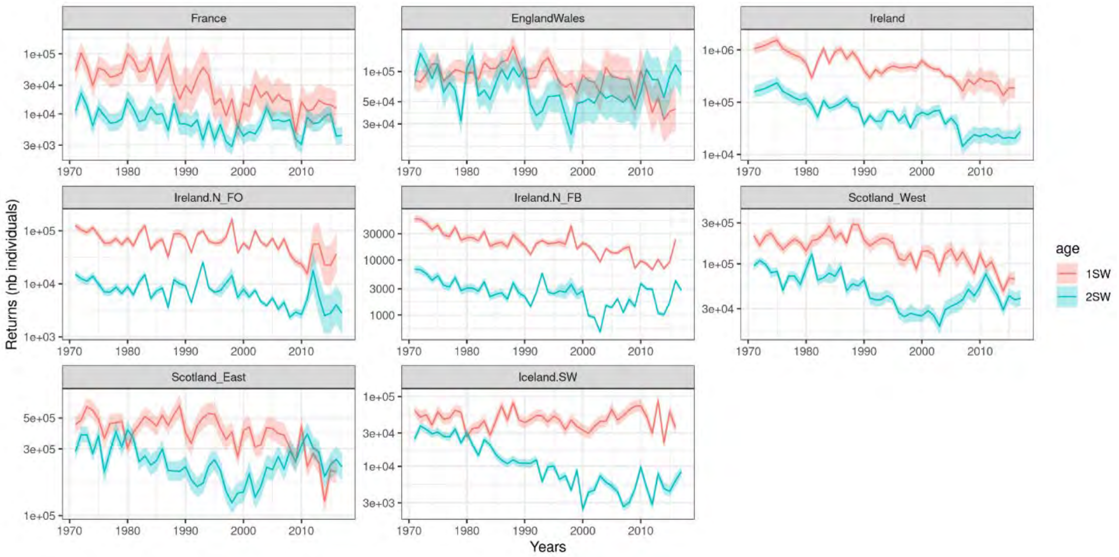
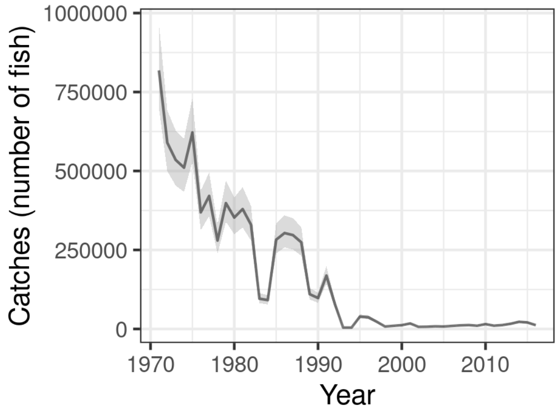


Figure 5. Returns to homewaters in Southern Europe. Probability distributions (median, quantiles 90% credibility interval) of the number of fish returning as 1SW (red) and 2SW (blue) for the eight SU of Southern Europe (Source: ICES, 2018). Notice: different scales are used for y-axis.

a)



b)

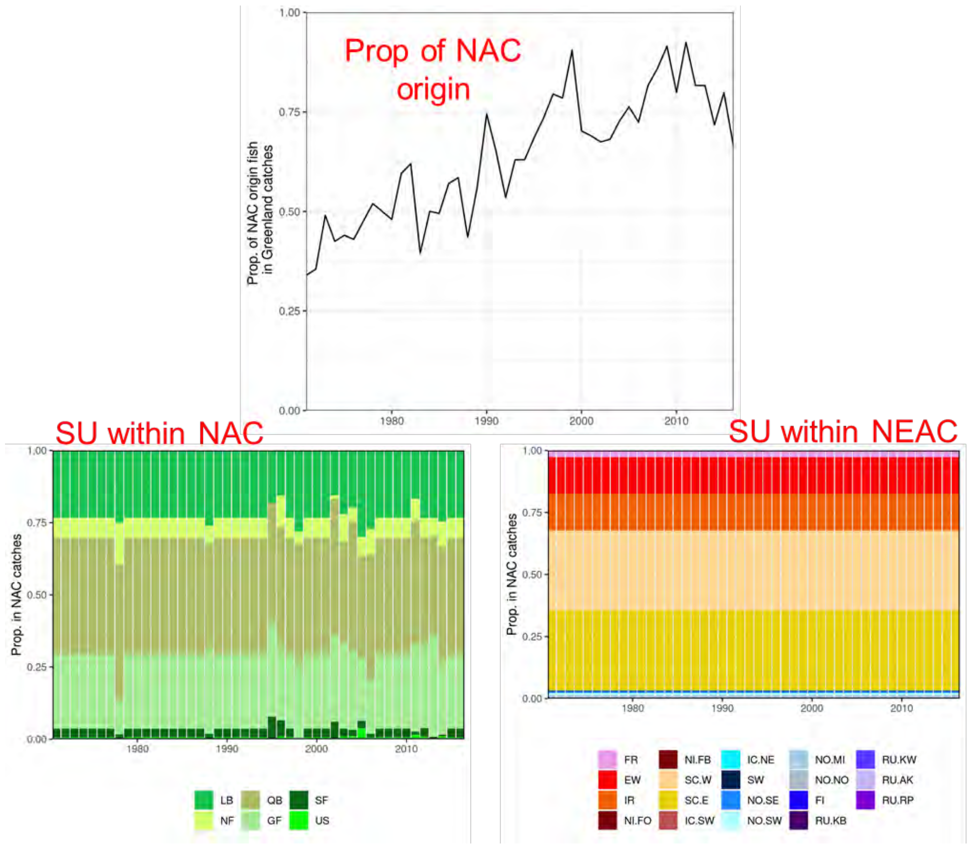


Figure 6. Time-series of total catches of 1SW non-maturing in the West Greenland fishery (Source: ICES, 2018); (b) proportions of the catches attributed to North American / European stock complex (top), attributed to North American stock units within North American stock complex (bottom left) and attributed to European stock units within European stock complex (bottom right). (Source: ICES, 2018 and Rivot *et al*., 2021).

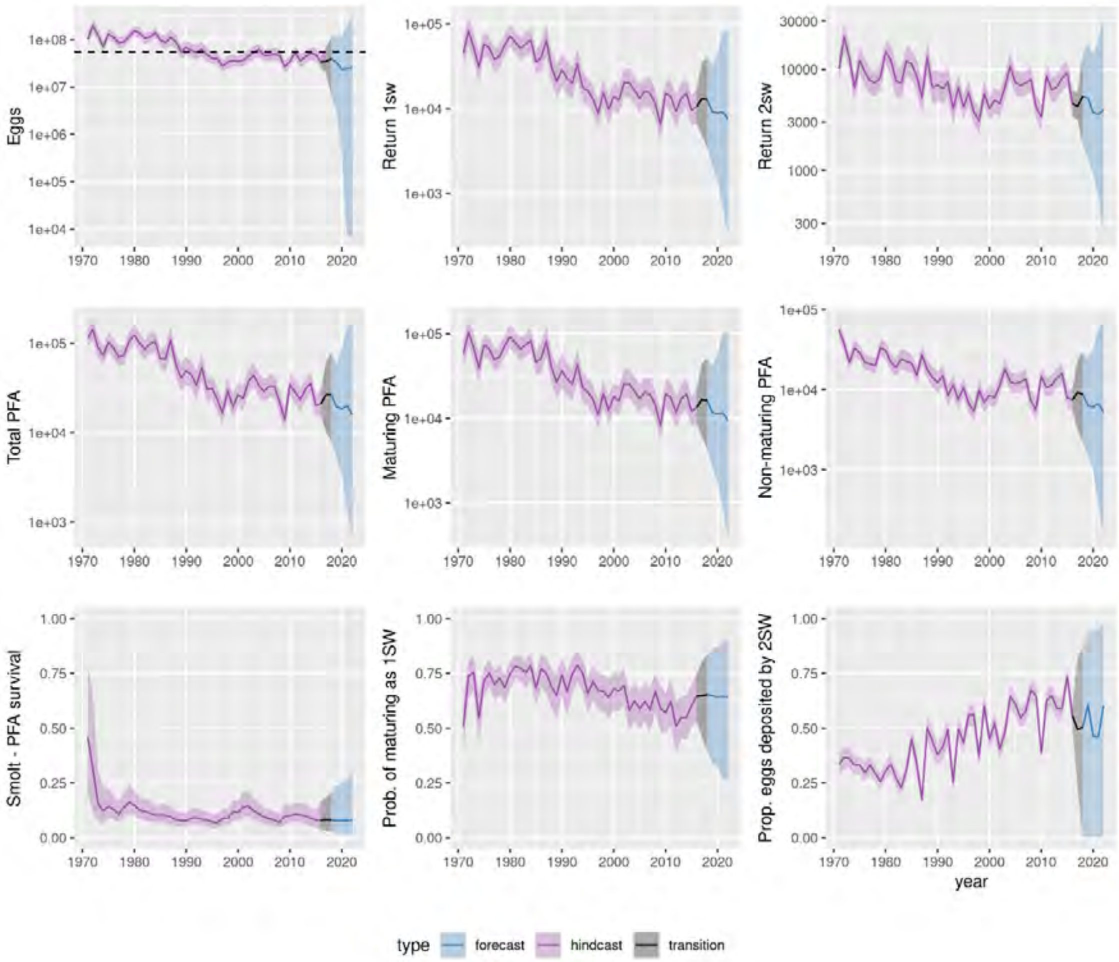


Figure 7. Example of summary figures of probability distributions for the key life stages of salmon for the SU France. Pink shaded: hindcasting on the historical time-series 1971–2017. Blue and grey shaded: forecasting obtained under a scenario with 0 catches in all mixed stock fisheries and homewater catches fixed to the average of the five last years. The horizontal dotted line in the top left panel is the conservation limit expressed in egg numbers.

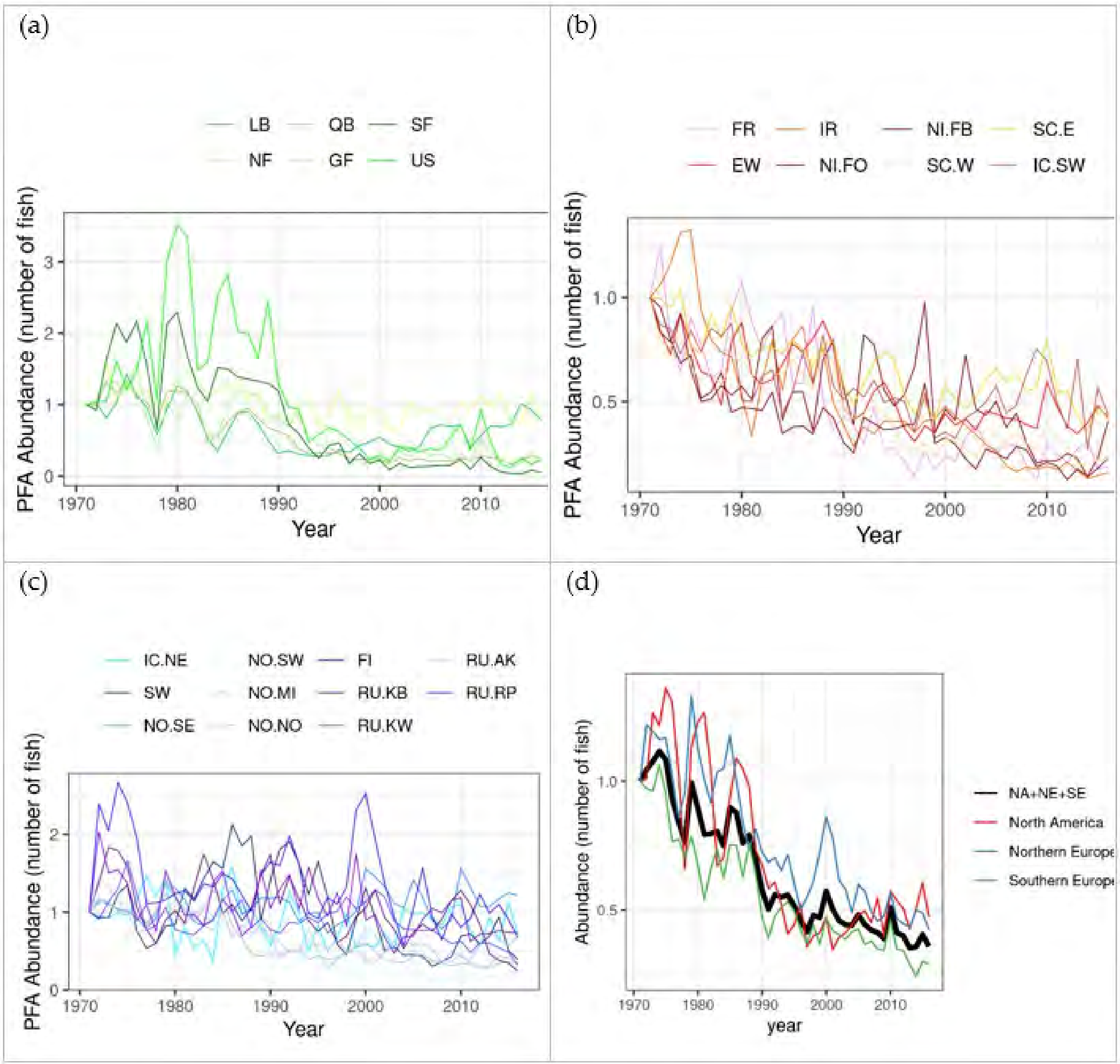


Figure 8. Time-series of estimated abundances at the PFA stage (maturing + non-maturing PFA) for all SU for the three continental stock groups: (a) North America, (b) Southern Europe; (c) Northern Europe; (d) summed by continental stock group. Thick lines: median of the marginal posterior distributions. PFA are standardized to the first year values.

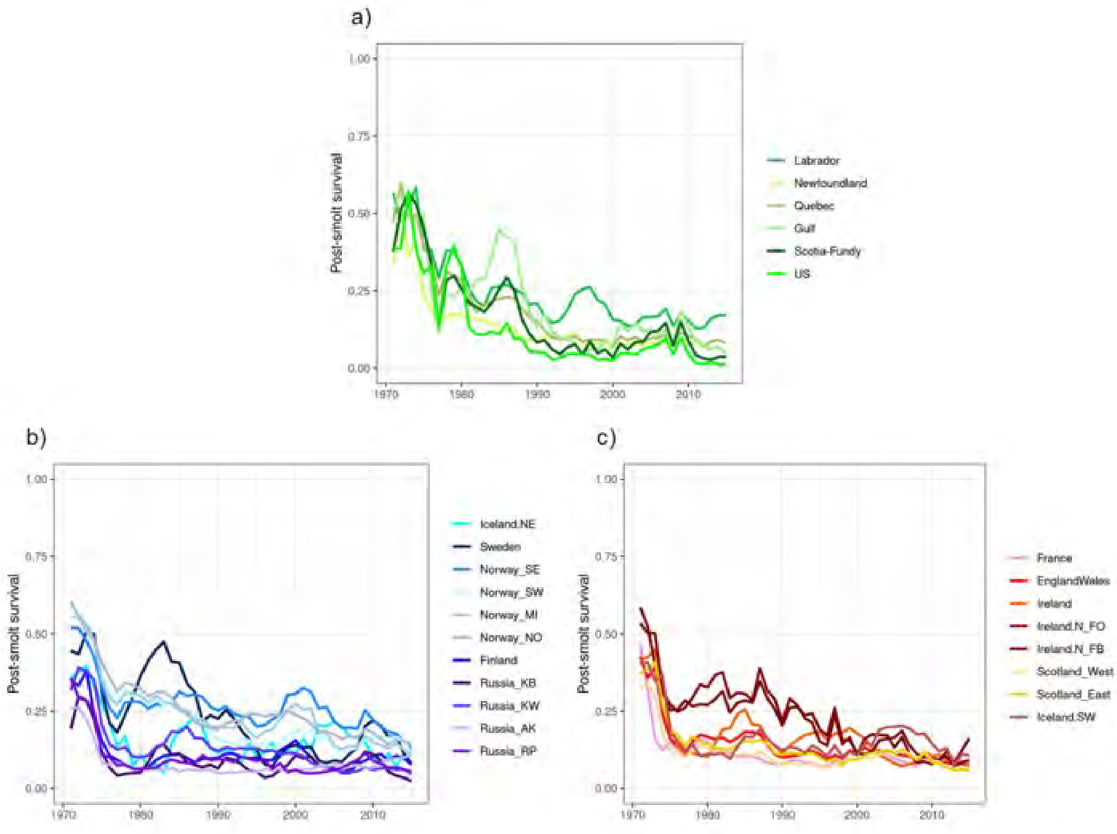


Figure 9. Time-series of smolt-PFA survival (median of the marginal posterior distributions plotted in the natural scale) for the 25 SU grouped by continental stock groups. The first five years are not represented as the inferences are too sensitive to initialization of the first cohorts.

4.2 Database and shiny app

The development of the data-base and the associated shiny app is also acknowledged as a new tool to substantially enhance and streamline the process from data preparation and maintenance to the provision of catch advices. The automatic versioning brings additional security to the updating process, increases transparency in the way the data are used and contributes to strengthening data quality control.

The first version demonstrated during the workshop is operational and will be used to update the data during WGNAS 2021 and to run the LCM from those updated data.

4.3 Priority for data and model improvements

The new LCM is easily expandable to assimilate new data or knowledge. Adopting this new framework encourages the improvement of the data by the different jurisdiction experts to better align the data with the knowledge and expertise available locally. Time was limited during the workshop and the multiple possibilities for model and data improvement were reviewed only briefly (and not exhaustively) and priority was given to issues that could be addressed realistically in the short/medium term:

- Data inputs for the LCM require the continuation of the ICES run-reconstruction model components that develop the returns and catches to homewaters. Jurisdictions would also have to update the annual catch and sampling data for the marine fisheries (Greenland, Labrador, Saint Pierre and Miquelon, Faroes).

- Biological characteristics of salmon by sea age groups in the stock units are required inputs in the LCM. It would be important for jurisdictions to review the biological characteristics (sex-ratio, fecundity of female 1SW, fecundity of female MSW or 2SW, proportion female in 1SW, proportion female in MSW or 2SW, smolt age proportions) currently assumed for the stock units. The LCM can also accommodate annual values in the biological characteristics; these characteristics may vary annually dependent on the relative annual contribution of individual rivers within stock units.
- Genetic data to allocate high sea catches among the different SU are key inputs in the LCM. They have direct impacts on the variation in mortality during the marine phase and of marine productivity among SU. Recent genetic data from samples collected from catch at sea should be reviewed and incorporated in the model.
- Life histories should be further harmonized between NAC and NEAC. The current version of the model considers the dynamics of two sea-age classes, 1SW and 2SW fish. However, there is an inconsistency between this hypothesis and the data used. Indeed, for NEAC jurisdictions, data interpreted as 2SW (returns, homewater catches, biological characteristics) include all multi-sea winter fish (a mixture of 2SW, 3SW, older fish and repeat spawners), whereas data provided for NAC only include the 2SW component of "large" fish. This inconsistency should be fixed in the near future. One option is to consider MSW (that is all "large" fish) in NAC in the same way as in NEAC. Alternatively, NEAC jurisdictions could separate 2SW from other sea ages classes in MSW. The model could also be developed to explicitly represent additional life histories at sea (3SW, repeat spawners), but this would require much development in terms of data preparation and modelling. Specifically, the LCM treatment of life histories has consequences on the parameters underlying the marine dynamics. If 1SW and MSW fish are used, the proportion maturing parameter would be underestimated because the MSW component includes repeat spawners in some jurisdictions. If only 2SW salmon are used, the egg depositions and consequently the potential smolt production would be underestimated, and the post smolt survival rate would be overestimated.
- A low but non-negligible proportion of fish from North American are found in Faroes catches. However, no fish from North America are considered to migrate to the Faroes in the current version of the model. A useful model development would be to extend the model to allow for a proportion of fish to migrate and be caught at Faroes.
- No spatial (among SU) and temporal (time trends) in egg-smolt survival rates are considered in the model and no data are used to inform egg-to-smolt survival. However, some data on index rivers exist that could be used to better inform those transitions.

4.4 WGNAS 2021 assessment and provision of catch advice

As 2021 is a full assessment year for WGNAS that requires the provision of catch advice for the 2021 to 2023 fishery years, the decision was made to provide the required assessment and provision for catch advice based on the previous PFA models used by ICES, rather than with the new LCM.

The LCM will be run in parallel, using the data updated to 2020. Results from the LCM will be compared to the PFA model outputs and this comparison will provide material to feed an ICES WGNAS benchmark process in 2022.

4.5 Preparation of ICES WGNAS benchmark 2022

Representatives from the group and ICES agreed to a have the first WGNAS benchmark in 2022. The precise ToRs for the benchmark are to be defined but should include the topics listed below.

- Review R and NIMBLE codes and workflow of the LCM.
- Define the default outputs to meet WGNAS needs.
- Prioritize data and model improvements and define a realistic and achievable time schedule for those improvements.
- Define a strategy for maintenance and hosting of the database and the shiny app. The version demonstrated during the workshop was developed at Institut Agro (France) and is currently hosted on an Institut Agro server. It is considered a "proof of concept" and ICES should define a strategy to set up the long-term management and housing of such a tool. Discussion should be initiated with other working groups that have proposed similar tools (e.g. WGEEL), and with ICES to establish effective means to support tool development and hosting.
- Examine adaptation of the data call to better fit to the need of the LCM.

In addition, the LCM includes forecasting and catch advice components that require guidance from managers to support the decision-making process. The LCM allows for forecasting returns for all SU simultaneously, given any scenarios. Abundance at any stages (e.g. PFA, returns, egg deposition) can be forecasted in a probabilistic (Bayesian) framework and compliance to any reference points can be calculated. It would be important for completing the LCM model framework and for the ICES Benchmark review of the LCM model that NASCO provide guidance / decisions on elements of the catch advice process. The most important ones are:

- How to treat marine fisheries scenarios in context of homewater fisheries. In the current PFA catch advice procedure, a sharing agreement value is used that raises the marine fishery catch scenario to account for a homewater allocation. Alternative approaches may consider using the previous five-year mean homewater catches in the marine fishery catch scenario analysis.
- The North America PFA catch advice model considers the probability of attainment of the 2SW specific conservation limits, whereas in NEAC the catch advice model considers the probability of attainment of 1SW and MSW conservation limits by sea age group. The LCM currently considers the attainment of total egg conservation limits, regardless of sea age contribution. Managers had previously expressed a desire to not only consider attainment of total egg conservation limits but also to conserve the sea age diversity of the salmon populations.
- The risk analysis of attainment of conservation limits can be presented for individual stock units, or as simultaneous attainment of some or all stock units within a continental complex. The LCM provides the flexibility to present these at whatever spatial scale is desired by managers.

Because of the importance of the topics to be addressed, it was proposed to have follow-up workshop in late 2021/early 2022 to prepare the elements described above in preparation for the Benchmark process in 2022.

5 References

Chaput, G. 2012. Overview of the status of Atlantic salmon (*Salmo salar*) in the North Atlantic and trends in marine mortality. ICES J. Mar. Sci. 69, 1538–1548.

Hernvann, P.-Y., Patin R., Guitton J., Olmos M., Etienne M.-P., Laobouyrie M., Bezier L., Rivot E. 2021. WGNAS-SalmoGlob ToolBox: a web application for supporting Atlantic salmon stock assessment at the North Atlantic basin scale. ICES WGNAS Working Paper 2021/27, 22 March–1 April 2021. 42 pp.

ICES. 2018. Report of the Working Group on North Atlantic Salmon (WGNAS), 4–13 April 2018, Woods Hole, MA, USA. ICES CM 2018/ACOM:21. 383 pp.

Olmos, M., Massiot-Granier, F., Prévost, E., Chaput, G., Bradbury, I. R., Nevoux, M., and Rivot, E. 2019. Evidence for spatial coherence in time trends of marine life history traits of Atlantic salmon in the North Atlantic. *Fish and Fisheries*, *20*(2), 322-342. https://doi.org/10.1111/faf.12345

Olmos, M., Payne, M. R., Nevoux, M., Prévost, E., Chaput, G., Du Pontavice, H., Guitton, J., Sheehan, T., Mills, K., and Rivot, E. 2020. Spatial synchrony in the response of a long range migratory species (*Salmo salar*) to climate change in the North Atlantic Ocean. Global Change Biology, 26(1319–1337). https://doi.org/10.1111/gcb.14913

Rivot, E., Patin, R., Olmos, M., Chaput, G., Hernvann, P-Y. 2021. A hierarchical Bayesian life Cycle model for Atlantic salmon stock assessment at the North Atlantic basin scale. ICES WGNAS Working Paper 2021/26, 22 March–1st April 2021. 106 pp.

Annex 1: List of participants

Name	Institute	Country	Email
April Julien	MFFP	Canada	Julien.April@mffp.gouv.qc.ca
Bardarson Hlynur	MFRI	Iceland	hlynur.bardarson@hafogvatn.is
Bolstad Geir H.	NINA	Norway	geir.bolstad@nina.no
Breau Cindy	DFO	Canada	cindy.breau@dfo-mpo.gc.ca
Brown George	AST	UK	george@atlanticsalmontrust.org
Bull Colin	AST	UK	colin@atlanticsalmontrust.org
Buoro Mathieu	INRAE	France	mathieu.buoro@inra.fr
Chaput Gérald	DFO	Canada	gerald.chaput@dfo-mpo.gc.ca
Dauphin Guillaume	DFO	Canada	Guillaume.dauphin@dfo-mpo.gc.ca
Diack Graeme	AST	UK	graeme@atlanticsalmontrust.org
Fitzgerald Colm	IFI	Ireland	colm.fitzgerald@fisheriesireland.ie
Gillson Jonathan	Cefas	UK (E&W)	jonathan.gillson@cefas.co.uk
Gregory Stephen	GWCT	UK (E&W)	sgregory@gwct.org.uk
Hanson Nora	MSS	UK (Scot)	n.hanson@marlab.ac.uk
Hernvann Pierre-Yves	Institut Agro	France	pierre-yves.hernvann@agrocampus-ouest.fr
Jan Arge Jacobsen	HAV	Faroes	Janarge@hav.fo
Jones Douglas	SLU	Sweden	douglas.jones@slu.se
Kelly Nick	DFO	Canada	nicholas.kelly@dfo-mpo.gc.ca
Maxwell Hugo	Marine Institute	Ireland	hugo.maxwell@marine.ie
Millane Michael	IFI	Ireland	michael.millane@fisheriesireland.ie
Nevoux Marie	INRAE	France	Marie.Nevoux@rennes.inra.fr
Nygaard Rasmus	GINR	Greenland	rany@natur.gl
Olmos Maxime	U Washington	USA	molmos@uw.edu
Ounsley James	MSS	UK (Scot)	j.ounsley@marlab.ac.uk
Patin Rémi	Institut Agro	France	remi.patin@agrocampus-ouest.fr
Raab Dustin	DFO	Canada	dustin.raab@dfo-mpo.gc.ca
Reader Jeff	DFO	Canada	Jeff.Reader@dfo-mpo.gc.ca
Rivot Etienne	Institut Agro	France	etienne.rivot@agrocampus-ouest.fr
Robertson Martha	DFO	Canada	martha.robertson@dfo-mpo.gc.ca
Sheehan Tim	NOAA	USA	Tim.Sheehan@noaa.gov
Walker Alan	Cefas	UK (E&W)	alan.walker@cefas.co.uk
Whitlock Rebecca	SLU	Sweden	rebecca.whitlock@slu.se